LABORATORY PLANNING
FOR WATER AND WASTEWATER ANALYSIS

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PREFACE

Despite the complexity of modern water and wastewater treatment plants, little attention has been given to the laboratories which must monitor and control them. The inadequacy of current laboratory facilities and practices has been singled out for criticism at various times by such agencies as the Environmental Protection Agency and the General Accounting Office. Too many water and wastewater laboratories have been designed and constructed with inappropriate materials, inadequate size, and improper and unsafe arrangements of equipment and furniture.

Part of the problem has resulted from a lack of adequate guidelines to assist the individuals involved in establishing these laboratories. Design engineers, laboratory analysts and treatment plant operators have been forced to rely on their own ingenuity and often limited experience in this specialized field when planning and developing laboratory facilities, often with unfortunate and inadequate consequences.

The purpose of this handbook, therefore, is to present comprehensive, standardized guidelines for the design, construction, equipping and level of staffing of water and wastewater treatment plant laboratories. More specifically, this handbook covers the following:

- The kinds and quantities of laboratory analyses which should be performed by various sizes and types of treatment installations;
- The numbers of laboratory personnel required to accomplish the above analyses;
- The size of laboratory which must be provided for the number of laboratory personnel to be employed and the types of analyses to be performed at specific treatment plants;
- The effective design and construction of the laboratory facility, including layout or floor plan, internal dimensions and materials of construction;
- The furnishings to be installed, including bench tops and work surfaces, balance and instrument tables, base units and storage cases, sinks and drains, fume hoods, and emergency showers and eyewashes;
- The services and utilities to be provided, including ventilation, heating, cooling, lighting, electricity, water, gas, vacuum and compressed air;
- The equipment and supplies needed to carry out the analytical workload and other routine operations of the specific laboratory facility; and
- Example design applications which demonstrate the proper use of all the preceding materials and information.

The guidelines presented are appropriate for use in all treatment installations, regardless of type or size. Special considerations and options are also provided for tailoring individual laboratories to meet particular treatment conditions.

Because guidelines of sufficient scope and depth have not been previously available for planning laboratories serving water and wastewater treatment installations, this handbook compiles into a single source the information most needed by design engineers, laboratory analysts and treatment plant operators when confronting this task. Ultimately, such information will better enable all those involved to achieve the federal and state water quality standards for which they are responsible.

INTRODUCTION

During the past decade, tremendous advances have been made in water and wastewater analysis. Much of this has been due to significant improvements in the equipment and procedures involved. Equipment has far transcended the simple pH meters and filter photometers characteristic of earlier years. Atomic absorption spectrophotometers, for example, are routinely used for trace metal analysis, and gas chromatographs, sometimes coupled with mass spectrometers, are often used to detect trace organic contaminants. As improved instruments develop, new analytical procedures are created to make use of them. Numerous instrumental techniques, for example, have now become standard.

The flexibility of many instruments has improved as well. Automated systems have been developed which can analyze large numbers of samples in time periods far shorter than would be possible for analysts using traditional techniques. Electrical sensing devices provide continuous monitoring at individual locations, often remotely. Semi-automated, portable instruments and procedures have enabled analyses to be carried out in the field, often far from conventional laboratory facilities. While not always of sufficient quality to meet regulatory requirements, portable analytical systems have proven invaluable for operational control and survey purposes.

New techniques are available for identifying a wide range of microorganisms, organic compounds, and inorganic substances. Many older techniques have also been refined to make them more powerful analytical tools. Other, once-familiar procedures have passed into disuse because they lacked either the sensitivity or the selectivity needed to monitor the increasingly broad array of pollutants found, often in trace amounts, in the aquatic cycle.

Implementation of these new techniques and instruments has been encouraged through passage of more stringent water quality legislation at the federal, state, and local levels, particularly the Water Pollution Control Act and the Safe Drinking Water Act. Rigorous testing requirements have been instituted under these laws which define acceptable analytical procedures and establish minimum frequencies with which they are to be applied for most water and wastewater systems.

With these developments, water quality analysis has grown in many areas from a part-time effort into a full-time and highly sophisticated endeavor. Treatment plant personnel responsible for performing laboratory analyses are capable of applying many of the newer instruments and techniques as technical schools and certificate programs continue to upgrade the standards and educational level of the profession. College graduates trained in chemistry and microbiology are also entering the field in increasing numbers. In larger laboratories, such individuals may specialize in the use of a single instrument or type of analysis.

The evolution of all these elements has brought about corresponding improvements in the laboratories where the analyses are conducted. Previously, where laboratories existed at all they were too often cramped, inadequately designed, and lacking in many essentials. But sophisticated instruments, sensitive procedures, and trained personnel require appropriate housing. The result has been the emergence in recent years of water quality laboratories as true analytical facilities on a national scale. Laboratories have been upgraded or established in many settings during this time, all with slightly different emphases. Industries, local government, state government, regulatory agencies, and private laboratories have all been involved in expanding the nation's capabilities for analyzing various types of waters and wastes.

The role these laboratories perform has shifted as well. While the operator-analyst of the past was concerned almost entirely with controlling treatment processes and ensuring the quality of the finished product or effluent, the developments of the last decade have broadened this orientation. Efficient plant operation continues to be the major concern of many laboratories, but other responsibilities are often involved now as well. Some of these include:

SURVEILLANCE

Even the most extensive treatment process leaves some contaminants, both chemical and biological, in a water supply or wastewater effluent. Contaminants entering or remaining in these waters need to be identified and assessments conducted to determine their effects on either the human consumer or the general aquatic environment. Part of this involves monitoring pollutants unaffected by present treatment processes or not regulated under existing water quality laws. Proper treatment system design requires detailed historical data, and this data may include information which has little immediate value at the time it is collected but which would be needed for more stringent treatment processes or legal requirements in effect in the future.

ENFORCEMENT

No longer limited primarily to regulatory agencies, this area of activity now includes water and wastewater utilities which must detect accidental or illegal discharges into water sources or wastewater collection systems. This involves protection of not only general public health, but also of treatment personnel and facilities, for both water and wastewater treatment plants are susceptible to harmful dumps and spills. A broad range of water quality laws and ordinances must be enforced at all levels of society, and all require analytical documentation.

RESEARCH

New treatment processes, as well as new analytical procedures themselves, must be developed and evaluated. Not all treatment methods work equally well in all situations. With the variety of advanced treatment processes available and the high cost of installing them, many communities and industries conduct their own tests of possible options before committing to any particular process. Similarly, as new treatment methods develop, so must the analytical tools used to test them. Additional procedures are also needed for purposes other than treatment plant control. Many tests are still imperfectly understood and are used simply because they have been found to work reasonable well in the past. Analysts are continually attempting to refine the tools of the laboratory, both through formal programs at recognized research facilities and in less conspicuous efforts conducted at the local level to meet specific needs.

These broadened applications of laboratory analysis on a large scale have also provided the impetus for another major change--the combining of various water quality analysis problems into a common category, regardless of the water source. Water and wastewater are increasingly being seen as a single medium, differing only in the degree of contamination, and therefore capable of being analyzed by the same laboratory. This first began to receive widespread recognition a little over a decade ago with the 14th edition of *Standard Method,* which stated:

> With higher standards of effluent quality and the increasing use of natural waters for receiving treated effluents, the distinction, emphasized in previous editions, between polluted and unpolluted waters has been abandoned in favor of a unified treatment that reflects growing realization of the unity of the fields of water supply, receiving water quality, and wastewater treatment and disposal.

Many institutions are turning to the concept of a central laboratory for all water quality evaluations. This trend can be expected to continue as increasingly sophisticated equipment and techniques enable future analysts to cover a broader range of concerns with a greater degree of analytical capability. To do otherwise would require needless duplication of expensive facilities, equipment, and personnel.

With the introduction of all these foregoing changes, however, new problems have arisen, not the least of which are numerous questions and uncertainties regarding the appropriate nature of the laboratory facilities involved. Systematic design of these facilities has become an issue of considerable concern. Operators, analysts, and design engineers have few guidelines available for helping them determine the size, equipment needs, and analytical capabilities needed to meet specific laboratory situations. A standardized approach to layout, materials of construction, and laboratory furnishings which reflects the unique demands of water quality analysis has also been unavailable. This handbook has been developed to help meet these needs.

CHAPTER 1

ANALYTICAL CAPABILITIES

Since the purpose of analysis is to make measurements, and the laboratory is the place where these measurements are made, the design of any particular laboratory must ultimately depend upon the kinds and quantities of measurements to be performed. These measurements will determine the numbers of people involved and the equipment and conditions required, which in turn will establish basic limitations on the size and arrangement of the facility. Therefore, to design an effective laboratory, it is necessary first to consider the influence of each of these related factors.

DETERMINING PROGRAM SCOPE

The designer's goal in determining the scope of a laboratory's analytical program is to establish the broad outlines of that program for some point or points in the future. Usually these would include the initial level of activity upon completion of the facility and the eventual level anticipated upon reaching some maximum state (as for example, when the treatment plant associated with a particular laboratory reaches its design flow). For design purposes, the latter is the most important as it establishes the minimum laboratory size necessary to meet plant requirements at all anticipated volumes of treatment. This ultimate level of activity is also the hardest to estimate due to the increasing dependence of treatment systems on laboratory control, new developments in analytical technology, and changing legal requirements for laboratory monitoring. Therefore, attempts to limit the laboratory's eventual analytical capabilities too narrowly at the design stage should be discouraged; instead, the emphasis should be on guaging the overall range of this program while ensuring adequate space for future flexibility and expansion.

LABORATORY ACTIVITIES

The first step in considering how a laboratory program is to develop is to determine the kinds of activities in which that laboratory will be engaged. Typically, these activities will focus on treatment plant control and effluent analysis. Additional areas of concern are becoming increasingly important, however, and include such responsibilities as instream surveillance, enforcement programs, and applied research. The extent to which the laboratory will be involved in each of these activities should be estimated and their cumulative influence on the analytical program determined. For example, a wastewater treatment plant in a highly industrialized community may require an aggressive surveillance and enforcement program. The nature of the industries involved will determine the types of analyses to be performed, the number of industrial plants will establish the number of sampling stations, and the extent and rate at which waste from these industries can alter the makeup and treatability of the waste reaching the treatment plant will influence the frequency of sampling and analysis. It is also important to consider how industrialization in an area may change over the lifetime of the treatment facilties. All these factors must be considered when designing a laboratory responsible for a surveillance and enforcement program.

TREATMENT PLANT CONTROL

The analyses associated with treatment plant control and effluent monitoring can be more accurately determined in advance than can those of most other areas. Detailed recommendations on the kinds of analyses to be performed and the frequencies with which they should be applied are available for specific types of treatment facilities in a variety of publications (see Selected References). Necessary analytical capabilities will also be partially determined by the monitoring requirements legally mandated for particular treatment plants under either the Safe Drinking Water Act or the Clean Water Act.

Historically, more sophisticated laboratory monitoring has generally been required for wastewater treatment plant control than for control of water treatment plants of comparable size, particularly where groundwater sources of potable water were involved. However, this discrepancy has been rapidly changing in recent years as more complex contaminants are discovered in drinking water supplies, requiring refined monitoring and treatment practices.

QUALITY CONTROL

The importance of quality control procedures should also be considered when estimating laboratory needs. While adequate quality control efforts have frequently been overlooked in the past, attention to this area is improving as a result of increased emphasis on laboratory certification and the need for legal authentication of laboratory data. Quality control procedures can account for up to 15 to 20 percent of the overall activity in a laboratory. Estimates of laboratory space and analyst time based on the numbers of analyses performed should therefore be adjusted accordingly.

PROBLEM SOLVING

Applied research, or problem solving, is a larger part of many laboratory programs than most individuals not directly associated with these programs might realize. Applied research seeks answers to specific and often highly localized problems. An applied research program can result in considerable time and money savings for the organization involved. An adequate investment in the problem solving needs of a particular area therefore represents an important consideration which should not be overlooked or arbitrarily dismissed by designers or administrators responsible for planning and funding laboratory construction and operation.

RECOMMENDED CAPABILITES

Recommended analytical capabilities are listed in Tables 1 and 2 for laboratories associated with water and wastewater systems, respectively. The recommendations are based upon treatment plant size and represent those tests which are likely to be required on a sufficiently routine basis to justify inclusion in laboratory design considerations. While specific requirements may vary somewhat in individual situations, these tests provide a generally applicable capability base. The laboratory staffing, size, layout, and equipment recommendations presented in subsequent chapters are based in part on the capabilities contained in these tables. Some plants may require greater capabilities than those indicated, in which case other design factors should be adjusted accordingly.

TABLE 1 *RECOMMENDED ANALYTICAL CAPABILITIES FOR WATER TREATMENT PLANT LABORATORIES*

ANALYSIS	*PLANT DESIGN FLOW (MGD)* <0.1	0.1–1.0	1.0–10	10–100	>100
pH	R	R	R	R	R
Chlorine residual	R	R	R	R	R
Turbidity	R	R	R	R	R
Taste and odor	R	R	R	R	R
Alkalinity	O	R	R	R	R
Residue (filtrable)	O	R	R	R	R
Total coliform	O	R	R	R	R
Hardness	O	R	R	R	R
Flouride	O	O	R	R	R
Total plate count		O	R	R	R
Jar test		O	R	R	R
Dissolved oxygen		O	R	R	R
Color		O	R	R	R
Calcium		O	R	R	R
Chloride		O	R	R	R
Iron		O	R	R	R
Manganese		O	R	R	R
Ammonia		O	R	R	R
Nitrate			O	R	R
Total Kjeldahl nitrogen			O	R	R
Conductivity			O	R	R
Atomic absorption spectrophotometry			O	R	R
Total organic carbon			O	R	R
Gas chromatography			O	R	R
Mass spectrometry				O	O
Viruses					O
Radioactivity					O

R = Recommended; O = Optional

SMALLER TREATMENT SYSTEMS

Some of the analyses which are legally required of very small treatment systems (those less than about 0.1 MGD) may be beyond the reasonable capabilities of those systems and should therefore be performed through contract arrangements with larger laboratories. This is particularly true where such tests as biochemical oxygen demand (BOD) and fecal coliform analyses are required only quarterly under the discharge permits of the National Pollutant Discharge Elimination System (NPDES). Neither the chemical reagents nor the analyst's technique can be trusted where these kinds of tests are performed by treatment plant personnel on anything less than a routine basis. The same is true of requirements for infrequent analysis of total coliforms in very small water treatment systems, and trace metal and trace organic analyses in somewhat larger systems.

UNIVERSAL ANALYSES

Some tests should be performed by treatment personnel on all water or wastewater systems, regardless of size. For instance, all water systems should conduct chlorine residual, turbidity, pH, and flow readings. And even the smallest wastewater treatment plants should monitor such simple but important parameters as pH, settleable solids, dissolved oxygen, temperature, chlorine residual (where this

TABLE 2 *RECOMMENDED ANALYTICAL CAPABILITIES FOR WASTEWATER TREATMENT PLANT LABORATORIES*

ANALYSIS	*PLANT DESIGN FLOW (MGD)*				
	<0.1	*0.1–1.0*	*1.0–10*	*10–100*	*>100*
pH	R	R	R	R	R
Chlorine residual	R	R	R	R	R
Settleable solids	R	R	R	R	R
Dissolved oxygen	R	R	R	R	R
Alkalinity	O	R	R	R	R
Residue (total and filtrable)	O	R	R	R	R
Volatile acids	O	R	R	R	R
Fecal coliform	O	R	R	R	R
Biochemical oxygen demand	O	R	R	R	R
Acidity		R	R	R	R
Fixed residue		R	R	R	R
Ammonia		O	R	R	R
Nitrate		O	R	R	R
Chemical oxygen demand		O	R	R	R
Grease and oil		O	R	R	R
Sulfides		O	R	R	R
Turbidity		O	O	R	R
Total Kjeldahl nitrogen			O	R	R
Phosphate			O	R	R
Atomic absorption spectrophotometry			O	R	R
Total organic carbon			O	R	R
Gas chromatography			O	R	R
Cyanide				O	R
Radioactivity				O	O
Mass spectrometry					O
Viruses					O

R = Recommended; O = Optional

method of disinfection is used), and flow. Because these tests can be satisfactorily performed in the field with a minimum of equipment, water or wastewater plants with flows of less than about 0.1 MGD may not need as elaborate a laboratory as the recommended "baseline" or minimum laboratory facilities outlined in this handbook. In some cases, for instance, good portable equipment, access to a sink for cleaning, and shelf or drawer space for storage may be sufficient. Under these circumstances, more complex analyses would then be handled by a contract arrangement with a full-scale laboratory. A more elaborate setup for such small treatment systems would only be required if additional in-house testing is desired.

FUNCTIONAL RELATIONSHIPS

Once the types of analyses and frequencies of performance have been estimated, the next step is to categorize the analyses according to function. A typical breakdown might include such groups as general wet chemical, instrumental trace metal, instrumental trace organic, and bacteriological analyses. Each of these groups will require a separate laboratory area with differing support characteristics. Such groupings will therefore influence the size and arrangement of the laboratory, the equipment needed, and the number and capabilities of the analysts employed to carry them out. The need for portable or mobile facilities should also be considered at this time.

CHAPTER 2

STAFFING LEVELS

In order to accomplish the objectives of the analytical program, it is necessary to ensure that adequate personnel time is available. Requirements for total analyst time as a function of treatment plant size are considered in this chapter.

EPA STAFFING SYSTEM

Perhaps one of the most widely known systems for determining laboratory staffing needs for wastewater treatment plants was developed by Environmental Protection Agency (EPA) and presented in the manuals, *Estimating Staffing for Municipal Wastewater Treatment Facilties* and *Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities*. The system graphs annual hours spent on laboratory tasks against plant design flow for two kinds of systems: (1) advanced waste treatment and activated sludge plants, and (2) primary and trickling filter plants. Laboratory tasks for this purpose include collecting samples, performing analyses, assembling and reporting data from tests, evaluating data in terms of plant process performance, preparing common chemical reagents and bacteriological media, recommending process changes based on laboratory data, and reporting to regulatory agencies on the operation of the plant. The annual hours of analyst time needed for a particular plant, as obtained from the graphs, are adjusted to meet local conditions through a table which considers such factors as the level of treatment used, the presence or absence of industrial wastes, and the presence or absence of automatic monitoring and sampling equipment.

LIMITATIONS TO THE EPA SYSTEM

The EPA system for determining laboratory staffing needs suffers from several limitations, some of which have been outlined in a *Journal WPCF* article, "Evaluating wastewater facility staffing needs." One of the limitations to the EPA system stems from the fact that the data used to develop the system were taken largely from actual plant staffing levels. Since laboratory control of treatment plants has been seriously under-utilized in the past, and frequently remains so even today, it is hardly surprising that historical data such as these underestimate staffing needs. In addition, the data are several years old and fail to reflect the broadening scope of laboratory related involvement in water and wastewater operations. Finally, other laboratory related functions not directly reflected in analytical activities, such as clerical and supervisory tasks, were not included in the graph for estimating the necessary annual hours of laboratory work. When determining laboratory staff size, it is necessary to consider these tasks as a part of the overall laboratory operation.

Staffing levels obtained from the EPA system should therefore be taken as reference points in estimating actual laboratory staffing needs rather than as absolute, prescriptive limits to the number of laboratory personnel required. Differences between the level of laboratory staffing anticipated by other means for a given facility and the level recommended by the EPA system may then signal a need for closer evaluation of the projected personnel requirements, but should not be used to justify arbitrary reductions in planned laboratory staffing needs.

RECOMMENDED STAFFING GUIDELINES

A laboratory staffing guide which compensates for the limitations in the EPA system is presented in Figure 1. This guide also contains other significant changes, primarily the inclusion of water treatment plant laboratory staffing needs as well as those for wastewater treatment plants. For laboratories responsible for more than one water or wastewater treatment plant (or for a combination of both), "design flow" refers to the sum of the individual design flows for each of the plants involved.

The recommendations presented in Figure 1 also reflect the numbers of fulltime equivalent analysts required for various treatment plant capacities rather than the total annual hours of personnel time involved. While it may be useful to use an annual hours basis in some instances to estimate laboratory staffing requirements, ultimately it is the number of actual individuals to be employed that must be determined. A "fulltime equivalent person" represents 1500 actual working hours per year and may be composed of two halftime individuals for a particular situation, or any other reasonable combination. In addition, the use of detailed annual hours, as presented in the EPA guidelines, suggests a level of precision and inflexibility in the data which is unjustified. These are to be considered as approximate staffing levels only and must be modified as necessary to meet particular treatment situations.

ADJUSTMENTS TO THE GUIDELINES

Conditions which might affect the recommended level of laboratory staffing needed for a given plant include:

Type of treatment facility

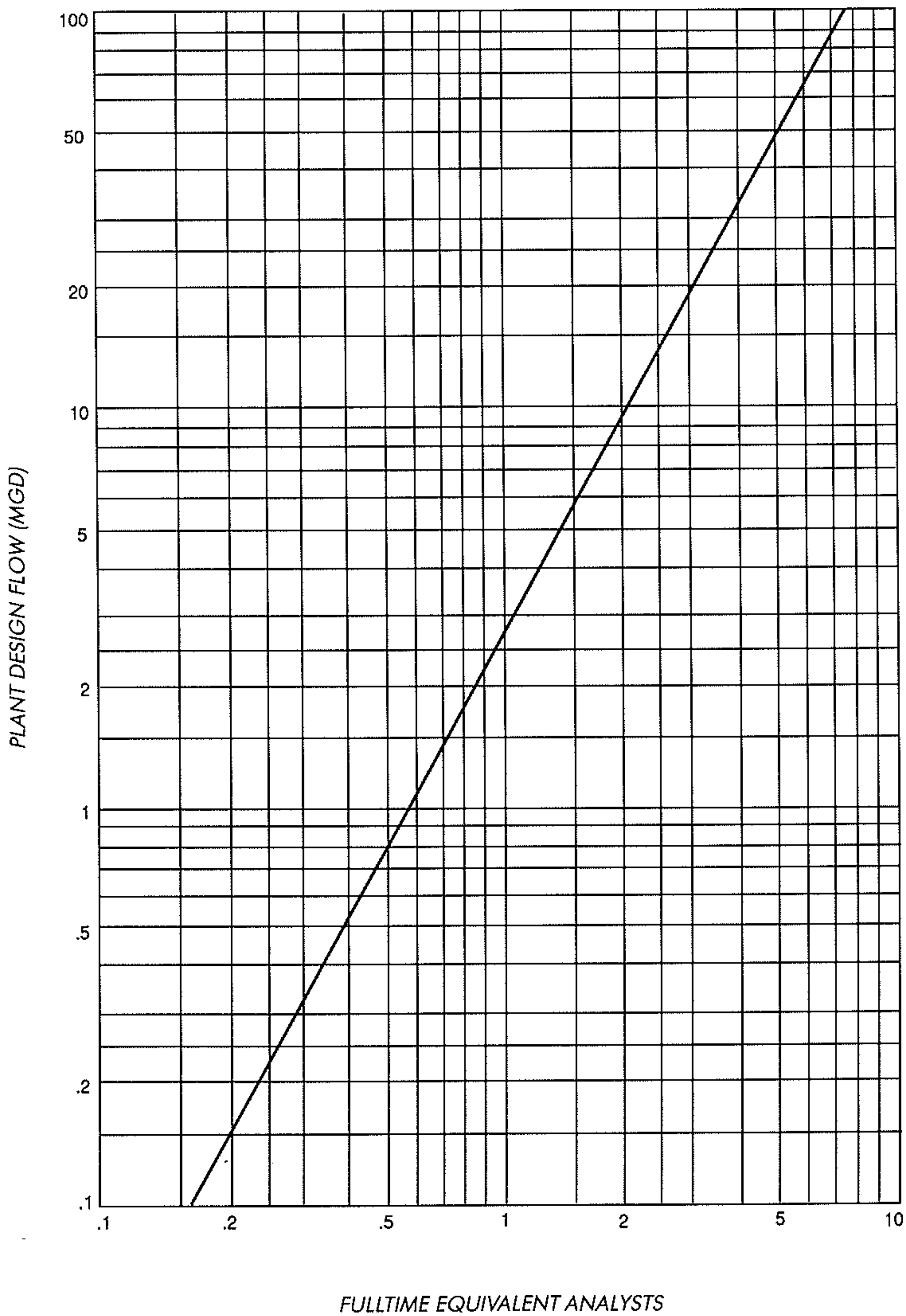
The laboratory requirements for water treatment plants have traditionally been somewhat lower than those for wastewater plants of similar design flow. Although the difference between these requirements has been diminishing in recent years as the analyses performed at each type of plant approach one another in relative complexity, in some instances water treatment plants still may require only about 70 percent as much laboratory capability as comparably sized wastewater plants. This difference tends to be more pronounced for potable water systems using groundwater supplies than for systems using surface waters. Such special situations must be evaluated on an individual case basis and are not incorporated into the general laboratory staffing and size guidelines presented in this handbook.

Complexity of the treatment system

The staffing guidelines shown in Figure 1 are based on typical median level treatment plants: water plants using coagulation-flocculation followed by filtration, and wastewater plants employing either trickling filters or activated sludge. Deviations from these levels of treatment will require corresponding adjustments in staffing. For example, any advanced water or waste treatment systems such as ion exchange, reverse osmosis, or carbon absorption will increase the amount of analyst time needed. The increase may be on the order of several percent for each additional process. Treatment plants which are simpler than the median level and therefore possess fewer options for control may require considerably reduced laboratory staffing, perhaps by a total of as much as 20 to 30 percent in some cases (see "Type of treatment facility" above).

FIGURE 1

RECOMMENDED LABORATORY STAFFING



Relative difficulty in treating a particular water or waste

Some water plants may be subject to treatment problems resulting from unusual conditions or wastes entering the water source upstream or contaminating portions of an underground aquifer. Similar problems also occur frequently in wastewater plants as a result of industrial wastes discharged into the collection systems; although pretreatment requirements are intended to reduce these problems, considerable time must still be spent determining whether the pretreatment requirements are being met. Where waters or wastes are relatively constant or seasonal in nature, and have been adequately considered in the plant design, little or no additional laboratory staffing may be required. However, highly variable waters or wastes encountered throughout the year can cause sufficient treatment problems to warrant increasing laboratory personnel by as much as 10 to even 100 percent.

Automatic samplers

Automatic sampling at the influent, effluent, and other critical points in a treatment plant may reduce the time required for this particular responsibility by laboratory personnel. However, this reduction is often offset by an increase in the number of tests run and the amount of information which must be assimilated. This is particularly true where a sampler is used to collect a number of discrete samples throughout the day rather than a single composite sample. Although compositing may be done by the analyst prior to performing most tests, discrete samples also provide the option of following fluctuations in a stream flow or specific treatment process throughout the day. This information can have important consequences for operational control of a treatment plant. Automatic samplers should therefore not be relied upon to necessarily reduce overall laboratory staffing needs.

Automated analyses

Automated analytical systems result in less time being spent on actual analyses, but often require skilled personnel to maintain the equipment and to deal with the large volumes of data obtained. The instruments must be calibrated and the results verified. The data accumulated by such systems must be properly interpreted and summarized for operational control. As a result, any plant relying upon automated analytical systems should also possess a laboratory capable of performing these same tests independently. The overall capability levels of the laboratory and its staff would therefore remain largely unchanged, although the time devoted to laboratory functions would probably be reduced by several percent for each parameter automatically monitored.

Geography of sampling locations and the need for field measurements

Sampling or monitoring stations which are located at considerable distances from the laboratory may result in analysts spending significant amounts of time in travel. Such stations might be used for stream surveillance for water and wastewater plants, and for industrial waste monitoring in collection systems. Centralized laboratories serving more than one treatment plant would also face this problem. Laboratory staffing would have to be increased in these cases by an amount corresponding to the degree of travel anticipated.

Level of analyst training

Treatment plant operators who are required to perform laboratory analyses frequently lack formal training in biology, chemistry, and laboratory techniques. Even trained analysts are sometimes called upon to carry out procedures which lie outside their areas of expertise. These individuals will need more time to complete the necessary analytical procedures properly. Where such conditions can be expected to occur routinely, laboratory staffing levels should be increased by anywhere from as little as 5 to as much as 20 percent.

TIME REQUIREMENTS FOR SPECIFIC TESTS

With very small plants, particularly those under about 0.1 MGD, it becomes more difficult to estimate the amount of operator time which will be taken up by laboratory activities during the year. The total time is much more directly related to the specific tests performed and their frequencies than is the case with larger laboratories where variations in analytical programs usually even out. For this reason, Table 3 is included to help estimate the amount of operator time required for analysis in very small treatment facilities. The table lists approximate time requirements for various tests, with each time requirement presented two ways: (1) the total elapsed time from when the test is started to when it is completed, and (2) the actual working time the operator must spend in performing it. Both estimates take into consideration media or reagent preparation, setting up apparatus, performing the tests, and cleaning the apparatus used. It should be stressed that these values are only approximate; frequent analysis and thorough operator training may considerably reduce the time required, while infrequent analysis and inadequate training may require much more.

TOTAL TIME REQUIREMENTS

The times listed in the table are for the analysis of a single sample only. Simultaneous analysis of additional samples, more than one dilution, or multiple analyses of the same sample dilution will all increase the time involved. For example, in *Microbiological Methods for Monitoring the Environment*, EPA estimates that a single analyst requires one full day to prepare 30 samples (assuming three dilutions per sample) for fecal coliform analysis using the membrane filter (MF) technique. On the second day of the test, another two hours are required for the analyst to count, calculate, and verify the results. If both fecal and total coliform analyses are being performed on the samples, EPA estimates a single analyst can prepare 20 samples (again assuming three dilutions per sample) on the first day. On the second day, two and one-half hours more will be required to count, calculate, and verify the results. In addition, another four hours are needed in each case over a five-day period for preparing media, dilution water, dishes, and pipets for these tests. These time estimates include 10 percent devoted to quality control procedures.

Other activities will also add to the total time spent in the laboratory. These include ordering supplies, maintaining equipment, preparing stock reagents, analyzing results, and preparing records and reports. For example, the operator of a wastewater plant receiving less than 0.1 MGD can expect to spend approximately four to eight hours on laboratory analyses each month in order to meet the NPDES requirements alone, if BOD, suspended solids, fecal coliform, and any other relatively complex analyses are contracted out. Additional monitoring necessary for proper plant operation should bring the total time to about 16 hours per month, spread over the entire period. For a 0.1 to 1.0 MGD wastewater treatment plant, approximately 40 hours of operator time must be spent each month in order to meet NPDES required tests. Additional testing needed for plant operation will roughly double the total time spent on analysis.

TABLE 3

*ESTIMATED TIME REQUIREMENTS FOR SPECIFIC ANALYSES**

ANALYSIS	*TOTAL RUN TIME*	*OPERATOR TIME*
Chlorine residual	10 min	10 min
pH	15 min	15 min
Turbidity	15 min	15 min
Fixed residue	1 hr	15 min
Settleable solids	1¼ hr	15 min
Dissolved oxygen	½ hr	½ hr
Hardness	½ hr	½ hr
Color	½ hr	½ hr
Acidity	½ hr	½ hr
Nitrate	½ hr	½ hr
Residue (total or nonfiltrable)	½ hr	½ hr
Alkalinity	1½ hr	1 hr
Residue (filtrable)	2 hr	1 hr
Volatile acids	2 hr	2 hr
Ammonia	2 hr	2 hr
Chemical oxygen demand	4 hr	2 hr
Fecal coliform (MF)	1 day	2 hr
Total coliform (MF)	1 day	2 hr
Biochemical oxygen demand	5 days	2 hr
Total phosphorous	4 hr	3 hr
Total Kjeldahl nitrogen	4 hr	3 hr

*Times given are for analysis of one sample only. Another sample analyzed simultaneously will generally require much less additional time.

CHAPTER 3

FACILITY SIZE

Proper application of the materials in each of the preceding chapters will determine how large a laboratory needs to be in order to meet the requirements of a particular water or wastewater facility. When establishing laboratory size, it is imperative that adequate consideration be given to the flexibility and adaptability of the facility to meet changing conditions in the future. Failure to do so could seriously impair the laboratory's capacity to accommodate the demands placed upon it.

TRADITIONAL APPROACHES

A wide variety of formulas traditionally have been presented for sizing water and wastewater treatment laboratories. Typically, these formulas specify some minimum amount of floor space which is sufficient for a single analyst; a few then also indicate how much additional space should be allotted for extra individuals. For example, EPA recommends in the *Manual for the Certification of Laboratories Analyzing Drinking Water* that 150 to 200 sq. ft. per person be allotted for chemical analysis in water treatment facilities, and that 200 sq. ft. per person be allotted for microbiological analysis in such facilities. EPA also recommends in *Estimating Laboratory Needs for Municipal Wastewater Treatment* that primary, trickling filter, and pond-type wastewater treatment facilities be provided with at least 150 sq. ft. of laboratory space, while activated sludge, physical-chemical, and advanced wastewater treatment facilities be given at least 180 sq. ft. of laboratory space. The New York State Department of Health recommends a wastewater plant minimum laboratory size of 200 sq. ft. for one person, with another 100 sq. ft. provided for each additional person. The Great Lakes-Upper Mississippi River Board of State Sanitary Engineers recommends a minimum laboratory size for wastewater plants of 400 sq. ft., suitable for one or two persons, with another 100 sq. ft. provided for each additional person beyond the first two. A 1959 recommendation by the Water Pollution Control Federation and the American Society of Civil Engineers suggests 250 to 300 sq. ft. of laboratory space be provided for use by one analyst in wastewater treatment plants.

FORMULA INADEQUACIES

While these formulas may provide acceptable (though usually minimal) laboratory space for relatively small facilites, they are subject to a number of shortcomings, particularly when applied to facilities at the opposite end of the size spectrum. The one example which violates this general tendency is the recommendation given by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers. The 400 sq. ft. of laboratory space this board recommends as a minimum represents an extravagant amount of floor space for plants smaller than about 1 MGD. The analyses performed and the amount of operator time spent performing them in plants of this size do not justify the expense of such a laboratory.

Usually, however, the recommendations cited above will result in laboratories which are too small for safe, efficient operation. Even the relatively generous space recommendations of the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers may be inadequate for larger laboratories (and possibly intermediate ones to some degree). The incremental additions of floor space (an additional 100 sq. ft. for each person beyond the first two) are simply insufficient to support increased staff and facility needs. Adequate space is not provided for equipment and reagent storage, offices, or complex analytical instrumentation and support activities. This can result in overcrowding and consequent loss of data reliability and personal safety.

This problem highlights a major failing of most laboratory size formulas currently used in the water and wastewater treatment industry, in that they fall below the size recommendations usually followed by professionals in the general chemical and microbiological laboratory design field. These more liberal size recommendations (several of which are discussed in the Selected References at the end of this handbook) frequently cite minimum gross laboratory space recommendations of 300 to 450 sq. ft. or more per person, with corresponding allotments for net space and other divisions of the overall area.

Typical formulas for determining laboratory space in water and wastewater treatment facilities also tend to be overly simplistic in that they do not differentiate between net and gross laboratory space requirements in their recommendations. In the laboratory design field, net space refers to those areas actually available for performing analyses, while gross space also includes non-analytical areas such as storage, service ducts and shafts, mechanical spaces, stairs, corridors, principal aisles, break areas, and restrooms. The proportion of net to gross space is normally about 65 to 70 percent for general analytical laboratories.

RECOMMENDED FLOOR SPACE

To overcome the deficiencies in the types of formulas discussed above, a more generally applicable formula is recommended in this handbook. This formula is suitable for sizing all types of water and wastewater laboratories. It provides 150 to 200 sq. ft. of net floor space (that space used strictly for analytical functions) for each person working in the laboratory at any one time, with a corresponding allotment of 300 to 350 sq. ft. of gross or total floor space for each fulltime equivalent person employed. The net or strictly analytical area would include only such space as is needed for laboratory benches, tables, and other work areas directly involved with the generation of raw data. The gross or total space requirement would include bulk storage facilities, centralized cleaning and sterilizing services, offices, corridors, staff rest areas, and all other necessary support features, in addition to those areas directly involved in analysis.

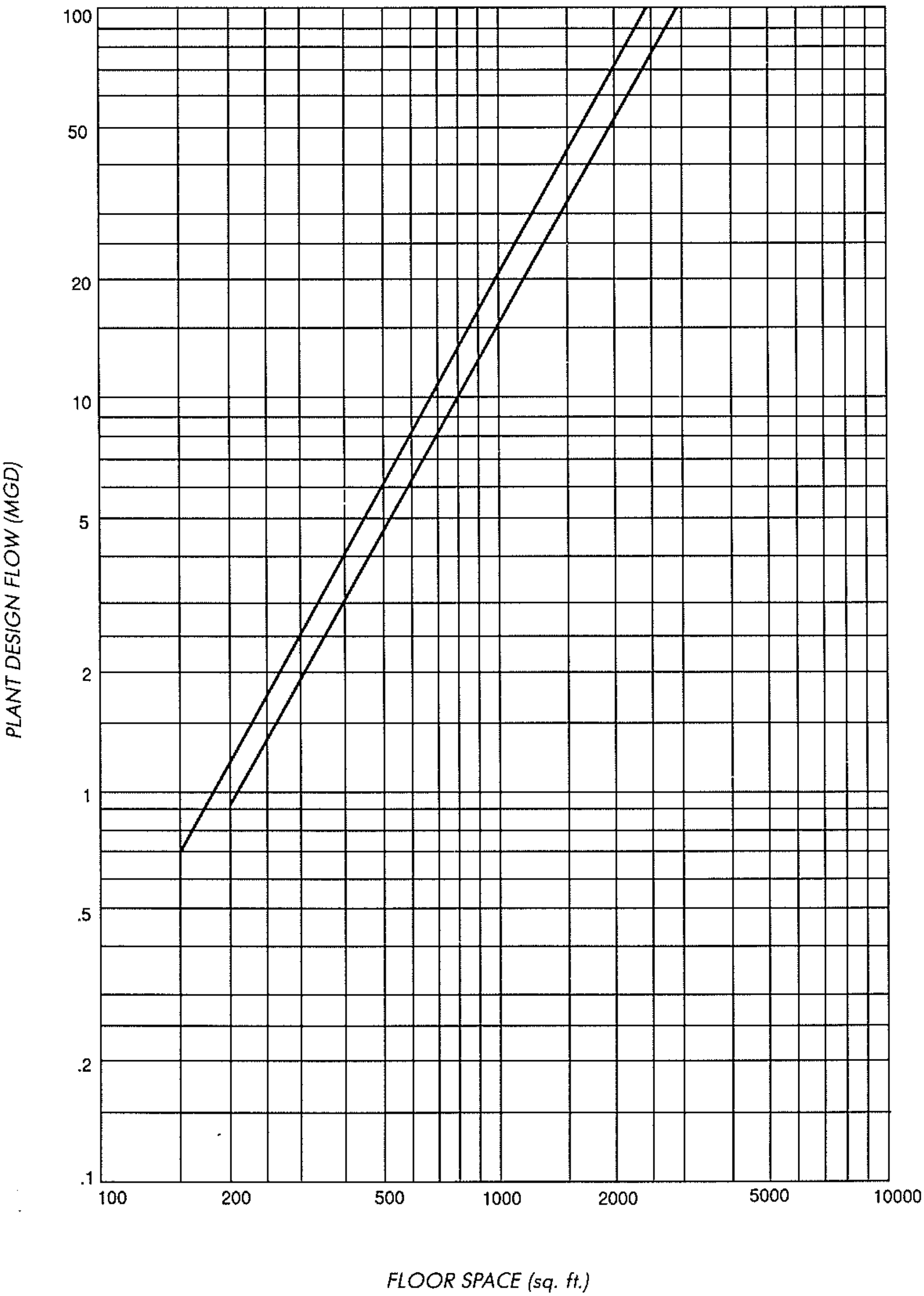
It should be recognized that even this formula may be inadequate for very large laboratories, as the total space requirements imposed by support activities may increase disproportionately for highly complex instrumental analyses.

PLANT DESIGN FLOW

Since the analytical program and staffing requirements presented in the first two chapters of this handbook have been related to treatment plant design flow, it is useful to do the same with laboratory floor space. Such a correlation is illustrated in Figure 2. The lines shown on the graph represent 300 and 350 sq. ft. per person, respectively, for the staffing levels previously recommended in Figure 1. The

FIGURE 2

RECOMMENDED LABORATORY FLOOR SPACE



laboratory associated with a particular plant should fall on or between these two lines at the appropriate design flow. As in the case of Figure 1, whenever a laboratory is to be responsible for more than one plant, the size of the laboratory should be based on the sum of the individual design flows involved. The floor space indicated includes that necessary to perform laboratory related supervisory, clerical, and support functions as well as strictly analytical tasks. Floor space recommendations taken from Figure 2 should of course be adjusted for any deviations from the recommended staffing levels presented in Figure 1.

MINIMUM SPACE REQUIREMENTS

Two minimum floor space recommendations are shown in Figure 2, the first at 150 sq. ft. and the second at 200 sq. ft. These values correspond to the limits on analytical floor space needed for any one person working in a laboratory at a given time, as mentioned earlier. The smallest feasible size for a functional laboratory is generally considered to be 150 sq. ft. It also corresponds to the EPA minimum recommended laboratory size for simple wastewater treatment plants (primary, trickling filter, and aerated and stabilization ponds) and for chemical analysis in water treatment plants. The larger recommended minimum of 200 sq. ft. represents a more flexible area in which a single individual can operate efficiently and safely. It also corresponds to the minimum amount of space per analyst recommended by EPA for microbiological analyses in water laboratories certified under the Safe Drinking Water Act. In addition, EPA also recommends a minimum of 180 sq. ft. for laboratories associated with activated sludge, physical-chemical, or advanced wastewater treatment plants. This minimum is not specifically shown in Figure 2, but falls within the recommended laboratory size range indicated on the graph.

MEETING SYSTEM NEEDS

Using the guidelines presented in these first three chapters, laboratory analysts and design consultants will be able to develop laboratories capable of meeting individual system needs. The laboratories will possess the analytical resources, personnel, and floor space necessary for efficient, effective operation. The remaining chapters will show how to arrange and furnish that space and how to equip the laboratory to further enable it to meet the analytical needs of various treatment systems.

CHAPTER 4

DESIGN AND CONSTRUCTION

Design is the most critical aspect of a laboratory because it is the least readily changed once the facilities are constructed. The types of analyses conducted, staffing levels, and instrumentation can all be altered to meet changing needs, but modifications to the building itself are expensive and time consuming. Improper design can limit efficiency in laboratories having an abundance of floor space while even inadequately sized facilities can be improved through effective design. For these reasons, it is imperative that the design and subsequent construction of a laboratory be given thorough attention with the full participation of all individuals who will be involved in the analytical program. Some of the features which should be considered when designing a laboratory are its location, the arrangement or layout of the facilities, internal dimensions, and building construction. These topics are discussed in this chapter.

LABORATORY LOCATION

A basic consideration in designing an effective laboratory is location. The laboratory should be located as near as possible to the source of the samples to be analyzed in order to reduce the distance these samples must travel and the time that passes between sampling and analysis. In a water or wastewater treatment plant, this means that laboratory personnel should have ready access to all parts of the plant. Where samples are to be collected from a wide area, such as a collection or distribution system or from the length of a waterway, the laboratory should be located so as to minimize overall sample travel time. Where distances are great, special sample handling methods will need to be employed and the use of a mobile laboratory facility might be investigated. The laboratory should also be located near the plant or other administrative offices so results and process recommendations can be communicated readily. If a laboratory is isolated from the operation it is to serve, its usefulness will be greatly decreased. However, the laboratory should not be located in such a way that it becomes a corridor for traffic between other areas. This can introduce contamination into the laboratory and may cause hazardous distractions to laboratory personnel. In addition, the laboratory should be located away from heavy equipment and other sources of vibration, noise, and dust which could interfere with analyses. Wherever possible, the building site should be of sufficient size to allow for logical expansion of the laboratory facilities in the future, should this become necessary. The internal floor plan of the building should also be developed with the possibility of expansion in mind.

PATTERNS OF WORK

Once the necessary floor space of a laboratory has been determined and a site chosen, the next stage is to arrange the facilities in such a way that the analyses can be readily carried out. In doing this, it is helpful to consider the flow pattern of the work to be accomplished. The generalized flow diagram presented in Figure 3 shows how the various steps in the analytical process interrelate, with the broken line representing the functional boundaries of the laboratory. With larger facilities where the work is departmentalized, it might be necessary to develop more detailed diagrams for each major analytical grouping, including the instruments to be used and essential preparation or calibration procedures. Such diagrams can help in determining what types of work areas to provide and where they should be placed in relation to one another. For example, based on Figure 3, a typical water quality laboratory of moderate size might need one or more separate areas for each of the following:

Storage

Glassware, chemicals, bacteriological media, samples, instruments, spare parts, gas cylinders, workshop materials, data and report files, computer output, and janitorial supplies.

Preparation facilities

Bulk solutions, media preparation, reagent standardization, dispensing, and glassware and instrument assembly.

Glassware cleaning and sterilization

Washing and drying facilities, supplies, autoclaves, and other types of sterilizers.

Waste disposal

Waste solvents, toxic or explosive chemicals, pathogenic cultures, broken glass, and other hazardous wastes.

Analysis

General wet chemical, physical, bacteriological, trace metal, trace organic, and radiological.

Administrative and general staff needs

Office space, conference areas, calculators or computer terminals, typewriters, desks, library and reference materials, restrooms, and lunchroom or break facilities.

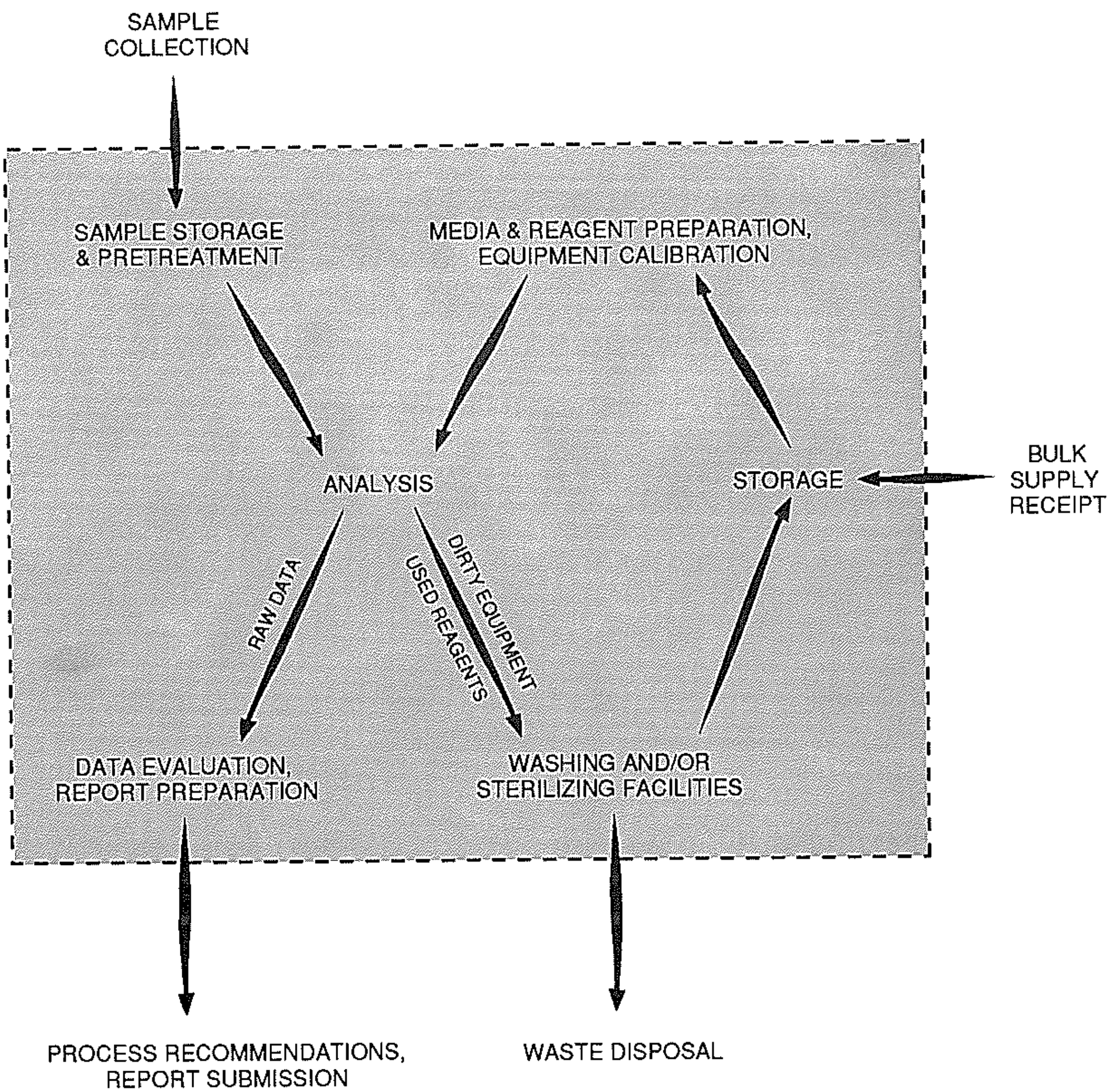
SPECIAL NEEDS

In each case, it is necessary to consider whether laboratory services are to be centralized or dispersed. Unusual needs for some procedures should also be considered, such as special ventilation, sterility, or other support requirements. These requirements may dictate special rooms for certain instruments or operations to minimize the chances of sample contamination and instrument fouling. Examples would include individual rooms for bacteriological, trace metal, and trace organic analyses.

For safety reasons, it is also important to provide some kind of break or lunchroom facilities for the laboratory staff, either in the laboratory complex itself for larger facilities, or in an adjacent area for smaller laboratories associated with water or wastewater treatment plants. Failure to provide such areas might result in the hazardous situation of laboratory personnel eating, drinking or smoking in analytical areas.

FIGURE 3

THE ANALYTICAL PROCESS



INTERNAL LAYOUT AND DESIGN

The facilities in a laboratory should be arranged in such a way that the work can be carried out in a safe, logical and efficient manner. There are two factors in this which require special attention. One is the human factor: the laboratory should provide an environment which minimizes the chances for human error and which maximizes the efficiency of the work performed. The other factor is concerned with equipment: the laboratory should be designed in such a way that the useful life and accuracy of its instrumentation is maintained. When planning a laboratory, some free wall and floor space should be reserved if at all possible for future uses.

Floor-to-ceiling height should be about 9 to 9.5 ft., with a minimum height of 8.5 ft. to allow for fume hoods, distillation racks, stills, and other tall or wall mounted equipment. The principal work areas should be readily accessible, with sufficient aisle space to permit convenient movement of laboratory carts and large pieces of equipment, and should be designed so they are free of obstructions. Drawers and cabinet doors should open so as not to interfere with work in progress. Door widths should be at least 3 ft. to permit large instruments and equipment to pass through. Because of the danger of bumping a person carrying chemicals, each door should have a window large enough to provide visibility from either side. Swinging doors should be avoided, but automatic door closers should be installed.

TRAFFIC FLOW

Attention to layout will help control traffic flow through the laboratory. For example, for reasons of both safety and quality control, visitors should be able to reach the laboratory office without having to pass through analytical areas. If it is desirable for visitors to be able to view the analytical areas, windows should be provided for this purpose. Similarly, samples should be received for pretreatment and storage near the entrance of the laboratory where these activities will not interfere with other operations. Where a centralized store room opens directly onto a laboratory, outside access might also be provided to enable bulk shipments to be received and processed without transporting them through the work area. Direct outside access in a store room may also be necessary for safety reasons, depending upon the size and arrangement of the storage facilities.

In general, any laboratory area larger than about 300 sq. ft. should have at least two exits. Work or storage areas smaller than 300 sq. ft. but involving hazardous procedures or materials may also need to be designed with at least two possible escape routes as well. The layout of a proposed laboratory should be carefully inspected prior to acceptance to ensure that foreseeable accidents could not cut personnel off from all exits, thus trapping them in the laboratory.

Routine traffic flow can be further controlled by placing support services and multiple user equipment (store rooms, cleaning and sterilizing facilities, preparation areas, analytical balances, etc.) in central locations where they can be easily reached by all personnel. Related furnishings and equipment in a laboratory should be grouped together for maximum efficiency.

BENCH SPACE

A critical aspect of internal dimensioning involves the amount of bench surface available for analytical activities. Recommendations for bench space are usually given as the number of linear feet of bench top and other work surface to be allotted per person. In some cases, however, bench space may be specified as the number of square feet to be provided, in which case the value may be expressed as a percentage of the overall laboratory floor space.

In general, laboratory design professionals recommend at least 12 to 15 ft. of bench space per person for most laboratory applications. Some EPA publications only recommend 6 ft. of bench space per person for microbiological analysis of water and wastes, although it is possible that additional bench space for sample preparation, cleaning, and other ancillary task have not been included in these figures. More in keeping with overall guidelines for the laboratory design field is EPA's recommendation in the *Manual for the Certification of Laboratories Analyzing*

Drinking Water that a minimum of 15 ft. of bench space per person be provided for chemical analyses.

It is the recommendation of this handbook that at least 12 to 15 ft. of bench space be provided per analyst. Where much of the workload consists of relatively routine, repetitive tasks performed by laboratory assistants, 12 ft. may be sufficient. However, it should be recognized that in special cases, particularly where skilled analysts are engaged in highly variable work requiring complex instrumentation, as much as 18 to 20 ft. per person or more may be required.

Additional laboratory bench space recommendations are included in another EPA publication, *Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities.* This publication treats bench space as an area rather than as a linear measurement, and relates bench space to treatment plant size. A similar curve showing bench surface as a percentage of gross laboratory floor space is presented in Figure 4. These percentages are appropriate for laboratories associated with either water or wastewater treatment facilities. For laboratories larger than about 3,000 sq. ft., at least 20 to 25 percent of the gross laboratory floor space and 35 to 40 percent of the net or analytical space should be occupied by benches and other work surfaces.

STORAGE VOLUME

The final dimensional aspect of laboratory design to be considered is storage volume. Storage volume may take either of two forms: centralized store rooms or decentralized cabinets spaced throughout the laboratory work areas. Smaller laboratories (those of only a few hundred square feet) will frequently be able to meet their storage needs with cabinet space alone. Larger facilities will require the use of both. Some facilities may even need separate store rooms for each major area of analysis with perhaps a larger central store room for bulk storage of items used in all areas. Recommended cabinet storage volumes for laboratories ranging from 150 to 3,000 sq. ft. are shown in Figure 5. This figure, which has been adapted from EPA recommendations, is also applicable to both water and wastewater laboratories. The figure does not, however, include the centralized storage needed in larger facilities, which may require an area equivalent to 12 to 17 percent of the laboratory floor space. Centralized store rooms should contain enough space to store large pieces of equipment, spare parts, and bulk orders of chemicals and glassware, while still enabling an analyst to move about freely and safely.

FLOOR CONSTRUCTION

The details and finishes used in the construction of a laboratory contribute significantly to the effectiveness with which the facilities can be used. Finishes should be resistant to wear and chemical attack and be pleasing in appearance. Floors in particular should be covered with a material which is capable of withstanding chemical and physical abuse and which can be readily cleaned. It should be able to withstand water, acids, alkalies, solvents, and stains; be capable of supporting heavy equipment without damage; and be comfortable to stand on. The floor covering should be coved at all junctions with walls to help contain spills.

Untreated concrete floors tend to be dusty, uncomfortable for standing, cold, and unattractive. They are durable and can resist acids if high silicon content cement is used. For greater resistance and comfort, concrete floors should be painted or covered. For general use, vinyl or PVC flooring is a durable, long-lasting material

FIGURE 4

RECOMMENDED LABORATORY BENCH AREA

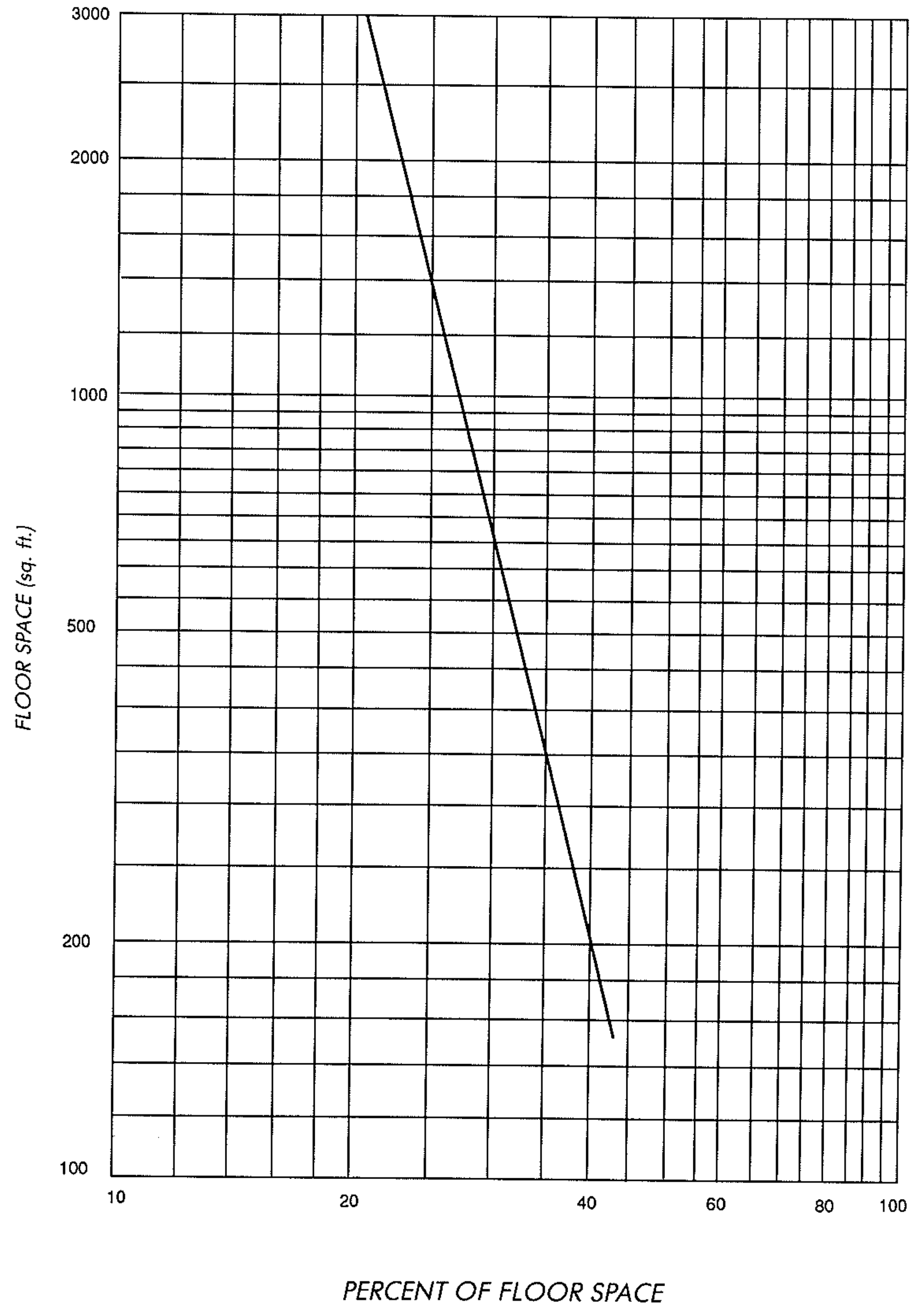
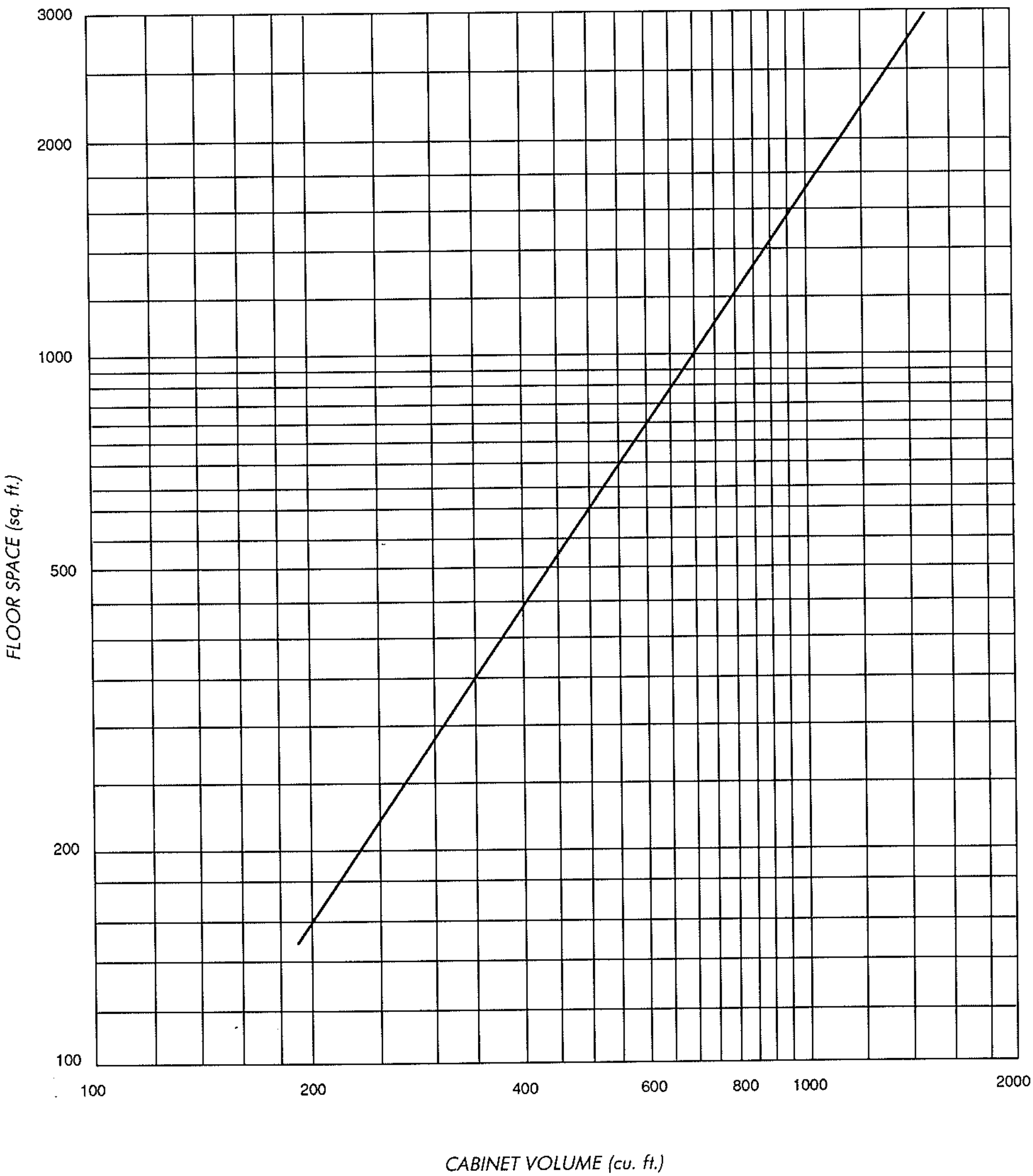


FIGURE 5

RECOMMENDED LABORATORY CABINET VOLUME

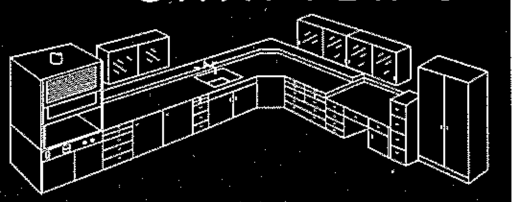


with high resistance to acids and alkalis and a pleasing appearance. It is, however, attacked by organic solvents. Asphalt tile is less suitable as it can be affected by solvents, water, and heavy equipment. Such coverings as terrazzo and quarry or vitreous tiles tend to be cold, hard, and noisy as well as expensive. Terrazzo is also attacked by acids. Quarry and vitreous tiles are chemically resistant and are available in a range of colors which can soften their appearance. Hardwood floors are well suited for laboratory use when properly treated and cared for. Carpet should only be used in offices and other areas which will not be subjected to chemical or physical abuse.

WALLS AND CEILINGS

The primary considerations for laboratory walls are that they should have a slow flame-spread characteristic, be smooth and readily cleaned, and not have any ledges that would form dust traps. Wall materials or coatings should also be chemically resistant and easily cleaned. A gloss surface is more readily cleaned and disinfected than is a matte finish, but the gloss surface may produce more glare, resulting in possible discomfort for laboratory personnel. Alkyd resin paint is a suitable finish for most laboratory purposes, although polyurethane may be used where an extremely tough finish is needed. Ceramic tile is chemically resistant and readily cleaned, but has poor accoustical properties and may also produce glare. White or light, neutral colors should be used so as not to interfere with color observations and to augment illumination. Ceilings should be white or light colored and be sound absorbing. Many laboratory instruments produce noise which can interfere with an analyst's concentration and can be quite tiring over a period of time. Sound absorbing materials in the ceiling can help decrease distracting noise.

CHAPTER 5



FURNISHINGS

The furnishings provided in a laboratory and where these furnishings are located have a considerable effect on the quality and quantity of work performed. Furnishings considered in this chapter include bench tops and work surfaces, balance and instrument tables, base units and storage cases, sinks and drains, fume hoods, and emergency showers and eyewashes.

LABORATORY BENCHES

Benches are the most important work areas in a laboratory. They can combine all the functions of work tables, storage cabinets, drawers, and desks. They can be in wall, island, or peninsular arrangements. Benches are usually set at a height of 36 to 37 in. for standing work and 30 to 31 in. for seated work. Where the lower height is used, an empty space or "kneehole" should be left beneath the bench top for convenient seating. Kneeholes should not be less than 2 ft. wide and generally not more than 3.5 ft. Where work is to be done from one side only, benches may be either 24 or 30 in. deep. The 30-in. depth is necessary wherever service lines are to follow the bench, either behind the cabinet units or in a pipe run above the bench top. The 30-in. style can also incorporate a reagent rack, which is normally about 8 in. deep and 5 in. high, at the back of the bench. This is recommended for safe and convenient placement of commonly used reagents. If a reagent rack is not part of the bench design, a backsplash of at least 4 in. should be included. Benches to be used from both sides are commonly 54 in. deep, which includes space for a utility run down the middle of the bench.

BENCH LOCATION

Benches and other work areas should be located so they are readily accessible and with sufficient aisle space between them to permit convenient movement of laboratory carts and large pieces of equipment. Minimum aisle space where analysts will be working at a bench on only one side of the aisle should be about 4 ft. A more reasonable allowance would be an aisle in the range of 4.5 to 5 ft. Where work will be performed by analysts working back to back at benches on both sides of the aisle, the aisle should be at least 4.5 and preferably as much as 5.5 ft. wide. For more specific recommendations on aisle space between benches, see Table 4.

The ergonomics of various recommended bench and aisle dimensions are illustrated in Figure 6.

BENCH CONSTRUCTION

Bench tops should be at least 1 in. thick and have no less than a 1 in. overhang on all exposed sides. Exposed edges should also be provided with a drip guard in the form of a groove cut just inside the under edge, or be provided with a lip on the forward edge to retain spilled liquids. Bench tops should be nonporous and resistant to chemical attack, physical abuse, heat, and staining. Cast epoxy resin is excellent for this purpose, although it is also relatively expensive. A good general use material for most laboratories is the cheaper epoxy resin coated or impregnated asbestos cement. Plastic veneers, ceramic surfaces, uncoated asbestos cement, and other materials are generally not practical for water or wastewater laboratory bench tops except in specific cases where a bench is to be limited to special uses. Plastic veneers, for example, may be satisfactory in areas to be used solely for bacteriological analyses. Bench top sections should be joined by chemically resistant cements which are at least as strong as the tops themselves. Laboratory desks or writing surfaces may adjoin sections of bench and be surfaced with bench top materials for more flexible use. Utility tables can be easily moved and make use of otherwise empty floor space. They should be sturdy enough for heavy equipment, surfaced with bench top materials, and have levellers in each leg.

BALANCE TABLES

Separate tables should be used for balances and other instruments which are sensitive to vibration. These tables should be free-standing and of heavy construction to minimize the effects of vibration conducted through the walls or floor. The slab surface of such a table should be insulated by a layer of cork, neoprene, rubber, or similar nonskid material. It may also be necessary to insulate the table legs from direct contact with the floor through the use of cork and lead sandwiches, rubber pads, or other antivibration devices. For the most sensitive microbalances and other equipment, the work surface may be supported by a specially designed brick column resting on an independent foundation. Commercial balance tables are adequate, however, for most analytical balances. Balance tables should be located away from windows and other sources of direct sunlight. They should also be placed away from doors and other centers of traffic and should not be located near outside walls or similar areas of temperature fluctuation and air currents. In large laboratories, it may be desirable to provide a separate room for conducting analytical weighings.

TABLE 4 — *AISLE SPACE BETWEEN BENCHES*

PHYSICAL ARRANGEMENT	OPTIMUM AISLE WIDTH	MINIMUM AISLE WIDTH
Aisle with no persons working on either side	4 ft.	3 ft.
Aisle with one person working on one side only	4 ft.	3.25 ft.
Aisle with a fume hood or similar apparatus on one side involving occasional use	4 ft.	3.5 ft.
Aisle with a person on either side working back to back	5.5 ft.	4.5 ft.

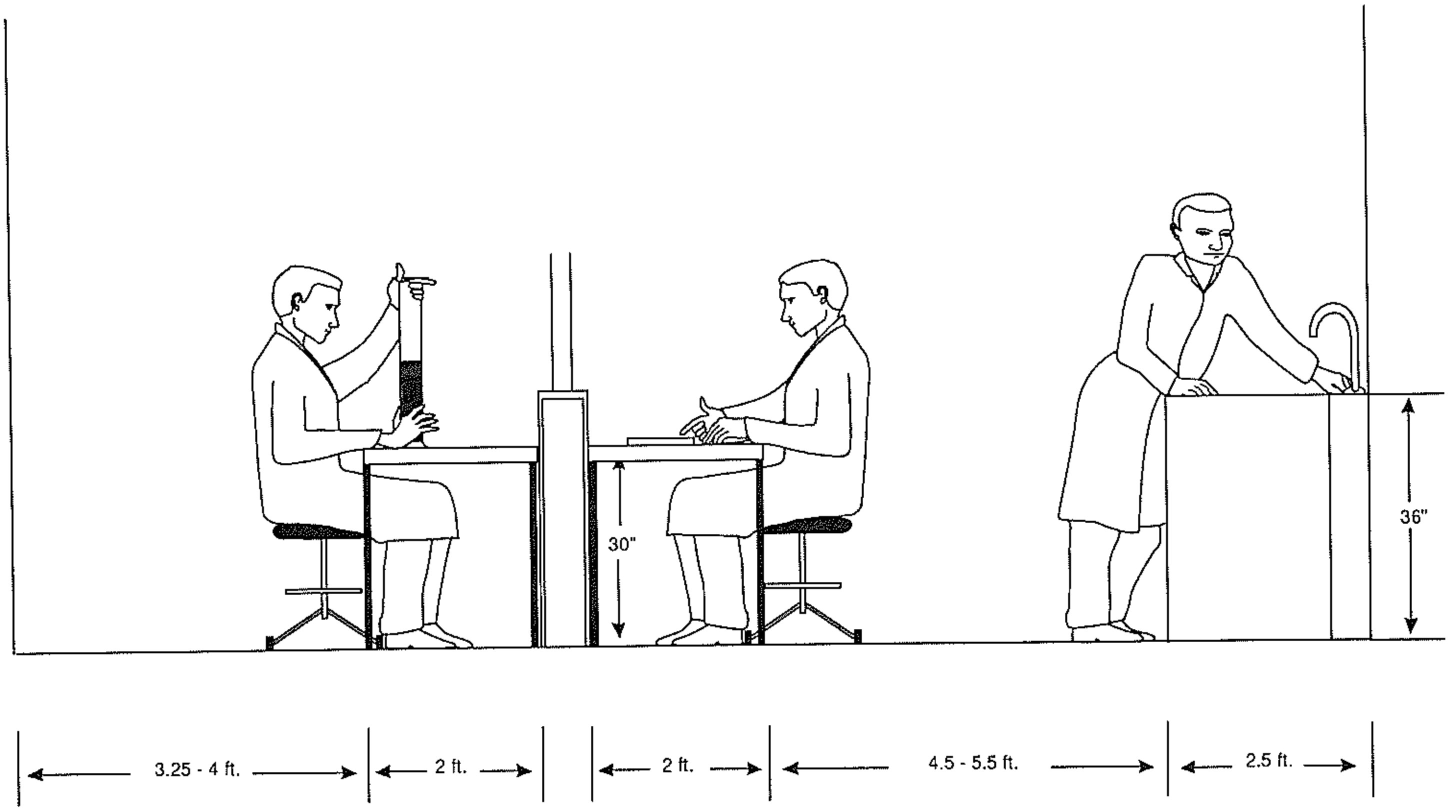


FIGURE 6
ERGONOMICS OF LABORATORY DIMENSIONS

BASE UNITS

A wide variety of base units are available for installation under bench tops (see Figure 7). Each unit should be independent and readily relocated. Adjacent units should be joined with concealed fasteners and should form a congruent whole. Each unit should have leveling screw adjusters and be provided with cove base moldings. At least one cupboard style cabinet should be provided per fulltime person for storing large or bulky pieces of equipment. In general, however, more of the base units should be drawer cabinets than cupboards. Several sizes of drawers should be provided, including one at least 3 ft. wide for burets and other long pieces of glassware.

UNIT CONSTRUCTION

Drawers should slide out so that their contents are readily visible. Rubber bumpers should be provided, as should stops to prevent the drawers from being accidently pulled free. The drawers should roll easily in adjustable steel channels and be supported by nylon rollers or ball bearings. Metal drawer fronts and cabinet doors should be of double wall construction and be sound deadened. Cabinet shelves should be adjustable and coated for resistance to chemicals and abrasion. Metal base units should be constructed of heavy-gauge cold-rolled prime steel. Drawers, doors, and shelves should be at least 18- to 20-guage steel. Welded joints should be ground flush with adjacent material and neatly polished. No bolts, screws, rivet heads, or fasteners of any kind should be visible on any exposed surface. All metal surfaces should receive a corrosion resistant coating after fabrication. Wood base units should be treated to resist chemical attack and physical abuse and be sealed to prevent damage by water.

OTHER UNITS

Under-the-counter refrigerators, freezers, incubators, and glassware washers can be substituted for cabinet base units where needed. This size refrigerator is particularly suited to the needs of very small laboratories, although larger laboratories will require full-size, free-standing refrigerators. Incubators of this kind are practical for BOD and bacteriological analyses in small laboratories. Freezers and glassware washers should also be installed in larger laboratories, but are optional for small facilities.

STORAGE CASES

Wall mounted storage cases should be positioned with care. If they are hung too low or extend too far over the bench top, they may interfere with work in that area. If they are hung too high, the top shelves may become dead space, out of convenient reach. Cases with sliding doors are recommended as these will not interfere with work at the bench when opened. Glass doors are recommended for their visibility of stored material. Where space permits, free-standing storage cases can also be used. These are particularly well-suited for chemical stocks, spare equipment, and other items that are either used infrequently or should be stored separately.

SINK LOCATION

The number of sinks which should be provided in a laboratory is often a matter of some controversy. Work may be seriously hampered in a laboratory which has an insufficient number of sinks. On the other hand, too many sinks can break up work areas and reduce the amount of available bench surface. A rule of thumb is to provide one sink for each work area such that an analyst can have access to it without moving far from his working position. This rule can be modified, however, depending upon the anticipated uses of the sinks. Sinks serve a variety of purposes, including sources of water for cooling systems and analytical uses, disposal sites for waste reagents, and as places for washing glassware and cleaning up. Where centralized cleaning facilities are available, the number of full size sinks can be reduced and other needs met through the use of auxillary cup sinks and troughs. Peninsular benches fitted with a large sink across the end of each unit and with cup sinks or disposal troughs down the center may be adequate for most situations. At least one double-basined sink with drainboards should be available in each room or major work area for washing purposes.

SINK CONSTRUCTION

Sinks should be highly resistant to attack by acids, alkalies, solvents, and salts as well as able to withstand physical and thermal shock. Epoxy resin and polypropylene are suitable for most laboratory sinks and troughs. Cup sinks may also be made of polyethylene. Stainless steel has many desirable characteristics for sinks, including that it is kind to glassware, but it is attacked by acids. Sinks should be fitted below the bench top with the top overhanging. A drip groove should be cut around the edge of the overhang to prevent water buildup along the seal. Particular attention should be given to the seal to ensure that it is tight and resistant to chemical attack. Reversible plugs can be fitted in waste outlets to avoid heavy wear on sinks. This allows a thin layer of water to remain in the sink which will dilute any corrosive wastes dumped in for disposal. It also helps prevent splashing from the taps.

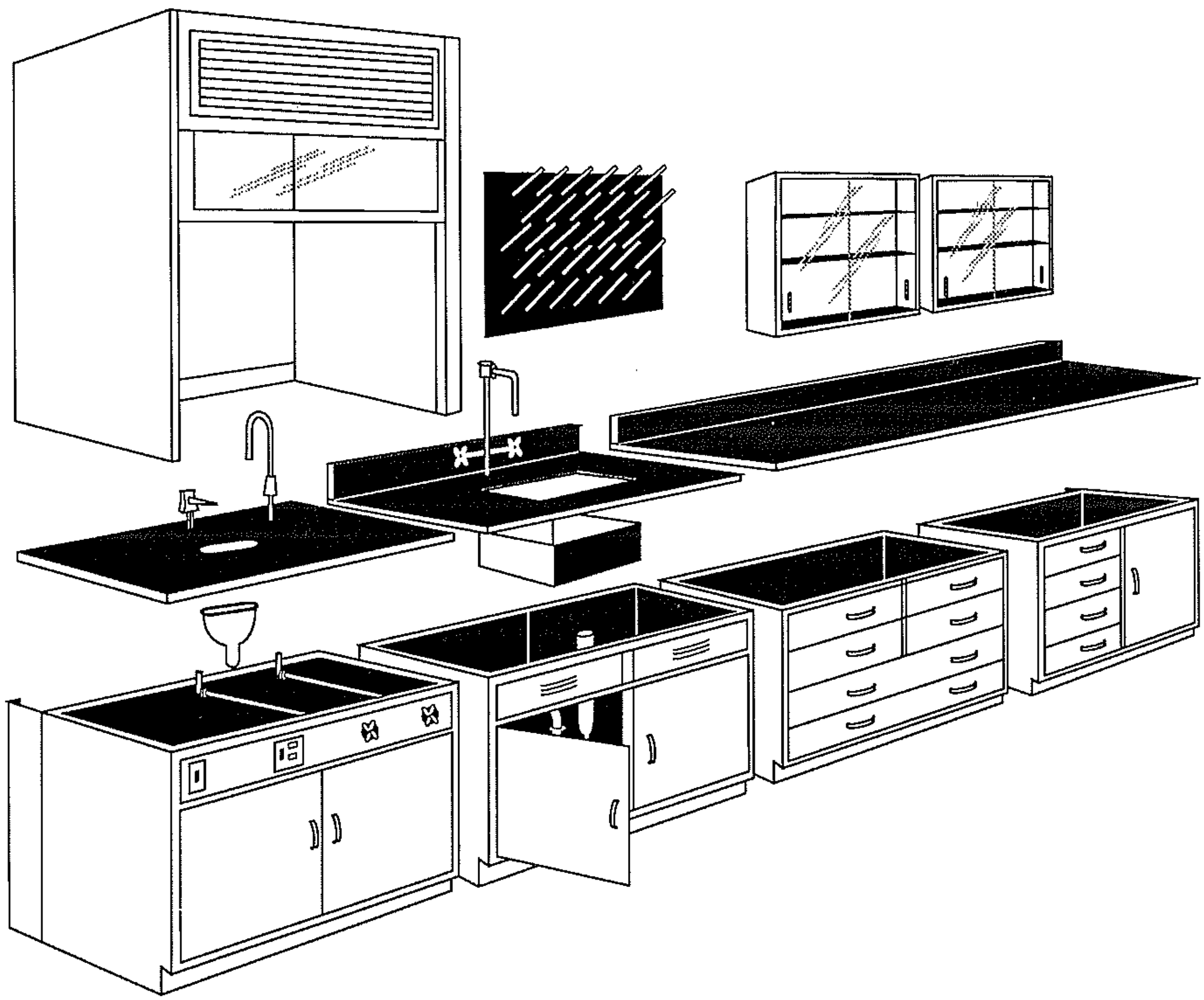


FIGURE 7
TYPICAL LABORATORY FURNITURE COMPONENTS

TRAPS AND DRAINS

Normal "S" bend traps are not advisable for laboratory purposes as they may be attacked by corrosive wastes and cannot be readily inspected and cleaned. Sinks subjected to normal use may be fitted with traps of polythene or similar material. The type with a visual glass base is particularly good. For sinks or troughs where chemical wastes requiring dilution are to be disposed, catch pot recovery traps and diluting receivers are recommended. These completely enclose the effluent, preventing the escape of fumes and smells.

Drainage systems must be capable of withstanding the effects of any wastes they might receive. They should also be of sufficient width to permit the small objects or glass fragments which occasionally find their way into the system to pass without causing blockages. Polythene, polypropylene, and borosilicate glass are widely used and are satisfactory for most purposes. Polythene and polypropylene have the advantage of being flexible and easily worked during installation, but glass permits blockages to be easily detected. In general, materials used in conventional plumbing systems should be avoided for laboratory uses.

FUME HOOD LOCATION

Fume hoods prevent the release of hazardous or noxious fumes, dusts, and gases into the laboratory. The functioning of typical fume hoods is illustrated in Figure 8. All laboratory facilities should possess at least one fume hood, with the possible exception of laboratories serving water or wastewater treatment systems of less than 0.1 MGD. Laboratories larger than about 1500 to 2000 sq. ft. should have at least two hoods.

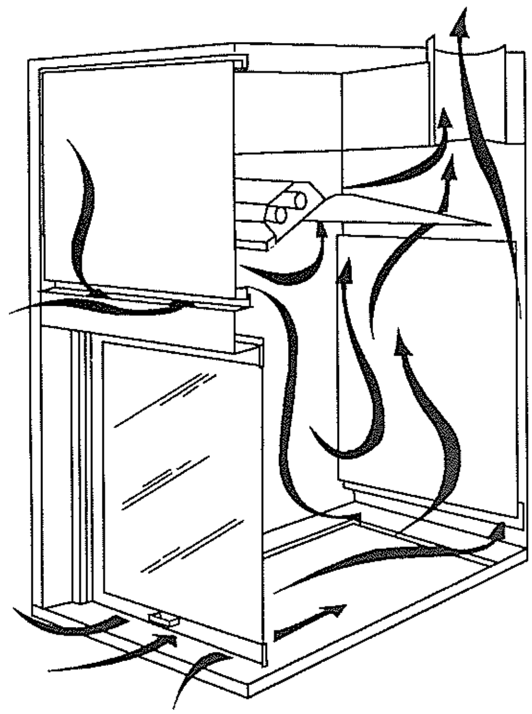
Fume hoods must be located away from disturbances and air currents which might affect air flow across the face of the hood. A person merely walking past an open hood face may create currents sufficient to pull hazardous fumes from the hood into the laboratory environment. Hoods should therefore be placed away from doorways, opening windows, and ventilation outlets. They should also be located such that an explosion or fire in a hood cannot block all means of exit for analysts working to either side. In addition, bench surface should be available near the hood for convenient use of chemicals and equipment.

HOOD CONSTRUCTION

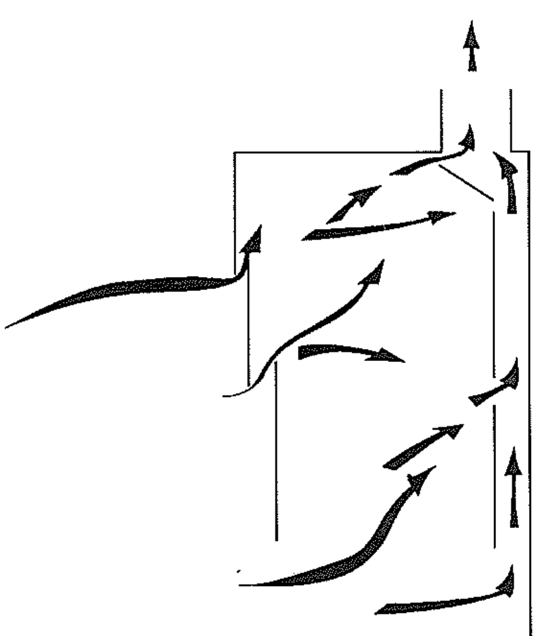
A minimum width of 4 ft. is suggested for fume hoods. Hoods of shorter width may not be large enough for the apparatus used in some procedures. A counter-balanced sash should be provided in the face of the hood for maximum protection of laboratory personnel. Each hood should have a bypass system so the air velocity across the face will remain unchanged with different sash positions (see Figure 8). An auxillary air system is recommended as well to reduce the amount of conditioned air exhausted from the laboratory. Baffles should be provided inside the hood to decrease turbulence and to prevent air from bouncing out of the hood. Air flow across the face of the hood should be 100 ft./min., regardless of sash position.

Hood materials must be highly durable to withstand corrosion and chemical attack. Cast epoxy or epoxy coated asbestos cement are suitable bench top materials for fume hood use. The hood itself should be either asbestos cement or fiberglass. Ducts should be constructed of materials such as asbestos cement, PVC, polythene, or polypropylene. The ducts should be as straight and short as possible to avoid

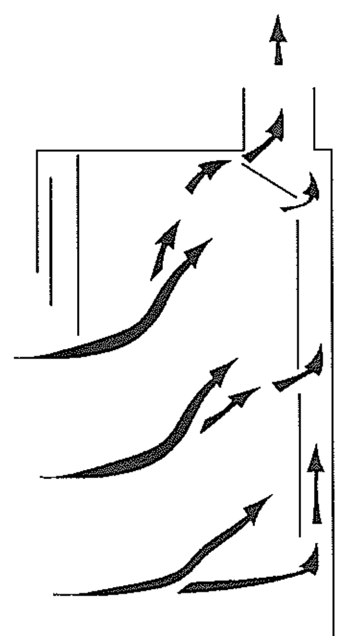
FIGURE 8
FUNCTIONING OF A TYPICAL FUME HOOD



SASH CLOSED; BY-PASS OPEN



SASH PARTIALLY RAISED



SASH FULLY RAISED

pressure changes in the system. Fans should also be constructed of highly resistant materials and the motors should be completely sealed off from the impeller housings to prevent fumes from coming into contact with the motors.

HOOD FIXTURES

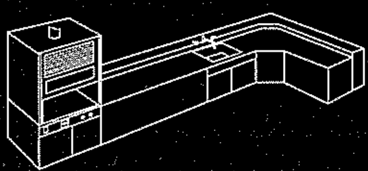
Each hood should be provided with a gooseneck water outlet, cup sink, gas outlet, two electrical outlets, and interior lighting. The light fixtures should be explosion proof, as should the exhaust fan. All switches, electrical outlets, and water and gas outlet controls should be located outside the hood. Hoods should be capable of 24-hour continuous exhaust and should be equipped with an alarm system to signal exhaust fan failure or excessive temperatures.

Where Kjeldahl nitrogen determinations are to be made on a routine basis, special hoods should be installed in which the necks of the flasks are supported in holes cut in the duct itself, allowing fumes to be conducted away directly from the point of liberation.

EMERGENCY SHOWERS AND EYEWASH STATIONS

Because of the high degree of danger from spills and burns in any chemical laboratory, at least one emergency shower and eyewash station should be provided in each major work area. These are available either as separate or combined units. Eyewashes should provide soft, aerated streams of water at a comfortable temperature. Chemical eyewash systems are also available which neutralize the effects of some types of reagents on the eye. Whatever type is chosen, these units should be placed where they are readily accessible by an injured person from any point in the laboratory. Care must be taken to ensure that the splash from an emergency shower will not reach electrical outlets or equipment.

CHAPTER 6



SERVICES AND UTILITIES

The proper functioning of a laboratory depends upon the maintenance of an adequate working environment and provision of essential services and utilities to the point they are needed at the time they are needed. This chapter will consider these aspects of laboratory design.

VENTILATION

Chemical dusts, gases, and fumes can reach obnoxious and even hazardous levels in a laboratory unless adequate ventilation is provided. Although 75 percent air recirculation is common in office buildings, this is unacceptable in a laboratory. On the other hand, "once-through" ventilation systems are excessively expensive and wasteful, and should be used only where absolutely necessary. In general, the air in a water or wastewater laboratory should be changed about four to ten times per hour.

For proper ventilation, it is generally best to introduce air at a low level and extract it at a high level. The entire working area should be cleansed with fresh air and drafts should be avoided. If windows are to be used for ventilation, they should be placed so they will not create drafts or interfere with the use of burners, and they should be designed to deflect incoming air upwards. For mechanical ventilation systems, propeller fans can move large volumes of air against slight resistance and are therefore suitable only for short ducts having no sharp bends. Centrifugal fans, on the other hand, can be used when considerable resistance must be overcome and are particularly suited to removing dusts and fumes. When installing a ventilation system, particular attention should be given to isolating air inlets from exhaust ducts, especially those from fume hoods, to prevent the return of potentially hazardous wastes into the laboratory environment.

HEATING AND COOLING

Heating and cooling may be accomplished either in conjunction with a central ventilation system or independently, depending upon the needs of the particular laboratory supplied. Air conditioning controls air temperature and humidity, but is also expensive. It provides ideal environmental control for many sensitive instruments without having to resort to special rooms for this purpose. Refrigerated air is preferable to evaporative cooling in laboratories due to the lower air turbulence involved. Also, evaporative cooling may introduce airborne contaminants, particularly bacteriological contaminants, into the atmosphere where they may interefere with some analyses.

In planning a cooling system, it should be remembered that much of the equipment used in a laboratory may contribute to the heat load. Routine electronic equipment such as centrifuges, ovens, glassware washers, and computers may produce heat loads equivalent to 2 to 10 watts per square foot of laboratory space, with more sophisticated instruments sometimes exceeding 25 watts per square foot. Under ordinary heat gain conditions, air quantities in institutional laboratories vary from 1.2 to 2.5 CFM (cubic feet per minute) per square foot of space. Excessive heat gain can sometimes be controlled by placing high heat generating equipment in a fume hood, under an exhaust hood, or by placing insulation or a water jacket around the item.

LIGHTING

Good lighting is of paramount importance in a laboratory. A light intensity of 60 to 100 foot candles is recommended at all working surfaces. Windows with a northern exposure provide good natural light. Windows with other geographic orientations may require shades or blinds to reduce direct sunlight in the laboratory, particularly at certain times of the year. Additional light provided artificially should be free of shadows and allow for easy reading of meniscuses, dials, color determinations, and other laboratory observations. A combination of direct and indirect lighting is generally best for high visibility with low eye fatigue. Table 5 indicates how light is distributed from various types of direct and indirect light fixtures, while Figure 9 illustrates three basic arrangements for providing artificial light to the bench surface.

When choosing particular light fixtures, care should be taken to ensure that they are appropriate for the laboratory environment. Metal housings and shades associated with fluorescent lights tend to deteriorate in the corrosive atmospheres common near the ceilings of many laboratories. Consideration should therefore be given to enclosing such lighting fixtures behind glass or plastic troughs. The lighting fixtures should be readily accessible, however, for maintenance and tube replacement.

ELECTRICITY

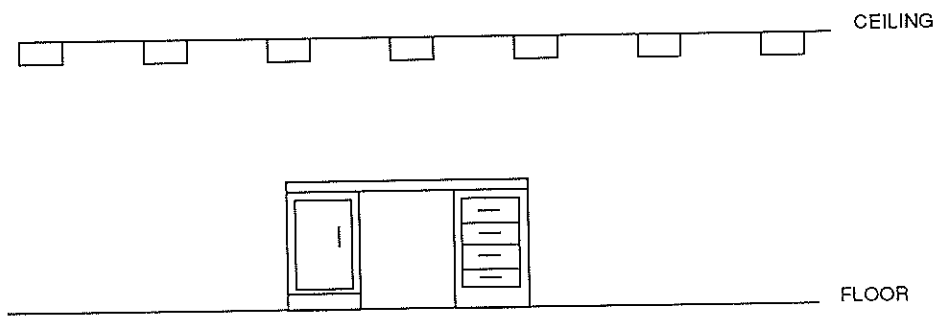
A generous number of electrical outlets should be provided in any laboratory situation. Indeed, it is difficult to imagine a laboratory with too many outlets, particularly when many facilities have replaced gas fixtures in recent years with electrical ones. In general, laboratories should be provided with outlet strips having 115–120 volt sockets spaced at one-foot intervals (or an equivalent density of individual outlets) extending the length of all work areas. Additional outlets wired for 220–240 volts should also be spaced intermittently throughout the laboratory for heavier equipment. Sufficient circuits should be installed to permit simultaneous use of the major laboratory appliances without danger of an overload. All electrical outlets should be located away from water outlets or where they can be affected by liquid splashes and spills.

TABLE 5
LIGHT DISTRIBUTION FROM VARIOUS TYPES OF FIXTURES

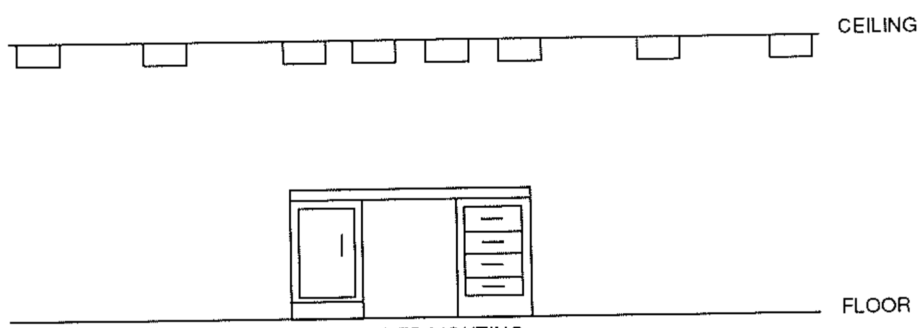
TYPE OF FIXTURE	*PERCENT OF LIGHT DIRECTED UPWARD*	*PERCENT OF LIGHT DIRECTED DOWNWARD*
Direct	0–10	100–90
Semi-direct	10–40	90–60
General diffusing	40–60	60–40
Semi-indirect	60–90	40–10
Indirect	90–100	10–0

FIGURE 9

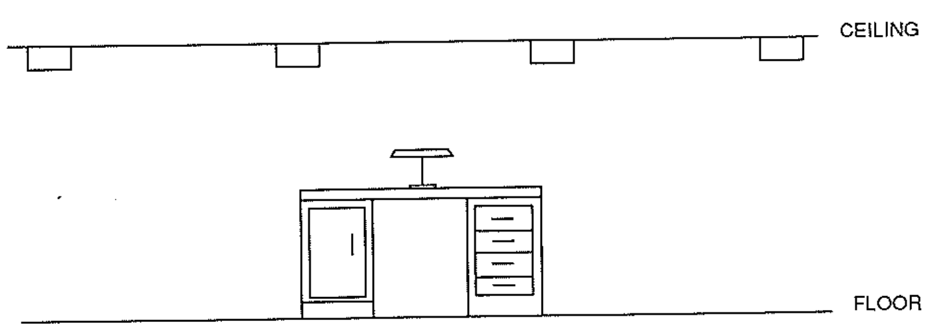
SCHEMATIC DIAGRAMS ILLUSTRATING LIGHTING LAYOUTS



UNIFORM LIGHTING



LOCALIZED LIGHTING



LOCAL LIGHTING

Voltage regulation should be used to eliminate power fluctuations, particularly where sensitive electronic instruments are involved. This can be achieved either through localized regulation for individual pieces of equipment or through regulation of the entire power supply reaching the laboratory. To regulate voltage in electrical lines supplying the laboratory, a constant voltage, harmonic neutralized type of transformer should be used. This transformer should contain less than 3 percent total root mean square (RMS) harmonic content in the output, and should regulate to ± 1 percent for an input range of ± 15 percent of nominal voltage, with an output of 118 volts. Where higher voltages are required, the 240-volt lines should be similarly controlled.

WATER

Water supply is one of the most critical considerations in laboratory design. Both hot and cold tap water should be available in large quantities. The outlets provided should be capable of meeting a variety of supply, cleaning, and cooling needs. The principal outlet at each sink should be a swivel gooseneck with a hose adapter; both hot and cold water should be supplied to this outlet. An auxiliary needle valve outlet of minimal length and aimed directly into the sink may also be provided to leave the main outlet free while the auxiliary outlet is being used with a condenser, deionizer, still, or other apparatus. Such an auxiliary outlet should receive cold water only. All water fixtures with hose adapters should be equipped with vacuum breakers, which prohibit backflow into the water line.

Water pressure should be constant throughout the laboratory despite changes in the number of taps in operation. Water flows which have been calibrated to provide proper cooling for tests in progress must not be affected by turning on additional taps. If the pressure were to drop through such additional use, hazardous overheating situations could be created, possibly leading to fires or explosions. Water pressure should be sufficient to obtain a vacuum with a water pump, but not so great that excessive splashing occurs at sinks. Care must be taken to ensure constant water pressure throughout multi-story buildings. The recommended pressure for a water pump is 50 lb/sq. in. Water service should therefore be maintained at this pressure ± 10 lb/sq. in.

ADDITIONAL PIPED SERVICES

In larger facilities, it may be appropriate to pipe additional services such as distilled or deionized water, gas, vacuum, or compressed air to work areas from a central source. The need for each of these services should be carefully estimated during the design stage because of the considerable additional investment required to provide each of these services. If distilled or deionzed water is piped to bench areas, it should be supplied through polyethylene or glass tubing to protect its purity. Even then, such water may not be suitable for certain uses.

APPENDIX A DESIGN APPLICATIONS

The following examples demonstrate how the various criteria presented in this handbook are to be applied in actual laboratory design. The laboratories shown represent example designs from each end of the recommended laboratory size scale presented in Figure 2; the emphasis, however, is on designs from the smaller end of the scale. This is because the relative lack of analytical training among most treatment plant operators leaves them largely unprepared to handle matters of laboratory design. The trained, professional analysts found in larger water and wastewater plants, on the other hand, are better qualified to determine the specific analytical needs of their particular treatment facilities, and to apply the recommendations contained in this handbook to meeting those needs.

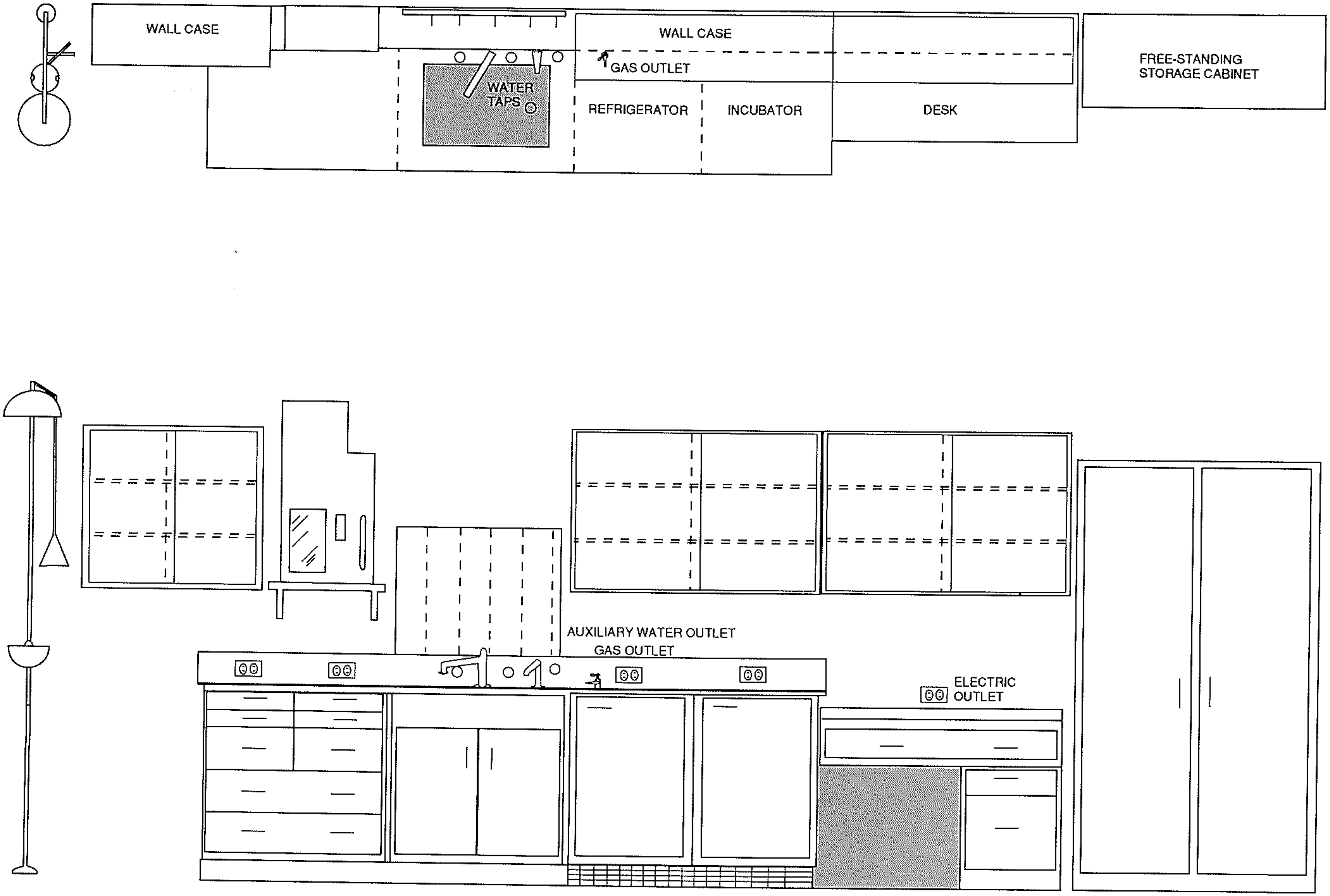
The designs shown represent example laboratories with floor spaces of approximately 150 sq. ft. (Laboratory A), 200 sq. ft. (Laboratory B), 300 sq. ft. (Laboratory C), and 2,100 sq. ft. (Laboratory D).

LABORATORY A

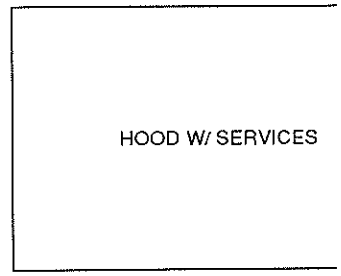
This design represents the smallest acceptable size (150 sq. ft.) for a fully functional water or wastewater laboratory. It is appropriate for treatment plants in the range of about 0.1 to 1.0 MGD where an operator will devote approximately quarter-time to laboratory testing. Because of its small size, the laboratory is designed to occupy a portion of a larger treatment plant office and administrative area. It includes 14 linear feet of bench space, for a total bench area of 33 sq. ft. (22 percent of the total or gross floor space; 52 percent of the net or analytical floor space). Cabinet storage volume is about 120 cu. ft., although additional storage space could be provided if necessary from the centralized administrative area of which the laboratory is part.

The design includes an emergency shower-eyewash station, a standing height bench area with services, various types of cabinet storage, a desk, and one each under-the-counter refrigerator and incubator. Services include two potable water outlets (one main gooseneck outlet and one smaller auxiliary outlet, each with vacuum breakers), five double-socket 115–120 volt electrical outlets, one gas outlet, and one sink. Also shown is a still for providing reagent grade water, although with a facility of this small size it might be better to to obtain distilled or deionized water commercially. A pegboard for drying glassware is also shown mounted between the still and the bench above the sink.

The desk should be constructed of the same materials as the rest of the bench and should have a backsplash at the rear, enabling it to be used for seated analytical work in addition to its normal functions, if necessary. At least one letter-size file drawer should be included in the desk for storing laboratory records and reports. Particular attention should be paid to the lighting above the bench and desk to ensure that it is nonglaring and adequate for close work.



LABORATORY A SCALE 1/2" = 1'0"



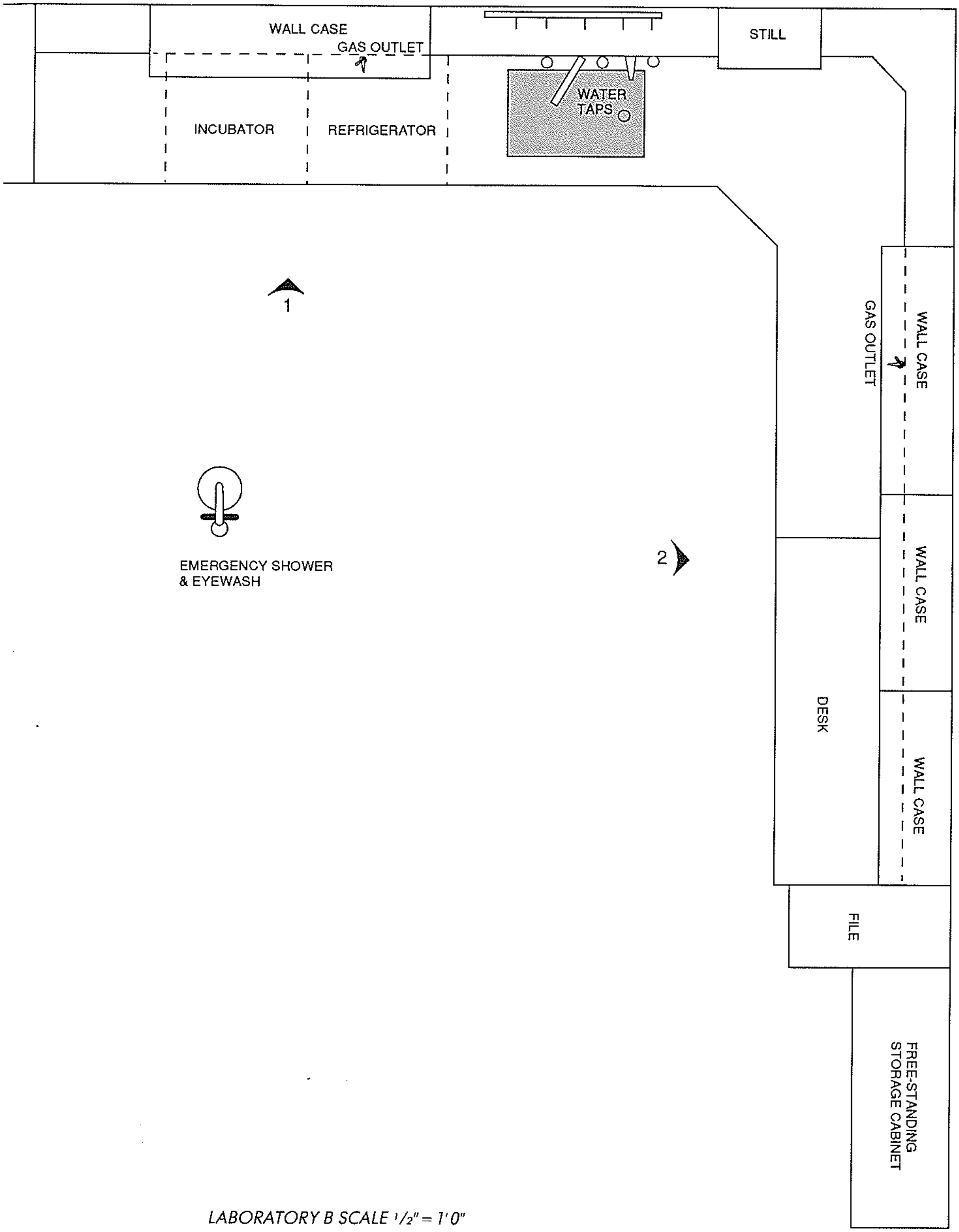
LABORATORY B

A somewhat larger (approximately 200 sq. ft.), more versatile laboratory is represented in this design, although it also is intended to occupy a portion of a larger treatment plant office and administrative area. Like the first design, this one is also suitable for treatment plants in the range of 0.1 to 1.0 MGD, but where an operator will devote approximately half-time to laboratory testing. The laboratory provides about 28 linear feet of bench surface, for a total bench area of 70 sq. ft. (35 percent of the gross or total floor space; 61 percent of the net or analytical floor space). It also includes approximately 200 cu. ft. of cabinet storage volume.

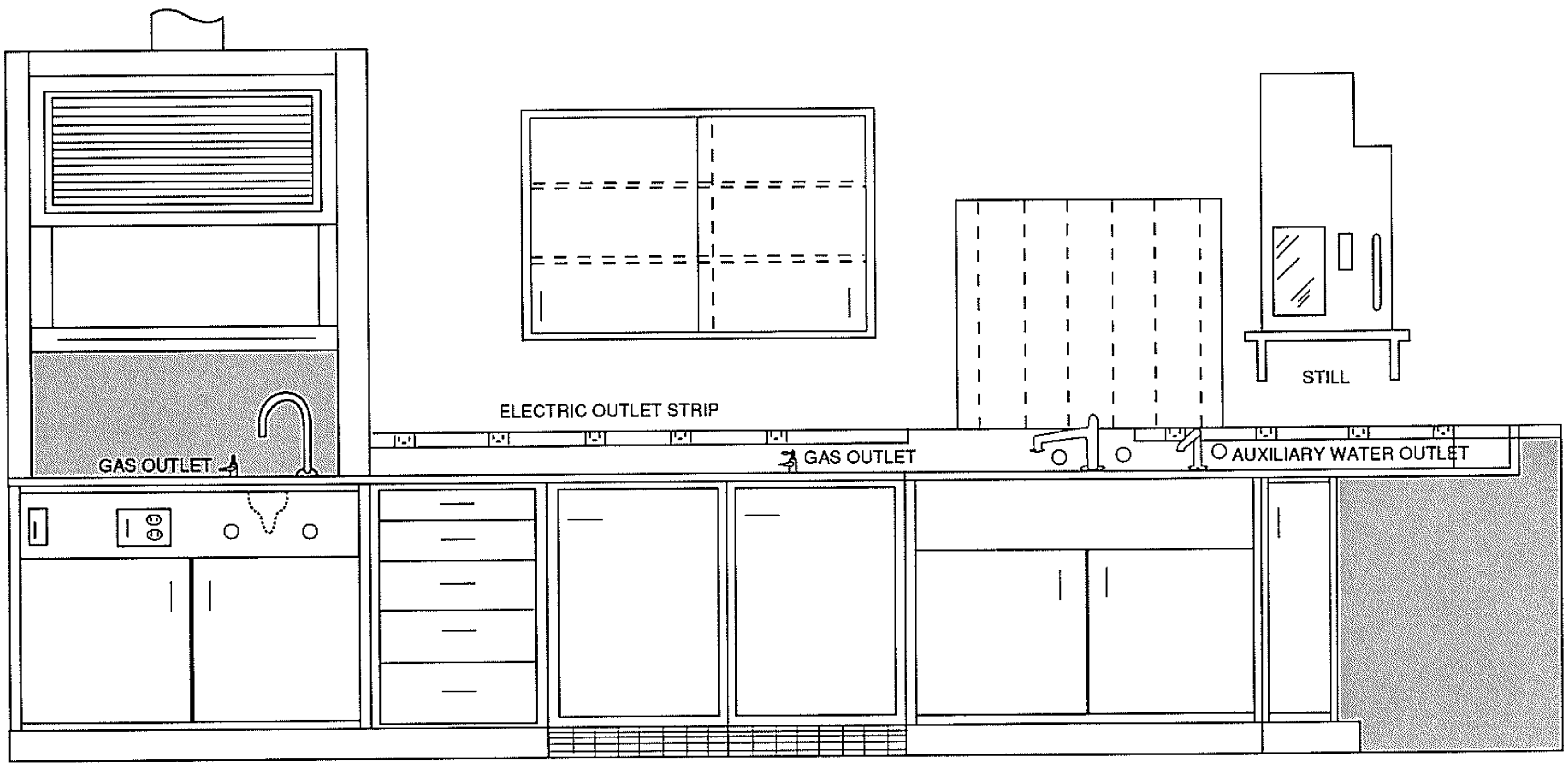
The fume hood indicated in the design would be provided with a counter-balanced sash with window, a cup sink and gooseneck water outlet, a gas outlet, an external set of electrical controls, and external mounting of all other controls. An under-the-counter refrigerator and similar incubator are shown between the hood and sink. The water spigot at the main sink includes a vacuum breaker to prevent back-siphoning. The desk would be surfaced with the same material as the rest of the bench and would be provided with a backsplash at the rear, enabling it to be used for seated analytical work in addition to its normal functions. The laboratory also includes an emergency shower-eyewash unit in an easily accessible location near the fume hood, a couple of gas outlets to the rear of the bench area, and electrical outlets spaced regularly along the length of the bench.

The design emphasizes compactness and flexibility. While all of the essential laboratory operations illustrated in Figure 3 are incorporated into the design, the laboratory is arranged to enable a single individual to carry them out within the one area. The design is not conducive to performing specialized analyses, but rather it offers the general capabilities required of relatively small water and wastewater systems. Its basic applications would be plant operational control and compliance monitoring.

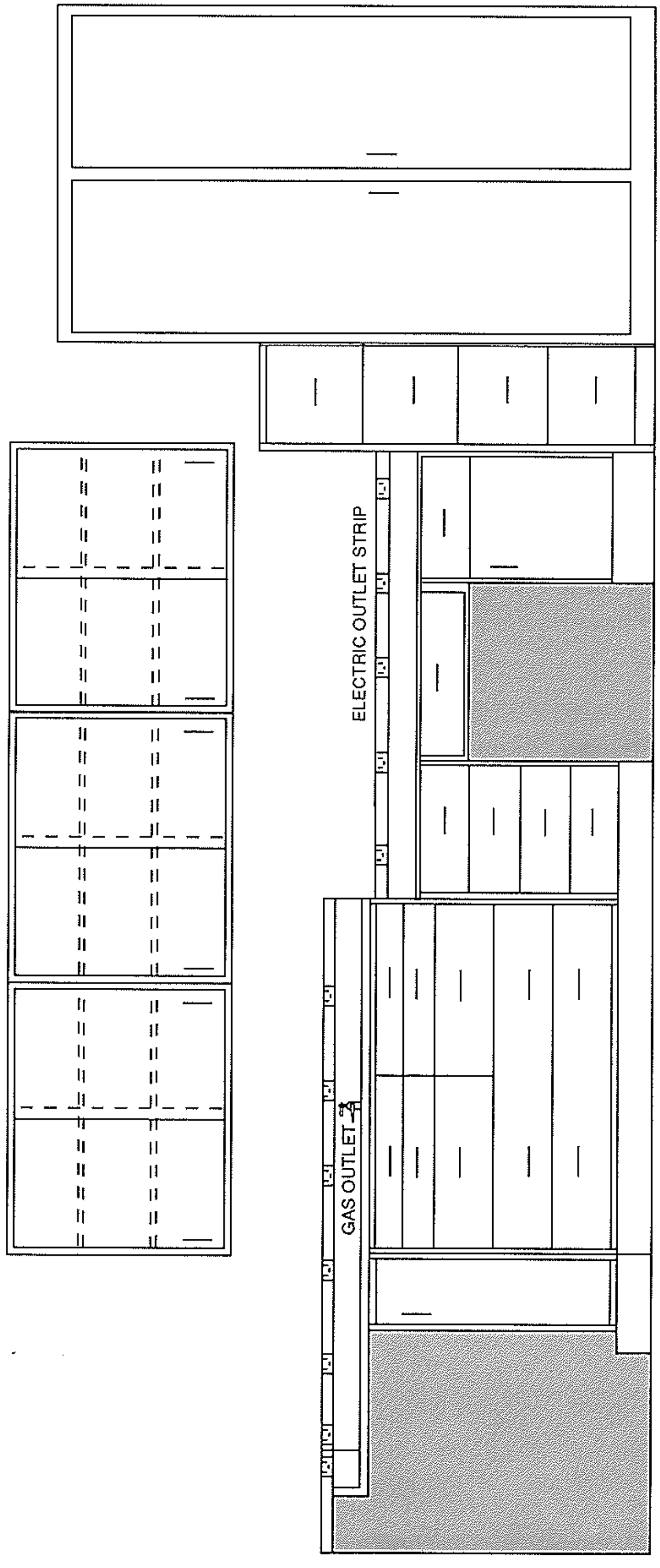
This laboratory design can readily be expanded to about 250 sq. ft. by adding a couple of laboratory tables parallel to the bench area containing the hood and sink, and placed about 5 ft. away. This would bring the total bench surface to about 85 sq. ft. (34 percent of the gross floor space; 52 percent of the net floor space). If desired, electrical power could be supplied to the table by outlets suspended from the ceiling. Greater utility would be provided by using an island bench installation in place of the tables. This would enable full services, including one or two cup sinks (or even one full-size sink), to be supplied to the island, and would also increase the total laboratory cabinet storage volume to a level more appropriate for a facility with this amount of floor space.



LABORATORY B SCALE 1/2" = 1' 0"



LABORATORY B VIEW 1 SCALE 1/2" = 1'0"



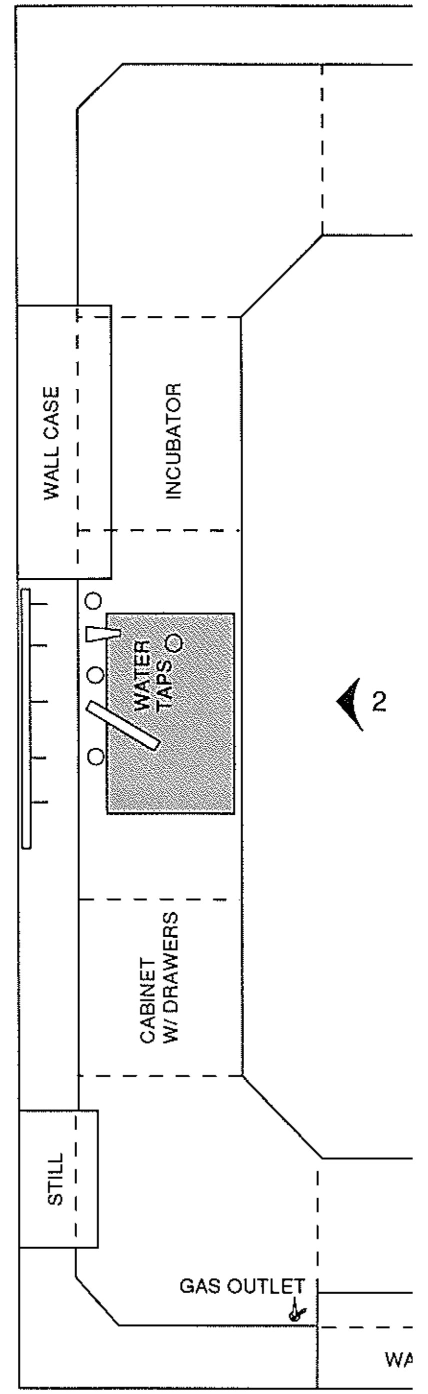
LABORATORY B VIEW 2 SCALE 1/2" = 1'0"

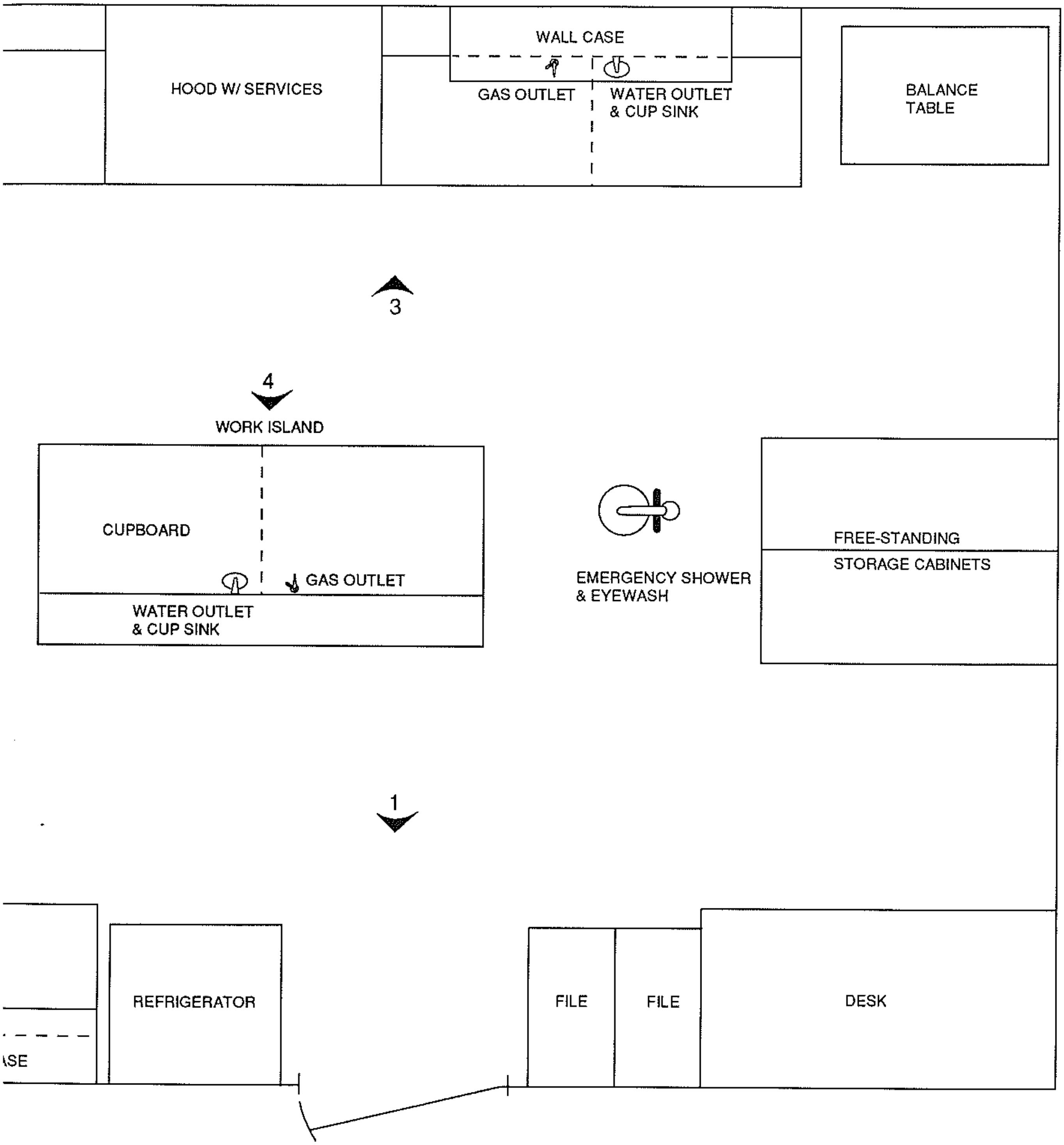
LABORATORY C

The laboratory in this design occupies its own room, measuring 15 by 20 ft. With a resulting gross floor space of 300 sq. ft. and about 200 sq. ft. of net or analytical space, this laboratory represents the minimum size acceptable for one individual working full-time, or two part-time individuals working in the laboratory at the same time. It is appropriate for plants in the range of about 1 to 5 MGD, depending on the specific treatment process used and the degree of complexity imposed by other factors, such as the presence or absence of industrial wastes or unusual source water contaminants.

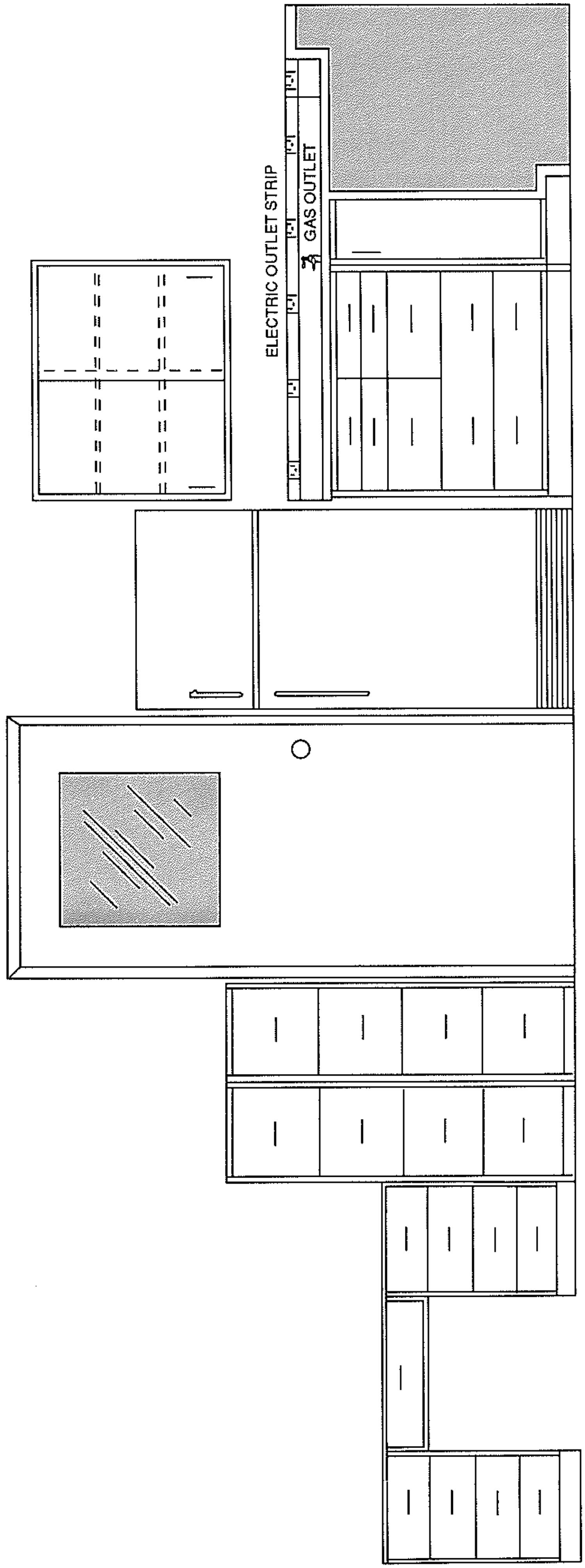
The laboratory in this design has about 43 linear feet of work space, for a total of about 107 sq. ft. of work surface (36 percent of the gross floor space; 54 percent of the net floor space), and 340 cu. ft. of cabinet storage volume.

The hood and the balance table are each located as far from the doorway and other sources of traffic as possible to minimize air currents and distractions. The emergency shower and eyewash station is readily accessible from all points in the room. The under-the-counter refrigerator used in the previous two designs has been replaced by a full-size floor model in order to handle a larger volume of samples and reagents. This refrigerator should also include a separate freezer compartment for extended sample storage. The under-the-counter incubator would be either for BOD or for total coliform incubation, depending upon the application of the laboratory. The number of water outlets has been extended through the addition of two cup sinks and gooseneck faucets, one along a wall and the other on the island work space. Storage has been increased by providing two free-standing double-doored cabinets back-to-back at one end of the room.

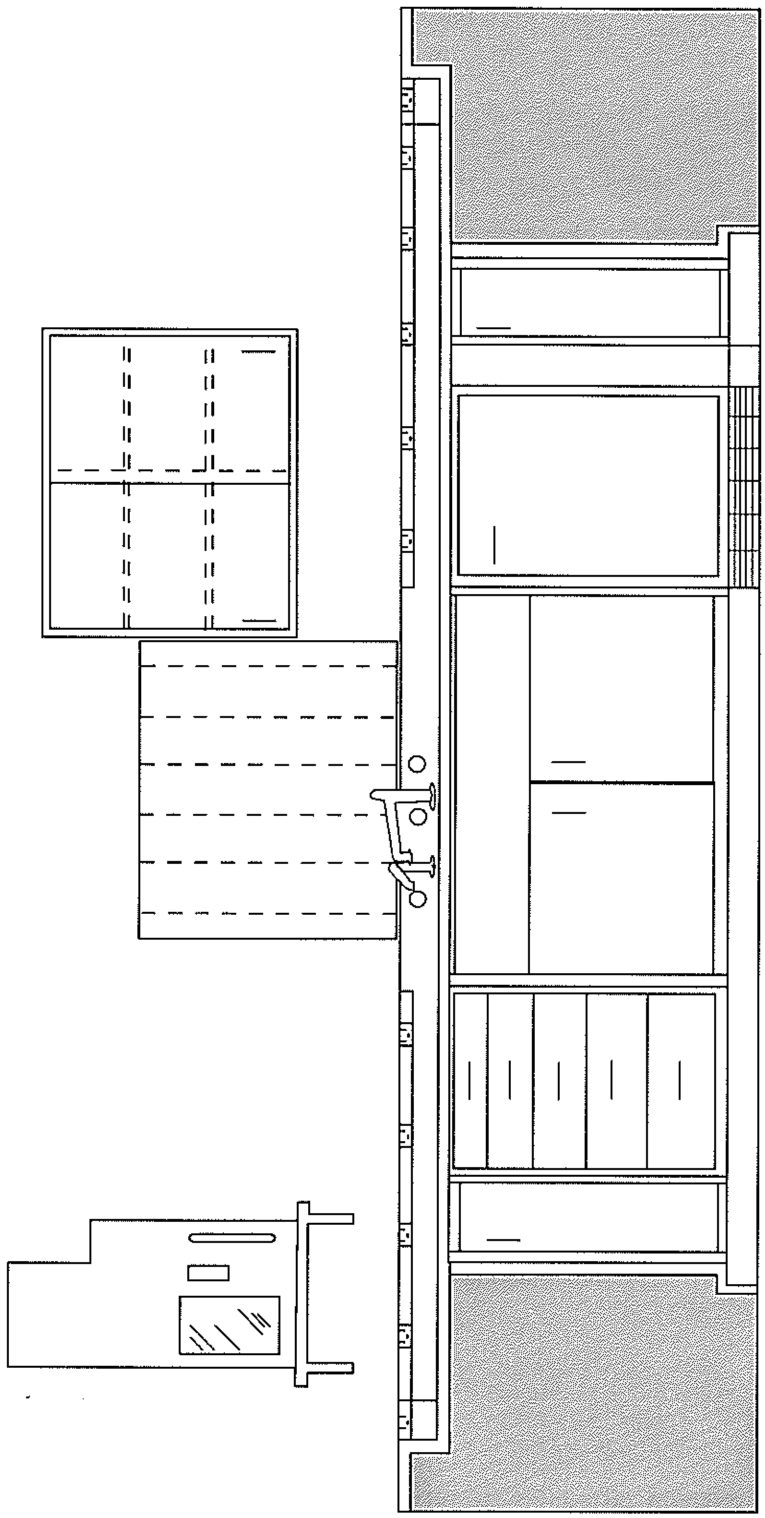




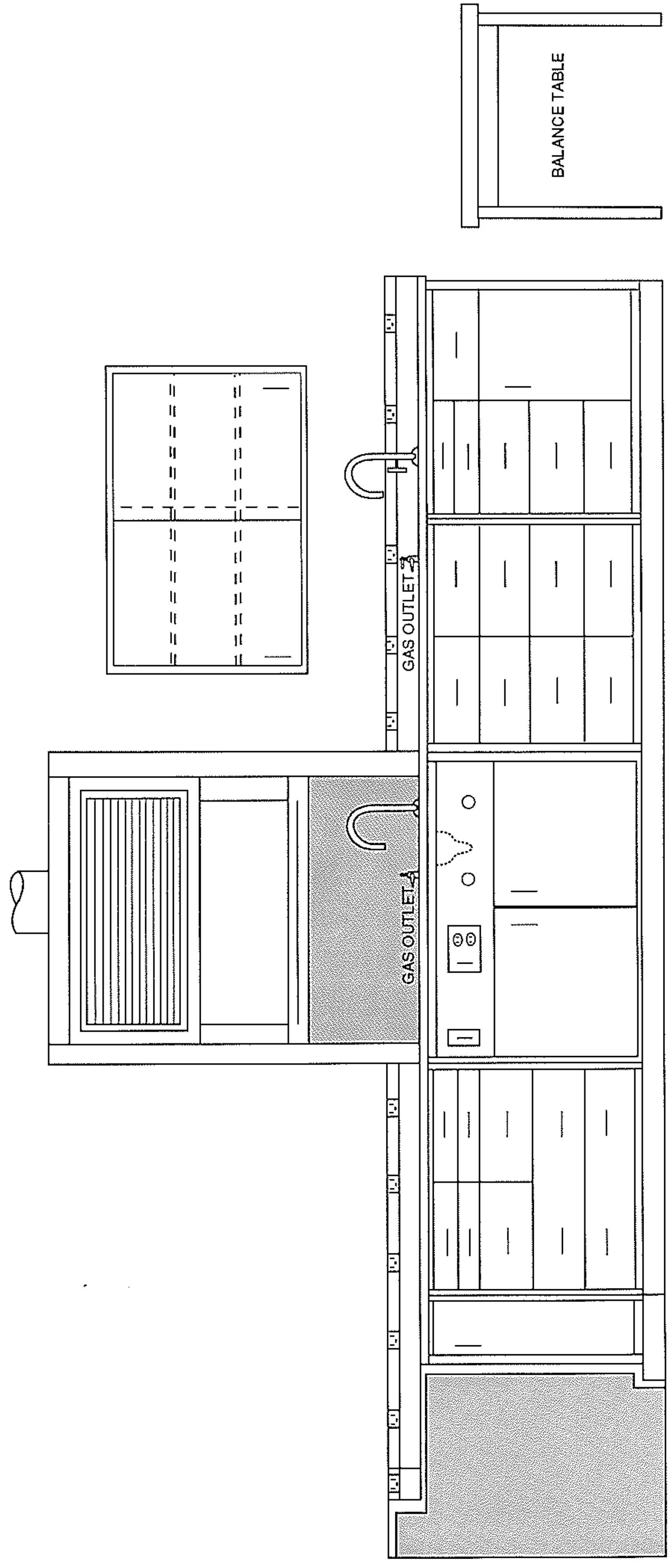
LABORATORY C SCALE 1/2" = 1' 0"



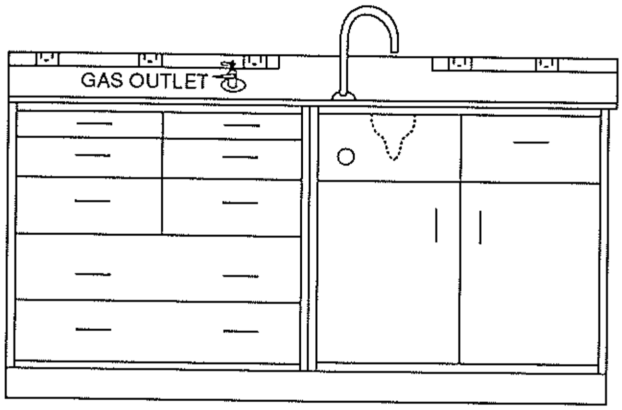
LABORATORY C VIEW 1 SCALE 1/2" = 1'0"



LABORATORY C VIEW 2 SCALE 1/2" = 1'0"



LABORATORY C VIEW 3 SCALE 1/2" = 1'0"



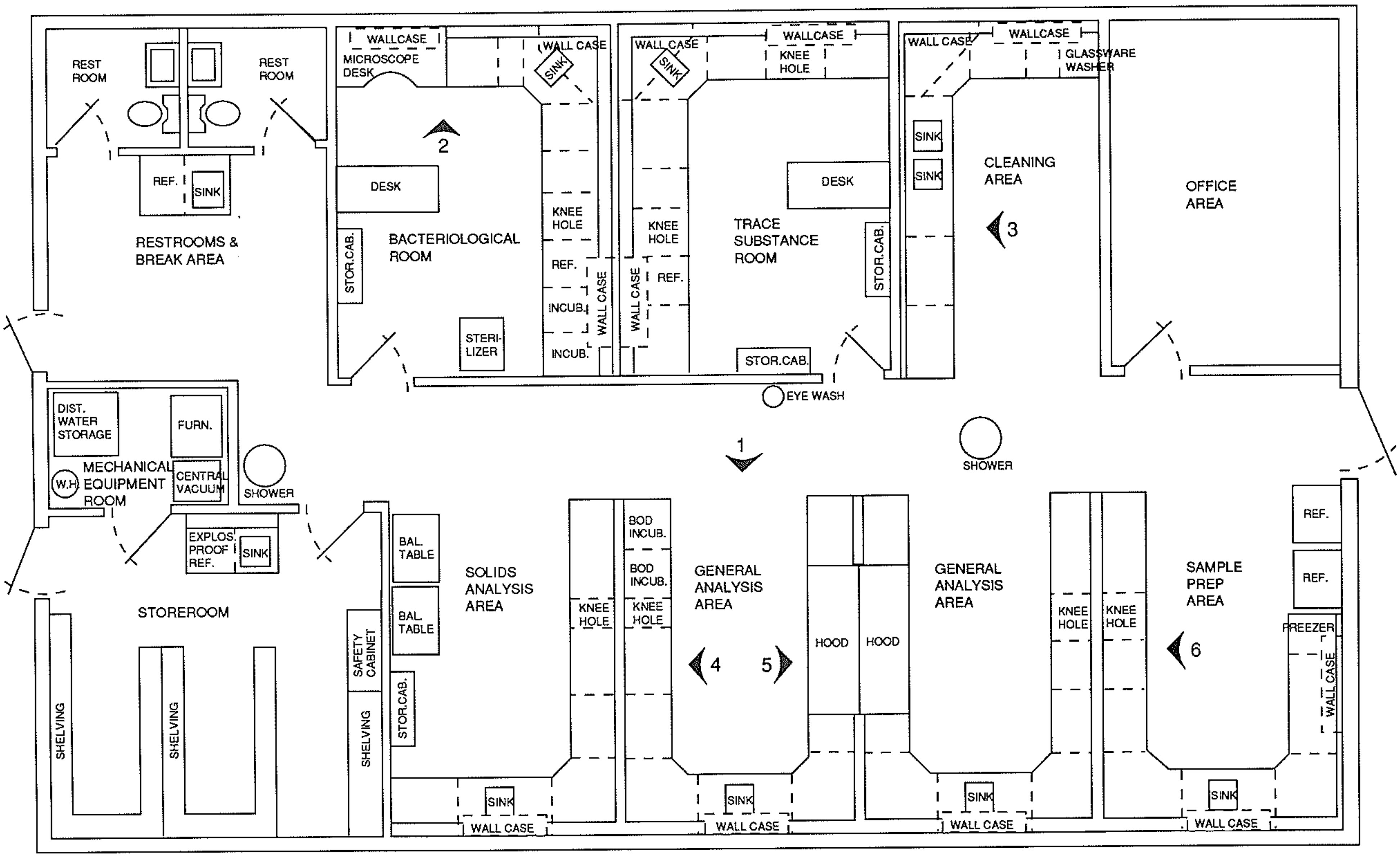
LABORATORY C VIEW 4 SCALE 1/2" = 1' 0"
WORK ISLAND, FRONT VIEW

LABORATORY D

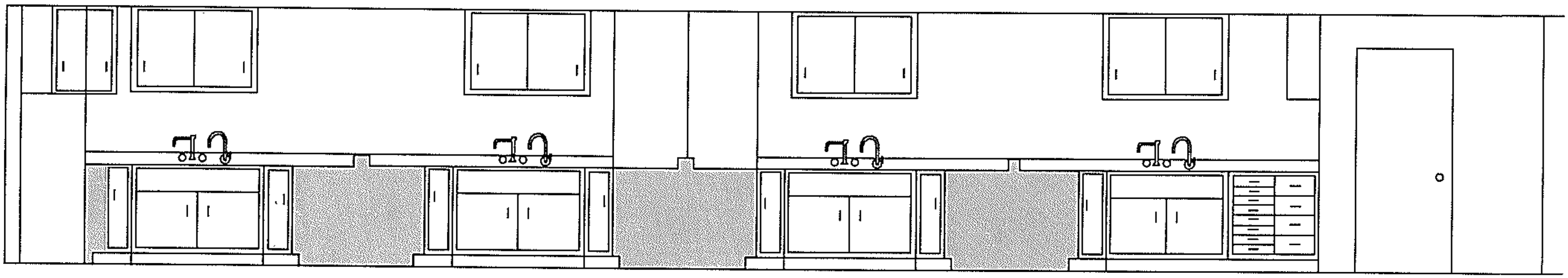
Representing the high end of the size spectrum, this laboratory contains 2,100 sq. ft. of gross floor space. It has approximately 237 linear feet of bench space, amounting to an area of 592 sq. ft., or 28 percent of the gross floor space. The laboratory is capable of supporting up to seven fulltime equivalent analysts, and can accommodate as many as 12 to 14 individuals working in the facility at any one time. It contains approximately 1,200 cu. ft. of cabinet storage volume, excluding the stockroom. (Some of this storage would be provided by wall cases, which are not illustrated.) The stockroom adds 210 sq. ft. of floor space to the total amount of available storage.

Freezers and incubators (including BOD incubators) are all assumed to be under-the-counter models. Two free-standing refrigerators are provided in the sample preparation area. An explosion-proof under-the-counter refrigerator should also be supplied in the short bench section shown in the stockroom. A number of sinks are provided in positions which are accessible yet which will not interefere with analyses. The peninsular bench sections should be equipped with utility runs down the middle of the benches, including water outlets and drain troughs. Kneeholes are spaced throughout the bench areas to enable work to be done from a seated position. Overhead emergency showers and wall-mounted eyewashes would be provided along the central aisle. While desks are shown occupying one wall each in the bacteriological and trace substance rooms, these could be replaced with free-standing or table-mounted support equipment if necessary. These might include additional incubators, sterilizers, pressurized gas cylinders, and similar items. The mechanical equipment room would contain the building heating and cooling system, a water deionization or distillation system and reservoir, a centralized vacuum system, and a hot water system.

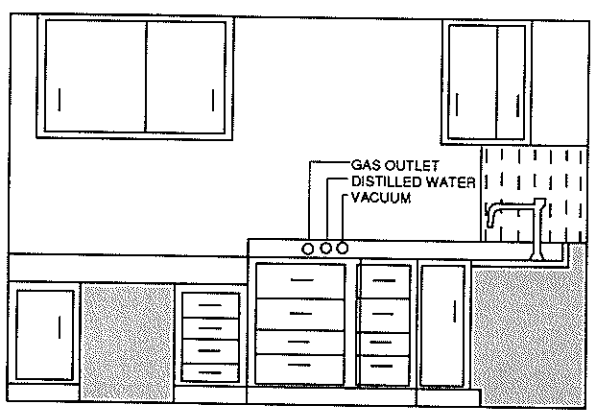
The design of this laboratory incorporates most of the functional areas listed in Chapter 4 in the section dealing with the patterns of work in a laboratory. Each area in the design supports a specific type of operation, demonstrating how the steps in the analytical process presented in Figure 3 can be centralized for increased effectiveness in larger laboratories. Equipment and furnishings are grouped according to purpose and frequency of use, with the various areas arranged to provide a logical flow of sample handling and analysis with a minimum of traffic through the laboratory. Internal dimensioning is also consistent with the recommendations presented earlier.



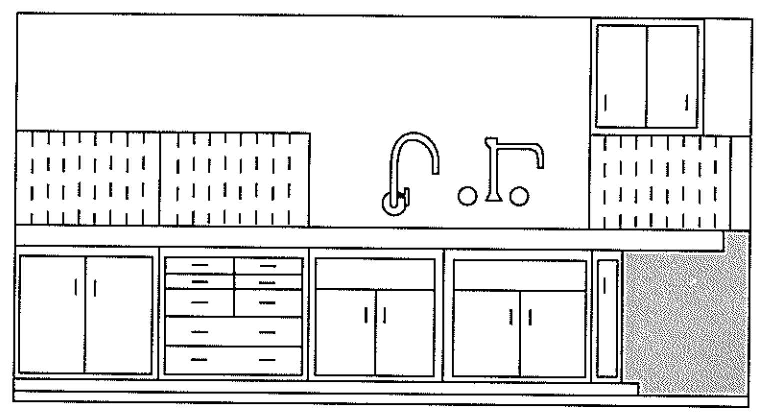
LABORATORY D ACTUAL SIZE=59' × 36'



LABORATORY D VIEW 1 SCALE 1/4" = 1'



LABORATORY D VIEW 2 SCALE 1/4" = 1'



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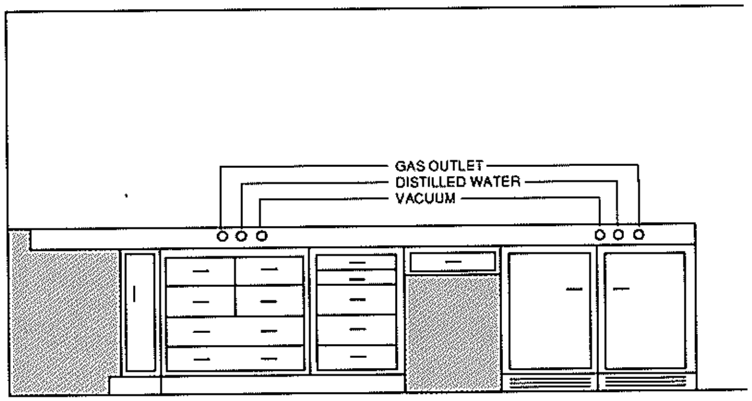

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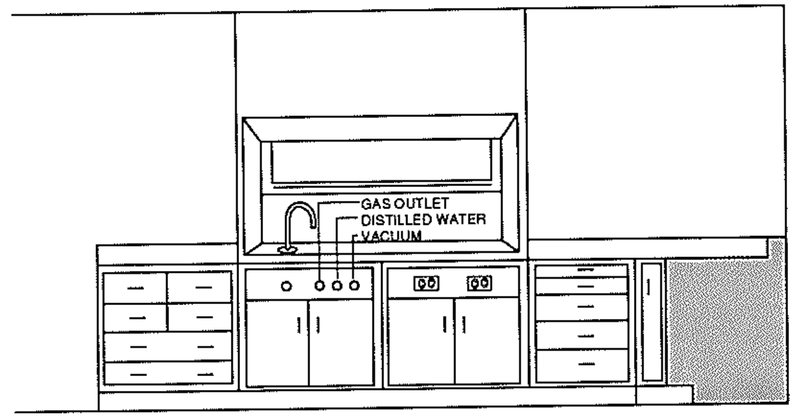
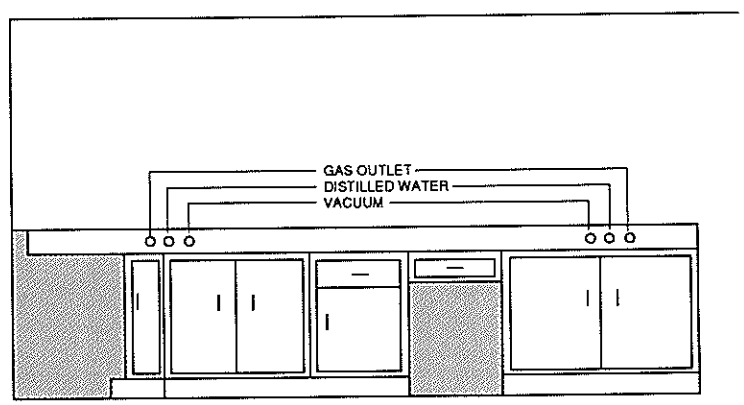


LABORATORY D VIEW 5 SCALE 1/4" = 1'



LABORATORY D VIEW 6 SCALE 1/4" = 1'

SUMMARY

These designs illustrate how the features discussed in this handbook can be applied to laboratories encompassing a wide range of sizes and applications to develop facilities which are efficient, effective, and safe to use. The laboratories shown meet or exceed the design criteria presented previously in this handbook. Such facilities will help ensure that the quantity and quality of data provided in an actual treatment situation are satisfactory, thereby enhancing the value of the laboratory to the system it serves.

APPENDIX B EQUIPMENT AND SUPPLIES

The materials presented in this appendix are those needed to supply the three example laboratory designs A, B, and C in Appendix A. The materials listed would enable each laboratory to perform all essential analytical operations appropriate to a facility of its size, as specified in Tables 1 and 2. Items needed for either water or wastewater analysis, but not for both, are indicated by footnotes. Wherever the materials listed are considered optional rather than a requirement for operation, the quantities have been placed in parentheses. In some cases, indefinite amounts are given (such as box, or "pkg" for package) to indicate that the minimum quantity available from a supplier should be sufficient, regardless of the specific number of items involved.

EQUIPMENT AND SUPPLIES FOR RECOMMENDED LABORATORY OPERATIONS

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
ASBESTOS BOARDS: 6×6 in. sq., 1/8 in. thick	1	1	2
BAGS: Plastic, waterproof, for 44.5° C waterbath incubator	200**	400**	600**
BALANCES: Analytical, single pan, automatic, digital readout, sensitive to 0.1 mg, with 160 g capacity	1	1	1
Triple beam, with attached sliding weights, sensitive to 0.1 g, 600 g capacity	1	1	1
BEAKERS: Griffin low form, with spout and graduations, Pyrex or equivalent (a few of each size may be polypropylene, if desired), heavy duty (where available), capacities:			
100 mL	12	12	24
250 mL	—	—	12
400 mL	12	12	12
600 mL	—	—	6
1000 mL	6	6	6
2000 mL	—	—	4
BOILING GRANULES: Anti-bumping, insoluble, insert	pkg	pkg	pkg
BOTTLES: Aspirator, with tubulature, polyethylene, with screw cap, 5 gal. capacity	1	1	2
BOD, 300 mL, serial numbered	1 doz**	2 doz**	3 doz**
	—*	(1 doz)*	1 doz*
Dilution, 99 mL mark, screw cap, Pyrex or equivalent	2 doz	3 doz	4 doz

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
Dropping, capacities:			
30 mL	12	12	12
60 mL	—	—	12
Reagent, narrow mouth, amber glass, with ground glass stoppers, low form, capacities:			
240 mL	12	12	12
500 mL	—	—	12
Reagent, narrow mouth, Pyrex or equivalent, with ground glass stoppers, low form, capacities:			
250 mL	—	—	6
500 mL	6	6	6
1000 mL	6	6	6
Reagent, narrow mouth, glass, with plastic screw caps, capacities:			
250 mL	—	—	12
500 mL	12	12	12
1000 mL	—	12	12
Sample, wide mouth jars, polypropylene, autoclavable, with screw caps, capacities:			
125 mL	6	12	12
250 mL	—	—	6
500 mL	12	12	24
1000 mL	—	6	12
1/2 gal	4	6	8
1 gal	2	2	4
Sample, glass, wide mouth, screw cap, autoclavable, capacities:			
130 mL	6	12	12
210 mL	6	12	12
Washing or dispensing, polyethylene, capacities:			
250 mL	4	4	4
500 mL	—	—	4
BRUSHES: Balance, camel's hair	3	3	3
Beaker	2	2	4
Bottle	5	5	5
Buret	5	5	5
Test tube, small	1/2 doz	1 doz	1 doz
Test tube, large	—	1/2 doz	1 doz
BURETS: Straight, stopcock, with Teflon plug and vented plastic dust cap, Kimax or equivalent, capacities:			
25 mL	2	4	4
50 mL	2	4	4
Automatic, with 1/2 gal reservoir, capacities:			
25 mL	—	(1)	1
50 mL	—	(1)	1

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
BURNERS: Tirrill, adjustable	1	2	2
Fisher, high temperature, adjustable	—	1	1
BURNER TIPS: Wing top compatible with Tirrill burner	2	4	4
BURNER LIGHTER: Friction produced spark igniter	(1)	(1)	2
CALCULATOR: With addition, subtraction, multiplication, division, and memory functions	1	1	1
CART: Utility, stainless steel	—	1	1
CENTRIFUGE: General purpose table model, with adjustable speed control, 1- to 30-minute timer, electric brake, safety cover, head capable of holding four tubes of at least 50 mL capacity, cushioned shields, and set of tubes compatible with head size(s)	—	(1)	1
CHLORINE AMPEROMETRIC TITRATOR: Line or battery operated, sensitive to 0.01 mg/L residual chlorine, with phenylarsene oxide titrant solution	—	—	(1)
CHLORINE COLOR COMPARATOR: With gradations from 0.1 to 3.0, and suitable reagent supply	1	1	1
CLAMPS: Day, pinchcock	3	6	9
Extension, vinylized jaws, medium	1	2	3
Extension, asbestos sleeves, medium	1	2	3
Versatile, vinylized jaws, medium	1	2	3
Versatile, asbestos sleeves, medium	1	2	3
Chain	—	—	1
Hoffman, screw compressor, open side, small	pkg	pkg	pkg
Hoffman, screw compressor, open side, large	—	pkg	pkg
Rubber tubing, worm drive, for tubing 7/16 to 24/32 in. O.D.	—	—	pkg
CLAMP HOLDERS: Regular, of non-ferrous alloy	6	12	24
CLEANING TISSUES: Kimwipes or equivalent, 5 × 9 in. sq.	pkg	pkg	pkg
COATS: Laboratory, 100% polyester, chemically resistant, white, wash-and-wear, full length, in appropriate size(s)	1	2	2
COLORIMETER/SPECTROPHOTOMETER: Bausch & Lomb "Spectronic 20" or equivalent, with adapters for use with 1/2 and 1 in. test tubes, set of matched 1/2 and 1 in. test tubes	—	(1)	1
CONDENSERS: Liebig, with ₸ 24/40 ground glass joint and drip tip at bottom, Pyrex or equivalent, 300–400 mm jacket length	—	(2)	2
Liebig, West or Friedrichs; 300 mm jacket length; with ₸ 24/40 ground glass bottom joints	—	(6)**	6**
CORK BORERS: Hard polished brass, set of 15, with individual wing handles	set	set	set

*WATER LABORATORIES ONLY **WASTEWATER LABORATORIES ONLY QUANTITIES IN PARENTHESES INDICATE OPTIONAL MATERIALS

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
CORK BORER SHARPENER	1	1	1
CORK KNIFE	1	2	4
CORKS: Assorted, nos. 0 to 11	100	100	200
COUNTER: Mechanical, hand type	1	1	1
CRUCIBLES: Filtering, Gooch-type, high form, fritted disc, 30 mL capacity, with rubber adapter to attach crucible to vacuum filter flask	4**	6**	8**
CYLINDERS: Single graduated, with spout, Kimax or equivalent (a few of each size may be of autoclavable polypropylene, if desired), capacities:			
10 mL	(2)	2	4
25 mL	—	2	2
50 mL	6	12	18
100 mL	6	12	18
250 mL	—	2	2
500 mL	1	1	2
1000 mL	1	1	2
DESICCANT: Restorable, with color change to show saturation with moisture	1 pkg	2 pkg	3 pkg
DESICCATORS: Clear, heavy glass; ground cover with knob; with porcelain plate of appropriate size:			
small	1	—	—
large	—	1	1
Cabinet, stainless steel or fiberglass, air tight and moisture-proof seal on door, with two asbestos shelves, overall dimensions 12 × 12 × 12 in.	—	1	2
DETERGENT: Phosphate-free detergent specifically for cleaning laboratory ware, Alconox or equivalent	1 box	2 boxes	3 boxes
DISHES: Aluminum, soft, flexible, with finger-grip handle, 2 3/8 in. diameter, 5/8 in. depth	box	box	box
Evaporating, regular form, porcelain, Coors, size no. 00A	doz**	doz**	doz**
Petri, plastic, tight-lid, 50 mm × 12 mm	200	400	600
DISSOLVED OXYGEN METER: Portable; with temperature, salinity and altitude compensation; YSI Model 51B or equivalent; with oxygen-temperature probe	1** —*	1** (1)*	1** 1*
DISSOLVED OXYGEN SAMPLER: For 300 mL BOD bottles, providing 3-fold displacement of sample bottle volume	1** —*	1** (1)*	1** 1*
FILES: Triangular, for cutting glass tubing, medium length	pkg	pkg	pkg
FILTER PADS: Absorbent, 47 mm	200	400	600

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
FILTER PAPER: High grade, medium weight, rapid filtering, for general qualitative work, 12.5 cm diameter	1 pkg	1 pkg	2 pkg
Whatman No. 4 or equivalent, 9 cm diameter	—	(pkg)**	(pkg)**
FILTERS: Glass fiber, 47 mm diameter	pkg	pkg	pkg
Membrane, white, gridded 47 mm, 0.45 μm or equivalent pore size	200	400	600
FIRE EXTINGUISHER: Dry chemical type, A-B-C	1	1	1
FIRST AID KIT: Industrial type	1	1	1
FLASKS: Erlenmeyer, wide mouth with reinforced beaded rim, graudated, Pyrex or equivalent, capacities:			
125 mL	—	—	12
250 mL	12	12	12
500 mL	6	6	6
1000 mL	6	6	6
2000 mL	—	—	(2)
Erlenmeyer, with ₮ 24/40 ground glass joints, Pyrex or equivalent, capacities:			
250 mL	—	(6)**	6**
500 mL	—	(6)**	6**
Filtering, heavy wall, with tubulation, Pyrex or equivalent, capacities:			
500 mL	1	2	2
1000 mL	2	3	4
Volumetric, with ground glass stoppers, Class A, Pyrex or equivalent, capacities:			
50 mL	—	1	2
100 mL	1	2	2
250 mL	—	1	2
500 mL	1	2	2
1000 mL	1	2	2
Volumetric, without stopper, Pyrex or equivalent, 200 mL capacity	2	2	2
FORCEPS: Brass or stainless steel, with medium points, 4 in. long, curved	pkg	pkg	pkg
Blunt with smooth tip, for use with membrane filters	1	1	1
FUNNELS: Accurate 60°, beaded lip, ribbed, Pyrex or equivalent, 75 mm diameter	3	6	6
Buchner, size No. 2A, porcelain	—	(1)**	(1)**
Heavy weight, polypropylene, 60°, 75 mm diameter	—	3	6
Powder, polypropylene, 64 mm top diameter	3	6	6
Powder, polypropylene, 100 mm top diameter	—	(3)	3

*WATER LABORATORIES ONLY **WASTEWATER LABORATORIES ONLY QUANTITIES IN PARENTHESES INDICATE OPTIONAL MATERIALS

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
Separatory, Squibb, pear-shape, Pyrex or equivalent, with Teflon stopcock and ground glass stopper, 1000 mL capacity	1**	1**	1**
GLASS BEADS: Chemically resistant	pkg**	pkg**	pkg**
GLASS ROD: Pyrex or equivalent, 7 mm diameter, 4 in. length	—	pkg	pkg
GLOVES: Asbestos, five-fingered, lined	1 pr	1 pr	1 pr
Neoprene, light weight, nonslip, chemical resistant, medium size	1 pr	2 pr	2 pr
GOGGLES: Chemical splash protection, with indirect ventilation, capable of being worn over regular glasses, with shatterproof safety lenses	1	1	2
ILLUMINATOR: Microscope, fluorescent, fits round tube microscope	1	1	1
IMHOFF CONES: Pyrex glass or equivalent, or styrene; with supports	1**	2**	3**
INCUBATOR: BOD, under-the-counter style, thermostatically controlled at 20 ± 1° C, capacity 5.5 cu. ft.	1**	1**	1**
Gravity convection, 35 ± 0.5° C, 18 × 19 × 28 in. (DWH)	1*	1*	1*
Waterbath, 44.5 ± 0.2° C, 18 × 12 × 7½ in. (LWH)	1**	1**	1**
INK: Ceramic marking, 1 oz bottle	1	1	1
KJELDAHL EQUIPMENT: Digestion rack, twin-unit, portable electric, with exhaust manifold, for use with 800 mL flasks	—	—	(1)
Distillation apparatus, twin-unit, portable electric, for use with 800 mL flasks	—	—	(1)
Flasks, 800 mL, round bottom, long neck, Pyrex or equivalent; connecting bulbs; and rubber stoppers, one-hole, to fit 800 mL flasks	—	—	(4 each)
Boiling granules, Hengar	—	—	(pkg)
MANIFOLD: PVC, 3-place, for multiple filtrations	—	(1)	1
MEMBRANE FILTRATION ASSEMBLY: For 47 mm filters	1	3	6
MICROSCOPE: Dissecting, binocular, 15 power	1	1	1
MORTAR & PESTLE: Porcelain, size #2	—	—	(1)
MUFFLE FURNACE: With stepless controller and pyrometer to hold 600° C temperature	1**	1**	1**
NEEDLE: Inoculating, in holder	2	2	2
OVEN: Double wall, thermostatic control capable of maintaining 103 ± 2° C and 225° C; internal dimensions: 19 × 18 × 16 in. (LHD)	1	1	1

ITEM	*QUANTITIES NEEDED FOR LABORATORY DESIGNS:* A	B	C
PENCILS: Wax, heat resistant, for marking glass or glazed surfaces:			
red	doz	doz	doz
black	—	doz	doz
PENS: Laboratory; capable of writing with opaque ink on glass, metal, plastic, cloth, paper and other surfaces; ink permanent, heat, chemical and water resistant:			
orange ink	1	2	3
black ink	1	2	3
pH METER: Line or battery operated, solid state, temperature compensated, with millivolt readout, with combination probe having heavy duty glass membrane	1	—	—
Line operated, solid state, temperature compensated, expanded scale, with millivolt readout, with combination probe having heavy duty glass membrane	—	1	1
pH METER ELECTRODES: Extra set	1 set	1 set	1 set
pH PAPER: From pH 0–14	1 roll	1 roll	1 roll
PIPET CAN: Stainless steel, 2.5×2..5×16 in.	3	3	3
PIPETS: Measuring, Mohr type, color-coded, tempered tip, capacities:			
1 (or 1.2) mL	12	12	12
2 (or 2.2) mL	12	12	18
5 mL	12	12	12
10 mL	12	12	12
Serological, large tip, color-coded, tempered tip, capacities:			
1 mL	12	12	12
5 mL	12	12	24
10 mL	12	12	24
25 mL	12	12	24
Volumetric, color-coded, tempered tip, capacities:			
1 mL	12	12	12
2 mL	12	12	12
3 mL	—	12	12
4 mL	—	12	12
5 mL	12	12	12
10 mL	12	12	12
15 mL	—	12	12
20 mL	12	12	12
25 mL	—	12	12
50 mL	—	—	12
100 mL	—	—	(12)

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
PIPET FILLERS: Rubber bulb, to fit all standard laboratory pipets and micropipets, with ball valves	2	2	4
PIPET JAR & BASKET: Polyethylene; jar 6.5 in. diameter, 27 in. height; basket to fit	1	1	1
PIPETTOR: Automatic, volume of 5–50 mL, speed of 10–60 deliveries/min. with glass syringe	—	(1)	1
PROBE: BOD, self-stirring recommended, compatible with dissolved oxygen meter	(1)**	(1)**	(1)**
PUMPS: Vacuum, polypropylene, water powered, capacity 11.5 L/min.	1	1	1
Vacuum and pressure, portable, capable of up to 27 in. vacuum and 20 psi pressure	1	1	1
REFRIGERATOR: Under-the-counter, 5.5 cu. ft.	1	1	—
Free standing, with separate freezer compartment, 13 cu. ft.	—	—	1
SCOOPS: Stainless steel, with handles	pkg	pkg	pkg
SELECTIVE ION ELECTRODE: For ammonia, compatible with pH meter having an expanded millivolt scale	—	(1)	(1)
SPATULAS: Stainless steel, 6 in. blade length	1	2	2
Micro, with flat spatula at one end and spoon at other, stainless steel or Teflon coated, 6 in. length	3	3	6
SPONGES	1 pkg	1 pkg	2 pkg
STERILIZER: Steam, bench top, electric heat with temperature and pressure controls and gauges; internal dimensions: 9 in. diameter chamber, 16 in. deep	1	1	1
STIRRERS: Magnetic, electric, small (approximately 20 sq. in. surface)	1	1	2
STIRRER-HOT PLATE: Magnetic, electric, with at least 9 watts/sq. in., approximate surface areas:			
35 sq. in.	(1)	1	—
70 sq. in.	—	—	1
STIRRING BARS: Magnetic, Teflon, lengths:			
1 in.	2	2	4
1.5 in.	2	3	6
2 in.	2	3	6
STIRRING BAR RETRIEVER: Magnetic, polyethylene, 18 in. length	1	1	1
STOPCOCK GREASE: Silicone, inert, 2 oz tube	1	1	2
STOPPERS: Rubber; assorted sizes 00 through 8; solid, one- and two-hole	2 lbs	4 lbs	6 lbs

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
SUPPORTS: Buret; porcelain base, 13 × 7 in., 24 in. support rod; double buret clamp for micro to 100 mL burets, with vinylized jaws	1	2	3
Pipet, vertical rack	—	(1)	1
Rings, iron, diameters:			
3 in.	—	1	2
4 in.	1	1	2
5 in.	—	1	2
Triangular base, cast iron, with 24 in. rod	—	—	1
Tripod, iron, with four concentric recessed rings	1	1	1
THERMOMETERS: Double scale (C and F), 3 in. immersion depth, mercury-filled, from −20 to +110° C, 12 in. length	2	3	4
Mercury, from 0 to 50° C, graduated in 0.1° C, meets NBS specifications	1	1	2
THERMOMETER ARMOR: To fit 12 in. thermometer	1	1	1
TIME TAPE: Labeling, roll form, white, to take pen or pencil, with dispenser	1	1	2
TIMER: Interval, from 15 sec. to 2 hr.	1	1	1
TONGS: Beaker, steel with plastic-covered jaws, for 50 to 2000 mL beakers, 9 in. length	1	1	2
Crucible, stainless steel, 9 in. length	3	3	3
Crucible, steel, 20 in. length	1	1	1
Dish, stainless steel, 9.5 in. length	1	1	2
Flask, stainless steel, for flasks taking #4 to #8 rubber stoppers	1	1	2
TRAYS: Polyethylene, approximately 15 × 12 × 6 in.	1	1	2
TUBING: Glass, standard wall, Pyrex or equivalent, 4 ft. lengths, sizes:			
6 mm O.D.	—	—	15
8 mm O.D.	15	15	20
10 mm O.D.	—	—	15
Plastic, Tygon, sizes:			
3/16 in. I.D. × 1/16 in. wall	—	—	10 ft.
1/4 in. I.D. × 1/16 in. wall	20 ft.	50 ft.	50 ft.
3/8 in. I.D. × 1/8 in. wall	—	—	50 ft.
Rubber, medium wall, amber, pure latex, translucent, 1/4 in. I.D. × 1/16 in. wall	—	—	(50 ft.)
Rubber, vaccuum, 3/16 in. I.D. × 3/16 in. wall, red	10 ft.	10 ft.	20 ft.
Rubber, vacuum, 3/32 in. I.D. × 3/6 in. wall	4 ft.	4 ft.	4 ft.

ITEM	*QUANTITIES NEEDED FOR LABORATORY DESIGNS:* A	B	C
TURBIDIMETER: Nephelometric, with tubes	1*	1*	1*
	—**	(1)**	(1)**
WATCH GLASSES: 100 mm diameter	12	12	12
150 mm diameter	—	12	12
WATERBATH: For media preparation	1	1	1
WATER TRAP: Glass bottle, stoppered with glass tube inlet/ outlet	1	1	1
WATER PURIFICATION SYSTEM: Still, all internal surfaces Pyrex glass (or equivalent), capable of producing approximately 1.5 L/hr., with high temperature safety cut-off switch	1	1	1
OR			
Mixed-bed ion exchanger, commercial assembly, suitable for preparation of reagent grade water	1	1	1
WIRE GUAZE SQUARES: Iron, asbestos center, sizes:			
5×5 in.	pkg	pkg	pkg
6×6 in.	—	pkg	pkg

APPENDIX C

CHEMICALS AND REAGENTS

The chemicals in this appendix are those needed to supply the three example laboratory designs A, B, and C in Appendix A. The compounds listed would enable each laboratory to perform all essential analytical operations appropriate to a facility of its size, as specified in Tables 1 and 2. Items needed for either water or wastewater analysis, but not for both, are indicated by footnotes. Wherever the chemicals listed are considered optional rather than a requirement for operation, the quantities have been placed in parentheses.

For relatively small laboratories such as A, B, and C, the use of premeasured powder capsules, bacterial media in sealed ampoules, and other commercially prepared solutions are generally recommended over solutions made within the laboratory. Premixed reagents may eliminate the need for some of the chemicals listed in certain cases. Although such reagents may be more costly, this will be compensated for by the relatively small volumes used in most instances and the reduced possibilities for error through improper preparation. In addition, many of these commercially prepared, sealed reagents will have a longer shelf life than will corresponding solutions made in the laboratory. Such premixed chemicals should only be purchased, however, from reputable dealers.

CHEMICALS AND REAGENTS FOR RECOMMENDED LABORATORY OPERATIONS

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
ACETIC ACID: Glacial, ACS, reagent	1 pt* —**	2 pt** —**	2 pt* (1 pt)**
ACETONE: ACS, reagent	—	—	(1 pt)
AGAR: LES Endo	(1/4 lb)*	(1/4 lb)*	(1/2 lb)*
AMMONIUM CHLORIDE: Granular, ACS, reagent	1 lb	1 lb	1 lb
BROTH: M-Endo MF	(1/4 lb)*	(1/4 lb)*	(1/2 lb)*
M-FC	1/4 lb**	1/4 lb**	1/2 lb**
BUFFERS: For pH standardization, in premeasured capsules to make 50-mL of sample:			
pH 4.0	20	30	50
pH 7.0	20	30	50
pH 10.0	20	30	50
BUTANOL: Normal, ACS, reagent	1 pt**	1 pt**	1 pt**
CALCIUM CHLORIDE: Anhydrous, 20 mesh, ACS, reagent	1 lb**	1 lb**	1 lb**

*WATER LABORATORIES ONLY **WASTEWATER LABORATORIES ONLY QUANTITIES IN PARENTHESES INDICATE OPTIONAL MATERIALS

ITEM	*QUANTITIES NEEDED FOR LABORATORY DESIGNS:* A	B	C
CHLOROFORM: ACS, reagent	1 pt	1 pt	1 pt
ETHANOL: Unadulterated, 95%, for M-Endo, MF broth, and LES Endo agar	500 mL*	500 mL*	500 mL*
FERRIC CHLORIDE: Lump, ACS, reagent	1 lb**	1 lb**	1 lb**
FERROIN INDICATOR:	—	(1 oz)**	1 oz**
FERROUS AMMONIUM SULFATE: Crystal, ACS, reagent	—	(1 lb)**	1 lb**
GLUCOSE: Granular, ACS, reagent	—	(1 lb)**	(1 lb)**
GLUTAMIC ACID:	—	(10 g)**	(10 g)**
HYDROCHLORIC ACID: ACS, reagent, 36.5–38%	1 pt	1 pt	6 lbs
IODINE: Resublimed	1 lb*	1 lb*	1 lb*
ISOPROPYL ALCOHOL: ACS, reagent	1 pt	1 pt	1 pt
MAGNESIUM CHLORIDE: ACS, reagent	1 lb	1 lb	1 lb
MAGNESIUM SULFATE: Crystal, ACS, reagent	1 lb**	1 lb**	1 lb**
MERCAPTOSUCCINIC ACID: Practical	500 g*	500 g*	500 g*
MERCURIC IODIDE: Red, powder, ACS, reagent	—	(1 lb)	1 lb
MERCURIC SULFATE: Powder, reagent	—	(1 lb)**	1 lb**
METHANOL: Absolute, ACS, reagent	1 pt**	1 pt**	1 pt**
METHANOL: 95%, in small vial for forceps disinfection	1 pt	1 pt	1 pt
METHYL ORANGE: Sodium salt, powder, ACS, reagent	1 oz	1 oz	2 oz
NITRIC ACID: ACS, reagent, 69–71%	1 pt	1 pt	1 pt
PHENOLPHTHALEIN: Powder, ACS, reagent	1/4 lb	1/4 lb	1/2 lb
POTASSIUM ACID PHTHALATE: Primary standard, crystal, ACS, reagent	—	(1 lb)	1 lb
POTASSIUM BI-IODATE: Purified	1/4 lb*	1/4 lb*	1/4 lb*
POTASSIUM CHROMATE	1 lb*	1 lb*	1 lb*
POTASSIUM DICHROMATE: Primary standard, crystal, ACS, reagent	1 lb	1 lb	1 lb
POTASSIUM IODIDE: Anhydrous, crystal, ACS, reagent	2 lb* —**	4 lb* (1 lb)**	6 lb* 1 lb**
POTASSIUM PHOSPHATE: Monobasic, crystal, ACS, reagent	5 lb	5 lb	5 lb
POTASSIUM PHOSPHATE: Dibasic, powder, ACS, reagent	1 lb**	2 lb**	3 lb**
ROCHELLE SALT (POTASSIUM SODIUM TARTRATE): ACS, reagent	—	(1 lb)	1 lb
ROSALIC ACID: For M-FC broth	6 g**	9 g**	12 g**
SILICIC ACID: A.R., 100 mesh, for chromatography	1 lb**	1 lb**	1 lb**
SILVER SULFATE: Powder, ACS, reagent	—	(1/4 lb)	1/4 lb
SODIUM ARSENITE: Meta	1 lb*	1 lb*	1 lb*

ITEM	QUANTITIES NEEDED FOR LABORATORY DESIGNS: A	B	C
SODIUM BICARBONATE: Powder	—	1 lb*	1 lb*
SODIUM BORATE: Tetra	—	1 lb*	1 lb*
SODIUM CARBONATE: Anhydrous, primary standard grade, ACS, reagent	1 lb	1 lb	1 lb
SODIUM HYDROXIDE: Pellets, ACS, reagent	1 lb	1 lb	1 lb
SODIUM PHOSPHATE: Dibasic, heptahydrate, crystal, ACS, reagent	1 lb	1 lb	1 lb
SODIUM THIOSULFATE: Crystal, ACS, reagent	1 lb	1 lb	1 lb
STARCH: Soluble, powder, ACS, reagent	1/4 lb	1/4 lb	1/2 lb
SULFAMIC ACID: Reagent	—	—	(100 g)**
SULFURIC ACID: ACS, reagent, 95–98%	9 lbs	18 lbs	54 lbs
THYMOL BLUE: Powder, reagent	5 g**	5 g**	5 g**
ZINC SULFATE: Crystal, ACS, reagent	—	(1 lb)	1 lb

*WATER LABORATORIES ONLY **WASTEWATER LABORATORIES ONLY QUANTITIES IN PARENTHESES INDICATE OPTIONAL MATERIALS

APPENDIX D SELECTED REFERENCES

Although comprehensive guidelines of sufficient scope and depth have not previously been available for water and wastewater laboratories, other publications have touched upon portions of the material covered. The most pertinent of these publications, together with a discussion of the strengths and limitations of each, are as follows:

Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities, Office of Water Program Operations, Environmental Protection Agency (Washington, D.C., 1973). This manual considers primarily the size, staffing and analytical capabilities which were considered appropriate for certain wastewater laboratories at the time of publication. Its major weakness is that the data used to support its recommendations were taken from actual laboratory size and staffing levels. Since laboratory control of treatment plants was often seriously under-utilized in the past, such historical data tended to underestimate laboratory needs even at the time the manual was published. These needs have grown even greater with the new treatment requirements and monitoring technologies which have since been introduced, leading to a further imbalance between current laboratory practice and the recommendations presented in this manual. Topics such as design, construction and equipping are not dealt with at all, nor is any consideration given to the needs of drinking water laboratories.

Recommended Standards for Sewage Works, Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, Health Education Service, Inc. (Albany, N.Y., 1978). Some recommendations are made on laboratory size, design and equipping. However, as with most other available discussions of these topics, the recommendations are applicable only in specific situations and only apply to wastewater treatment facilities. No effort is made to systematize the recommendations so they can be applied to a wide range of laboratory facilities, regardless of treatment technology or plant size. In addition, the recommendations for laboratory size are appropriate only for medium-size facilities; laboratories at the ends of the spectrum would be either over-sized (in the case of small treatment plants) or under-sized (in the case of large treatment plants). Either kind of error would be costly for the treatment installations involved. (The Great Lakes-Upper Mississippi River Board of State Sanitary Engineers also publishes a set of recommended standards for water works, but the laboratory portions of these standards are even less adequate. This is, unfortunately, typical of the lower priority drinking water laboratories traditionally received prior to passage of the Safe Drinking Water Act. Even now, drinking water laboratories have not caught up with their wastewater counterparts in either size or sophistication.)

Manual for the Certification of Laboratories Analyzing Drinking Water, Office of Drinking Water, Environmental Protection Agency (Washington, D.C., 1982). A variety of very general requirements and recommendations are presented on such topics as qualifications of laboratory personnel, minimal laboratory size, necessary equipment and analytical procedures. However, as with the other references cited, these recommendations are not formalized into a single, widely applicable system of guidelines which will ensure the development of an adequate laboratory facility. The recommendations are descriptive, not prescriptive. They can only be used to evaluate a laboratory facility after it is established and operating, not to design it properly beforehand. And the highly general nature of the recommendations limits the facilities and situations to which they can be effectively applied.

Establishing Wastewater/Water Laboratories in Smaller New Mexico Communities, Water Quality Division, N.M. Environmental Improvement Division (Santa Fe, N.M., 1976). The recommendations made in this manual are useful and sound, and have been used to improve laboratory operations in many communities both in and out of New Mexico. However, while certain portions of this earlier work provide a valid starting point from which to begin a more thorough and comprehensive treatment, it also suffers from several critical limitations. Principal among these are its limited scope (it covers only very small treatment plants lacking any full-time laboratory personnel), its limited depth (solutions are given to specific problems without presenting the underlying techniques which would enable unique solutions to be derived for other laboratory situations), and the dated nature of its contents (EPA had not at that time developed monitoring requirements under the Safe Drinking Water Act, and the needs of the state in other areas of water quality monitoring have changed considerably over the past ten years).

Although none of the above references provides the kind of standardized, comprehensive guidelines which are needed for efficient and effective laboratory planning, each reference does offer some part of the overall solution. This handbook therefore builds upon the best that each of these earlier works has to offer, combining this with other material on laboratory planning from the water and wastewater treatment industry, the field of laboratory design, and the chemical and biological research industries. Among the additional resources used in developing this publication were:

"The Efficient Design and Construction of a New Laboratory," W.R.. Tully and R.F. Young, in *Design, Construction and Refurbishment of Laboratories,* ed. by R. Lees and A.F. Smith, Ellis Horwood Limited (Chichester, England, 1984).

"Facilities Programming," Bryant Putnam Gould, in *Design for Research: Principles of Laboratory Architecture,* ed. by Susan Braybrooke, John Wiley & Sons (New York, 1986).

A Guide to Laboratory Design, K. Everett and D. Hughes, Butterworths (London, 1981).

Handbook for Evaluating Water Bacteriological Laboratories, 2nd ed., Edwin E. Geldreich, Municipal Environmental Research Laboratory, Environmental Protection Agency (Cincinnati, 1975).

Introduction to Safety in the Chemical Laboratory, N.T. Freeman and J. Whitehead, Academic Press (London, 1982).

"Laboratory Design," Albert H. Ullrich, in *Water Treatment Plant Design for the Practicing Engineer,* ed. by Robert L. Sanks, Ann Arbor Science Publishers, Inc. (Ann Arbor, 1978).

Laboratory Organisation and Administration, K. Guy, Crane, Russak & Company, Inc. (New York, 1973).

Laboratory Planning, M.J. Purvis, The Williams & Wilkins Company (Baltimore, 1973).

Laboratory Procedures for Wastewater Treatment Plant Operators, New York State Department of Environmental Conservation, Health Education Service (Albany, 1970).

Microbiological Methods for Monitoring the Environment: Water and Wastes, Environmental Monitoring and Support Laboratory, Environmental Protection Agency (Cincinnati, 1978).

"New Developments in Laboratory Design in the United States of America," J.R. Moody, in *Design, Construction and Refurbishment of Laboratories, op. cit.*

Practical Laboratory Planning, W.R. Ferguson, Applied Science Publishers Ltd. (London, 1973).

Sewage Treatment Plant Design, Water Pollution Control Federation and American Society of Civil Engineers (Washington, D.C., 1959).