# THE RESEARCH LABORATORY

by

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# CHAPTER I

## THE EVOLUTION OF MODERN SCIENTIFIC LABORATORIES

The current emphasis on the intense study of nearly everything from the parts of an atom to the whole of the universe has caused research to become everywhere organized on a massive scale. Although research activity is a vital element of man's present endeavors, the scientific discoveries of the past have always had a profound influence upon invention, upon industries, and upon comfort, health and welfare of the people in general. The systematic study and advancement of any physical or natural science requires trained workers, suitably constructed workrooms, the equipment, instruments and appliances needed for special work, a supply of the material to be studied and ready access to the more important books and journals containing the special literature of the science.

In ancient times, the structure of the universe and the nature of matter were fields of science peculiar to speculative philosophy.

> Aristotle claimed that matter consisted of four elements: fire, air, earth and water. The proportion in which these elements were mixed determined the properties of a substance. From this developed the logical theory that transformation of one substance to another was simply a matter of adjusting the proportion of the elements mixed in that substance. The conclusion was obvious--it was possible to change lead into gold.[1]

No stronger incentive to practical experiment could have been devised and the first practical scientists, the alchemists, appeared on the scene in the middle east at about the beginning of the Christian era. Their

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(1)Munce, James Frederick. Laboratory Planning, London, Butterworth, 1962, p. 3.

laboratories are the oldest of which we have any record and their apparatus served as a model for most chemical equipment in use until the seventeenth century.[(2)] The earliest alchemists worked in secret and any written records they made of their experiments were in code. In the painter's canvas we can still see the vaulted cobwebbed room, with its dim and mysterious light, the stuffed serpent, the shelves with their many-colored bottles, the furnace in the corner with the fire glowing through loose bricks, the fantastic alembics, the old alchemist in his quaint armchair reading a huge, worm-eaten folio, and the assistant grinding at the mortar. Fantastic and futile as it may seem, here was the birth of modern chemistry. The alchemists were the first to undertake the methodical experimental investigation of the chemical nature of substances. Although unsuccessful in making gold and silver the doctrines and work of the alchemists had profound influence upon man's ability to discover the nature of materials. The chemistry laboratory grew from the workshop of the alchemist searching for the philosopher's stone.

From its sources in Alexandria and Egypt alchemy gradually spread through the Greek-speaking world. After the fall of the Roman Empire, its practice was continued by the Arabs, who, during the Moorish ascendancy in the Mediterranean, were responsible for its infiltration into Europe.[(3)] Somewhere during this period the elements mercury and sulphur were discovered as well as the laboratory processes of distillation, sublimation, filtration, and precipitation. There was an immense variety of stills and furnaces. Soot-poisoning was not uncommon.

During medieval times, laboratories were used by apothecaries and

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(2) Ibid. p. 3.

(3) Ibid, p. 4.

doctors for compounding chemicals and drugs. Many noblemen had laboratories installed in their castles and hired alchemists to work for them, either on the production of the philosopher's stone or the elixir of life, however, they still worked in cellars and badly-lit basements shrouded in mystery and secrecy.[4]

In 1595 a German chemist, Libavius, published a book proposing an ideal laboratory designed specifically for the purpose of chemical experiments.[5]

Methodical experimentation in the sciences of nature was definitely established by Galileo in the seventeenth century. Much of the classical apparatus still employed in physical experiments was invented by him, his contemporaries and successors during this period.

Robert Boyle introduced the first true definition of an element. In 1670 Boyle set up a laboratory for his own use which exemplifies the gradual transition of alchemistical into chemical laboratories.[6]

The eighteenth century saw the appearance of the university laboratories. Early examples designed specifically for scientific teaching were erected at Altdorf, Germany, at Oxford in 1659, Cambridge in 1703 and Dublin in 1711.[7]

Joseph Priestley, who had discovered oxygen, because of his publicly expressed approval of the revolutionaries in France, was obliged to leave

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(4) Ibid, p. 4.

(5) Ibid, p. 5.

(6) Ibid, p. 8.

(7) Ibid, p. 9.

England and in 1794 emigrated to America where he established a well equipped laboratory at the University of Pennsylvania.[8]

In 1799 the Royal Institution of Great Britain was established with a fully equipped laboratory with adjacent lecture theatre, model room and workshop. Here worked such great scientists as Sir Humphrey Davy, Michael Faraday and John Dalton.[9]

About this same period a frenchman, Nicholas Leblanc, became the founder of the heavy chemical industry by discovering an economical method of producing soda from common salt.[10]

Lord Kelvin, then William Thomson, established a physical laboratory in the University of Glasgow about 1845 in an old wine cellar of a house.[11] In 1863 Magnus opened in Berlin his laboratory for experimental physical research. After 1870 there was a rapid development of physical institutes at many universities.

The birthplace of modern scientific laboratories, regarded as places freely open for instruction and research in the natural sciences was Germany.

A nineteenth century German chemist, Justus von Liebig, established his famous laboratory at Giessen. This laboratory, with its benches serviced by piped water and sinks, drawers, cupboards and reagent shelves, served as a model for almost all subsequent laboratories. At one end of the room

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(8)Ibid, page 10.

(9)Nuffield Foundation, Division of Architectural Studies, The Design of Research Laboratories, London, Oxford University Press, 1961, page 3.

(10)Munce, op. cit., page 12.

(11)Ibid, page 12.

there was a metal fume cupboard with a movable glass front, under which was a coal-fired furnace. As a result of Liebig's work, German apparatus became the major influence in laboratory equipment and instruction.[12]

Toward the end of the nineteenth century scientific work reached a level of unprecedented importance, especially in Germany, where industry had begun to realize the necessity of laboratory research for progress. New methods and refined techniques were constantly evolved. Through economic necessity there emerged processes which produced by-products of commercial value. Each new process presented a new by-product which in turn became the basis for a new industry.

War conditions required the creation of new synthetic materials. This called for more and more specialized laboratory equipment, until today only laboratories for routine industrial or medical testing and teaching laboratories have standardized requirements. Plant and equipment used in the chemical industry and for medical research rapidly becomes obsolete, and great flexibility and adaptability are essential.

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(12) Ibid, p. 12.

CHAPTER II

# A SURVEY OF TYPES OF RESEARCH FACILITIES

Research activities are often rather complex and overlap disciplines, yet the productive laboratory must fulfill a specific set of purposes and objectives. There is no standard model but laboratories can broadly be classified as a) teaching laboratories, b) research laboratories for the study and development of new possibilities, working to a flexible program c) service laboratories designed for the control and testing of products and conditions, working to a set program. Some of the fields using research facilities with their subdivisions are as follows:(13)

1) Chemistry--Analytical, Inorganic, Organic Physical
2) Engineering--Aeronautical, Automobile, Civil, Electrical, Mechanical.
3) Medical--Bacteriology, Biochemistry, Pathology, Pharmacology, Physiology.
4) Physics--Acoustics, Nuclear, Optical, Textile, Vacuum, X-ray and Infrared.

The exact use of facilities and the nature of the work will vary widely according to the subject under investigation and may very likely involve several of the general fields and subdivisions listed above in studying a specific project. This necessarily calls for research facilities to be designed to house a variety of scientists from different fields so that various talents and special techniques may be applied to specific problems.

It is difficult to provide fine distinctions between industrial and

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(13)Ibid, p. 15.

research facilities as often testing of processes and materials may be carried out in close contact with research activities. However, the analytical control laboratories are a basic type provided for the use of scientists in a factory producing manufactured goods. No modern manufacturing plant can hope for efficient production without proper testing facilities. The nature of the product to be tested is a vital factor in the size and complexity of the unit provided. The testing unit may vary from a small bench adjacent to a machine to a series of laboratories dealing with the wider aspects of control. The industries which involve the processing of metals and the production and assembly of relatively large metal components are all concerned with laboratory facilities and include such industries as iron smelting, steel production, ship building, aircraft production, machinery and automobile manufacture. It might be noted that the aircraft industry often requires a large amount of space for laboratory facilities as the installation of wind tunnels for aerodynamic testing is vital to understanding the performance of materials under stress. Laboratory spaces where engines are tested require special noise controls as sound levels above 120 decibels, the threshold of pain for human hearing, are encountered.

Light industries are those engaged in the manufacture and assembly of relatively small components and includes the manufacture of detergents, plastics, fabrics, building materials, machine tools, clothing and shoes, food products, electronic equipment, drugs and surgical goods. Flexibility is imperative in the design of plant facility producing small consumer articles. If the demand for a particular commodity diminishes or ceases, a factory may have to discontinue production of this item and convert to a new product. Control laboratories which are concerned with the constant testing of raw materials and quality control, such as would occur in pharmaceutical manufacturing, must be located within the factory while pure research facilities concerned with the development of new formulae are often sited away from the factory location.

Laboratories are essential to public utilities in control testing of processing water, gas, sewage treatment, and electrical generation and distribution.

Teaching laboratories such as are found at universities offer some problems different from those normally encountered in a research laboratory. Although research is often carried out by faculty and graduate students in laboratories demanding the usual requirements for flexibility and adaptation, there also exist many laboratories designed for specific purposes. Such laboratories may be designed for the teaching of a limited classification such as general science, general chemistry, analytical chemistry, organic chemistry, biochemistry, physical and electro-chemistry, chemical engineering, metallography, etc. The movement of large numbers of students simultaneously demands easy entrance, egress and traffic flow within the building.

Laboratories for research and development explore the bases of existence and uses applied research on definite projects for specific ends.

The rapid development of scientific techniques in recent years has emphasized the need for research buildings which can be quickly and easily adapted to meet specialized demands as they arise. There are two main trends in design both of which reflect the need for adaptable buildings.[14] First, there is the trend towards open serviced floor areas which can be divided up with demountable partitions, the aim being to give each scientist

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[14] Nuffield, op. cit., p. 19.

or groups of scientists a serviced area which may be divided up to provide any combination of rooms as and when required. Secondly, there is the trend towards a simplified, functional arrangement of benches in long unimpeded lengths, spaced and arranged in such a way to rationalize bench servicing. Often the depth of the building is such that many rooms are internal and rely on artificial lighting and ventilation. There is an increasing tendency to regard laboratories as workshops in which the service lines are an integral part of the equipment. Older laboratories, where service lines are inaccessible, have failed to meet the changing demands of modern scientific techniques. The criticisms levelled at exposed piping in the past are now largely invalid. Corrosion problems can be overcome with modern coatings and finishes, and dust collection becomes less a problem where proper ventilation and filtering equipment is installed.

# CHAPTER III

## GENERAL PLANNING CONSIDERATIONS

### Program and Development

Research laboratories are one of the most expensive types of modern commercial construction. Many phases of research require unusual and variable states of air conditioning. Special furniture, fume hoods, cabinet work, compact storage facilities, and similar furnishings are a major item of expense. Another added cost is the many services which must be installed in all the laboratories. The structure itself is more costly because of the addition of service shafts, slots, service trenches and provisions for attaching quite heavy loads to laboratory walls. The laboratory also demands built-in safety features, such as safety showers, additional exit facitities, special grounding devices, and often explosion-proof outlets and fixtures. In order to avoid early obsolescense, careful planning should be done to provide for internal changes which give flexibility to laboratory arrangements so that spaces may be adapted to new and changing demands.

As in most architectural problems, the development of program requirements is basic and of course must be carefully balanced and related to the amount of money available to the project. The master plan begins with a prediction of the ultimate research program, the number and size of laboratories and offices in terms of the number of researchers per unit. The master plan should accommodate independent expansion of all facilities; laboratories, administrative offices, amenities and service structures without causing site problems. The well defined program will provide obvious influences upon site selection as well as building design.

Questionnaires and physical inspection are the recognized method of determining needs.[15] In a research facility many individuals are involved in the decision making process. The administration generally determines the funds available, while the real occupants of the facility, the scientists, technical service men, safety engineers, etc. all have their own particular demands, a good many of which will conflict with the interests of others and will most certainly affect the ultimate cost of the project.

The chief variables are the type of research being conducted and the organization of the work. Certainly an organizational chart showing the departments and number of personnel assigned is most helpful.

A survey of the net area to be devoted to each of the various functions should include any special dimensional and other characteristics of each particular space. Any special facilities and the number of people using the space should be listed.

A survey of required utilities for each work operation should be conducted. The need for flexibility and the possible future use of spaces should be determined.

With the above data, the program is developed by assigning areas to each work task requirement, adjusting as necessary to avoid overcrowding of personnel or equipment.

The arrangement of the basic building areas depends largely on two factors (1) the ability of all areas to expand independently and (2) the need for maintaining good circulation between laboratory and all other services.

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[15] An Architectural Record Book, Buildings for Research, New York, F.W. Dodge Corporation, 1958, page 4.

At this stage the first evaluations of probable building costs can be made. This is usually done "by assuming that the net area required will be approximately one-half of the total gross area, and multiplying this gross area by a suitable factor for the cost per square foot of building area."[16] Research buildings vary in the per cent of net area to gross area from 40 to 60. It usually happens that when the gross area is kept to a minimum, by eliminating basement or equipment spaces, that the unit cost per square foot will rise. The 50 per cent figure represents a realistic first "guesstimate."

Other items which should be included in initial cost calculations include utilities, (cost of additions or new facilities for steam, power, water, and sewage), site development (roads, landscaping, fences, walks), furniture and decoration, and auxiliary buildings (gate houses, pilot plants, vehicle storage, etc.).

## Site Selection

The site chosen for a laboratory structure will have much to do with the ultimate success of the facility. The competition for all types of technically trained personnel makes it necessary to provide them with better working conditions, both to attract them initially and to assure their maximum effectiveness. Buffer areas with grass and landscaping to separate the laboratory structures from the adjoining property can be a considerable compensation.

It is important that any site selected be large enough to meet all present and forseeable needs. It should be readily accessible to both public

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(16) Ibid, p. 5.

and private transportation. Proximity to air and rail transportation as well as hotel or motel accommodations may be important if the site is frequently visited by personnel from out-of-town.

Todays research facilities are moving to suburbs that have high educational levels. This is a direct attempt to attract and stimulate researchers, who are hard to find and even harder to hold.[17]

An important community factor is access to a university to permit researchers to take graduate courses and rub elbows with fellow scientists. Other factors of community evaluation are the obvious ones: available housing, taxes, recreational and cultural activities, churches, medical facilities, distance to a metropolitan center and the quality of local government.

Soil conditions affect the final selection of any building site. A preliminary study of the bearing value and structure of the soil is necessary.[18] Good natural drainage is desirable. Water is the builder's natural enemy. The presence of water affects the soil-bearing capacity of different soils in different ways.

High water tables may render a site unsuitable if a basement is required as the uplift of a head of water will often crack floor and wall slabs. Also expensive membrane water-proofing and a sub-surface drainage system may be required to make the site usable.

Exploratory borings strategically located on the site usually supply enough information for site selection studies. Once the site is chosen

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[17] Whitney, Frank, Planning Industrial Research Facilities, Architectural Record, Nov. 1962, page 163.

[18] Lewis, Harry F., Laboratory Planning for Chemistry and Chemical Engineering, New York, Reinhold Publishing Corp., 1962, p. 14.

further design borings and laboratory studies will have to be made to determine allowable safe loads.

A site consisting of rock may have good soil bearing capacity but may still be found unsuitable because of expensive utility installation costs.

Both off-site and on-site roadways must be planned and provided in order to insure a smooth flow of traffic. Cooperation with state and municipal authorities will be necessary. Public parking, employee parking and service areas for deliveries must be integrated into the plan.

The availability of utilities to the site is sometimes of great importance in site selection. Each utility should be planned to serve and to fit into any proposed future development. Often the first buildings on a new site will be penalized in utility development costs but the added costs in sizing for future demands prove to be good investments in terms of long-range planning. The central plant concept of supplying heat, cooling, etc. to a large number of separate structures should be studied before several individual installations are created as the possible economies of a central facility may be lost because of prior investments in equipment.

In locating buildings on a site it is desirable to establish priorities and analyze building service and traffic requirements in order to achieve the best possible relationship of buildings to a particular site. Not only should buildings be sufficiently spaced to achieve good landscaping between units but even more important the possible need for future expansion should be anticipated and planned for at the beginning.

Flexibility and Adaptability

Scientific research can be concerned with quantities so small that they are invisible under a microscope, or with problems so large that they must be dealt with in conditions resembling a factory. The course of Science is by its nature quite unpredictable; this unpredictability affects the type of research facilities required and the design of laboratories in many different ways. It affects the relationship between office space, bench space and special equipment areas. It affects the location and distribution of piping and air-conditioning. It affects the design and placement of laboratory furniture and equipment as well as the elaborate shielding and insulation that many experiments require. Flexibility is likely to be the most expensive of requirements and provision for growth can often interfere with present operations.

The high initial cost of constructing laboratory facilities requires obsolescence be minimized by careful planning of structure, finish materials, utility services, and environmental controls. Expansion and radical modification are the only predictable qualities in today's laboratory buildings. Probably in no other field of building is there such consciousness of the need for maximum flexibility. Flexibility is the greatest safeguard against obsolescence. With today's rapidly changing methods and techniques, "obsolescence starts at the moment the design is approved."[19]

Approximately a fifth of the partitions in the typical laboratory are likely to be shifted once every year.[20] Maximum partition flexibility is therefore a standard requirement in almost every new laboratory. This

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[19] Allison, David, Building for Science, Architectural Forum, Feb. 1961, p. 131.

[20] Ibid, p. 132.

means more than simply the ability to move a partition, for if a space is not adequately serviced or conditioned after the change is made then true flexibility has not been achieved. It would be most desirable if virtually all equipment in the laboratory could be placed where it will be most convenient for the scientist. As his needs change, the equipment layout including utility needs should be capable of shifting accordingly to achieve maximum flexibility.

## Building Module

A laboratory designed on a modular plan permits maximum flexibility. It is also generally accepted that the repeating elements created by a regular module will substantially reduce building costs.

> The "building module" might be defined as the smallest repetitive unit of space. The module must be complete in its repetition of the characteristics that enclose and serve this space. The characteristics of this repetitive element are its three dimensions; its architectural, mechanical, electrical and structural features; as well as the services that may be added for the convenience of its occupant.(21)

It must be remembered that economy of construction can often conflict with efficient operation. Bench areas and special installations require elaborate piping services and air conditioning; while desk space, conference rooms and storage areas form smaller units. In terms of economy, it makes sense to group like functions and like areas; and separate desk space from research. Unfortunately most scientists prefer desk space to be near their research. Resolving these contradictory requirements, while still providing for flexibility and growth, is perhaps the most

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(21)An Architectural Record Book, op. cit., p. 9.

difficult problem in designing a laboratory.

In recent research buildings the emphasis has been on the development of a planning module which would permit great flexibility of room use without having to make major structural modifications. The laboratory layout is based on an assessment of the space needed for the number of personnel who are to use the room. The modules used will vary in width from 10 ft. to 13 ft., depending on the space allowed between benches (usually between 4 ft. and 7 ft.). The clear bench run needed for the work to be undertaken plus the amount of space required to accommodate special equipment, such as fumehoods, will determine the room depth.

There is a difference in the amount of area needed for an individual worker in a room by himself and the area he will need if he is in a room with others because in larger rooms circulation space and to some extent working space and special facilities are used in common. Because of this and for safety reasons nearly all laboratories are designed to provide for two or more workers.

In determining the space required between benches, safety and convenience is important including the need to move quickly back from the bench in order to avoid burns or other injury. The presence of mobile equipment on the floor and the scientists stool should not be forgotten. The recommended figures for bench spacing for a number of conditions of use are as follows.[22]

| | Conditions of use | Clear space |
|---|---|---|
| a) | Two workers back to back<br>No through traffic | 4 ft. 7 in. |
| b) | Two workers back to back<br>room for a third person to pass through comfortably | 6 ft. 3 in. |

[22] Nuffield, op cit., p. 45.

| | | |
|---|---|---|
| c) | Gangway only no working spaces either side | 2 ft. 7 in. |
| d) | Gangway with a fume cupboard or a table with a worker on one side only | 3 ft. 3 in. to 4 ft. 1 in. |
| e) | One worker at a bench | 2 ft. 6 in. |

The working width of a bench is determined by the arm reach from standing or sitting positions without leaning the body forward over the bench. In the laboratory where safety is of major importance, the criterion should be to provide a bench width which allows the scientist to work in comfort, but which does not encourage him to lean so far over the bench that quick recovery and retreat become impaired. "A bench width of 24 in. would allow comparatively easy manipulation of service taps and outlets. The nearer these are to shoulder height, the easier they will be to operate."[(23)]

It is important to bear in mind that the correct module in any particular case is not based on averages but must be related to the particular work function. It may be desirable to have a different module for different buildings or for different zones of adaptability within the same building. Also the mechanical services as well as the facilities of access and emergency exit must be capable of being provided to and from each module. The ease with which this can be done is a measure of the adaptability of the modular system being studied.

A procedure which might be used to establish a typical laboratory module is as follows:[(24)]

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(23) Ibid, p. 46

(24) Lewis, op, cit., page 103.

1) Determine the type of work to be done in the laboratory.
2) Determine the kind and amount of equipment required to do it.
3) Determine the degree of flexibility that will be required in coming years. (Based on the best available data).
4) Determine the number of scientists to occupy a room and allow for proper working and circulation space.
5) Relate the above to the square feet necessary to house needed laboratory and office equipment and supporting facilities.

Since a laboratory building is built essentially to house laboratories, the dominant consideration must be given to the optimum module for the laboratories. In most cases multiple or fractional modules will adapt for office or other service requirement.

## Identification of Service Requirements

An increasing proportion of laboratory space is being devoted to mechanical equipment. In order to provide adequate spaces for this complex arrangement of pipes, ducts, conduits and machines, a detailed analysis of the required services must be made before design studies can be commenced. The ability to add piping, cables, and trunking for new service locations to individual bench positions is most important. The ease with which extension and adaptation of services can be carried out is the yardstick by which success or failure of an installation is measured.

Constant maintenance is required to insure efficient operation. Inaccessibility or lack of space to accommodate new pipes, ducts or equipment may even cause loss or damage to experimental work if such work is interrupted while servicing changes have to be made. Initial capital expenditure must be carefully evaluated against maintenance and operating costs.

The cost of services is one of the most significant items in laboratory buildings and can range from 20% to 50% dependent upon the degree of built-in requirements. In many laboratories building costs have been greatly increased by piping to the benches services which are rarely, if ever, used. Before installing these services, it is advisable to study actual needs in terms of scientific techniques likely to be used in the building. A special service piped throughout the building must also be maintained whether it is used or not. Often mobile units for local use are quite satisfactory solutions to special requirements.

Although more detailed information about services and methods of distribution will be given under laboratory equipment a list of commonly used services is as follows:

(1) Cold Water
(2) Hot Water
(3) Distilled Water
(4) Demineralized Water
(5) Steam
(6) Gas
(7) Argon
(8) Nitrogen
(9) Oxygen
(10) Compressed Air
(11) Vacuum
(12) Electricity (AC and DC at varying voltages)
(13) Acid Waste

It is essential that early planning considerations adequately provide for the required service chases, pipes and equipment spaces.

## Ventilation and Air Conditioning

Unlike most other buildings, laboratories require not only heating and air conditioning for a comfortable working environment, but must have good ventilation for direct reasons of safety. This is particularly true in the case of chemical, biochemical, and other laboratories where fumes are generated during the course of the work. Although the most objectionable fume producing techniques may be carried out in fume cupboards or hoods, quite high rates of air change (perhaps 8 to 10 air changes per hour) may still be required in the laboratory itself. Even with high air-change rates, the amount of air drawn through a normal fume hood may well be a larger volume than that required for efficient ventilation of the room in which it is placed.

> When this occurs difficult problems of air imput and extract balance may arise. The difference in volume must be either made up by secondary air input to rooms with fume hoods or the resulting pressure differential between different parts of the building must be accepted. Air transfer of this kind may be undesirable or even dangerous depending upon the kind of work involved.[25]

The ventilation system must provide for safe comfortable, and flexible working conditions and also supply any special air requirements related to the scientist's work.

In any typical research laboratory, the total air quantities are dictated either by the thermal load or hood exhaust requirements. The peak load condition does not occur simultaneously in all laboratory spaces due to usage diversity, although sufficient capacity must be available for each laboratory to satisfy the peak demand. Initial and operating cost economics as well as flexibility for changes or additions should be main features of an acceptable design.

Some demands of a mechanical system are as follows:[26]

1. Flexibility in services to accommodate the system to new or changed techniques and procedures.

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(25)Nuffield, op. cit., p. 97.

(26)Architectural Record, Air Conditioning Matches Laboratory Loads Feb. 1965, pp. 188-189.

2. Flexibility in operation to permit the operation of individual laboratories during off hours and weekends without involving operation of the entire system at its full capacity.

3. Maintenance of proper levels of temperature and humidity, with proper controllability for comfort as well as experimental conditions.

4. Availability of sufficient quantities of fresh air to satisfy all hood exhaust requirements.

5. Installation of an adequate hood exhaust and general exhaust system with individual hood exhaust ductwork to outside and sufficient provision for additional hoods in the future.

6. The system must maintain a negative pressure in all laboratories which produce noticeable quantities of orders, contaminants, irritants, dust, etc.

7. Adequate filtration of all supply air for protection of equipment as well as maintenance of cleanliness in the laboratories.

8. Provisions for proper cooling capacity to handle all thermal loads in a laboratory.

9. Easy maintenance of all mechanical equipment, which preferably should be located in one or two central machine rooms.

10. Ease of operation of hood fan switches and room thermostats. Each hood should have its own switch and pilot light.

11. Economy of installation and operation of entire system.

The system operation should contain the following features:

1. All supply air to be 100% outside air (in laboratory buildings with large office areas, air from these spaces may be recirculated.)

2. Due to summer humidity conditions, no outside air will be introduced directly to the space during high humidity weather without first being dehumidified.

3. Dehumidification will be accomplished for all systems by cooling. Reheating of air will be done whenever dehumidified air temperature is too low for space comfort conditions.

4. All supply air must be heated to a minimum of 50-60$^{\circ}$ F. in winter.

5. Maximum supply air quantity to each space will be based on whichever of the following requirements is greatest (a) cold air required for thermal loads (b) air required for hood exhaust (c) minimum air required for ventilation.

Since air conditioning requires the maintenance of a required internal atmospheric condition within the laboratory irrespective of external conditions, a system of filters, fans, humidifiers, refrigerators, heaters, etc. with special controls are all necessary to obtain the required conditions of cleanliness, temperature and humidity. Air conditioning eliminates the need for open windows which often render impossible the maintenance of required internal sterile conditions.

In deciding upon the exact type of system required, the engineering designer must weigh the exact requirements of each of the particular laboratories and arrive at a system or systems which will meet often exacting and varying conditions. Here again it is most important that these items of equipment be carefully planned at an early stage so that adequate provisions can be provided for their installation.

## Cost Considerations

Laboratory projects have become more complicated and more specialized in character and function. The choice of materials and structural methods has widened greatly. Thus the many alternative factors must be carefully considered and examined so that building needs and capabilities are related at an early stage of design process.

In addition to initial costs of the building and site improvements, the cost of maintenance and operation must be given careful consideration. Thoughtful design and choice of materials can minimize future costs and problems.

> Although each facility must be planned to fit the needs of its particular research program certain yardsticks are helpful in checking planning efficiency.

1. Ratio of assignable area to gross area

The assignable space is that portion of the structure in which people work. Gross area is the total area of the building and includes service areas, corridors, toilets, lobbies, auditoriums, libraries, cafeteria, etc...about one-half of a research facilities gross area is assignable. If the percentage of assignable area is 60% or more, it is possible that there is inadequate provision for services and circulation. The reverse is true if the percentage falls under 50. This may indicate that the use of unassigned space is questionable and that the facility is overly luxurious.

2. Assignable area per worker

The amount of gross space per person should run between 200 square feet and 400 square feet. Much more than the maximum is usually inefficient, much less makes for cramped conditions. An often overlooked factor of laboratory costs is that the higher the personnel density, the greater will be the requirements for increased mechanical and electrical facilities to maintain worker efficiency and productivity.(27)

Cost analysis is an attempt to compile data relating total cost to the various elements of building and enables the cost of elements or selected groups of elements forming a chosen part of the building to be compared with other systems as well as to a per cent of the total cost. In this manner the distribution of expenditure can be considered and a determination made as to whether money is being spent in accordance with programmed objectives. Also the analysis can be compared with previous similar projects at the design stage.

A comparison of the cost analysis of various laboratories often shows a wide difference in cost. This is due to some extent from the fact that laboratory buildings are never identical, even when it might seem that their main functions are the same, By examination of the elements the cost differences can be located and the reasons understood.

The cost of constructing a laboratory ordinarily ranges from $20.00

(27)Whitney, op. cit., p. 169-170.

to $40.00 per square foot including land, site development, equipment and fees. This wide variation illustrates the difficulty of estimating laboratory costs. There is quite a wide range of choices in structural systems, roofing materials, wall materials and finishes, all subject to wide differences in initial cost as well as durability and appearance. The same wide range of options pertains to the equipment, mechanical and electrical aspects of the laboratory as well. Table I and Table II [(28)] illustrate a breakdown of probable cost ranges for various elements of the research laboratory.

Table 1. Cost ranges for laboratories.

| | Dollars per square foot |
|---|---|
| **Architectural and Structural** | |
| Foundations and first floor slab | 1.00 to 3.00 |
| Second floor slab and its structural frame | 2.50 to 3.50 |
| Roof decks, roofing and framing | 1.40 to 3.00 |
| Exterior walls | .25 to 2.50 |
| Interior partitions | .40 to 3.00 |
| Finishes | .25 to 3.00 |
| **Mechanical and Electrical** | |
| Fire protection | .50 to .75 |
| Building plumbing and piping | .50 to 2.50 |
| Heating plant | 1.00 to 2.00 |
| Refrigeration plant | 1.00 to 1.50 |
| Air conditioning, ventilation, etc. | 2.50 to 4.00 |
| Incoming power | .80 to 2.50 |
| Power distribution | 1.50 to 3.00 |
| Lighting system | 1.50 to 3.00 |
| Telephone and Signal system | .20 to 1.00 |

(28) Ibid, p. 170.

Table 2. Percentage breakdown of costs for three specific laboratory buildings.

| | Pharmaceutical | Industrial | Electronics | Average |
|---|---|---|---|---|
| Architectural | 31.0 | 39.6 | 28.2 | 32.9 |
| Structural | 14.5 | 12.0 | 23.8 | 16.8 |
| Mechanical | 44.0 | 36.7 | 26.4 | 35.7 |
| Electrical | 10.5 | 11.7 | 21.6 | 16.6 |
| | 100.0 | 100.0 | 100.0 | 100.0 |

The development of an analysis of costs serves as a guide to the Architect in his search for control over the difficult facets of his work. The collection and detailed study cf more and more data related to cost alternatives in all aspects of design is of prime importance. A proper combination of the various factors which make up a building is the goal of cost accounting so that an efficient economical building is the end result.

# CHAPTER IV

## SPECIAL PLANNING PROBLEMS

### Noise

Much of the work carried out in research laboratories requires a high degree of concentration. Noise nuisance seriously impairs efficiency in this respect. Reactions of individuals to the same noise environment vary widely and the dominant pitch or frequency of the intruding noise may be just as critical as its loudness. There are three basic methods of noise prevention: reduction by planning, reduction at source, and structural measures.[29]

Planning against noise begins with choice of site. Noise is reduced by distance from source. The acoustic shadow of other buildings or plantings can be used to screen sensitive areas against outside noise. The disposition of noisy areas in relation to quiet areas is important to insure against noise transfer without resorting to expensive structural measures. Areas in which noise is generated should be grouped and placed as far as possible from those areas where a quiet environment is needed.[30] Store rooms, darkrooms and similar spaces can often be placed between the two extremes as buffers. Very noisy rooms may have to be isolated and placed in separate buildings.

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[29] Nuffield, op. cit., page 119.

[30] Beranek, Leo L., Noise Reduction, New York, McGraw-Hill, 1960 page 594.

Consideration of noise during planning stages, both on site and within the buildings, may make other more expensive measures unnecessary or at least make noise problems easier to control.

Reduction of noise at the source is a method of noise control often neglected. Noise in a building is made up of many minor noises which may be either eliminated or reduced by good design and choice of materials and equipment. Many common building noises such as footsteps and door bangs can be dealt with by means of resilient floor finishes and door closers. Wheeled equipment should have resilient tires. Areas used for typing or computing must be regarded as major noise sources and structural measures should be taken to reduce the spread of airborne noise. Where large numbers of fans are used, selection of the right equipment can do much to limit the build-up of noise. In general, the amount of noise produced by rotating fan blades depends upon their peripheral speed. Large slowly rotating blades are quieter than smaller faster ones. There should be a good clearance between blade tips and the fan casing and the inner surface of the fan casing should be smooth and unbroken. Electric motors need resilient mountings to prevent amplification of noise by resonance where motors are fixed to the structure or laboratory benches. This is especially true for large motors such as those used in ventilating and refrigerating systems. Compressors, boilers, emergency generators and similar extremely noisy items of equipment should be placed in a separate room and insulated from working areas.

Noise in water, steam and other piping systems is caused by movement of water, or vibration of the piping system. Steps should be taken to reduce the spread of the noise by use of proper valves, air chambers and short lengths of flexible tube at the noise source. To prevent noise transfer from pipe to the structure of a building, pipes should be isolated from walls with resilient material. Pipes should be hung by spring isolators or other type of flexible pads as it is important that pipework not be rigidly connected to the structural frame.

Ducts can be conductors of noise. Care should be used in locating grille openings and often the duct may have to be lined with an absorbent material to reduce or prevent the transmission of objectional sounds or to gain privacy. Fans and similar items of equipment should be isolated from the duct work by a reinforced flexible fabric insert. The ducts should be sized to prevent wind noise in the ducts caused by a high speed of airflow. The same is true in sizing grille outlets as too much resistance will increase the noise level.

Noise transfer between rooms is dependent upon the density of the materials separating the spaces. It should be remembered that the quieter the site, the more attention must be paid to sound insulation between rooms, as the audibility of noise from adjacent rooms is greater. If sound transfer is important special care should be given to doors and other openings to insure a good seal between door and frame. Where it is necessary to run laboratory pipes and ducts through partitions, the holes should be sealed around the pipes.[31] For good sound insulation it is better to run services in a separate duct, keeping partitions between rooms continuous

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[31] Nuffield, op. cit. page 123.

from floor to floor. Floating floorings are often used to reduce impact noise between the stories of a building.

In noise-producing rooms where people must work for long periods of time, the environment can be greatly improved by means of sound-absorbent treatments. These treatments reduce the reverberation and thus the apparent loudness of noise in a room in which the noise is generated. There is a problem in providing chemical resistant sound absorbing materials as it is impossible to prevent fumes or corrosive gases from penetrating into perforations or other irregularities. Many acoustical boards such as wood pulp, mineral fibres, etc. are made from inert materials and should give good service where they are not subject to splashing.[32] There is usually little need to apply absorbents to laboratory walls, but they can often be used in the ceilings of the laboratory and adjacent corridors to prevent the spread of reverberant noise throughout the building.

## Vibration

Many processes and items of equipment used in research work are affected by vibration. Optical work and the observation of liquid surfaces are critical and can be affected by vibrations that are humanly imperceptible.

Sensitive apparatus should be housed in areas least susceptible to vibration. Possible external sources of vibration should be fully considered in choosing a site for a laboratory building. The building should be kept as far away as possible from known external sources of vibration, such as road and rail traffic or other buildings containing heavy machinery.

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[32] Munce, op. cit., page 339.

Wherever possible, the most sensitive work should be carried out at basement or gound floor levels. On framed floors, apparatus should be kept away from the middle of the rooms where the amplification of vibration is greater. Generally it is desirable to avoid contact between walls and benches which support sensitive apparatus. This prevents the transmission of vibration from the shell of the building to the apparatus.[33]

Machinery is a frequent source of vibration. It is most readily controlled by reducing the vibration at its source. This can be done by providing anti-vibration mountings for the machine or sometimes a slight variation in the running speeds of the machines will reduce vibration intensity. For light machines with high r.p.m. ratings a simple rubber mounting is often effective. For heavier machinery, heavy-duty rubber or steel spring mounting may be needed.[34]

The use of isolation piers gives protection against vibration produced in the room in which the sensitive apparatus is housed. It is particularly suitable for balances and galvanometers. The pier is built on its own foundation separate from the foundations of the building and passes through the room floor without making a structural contact with it. This method can only be used in ground-floor or basement rooms. While these blocks or piers can eliminate local vibrations, they are still subject to external vibrations transmitted through the ground. It is desirable in such cases to provide anti-vibration mountings between the top of the block and the instrument.

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[33] Nuffield, op. cit., page 126.

[34] Munce, op. cit. page 335.

Door slamming should be avoided. Door closers should be used wherever needed.

## Safety

There are two types of hazards in laboratories, accidents and long term cumulative effects on health.[35] The incidence of hazard has been directly related to the efficiency and convenience of the laboratory. Working in overcrowded conditions is conducive to accidents, especially if the normal equipment and materials in use are potentially dangerous. Wherever possible, potentially dangerous or noxious processes should be carried out in special rooms expressly designed for the purpose.

Because of the ever present danger of an accident the areas between and around benches should be ample enough to provide an escape route from the accident area. Consideration should be given to the fact that a portion of the isle space is likely to be blocked by stools, chairs, open cupboard doors, or pieces of mobile apparatus. It is recommended that small laboratories be designed for a minimum of two workers if the work involves accident hazard. The provision of communicating doors between laboratories allows a worker to seek immediate help in case of accident without going out into the corridor. Such a door can also serve as an alternate escape route should the corridor door become inaccessible.

Bench width is a critical factor in accident hazard. Benches which are too deep will encourage undue leaning forward and stretching to reach utility valves or articles stored at the back of the bench. A two foot width is a useful working width that takes into account both safety and functional efficiency. To prevent accidents caused by the mishandling

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(35)Nuffield, op. cit. page 143.

or faulty observation of apparatus, benches should be placed so that sufficient light is available for the task involved. Benches, tables and cupboards should be stable so that they cannot be overturned by pushing or leaning. Chair and stools correctly sized to benches with adequate kneehole space will reduce fatigue and facilitate movement in emergency.

Although an adequate and easily accessible supply of chemicals is necessary in many laboratories, often this supply is far more dangerous than need be because materials are kept in the laboratory in excess of actual requirements. If any large bottles or other heavy or bulky objects are kept in the laboratory, they should be stored below bench-top level to avoid hazardous lifting. Only small bottles should be kept above the bench top and whatever their size it is desirable that the shelf or rack on which they are kept have a lip or trays to contain spilled liquids and prevent accidental knocking or dripping. Inflammable liquids, reagents, etc. should not be stored at the back of benches because of the danger of spilling when reaching forward, possibly over or through assembled apparatus. In general, explosive or inflammable materials should be stored in detached and fireproof buildings with good ventilation and devices to relieve pressure build-up in the event of explosion.

Service outlets and controls should be carefully located so that the user does not have to risk accidentally coming in contact with apparatus on the bench. They can be mounted a convenient distance above the bench top in positions where they can be manipulated and seen easily. Control knobs and switches should be of distinctive shape and color coded where there is a multiplicity of supplies. It should also be most evident when the control is switched on. Whenever possible electrical outlets should be placed well away from watertaps and sinks. It is easy for plugs or cables to become immersed while in use.

Dilution of liquid wastes should occur as near the sink as possible. Inflammable wastes should not be discharged into the waste system, but deposited in metal containers provided with lids. Waste bins should be provided for each class of solid waste such as glass, chemicals, paper, etc.

Flooding is a frequent accident hazard caused often by a break in a hose when water is run continuously for an experiment. Floors should have a waterproof treatment to protect the rooms below. Where risk of flooding is high, consideration should be given to floor drains with adequate slopes toward the drains.

Electrical hazards may be reduced if careful planning is given to planning the electrical installations. Rooms should be separately wired and controlled with conveniently located fused switches so that supply can be cut off in an emergency without interfering with other parts of the building. The need for improvised wiring, which often causes accidents, can be greatly reduced by the generous provision of outlets. Sparking from electrical apparatus frequently causes fires and explosions in laboratories in which solvent vapors are present. In high hazard areas spark-proof switches, outlets and motors should be installed.

Gas cylinders containing corrosive or explosive gases under pressure are a common laboratory problem since the cylinders are often brought into the laboratory with the gas being piped to the bench. It is of utmost importance that provisions be made to properly support the cylinders so that they can be securely fastened to prevent tipping or dislodgement.

Provision should be made for the storage of protective clothing such as gloves, eye-shields, overalls, gas and dust masks, etc. in the laboratory. A convenient place will encourage the use of protective equipment.

Because there is a danger to the laboratory worker of dangerous chemicals coming in contact with his skin or clothing it is necessary to provide emergency showers. These showers should be located in an easily accessible position within the laboratory and fitted with valves which can be found and operated by the accident victim who may because of the accident be temporarily blinded.

Every laboratory space should have available a convenient access to a first-aid box equipped with medication and bandages for cuts, burns and other minor accidents. Often first-aid equipment is located in a corridor for use by several laboratory spaces.

### Laboratory Wastes

Neither large volumes of laboratory waste acids or solvents, nor even small amounts of certain high reactive, toxic, radioactive or potentially explosive chemicals should be indiscriminately disposed of through the sanitary sewer. This practice runs the risk of sewer main explosions set off by an accidental ignition of high concentrations of volatile vapors, and explosive and toxic atmospheres. The chance mixing of compounds could produce such products as hydrogen sulfide and hydrogen cyanide. Other hazards include the possible return of these toxic or explosive sewer atmospheres directly to the laboratory via drain traps with evaporated water seals.

If the quantity of waste materials warrant, it is recommended that a laboratory waste collection service be planned together with a waste chemical handling and disposal site.

Solvents can be fed into oil burners mounted in firebrick combustion chambers. By adjusting fuel-air ratios, smokeless combustion is obtained.[36]

Corrosives may be collected and either diluted or neutralized to minimum pH levels required by the local sewer authority.

In handling toxic compounds and unlabeled bottles or container suspect of containing peroxides, such safety disposal personnel safeguards as a safety barrier equipped with a bottle drop slot and a container breaking or crushing device should be planned.

Liquid wastes containing the short half-life elements, phosphorus-32 and iodine-131 can be disposed by dilution methods as can some levels of radioactive wastes as specified by the U.S. Atomic Energy Commission regulations. Any entrapping of active material within the plumbing may result in extraneous radiation fields. For this reason the most satisfactory location for the main disposal sink is as near the main sewer as possible.[37]

Where laboratories must dispose of contaminated biological products and sacrificed animals, an auxiliary fuel-fired incinerator should be provided. Only if the laboratory wastes present no hazards of infection should contract hauling and off-site disposal of these materials be considered. Where incineration is the recommended method of safe disposal, the waste-handling system must safely convey these wastes to the incinerator. Disposable plastic container or liners are often used.

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(36) Lewis, op.cit. page 93.

(37) Coleman, H.S. National Research Council Report on Design, Construction, and Equipment of Laboratories, New York, Reinhold, 1951, page 221.

Garbage grinders are used to dispose of small volumes of organic wastes at locations where they are produced.

Solid radioactive waste disposal procedures generally involve land burial or disposal at sea. Areas and containers for the temporary storage of these wastes must be provided and are preferably isolated from the bulk of the laboratory operations.

Shielding and Contamination

Many types of modern research activities present situations in which the scientist must be protected from the consequences of his experiment; or the experiment must be protected from outside contamination. Sometimes both requirements are present. The nature of the radioactive material to be handled will affect the planning, layout, construction and functional operation of the research facility housing it. The basic needs of conventional laboratories such as, work space, equipment storage, good ventilation and light, fume hoods, sinks, benches, etc. are equally basic in nuclear laboratories but everything about them is governed by the considerations of protection for personnel and building and equipment from the invisible radioactivity of the materials used in research.

The hazard involved in handling radioactive substances is due to the ionizing effect of this radiation of alpha, beta and/or gamma rays on living tissue. If taken into the body through nose or mouth or through a cut or abrasion, they can kill some body cells. The specific damage varies with the source and intensity of radiation.[38]

Working with these various kinds of emissions is hazardous, not only

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[38] An Architectural Record Book, op. cit., page 29.

because they can harm living tissue both externally and internally, but because equipment and buildings can be contaminated invisibly by their radioactivity and this secondary contamination can in turn harm living things. To protect against this radiation, distance and certain kinds and thickness of materials are effective in providing safe working conditions. The choice of shielding material and thickness is made by the health physicist but the architect must provide the necessary structural base for its support and the necessary space to house it.

Early work with radioactive materials was carried out in conventional bench type laboratories with only local shielding. As more became known about the phenomenon and its effects extensive and often expensive protective means have been used. A theory of laboratory operation known as DDD, "dilute, dispense and decontaminate" [39] has been further developed so that distance, shielding, increased air flow to remove radioactive particles, remote control manipulators and controls, all contributed to safer working conditions.

Protective clothing is worn during work. The worker must leave his contaminated clothing in a "contaminated" locker, take a shower, dress and leave the building without re-entering the contaminated area. Contaminated water, that is used to launder this protective clothing must be disposed of by special means. This is true of all radioactive waste, either liquid or solid, and the greater the volume, the more complex must be the disposal system.

Another accepted method of operation is the "concentrate and confine" philosophy in which radioactive material used in an experiment is surrounded

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[39] Ibid, page 30.

by a box and the contamination is limited to the area of this enclosure. The area of the enclosure is determined by the size of the experiment and varies from a glove box to a large room. Decontamination is greatly simplified and even more important total control of radiation provides a means of assuring personnel greater protection as well as minimizing the contamination of building and equipment. At the end of an experiment the box is moved to a decontamination area where it is either cleaned up and put back in service or allowed to "cool" until it can be cleaned or if too "hot" destroyed.

The selection of materials and equipment is important. Modular equipment makes for flexibility and simplifies replacement, inspection and monitoring. Demountable partitions of metal, concrete block, wood or glass make interior changes easy. Assembly of utility lines in service chases facilitates expansion horizontally and vertically. Non-porous and seamless materials do not absorb or hide radioactive materials. Rooms where radioactive work is performed should be made readily cleanable so that any radioactive material that is spilled or deposited gradually over a period of time may be removed without difficulty. Filtered air at intakes put less load on filters at exhausts.

## High Pressure Rooms

The design of laboratories in which high pressure equipment is to be used requires special treatment. Ideally this space should be in a separate building well removed from other occupied structures and circulation routes. These buildings should be provided with large windows or light blow out walls which will relieve pressure in case of accident. The pressures involved will range from a few hundred to as much as a million pounds per aquare inch. The laboratory staff should be protected by a barricade behind which all persons must stay when the equipment is under pressure.

The purpose of this protective barrier is to absorb and dissipate the force of a fragment projected from the equipment. The human body can resist pressures up to 400 lb. per square inch but it requires only a force of 1 lb. per square inch to displace it.[41] The great majority of injuries are caused by the body being forced against hard surfaces or moving parts and also by flying missiles from the laboratory equipment.

For temporary protection, barricades are formed with sand bags and blasting mats. For more permanent protection reinforced concrete or ateel plates are used. These barriers should be fixed as an integral part of the building by embedding in the floor and roof structure.

Portable equipment should be fastened down and all electrical lights, motors and switches should be explosion proof.

Good forced ventilation will prevent gas leaks from promoting explosions. Strict laboratory discipline should be exercised in the use and handling of equipment.

Special Laboratories

In any laboratory complex there are a number of special rooms such as dark rooms, controlled environmental rooms, instrument rooms, etc., which are used in common by the various other laboratories. Their use is often intermittent but is closely associated with work in the laboratory and should be located close by for convenience.

Photographic and photometric techniques are used by almost all scien-

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[41] Munce, op. cit. page 102.

tific disciplines. Dark room facilities are therefore of considerable importance. If the volume of work requires it, several individual rooms are preferable to one large room, as inconvenience will result from several people using the same space. The service requirements are filtered hot and cold water for use in preparing developing and printing solutions and for washing. Electrical outlets should be provided for safelights, enlargers, driers, etc. It is often desirable to provide light-trapped entrances where frequent traffic to and from the dark room is expected. Good ventilation is desirable as well as a constant temperature of between $65^{\circ}$ F. and $70^{\circ}$ F. Dark rooms should be protected from infiltration of chemical fumes from other parts of the laboratory building.

Balance and instrument rooms are often provided to house sensitive balances used for weighing micro-quantities. These balances require protection against vibration. Modern instrument mountings have reduced the need for special structural measures against vibration. A rigid bench installation combined with properly designed instrument mounting will meet most needs. Special concrete isolation mounts are used for extremely difficult conditions. Generally, instruments should be protected from excessive humidity, dust and corrosive fumes. Water and a sink for disposal of samples are normally required in all instrument rooms.

Controlled environment rooms are often provided in research laboratories. Not only is temperature controlled within a small range but often humidity is just as carefully controlled. Accurate control equipment is expensive. The rooms are specially insulated with insulated and sealed doors. Controlled environmental rooms in which scientists work must be ventilated. When the rooms are in constant use, failure in the environmental control can jeopardize months or even years of research work, so equipment must be carefully planned for instant service and repair. Also emergency power is often provided for these special spaces.

Work shops with tools for constructing in metal and wood are often provided. These spaces will contain a large number of power tools and provisions for welding. Space should be provided for the storage of stocks of wood and metal materials. Ample space is needed between tools for safe working conditions.

Dishwashing and sterilization operation are often centralized with one room serving several laboratories. In microbiological, biological, biochemical, and pathological disciplines, glassware, apparatus and media must be sterilized. Also soil samples, animal cages and bedding may require sterilization. Either dry heat or steam under pressure is used. The steam pressure at which an autoclave is operated determines the length of time needed for killing organisms. Autoclaves and ovens will frequently require hoods as good ventilation is exteremely important. Precautions should be taken against condensation by providing adequate room ventilation in addition to hoods.

# CHAPTER V

## LABORATORY EQUIPMENT

### Benches and Cabinets

The choice of laboratory equipment is governed by the money and space available, and the type of work to be done in the various laboratories. The type of materials being investigated often dictates special precautions if experiments tend to be flammable, odorous, unstable or generally in some way hazardous. Any of these conditions may influence hood design, the type of electrical fixtures, the location of equipment, etc. Other factors which influence equipment selection include the amount of working space assigned each scientist; the quality of maintenance; appearance desired; and the permanence of the installation.

"In general, industrial companies tend to favor steel furniture, while academic institutions favor wood."[42] Those who favor steel list the following advantages: greater fire resistance; epoxy-type finishes impervious to a wide variety of acids, bases and solvents; easier to clean; greater flexibility because interchangeable cupboard and drawer sections. Wood is claimed to be a "warmer" type of material, both in appearance and feel, creates less noise, easier to repair and refinish with unskilled maintenance personnel. Personal opinion is usually the deciding factor as initial cost is comparable on large orders.

Steel units are now generally fabricated of sheet steel and the entire unit given a phosphatizing treatment "bonderizing" which provides a non-reactive corrosion resistant surface to which paint adheres firmly.

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(42) Lewis, op. cit., page 66.

When a scratch goes through the double protection of paint and bonderizing film, corrosion is said to be confined largely to the area of the scratch rather than creeping under the adjoining paint film. Tough resistant coatings are obtained by baking on epoxy resin paints. Such finishes will resist solvents such as acetone, ethyl alcohol, and various aliphatic and aromatic compounds and strong acids and alkalies as well as concentrated sulfuric and nitric acids.

The construction of steel furniture requires special equipment and skills which tends to establish a sort of industrial standard. In wood construction there also exists a group of manufacturers who specialize in quality laboratory furniture. But almost every community has a wood working shop of some type and there is often a temptation to try and save money by having cabinets locally made. It is possible to achieve good results locally but often many disappointments are in order. A complete laboratory furniture installation requires coordination of millwork design hardware, fittings, plumbing and electrical provisions and special resistant finishes. The more complex the job, the more important it becomes to place the furniture order with a reputable laboratory furniture manufacturer who can ensure proper coordination of planning, production, and installation. He should also provide a performance guarantee. Generally, cabinetwork is made of top-quality oak, maple or birch with interiors of Douglas-fir plywood. The moisture content of the wood should be very low to ensure free movement of drawers and doors under laboratory conditions. After staining and sealing, a chemical-resistant synthetic varnish is often used as the finish surface. Newer more chemically resistant synthetic resins of the polyurethane type are now being used to finish wood laboratory equipment.

The quality and appearance of cabinetwork, either wood or steel is dependent not only upon the original construction and finishes but also upon the maintenance program. Good laboratory furniture will retain its usefulness and appearance for many years if properly cared for. Unfortunately, there seems to be no correlation between the professional level of the individual and the care with which he treats his laboratory furniture.

## Working Surfaces

Materials for work tops can be selected only after each situation is examined to establish what type of work the top will handle in terms of chemical corrosion or fire, heat, etc. There are a number of materials often used. Generally the lowest cost top material which will satisfy the necessary work tasks is selected. The most popular surfaces are as follows:[43]

(1) Natural Stone. "Alberene" quarried in Virginia is a silicate with or without talc. It has good structural strength, a low coefficient of absorption and is resistant to most reagents normally found in the chemical laboratory. With proper housekeeping "Alberene" tops will be useful for the life of the laboratory furniture.

(2) Natural stone, impregnated. These stones have great structural strength and are highly resistant to chemical attack. They are not recommended where subjected to high continuous localized heating unless protected. The overall excellence makes it a most desirable top material. This top material goes under the trade names of "Kemrock", "Labrock", "Imperial Stone", "Shelrock","Metrock", etc.

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[43] Ibid., p. 69.

(3) Cement asbestos compositions. "Kemstone" and "Colorlith" are cement asbestos, monolithic compositions. They are excellent in most ways except for a rather high coefficient of absorption which can be lessened by impregnation with sealers. These materials have the additional advantage of adding color to brighten laboratory areas.

(4) "Transite" is probably the poorest of the synthetic stones for chemical resistance and absorptivity but it is often used where heat resistance and physical toughness is desired. It has a low initial cost.

(5) Wood tops are attractive and are excellent for use on physical test tables. Carbonized (black) wood finishes and other type wood tops properly treated with acid and alkali-resistant finishes are serviceable where used with reagents.

(6) Laminated plastic gives moderate chemical and heat resistance. It is easy to clean and comes in several attractive colors and patterns.

(7) Stainless steel and porcelain enameled steel make excellent work surfaces when radioactive research is being conducted.

The choice of materials depends on the critical or maximum resistance to the types of chemicals and environmental conditions to which the top will be subjected. Cost differences and appearance are often somewhat influencial in determining which material will be selected.

## Fume Hoods

One of the most important items of laboratory equipment is the hood. For working safety or comfort, almost every type of scientific study requires that a portion of the work be performed in a hood, because of heat, odor, or toxicity.

The fume hood is an exhaust duct terminal, so conceived that it can enclose an experiment. One or more sides are openable with the suction of the duct transformed into a uniform movement of air across the face of the opening. This flow of air into the enclosure sweeps toxic and odor laden vapors and dusts into the duct to be exhausted outdoors, thus protecting the person working in front of the hood and preventing the toxic and odoriferous materials from mixing with the air of the laboratory.

Safety is generally enhanced by increasing the rate of airflow and it is usual to select fume hoods and to design the air conditioning system to maintain the face velocity appropriate for the maximum hazards anticipated for the particular hood. The recommended hood face velocity for various degrees of hazard is as follows:[(44)]

a) Low toxicity levels - 50 feet per minute.

b) Average toxicity levels in research involving a wide range of materials - 75 feet per minute.

c) Low-level radioactive tracer - 100 feet per minute materials.

d) Significant chemical toxic - 150 feet per minute levels and moderately radioactive materials.

e) Higher levels of toxicity - use glove boxes or total enclosures and highly radioactive materials.

Hoods of all types and varieties can be fabricated to meet special needs. Often a variety of built-in features, such as hot plates, variable voltage transformers, steam tables, remote control utilities, sinks, etc. are included in the hood.

A great many materials have been used for fume hood construction.

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[(44)] Horowitz, Harold and Heider, S.A. and Dugan, Caldwell N. Fume Hoods for Science Laboratories, A.I.A. Journal, July 1965, page 64.

Most of the normal materials used in other furniture construction have proven satisfactory when used correctly and are properly selected with regard to the experiments which will take place within the hood. It makes good sense to use the least expensive material that will perform well.

Hood interiors are often lined with a thinner version of the materials used for counter tops. All exposed fasteners inside the hood should be so covered as to render them as chemically resistant as the interior itself.

Hoods used for perchloric acid require special design because the perchloric acid generates perchlorates which detonate easily in the presence of organic matter. Collections of the residues must be removed and often water-spray pipes are installed in the hood and duct work for washing down the back surfaces of the baffles and other parts of the hood difficult to reach. Materials used in the construction of the hood and exhaust system should be inert, non-absorbent, and free of any organic impregnation. All joints should be liquid and gas-tight.

One must realize that in a laboratory the high cost of air conditioning is one of the unavoidable business expenses. Certain types of hoods have been designed to reduce the amount of conditioned air exhausted from the laboratory. These hoods introduce a quantity of unconditioned air directly into the hood and therefore reduce the amount of air exhausted from the room. Although often suggested, it is generally considered "a most dangerous practice from the standpoint of health, fire and explosion hazard and discomfort due to odors, to use a scheme which recirculates part of the exhausted air back into the room.[45]

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[45] Lewis, op. cit. page 78.

Unfortunately many of the ideas that have been explored to reduce the volume of conditioned air lost through fume hoods have lost sight of the basic function of the fume hood, which is to provide safety to laboratory personnel.

Another important consideration is the problem of maintaining a satisfactory balance between air exhausted and the volume of air supplied to a room. In many postwar laboratories only an exhaust system was provided with the supply air made up from infiltration. This practice puts the room under a negative pressure, which can make doors difficult to open as well as presenting a most unfortunate borrowing of air from other laboratory spaces within the building. Often this borrowed air contains toxic materials which may upset an experiment or produce a dangerous condition for personnel when mixed with the gaseous elements already within the laboratory. Present practice attempts to control fume hoods and return air registers in a system which provides a constant volume of exhausted air or to use constant volume fume hoods as the sole exhaust outlet.

There are three different types of fume hoods with respect to the air conditioning system:[46]

(a) The standard hood is one in which the volume and velocity of air varies as the sash is raised or lowered, since no means is provided to compensate for the variable area of face opening. This type of hood causes the greatest difficulty with balance in an air conditioning system. Laboratories containing such hoods must be supplemented with additional exhaust air openings to insure adequate room ventilation.

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[46] Horowitz, Heider and Dugan, op. cit. page 66.

(b) The constant-volume hood has an internal bypass feature permitting the same volume of air to be exhausted by the hood regardless of the sash position. Such hoods permit balancing of the air conditioning supply and exhaust.

(c) The auxiliary air-supply attempts to reduce air conditioning requirements by providing a separate supply of air that has not been cooled and dehumidified in the summer or fully heated in the winter. Such hoods can substantially reduce the required air conditioning equipment capacity and operating costs. A disadvantage with many auxiliary air hood designs is that the unconditioned air is discharged just in front of face of the hood. A scientist working at the hood must work in this unconditioned air. Attempts to rectify this problem by partially cooling or heating the auxiliary air supply, depending upon the season, substantially reduces the economic advantage of this hood type.

The location of a fume hood within the laboratory is important. The rate of airflow needed to satisfy minimum face velocity requirements is quite small. Because of this, air movement outside the hood is of great importance in insuring safe operation. The location of room air outlets and returns may cause drafts sufficient to counteract or even reverse the flow of air into a hood causing a hazardous condition. Opening and closing of room doors will also move a considerable volume of air. In all laboratories it is desirable to locate fume hoods as far away as possible from door and grille locations. Windows should not be used to provide ventilation for similar reasons. It is preferable that hoods be located only in spaces provided with supply air through a mechanical ventilation system which can control the volume and location of incoming air. Also hoods should not be located adjacent to major traffic patterns within a laboratory as persons walking by fume hoods will tend to produce some flow of contaminated air out of the hood.

Ideally the fume hoods of every room should be served by a separate exhaust duct to insure maximum safety and flexibility. Since fume hood ducts often discharge highly corrosive and toxic materials, consideration should be given to the fact that such ducts will have to be serviced or replaced during the life of the building. High-velocity air movement in the ducts is desirable to insure that dust and aerosol-sized materials are not deposited in the joints, cracks or corners of the duct system. A minimum suggested velocity is 2000 feet per minute[(47)] where perchloric acid is to be used, duct configuration should permit thorough washdown of duct surfaces.

The preferred location for fans is outside the building, usually on the roof, and as close as possible to the terminal. Such a location insures that the ducts within the building operate at a lower pressure than exists within the surrounding spaces in the building and that any leakage that does occur will be into the duct rather than into building spaces.

When radioactive materials are used, filters may be required to prevent discharge of these materials into the air. Scrubbers, burners and other types of air cleaners may also be used to treat fume hood discharges and reduce the potential hazzard from toxic, biological and radioactive wastes. Since there is considerable danger that the fume hood exhaust may be circulated back into the building, special care should be taken in locating intake louvers in relationship to building profile and prevailing winds.

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[(47)] Ibid, page 68.

Utilities and Services

The services available at the bench are an essential part of the scientist's equipment, and if they are inadequate, working efficiency is seriously impaired. Even though the majority of services are piped to benches from a central source, it is important to remember that the development of reliable portable equipment for the supply of compressed air, vacuum, demineralized water and so on, has to some extent obviated the need for centralized distribution of these services. Careful study should be made to determine whether a central distribution or a portable unit can best serve in an economical way the needs of each particular laboratory. Essentially there are two basic ways of bringing piped and air conditioning services to the laboratories: horizontally and vertically. The aim in planning any good system of services layout is maximum efficiency, flexibility, and adaptability. Distribution lines are separated into two categories: the supply main and the sub-mains which form the connection between the main supply and the bench supply lines. Sub-mains lead from vertical mains carried in vertical chases. Vertical sub-mains lead from horizontal mains carried at the highest or lowest levels.

Perhaps one of the most flexible of horizontal supply systems is used in Louis Kahn's Salk Institute of Biological Studies in San Diego, California.[48] It has a mechanical floor large enough for a man to walk around in located between each laboratory floor. These service areas are fed from vertical chases at the end of the building, so that the area devoted to mechanical distribution is actually greater than that devoted to

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[48] Architectural Record, Distribution of Laboratory Services, November, 1965, page 186.

research. The advantages of this system are its almost complete flexibility, and its ability to permit extensive changes in one area with a minimum of disturbance to other experiments. Flexibility on such a grand scale is obviously quite expensive and is by no means necessary in most laboratory situations.

A compact vertical system is used in Skidmore, Owing and Merrill's Center for Space Research at M.I.T.[49] Here vertical chases on 36 foot centers carry the laboratory services and most of the air conditioning ducts. The length of horizontal runs is kept quite short. These service shafts are fed from a single mechanical distribution floor and the chases are large enough that they can be entered and serviced.

These two concepts demonstrate the increasing proportion of laboratory space being devoted to mechanical equipment and distribution. The more common methods of servicing laboratory buildings are less elaborate. The most common method being a compromise between horizontal and vertical methods of distribution. Often the corridor ceiling is used for horizontal air conditioning runs, because a corridor ceiling need not be as high as a laboratory. The vertical chases are spaced out along the corridor and are not made large enough to enter as it is possible to service them from the circulation space. This is a simple and economical system which often meets the needs of many buildings.

Another scheme that is commonly being used as mechanical needs continue to increase is a consolidated vertical chase or core running either between laboratories or along the peripheral wall. These core areas are made large enough to enter and service.

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[49] Ibid., page 186.

The installation of service lines and pipes to the benches is achieved by several methods. For wall benches it is common for the services to be attached to the wall and an allowance is made in cabinet depth for clearance of these pipes if they are below the countertop. This independent fixing of the services allows bench construction to be simplified and for the placing of piping before the installation of cabinetwork. In the case of island benches the services are carried in a chase between cabinet units. Another method sometimes used is the placement of all services in carefully placed armature columns rather than spread along the bench. In all of these distribution patterns, allowance should be made for access.

The positioning of service outlets on the bench is important to safety. Services such as electricity, gas, and so on, should be grouped so that they are easily reached in an emergency and sectional controls for each group of benches or units should be provided for the emergency shutting down of service outlets in an area. Providing bench widths are not excessive the nearer the controls are placed to a horizontal arm-reach position, the easier they are to manipulate.[50] Where a large amount of glassware or other complex apparatus is anticipated, it may be that placing valve controls on the front of the bench will promote safety.

Piped services with outlets inside a fume hood should be controlled by handles in readily accessible locations outside the hood enclosure. Where washdown facilities are provided for perchloric acid hoods, the control valve handle should be located outside the hood. The same is true for switches, rheostats and other control devices for electrical appa-

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[50] Nuffield, op. cit. page 95.

ratuses located within hoods.

The following is a list of various materials suitable for service piping:(51)

a) Cold water - lead, copper, polythene, P.V.C., galvanized steel tubing.

b) Hot water - copper, galvanized steel.

c) Steam - black or galvanized steel, copper.

d) Condensate - copper.

e) Gas - black steel tube, copper or aluminum.

f) Compressed air - black or galvanized steel, copper or aluminum.

g) Vacuum - copper or aluminum, medium steel, chemical lead for corrosive conditions.

h) Distilled water - stainless steel, glass, P.V.C. polythene, aluminum, pure tin.

i) Drains and wastes - stainless steel, chemical lead, cast iron, silicon iron, chemical stoneware, vitreous enamel rubber lined, glass, glazed fireclay, copper, polythene.

j) Demineralized water - stainless steel, glass, P.V.C., polythene, aluminum.

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(51) Ibid, page 205.

CHAPTER VI

# BUILDING CONSIDERATIONS

## Room Finish Materials

The criteria which apply in all types of buildings such as durability, ease of maintenance, quietness, cost, etc. also applies in laboratories. However, there are special properties which are required in laboratories. The aim in laboratory design is often interchangeability and this requirement affects the selection of materials. Often the choice of materials is made in relation to chemical resistance, but the choice may not always rest upon this, even in chemical laboratories. The liquids which are spilled will only be highly corrosive on rare occasions, whereas water or very dilute solutions may be spilled quite frequently. If a surface material is made up of small units such as wood blocks or tiles, liquid may be allowed to penetrate to the structural sub-floor. With such materials it is advisable to place an acid-resistant, waterproof membrane between the floor finish and the sub-floor. Acid-resistant asphalt and bituminous felt, tarred paper and polythene films have all been used successfully for this purpose. Because of the protection they give against spilled liquids, sheet materials, which have few joints through which seepage may occur, have become popular for laboratory floors. Painted surfaces (walls, ceilings, etc.) are exposed to conditions which are only corrosive to a very mild degree. Fume extraction and ventilation are usually designed to maintain the atmosphere at reasonable levels of concentration for reasons of comfort and safety. The greatest danger of attack occurs when condensation is likely. Generally ample protection is given to walls and other surfaces by an exterior grade, lead-free alkyd paint. More stringent measures must be taken to protect areas exposed to heavy concentrations of fumes or where corrosive liquids may be spilled. Metal surfaces such as the exposed parts of lighting fittings, furniture, fume cupboards, and similar components may be protected by paints based on epoxy resins. These paints give good resistance to chemical attack. Clear epoxy resin varnishes and other clear plastic sealers provide a renewable method of obtaining an impervious surface on wood or cement asbestos board bench tops.

"Strippable" paints are often used on fume cupboard interiors, especially in radioactive work. The paint is removed and destroyed when contaminated.

Plastic coatings are becoming popular for laboratory fittings such as taps and valve handles. The application of such coatings is a factory process, and cannot easily be done at the job site. However, sprayed plastic wall finishes are being used in a number of recent buildings. These surfaces have good wearing and cleaning qualities and are usually quite resistant to chemical attack.

## Lighting

The quality and quantity of natural and artificial illumination affect the efficiency and comfort of those who work in the laboratory. Unlike many other work spaces, in research laboratories tasks of widely varying visual difficulty may be performed in the same room. The amount of light needed to carry out any visual task with a stated degree of efficiency (determined by speed and accuracy of performance) depends upon the size of the relevant task detail and the contrast between the detail and its background. In laboratories the range of visual difficulty is great and since the research worker is not restricted to one small portion of the room it is advisable to recommend one level rather than to specify a range. Where general work is involved a level of 30 lumens per square foot will cover a sufficiently large portion of seeing tasks.[52] Where work of extreme visual difficulty is to be performed special lighting can be used.

In addition to the provision of an adequate amount of light other considerations such as directional quality, the avoidance of discomfort, glare and the choice of color are also of major importance. A surface of known photometric brightness will appear darker or lighter according to the adaptation level of the eye of the observer. Adaptation is determined to be the brightnesses of all the surfaces in a field of view and therefore a very bright surface of large area such as a large window, through which a bright sky is visible, raises the adaptation level and will reduce the apparent brightness of less bright surfaces in a room. Window size and design must be related to the design of the brightness pattern in the room as well as illumination levels for efficient seeing. For workers at benches near a window it may be desirable to reduce the visible area of high sky in order to prevent glare if exacting visual work is to be carried out without discomfort. Horizontal baffles, roof overhangs and vertical baffles are all found to help in this respect although they do tend to reduce the daylight levels in the room.

The use of artifically controlled laboratory environments is increasing. Often the use of glass area is minimized or eliminated in order to achieve better control of heat gains and losses. Schemes which use this approach must then depend entirely upon the use of artifical lighting. Many

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[52] Ibid, page 112.

lighting engineers find this not only acceptable but claim that lighting levels and qualities can be carefully fitted to particular seeing tasks. There are still others who feel that the window is necessary for physiological reasons and that the human still needs to relate to nature's environment at least visibly. Whichever approach is used, strong uniform illumination levels are preferred to variations in light levels in order to provide efficiency in difficult seeing tasks.

The effect of color is of great importance as the overall impression experienced in a room may be changed by varying the hue and chrome of the surface finishes. The color of benches and work surfaces in relation to walls against which they are seen has an important effect upon the visual comfort of the worker. Many laboratory workers prefer a light colored wall behind the bench to give good color discrimination in relation to substances being handled in the course of their work. Light colored underbench cabinets tend to brighten a room environment generally.

## Choice of Structure

Each design requires an independent and exact cost analysis of those particular materials and building types which best satisfy the requirements of the project under consideration. Costs of various materials are relative to local unit material costs and labor conditions and should be weighed not only in terms of original cost but also in terms of maintenance over the normal life span of the building unit.

One-story structures require maximum ground area, but are most economical for building construction, however, the cost of mechanical and electrical service distribution is extended and expensive. Circulation and communication become difficult somewhere between 30,000 and 50,000 square feet but will depend on the organization of the laboratories and the need for physical interchange. When a single research building requires a floor area above 50,000 square feet, it probably should be constructed as a multi-story facility. Beyond this point, communications and circulation in the one story plant become difficult and inefficient. Personnel prefer to climb a flight of stairs rather than walk what may often be the length of a football field on one floor.

Two story structures increase the cost of building construction. They require heavier footings and framing to carry floor loads. Also elevators and stairs are required to move both supplies and people. A two story building will be more economical when effective savings can be made in the distribution of mechanical and electrical services, land costs and site development.

Multi-story buildings are most satisfactory for extremely large installations or where size of site is limited. Expansion of multi-story buildings is difficult except in large increments.

The campus plan is often used for research facilities and is well suited to an organization of essentially nonrelated functions. Advantages are the ability to separate operations, easy expansion of units and pleasant atmosphere, perhaps better scaled to the individual scientist. Disadvantages include increased cost of both structure and service distribution and difficulties of communication.

Materials and construction usually must comply with the requirements of local, state and national codes. In general all laboratory operations except the most temporary in nature will require fireproof construction to protect the safety of laboratory personnel. Except for small units which sometimes have load-bearing walls, most laboratory buildings have either a steel or concrete framework. Concrete structural systems are inherently more fireproof than steel however steel layouts may be more easily modified to accommodate unusual clearance problems. Construction speed is often a determining factor. But here again local conditions must be evaluated as precast concrete and newer methods of construction can dictate the choice of framing systems.

The materials available for exterior walls are many and include cement-asbestos; masonry-concrete block, brick and stone; sandwich walls; and curtain walls. The choice depends on local costs, appearance desired, window area required, weight, thermal and sound insulation requirements, and speed of erection.

An imaginative use of structure with proper use of materials is necessary to providing an environment conducive to output for the laboratory workers. Many factors influence choice of structure. The character of adjoining buildings may dictate architectural style or the use of particular materials for the exterior. Often certain materials are more readily available in one area than in another or are perhaps easier to transport than others.

It is evident that building costs and the available capital must affect the choice of building materials and structure. Data on cost and performance of alternative materials and structural types will be necessary before decisions can be made which will relate capital expenditure to maintenance and operating costs.

The expected life of the laboratory is important as certain industrial research facilities may employ techniques subject to rapid change needing a building for as little as ten years. Other conditions may determine a longer life expectance of fifty years or more.

In general, the longer the anticipated life, the more likely that initially expensive materials and forms of construction will prove economical.

Speed of erection is often of prime consideration in the choice of building structure. Generally if local fabricators are available or transportation is available, the prefabricated systems will have an advantage in speeding erection time. Examples are steel fabricated members, precast concrete, laminated timber and similar factory fabricated components. The sequence of operation becomes extremely important and proper scheduling, delivery and erection is essential if a saving in construction time is to be realized.

Other factors which influence choice of structure include; ease of future extension, fire protection requirements, flexibility of use, free span requirements, code requirements and support of heavy equipment such as overhead cranes. The availability and cost of land may dictate the number of stories which will again limit structural choices.

# CHAPTER VII

## TRENDS AND CONCLUSIONS

### Provision of a Stimulating Environment

Because of the high percentage of highly trained professional people employed in a research and development facility, a trend toward providing a stimulating environment both to attract and hold these highly sought scientists has developed. Research and development architecture has in recent years broken many of the shackles of accepted construction techniques and materials applications. This may be somewhat due to the leadership of the young imaginative men and women who are engaged in research and development work. Their willingness to try new things and their recognition of the constantly changing space needs tend to overflow into the building programs which they help create.

One example showing great concern for the setting in which the individual scientist would work is I.M. Pei's National Center for Atmospheric Research near Boulder, Colorado. The owners requested that the building be designed to avoid uniform and regimented environment, with special emphasis on personal, idiosyncratic spaces where scientists could "think". The resulting design was described by the October 1967 Architectural Record as "a castle with ivory tower aspects." Most of the interior spaces have extensive scenic views of the Rocky Mountain setting. Many other of the more recent laboratory projects have shown a similar interest in providing a more artistically stimulating environment. The present trend seems to be toward more creative surroundings even at the expense of higher cost sites, finishes and structures. If the environment can help create ideas then the price would seem justified.

## Flexibility

Although most certainly not a new trend, there is a continuing demand for increased flexibility within research spaces. The chief problem is to prevent the building and its supporting services from interfering with the research activities. As the type of experiment changes or the demand for a particular type of space changes, it is desirable to have physical facilities which are easily adapted to new requirements. Some recent projects have placed such high emphasis on flexibility that they have been willing to increase initial building costs considerably in order to achieve almost complete flexibility. Louis Kahn who designed the Salk Institute of Biological Studies Laboratories near San Diego, used a nine foot high mechanical service floor between each level of laboratory floors. The laboratory floors are designed as lofts with a perimeter corridor. The interior partitions and laboratory benches are demountable giving almost complete flexibility for determining floor size and equipment arrangement. The intent is for each scientist to be able to design his own laboratory space as differently as may be required. Obsolescence is reduced by a high initial investment in flexibility. Of course such complete flexibility is unusual and is not financially feasible for most projects, however, many projects benefit from an arrangement of services and equipment which allows for future changes. Also care in choosing lighting and air conditioning systems is important if maximum flexibility in room sizes is to be achieved.

New Techniques and Materials

The use of microanalysis as a laboratory technique has placed new demands upon laboratory planning. A wide range of auxiliary equipment is needed for recording, separating and studying the extremely small quantities of materials used. Accuracy is of extreme importance. Separate and special rooms are needed, involving humidity, temperature, air and vibration control. Filing and documentation are all-important. An adequate up-to-date library is essential. Computer equipment is becoming a common installation in laboratory facilities. The design of future laboratories should make special provisions for these special requirements so as not to cause the scientist to improvise and make do by adjusting to conventional laboratory space.

The demand for increased air purity is leading to sealed laboratories with complete air conditioning and filtered air installations. The temperature and humidity ranges allowed are becoming increasingly smaller so that future laboratory projects will have much more complex, mechanical equipment and controls than has been used in past research spaces.

Laboratory furniture continues to undergo change and refinement. Again the tendency is toward increased flexibility and adaptability. Prefabricated cabinets of modular sizes will be designed to give a large variety of drawer and cupboard combinations. The Salk Institute for Biological Studies has a system of independently mounted casework sections which can be rearranged to meet the constantly changing demands of today's laboratory disciplines. Installation of piping and electrical systems are arranged in such a manner and of such materials as to cause a minimum of lost time for making changes and repairs. The future will see further refinements and new solutions to the problems of equipment and working surfaces within the laboratory.

Ease of maintenance and the new demands for cleanliness in laboratory spaces has resulted in the use and development of new materials for wall and floor finishes as well as improved surfaces and work counters and cabinets. The use of seamless flooring and epoxy type wall finishes give smooth surfaces that are highly resistant to damage by the materials used in research activities. These finishes are easily cleaned and maintained. The future will undoubtedly give even better and perhaps less costly finishes that will withstand the extreme demands of laboratory research.

## Expediting Construction

To meet the anticipated large demand for future laboratory space, the construction industry as a whole will undergo a reevaluation of techniques and procedures used to design and construct buildings. The use of factory fabricated subsystems which will meet established performance specifications will increase. Often planning time is limited and will require solutions such as used by Charles Harper in the design of new research spaće for Globe-Union, Inc. A system of elevated flooring was used with the building structure completed while detailed planning of laboratory space was accomplished. All utility lines were installed on top of a concrete slab after completion of the building shell and the elevated finish floor then constructed. The use of prefabricated movable partitions is also increasing not only for the flexibility that results but also to reduce the time that would be required to construct these partitions on the job in the traditional manner.

## Planned Future Expansion

Most research institutions have grown enormously in the last twenty years, and there is no indication that this growth will cease. One of the principal objectives of planning should be to provide for growth to take place without disruption. There is a trend toward larger sites located away from congested areas. The size of site is often established not only to meet present demands for space but with additional space provided for future needs. The design of buildings and utilities should also be planned for future expansion. Single structures should have circulation and utilities designed for easy extension. The use of campus type planning with a number of separate structures arranged in a functional way to each other is being used by a number of the newer research laboratory centers. This provides for the addition of future space with little disruption of existing facilities.

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# THE RESEARCH LABORATORY

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The research laboratory has become a most significant building type. As research activities have become more complex and have included more disciplines, the demands placed upon physical facilities has presented designers with many new changes. Often research facilities are designed to house a variety of scientists from different fields so that various talents and techniques can be applied to specific problems.

The chemistry laboratory probably grew from the workshop of the alchemist about the beginning of the Christian era. The researcher's workshop gradually became more sophisticated. During medieval times the compounding of chemicals and drugs was carried out in great secrecy. The seventeenth century brought methodical experimentation and much of the classical apparatus employed in experiments was invented during this period. The eighteenth and nineteenth centuries saw a freer interchange of ideas and the development of the university laboratory for instruction and research. At the end of the nineteenth century industry realized the necessity of laboratory research in order to progress. Processes emerged which often produced by-products of commercial value. Often these new by-products became the basis for a new industry. Research began to have tremendous economic value. War conditions of the twentieth century required the development of new synthetic materials resulting in very specialized laboratory equipment and work space.

The rapid development of scientific techniques in recent years has created the need for research buildings which can be quickly and economically adapted to meet specialized demands as they arise. Since research spaces are one of the most expensive types of modern commercial construction, great care should be taken to develop a building program which accurately reflects research needs. Many general planning considerations are important and include: site selection, flexibility and adaptability provisions, the building module, service requirements, ventilation and other environmental controls, initial and maintenance costs.

In addition to these general considerations, research work creates a number of special planning considerations such as: control of noise and vibration, safety of personnel, disposal of contaminated wastes, radioactive shielding, and special laboratory room types.

Perhaps the one element that makes the laboratory different from other building types is the laboratory equipment which is used in research activities. The choice of work bench layout, services, materials, finishes and specialized equipment such as fume hoods, is tremendously important to the success of any laboratory.

General considerations of structural durability, ease of maintenance, good lighting, pleasant environment, colors, materials, etc. are important in the design of research facilities as in all building types. However, chemical resistance and the special demands of flexibility often limit choice of materials and methods. Research and development architecture of recent years has produced many highly imaginative solutions and new construction techniques. This may be somewhat due to the leadership of the young men and women who are engaged in research and development work. Their willingness to try new things and their recognition of their constantly changing space needs tend to overflow into the building programs which they help create.

Current research facilities show a great concern toward the creation of a stimulating environment both to attract and keep the highly trained and sought after scientist. This often results in higher building and operating costs but is becoming accepted as necessary to achieve the research effort sought.

One of the chief problems connected with research facilities is to prevent the building and its supporting services from becoming obsolete or interfering with the research activities. The present trend is toward more complete flexibility with physical facilities which are easily changed or adapted to new requirements.

The use of new techniques such as microanalysis is resulting in more specialized equipment and separate special rooms involving extreme control of humidity, temperature, air, vibration and other environmental elements. Ease of maintenance and new demands for cleanliness in laboratory spaces has resulted in the development and use of new materials for finishes.

Expediting design and construction time is often necessary in the creation of research facilities. Architects and contractors are constantly being asked to devise new methods for reducing the time required to convert a building program into a working structure. Most research institutions are experiencing enormous growth. It is necessary that planning for laboratory facilities anticipate and plan for future needs in site selection and design of structures. The addition of future space should be accomplished with little disruption of the activities within existing facilities.