

PROCESS PLANT LAYOUT AND PIPING DESIGN

*To the most important people in my life, whom I love
very much: my children, Peter, Karin, and Linda*

E. F. BAUSBACHER

To the memory of my brother, William

R. W. HUNT

PROCESS PLANT

LAYOUT AND

PIPING DESIGN



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P T R Prentice Hall, Englewood Cliffs, New Jersey 07632

Library of Congress Cataloging-in-Publication Data

Bausbacher, Ed.

Process plant layout and piping design / Ed Bausbacher, Roger
Hunt.

p. cm.

Includes index.

ISBN 0-13-138629-8

1. Chemical plants—Design and construction. 2. Plant layout.
3. Chemical plants—Piping. I. Hunt, Roger (Roger W.) II. Title.

TP155.5.B38 1993

660—dc20

93-9725

CIP

Editorial production: *bookworks*

Acquisitions editor: *Betty Sun*

Cover designer: *Lundgren Graphics, Ltd.*

Buyer: *Mary Elizabeth McCartney*



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A Simon & Schuster Company

Englewood Cliffs, New Jersey 07632

The publisher offers discounts on this book when ordered in bulk quantities.
For more information, contact:

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Phone: 201-592-2863
FAX: 201-592-2249

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Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

0-13-138629-8

Prentice-Hall International (UK) Limited, *London*

Prentice-Hall of Australia Pty. Limited, *Sydney*

Prentice-Hall Canada, Inc., *Toronto*

Prentice-Hall Hispanoamericana S.A., *Mexico*

Prentice-Hall of India Private Limited, *New Delhi*

Prentice-Hall of Japan, Inc., *Tokyo*

Siomon & Schuster Asia Pte, Ltd., *Singapore*

Editora Prentice-Hall do Brasil, Ltda., *Rio De Janeiro*

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Foreword

During the 43 years of my career, it was extremely difficult and time-consuming for an individual to become knowledgeable and competent in the field of piping design and plant layout. Little was written in a format that would provide the designer with educational or reference material. About the only ways knowledge and techniques were absorbed were by tedious, repetitious design functions and through working with experienced peers.

Today, the learning cycle is even more constricted, reducing exposure to the design basics that are so essential to the development of the plant layout designer.

I have spent considerable time in reviewing and studying *Process Plant Layout and Piping Design* and

am convinced it provides an excellent tool to enhance the education of individuals who aspire to such a career. In addition, I believe it should attract widespread use as a textbook and reference manual by refinery and petrochemical companies, engineering and construction companies, and technical schools and colleges.

I commend the authors on their remarkable effort in accumulating and developing this data, and presenting it in such a practical and commonsense manner.

VINCENT L. SURDI
Piping Design and Plant Layout
Engineer and Manager

Preface

Whether one is entering the employment ranks in the process industry for the first time or is well established in the design field, it is imperative to understand the true nature of today's marketplace. Competition formerly limited to cities, states, provinces, or country, must now be considered in the world marketplace. A sustained level of success can only come about as a result of "meeting or exceeding" client requirements. Introduction of automated technology has added another dimension to the already dynamic process industry. Formal education of designers and engineers has become a necessity. Rapid changes in process technology, environmental and safety laws, along with work execution methodology, place a constant demand for education in this industry.

The intent of this book is to help train, on an accelerated basis, the young engineers and technicians entering the field of process plant layout and piping design. It also updates equipment spacing requirements and addresses the latest feature of electronic data transfer for the experienced layout designer.

Process Plant Layout and Piping Design represents the accumulated, practical experience of two plant layout designers who, through more than 70 years of trial and error, have devised workable methods and rules of thumb for plant layout and piping design. Illustrations that make up the heart of this book are its key aspect, because plant layout and piping design is visual by nature, requiring the designer to make in essence the conceptual leap from a two-dimensional process flow diagram, to a three-dimensional, physical process facility that comprises extensive networks of process and piping equipment.

This book has been arranged into 17 chapters. The first three deal with general concepts and principles of plant layout from basic technology and input requirements to actual deliverables. Plant layout specifications have been included for spacing, clearances, and safety requirements leading to equipment arrangement

within the process unit plot plan. Chapters 4 through 15 deal with specific pieces of process equipment, or components of a plant such as piperacks, structures, underground piping, instrumentation and their most efficient layout in the overall plant design configuration. Chapter 16 deals with stress analysis by step approach to basic stress analysis, which is a must for designers and engineers. The last chapter in this book is dedicated to the computerization tools that are now available to help plant layout and piping designers in the execution of their work. During the past decade or two, the way these designers learned their craft has changed dramatically. Historically, secondary school as well as two-year technical college graduates entered the profession and spent many years learning the business. Novices were trained through such manual exercises as revising drawings, drawing single-line isometrics, and preparing material takeoff sheets; eventually they were given an opportunity to do simple design work. Today's computers vastly alter this learning process. One designer at a computer graphics terminal can route a line and extract the single line isometric, which includes a complete bill of material. This information may then be electronically transmitted to a shop or field fabricator.

Such rapid changes in technology demand that industry adopt a more formal means of educating future designers, because new trainees today must learn in a few short years what our talented predecessors spent a lifetime learning by repeated manual exercise. Although the availability of the computer vastly facilitates the design of process plants, the tool itself does not confer the knowledge of fundamental principles of plant layout and piping design that are the basis of any creditable effort at such design work. The computer remains, at best, a tool for learning and execution.

A plant layout designer is primarily skilled in the development of equipment arrangements and piping layouts found in process plants. The position offers a

PROCESS PLANT LAYOUT AND PIPING DESIGN

The Basics of Plant Layout Design

Plant layout design plays an important part in the design and engineering phases of any industrial facility. This chapter discusses the role and responsibilities of the plant layout designer, provides advice on how to use project data, describes the timing of various activities, offers an approach to a basic piping design layout, and lists abbreviations and common terminology. Subsequent chapters cover plant layout specifications, major equipment layouts commonly found in such facilities, pipe rack layout, underground design, and instrumentation.

THE PLANT LAYOUT DESIGNER

The plant layout designer is skilled primarily in the development of equipment arrangements and piping layouts for process industries. The position offers an opportunity to demonstrate technical ability along with a creative talent and common-sense approach to problem solving. Process facilities must be designed and engineered within extremely short schedules while adhering to maintenance, safety, and quality standards; moreover, the design must take constructibility, economics, and operations into account. Although the tools to achieve these goals are changing from pencil and paper to computer graphics terminals, the responsibilities of the plant layout design remain the same.

The plant layout designer must develop layout documents during the conceptual and study phases of a project. The skills needed include:

- Common sense and the ability to reason.
- Knowledge of what a particular plant is designed to do.
- A general understanding of how process equipment is maintained and operated.
- The ability to generate a safe, comprehensive layout within a specified time and with consideration toward constructibility and cost-effectiveness.

- Creativity.
- Sufficient experience to avoid reinventing the wheel.
- Knowledge of the principal roles of other design and engineering groups and the ability to use input from these other disciplines.
- The ability to resolve unclear or questionable data.
- Willingness to compromise in the best interest of the project.
- The ability to generate clear and concise documents.
- The ability to defend designs when challenged.

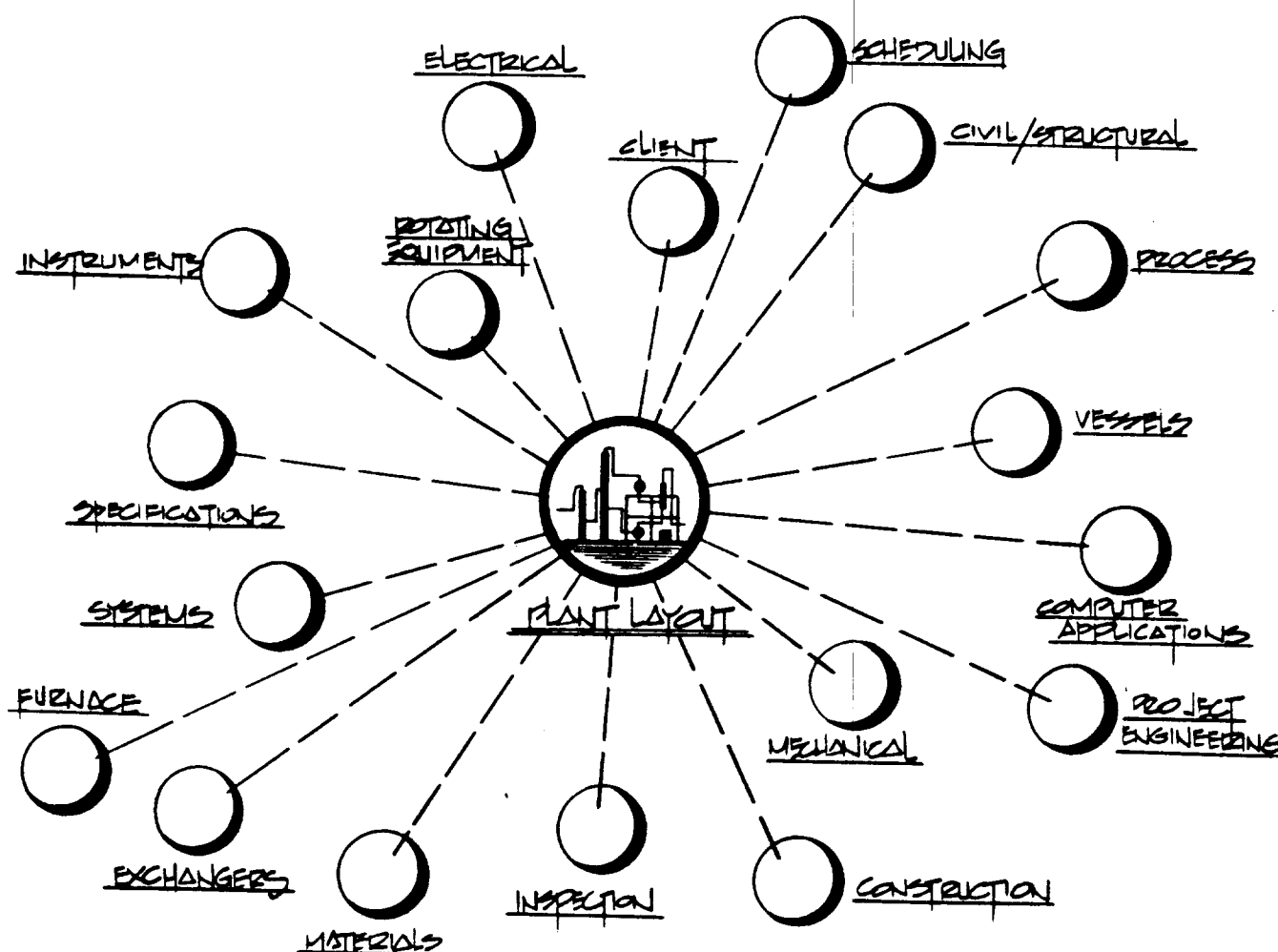
The Designer's Role

Exhibit 1-1 shows the factors, departments, and personnel with which the plant layout designer can expect to work throughout the engineering phase of a project. The principal activities of the plot plan development, equipment layout, and piping design, which often account for a significant portion of project engineering costs, become a focal point for clients, project management, construction, engineering, and supporting disciplines. The designer must realize that time and care spent during engineering help shorten construction schedules and thereby lower overall project costs. The designer must be conscious of the constructibility of every layout.

Principal Functions

The principal functions of the plant layout designer include the conceptual and preliminary development of process unit plot plans, sometimes referred to as equipment arrangements; the routing of major above- and below-grade piping systems; and the layout of equipment and its associated infrastructure. Plot plans show the positions of major units and equipment within units and their associated infrastructure. Creating a well-designed facility involves meeting all client specifications and local government codes and regulations and adhering to design engineering practices.

EXHIBIT 1-1 Plant Layout Interface



With the planning plot plan as a basis, the following functions are a standard part of the plant layout designer's activities:

- Setting all equipment locations—This activity includes input from construction on erection sequences or on special problems associated with setting large pieces of equipment. Choosing equipment locations includes setting coordinates in two directions and finalizing equipment elevations, whether they are centerline, tangent line, or bottom of baseplate.
- Designing all structures and positioning the associated stairways, ladders, and platforms—In general, the designer makes provisions to satisfy all operational, maintenance, and safety requirements for access to and clearance around equipment.
- Planning unobstructed areas for necessary steel members or structures that facilitate all plant maintenance requirements.

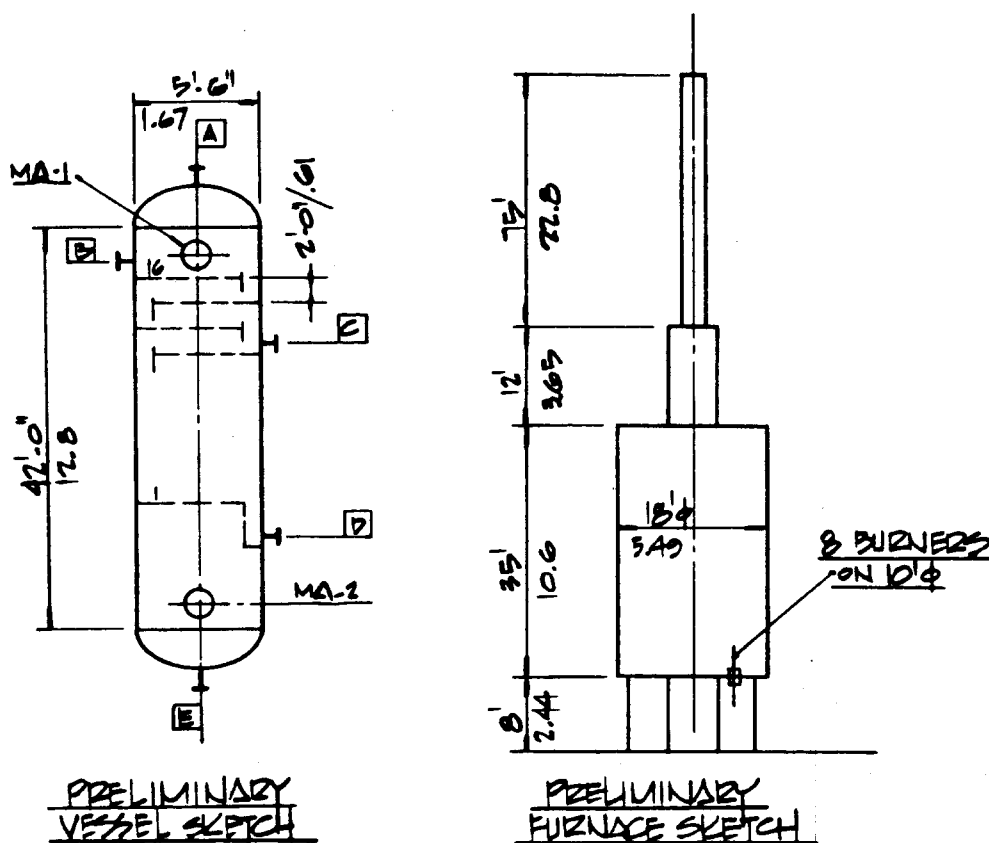
- Establishing all equipment nozzle locations that satisfy all process, utility, and instrument requirements.
- Locating all safety items (e.g., fire hydrants, monitors, and safety shower stations).
- Locating all miscellaneous items (e.g., filters, silencers, and analyzer houses).

These activities must be closely coordinated among all the plant design and construction participants involved in the engineering and construction phases of a project to reduce costly rework and enable the plant layout designer to generate the optimum design on schedule.

PROJECT INPUT DATA

Although there is a vast amount of input data throughout the life of a project, the data basically falls into

EXHIBIT 1-2
Internally Generated
Engineering Data



three distinct categories:

- Project design data—Is supplied by the client or project engineering.
- Vendor data—Pertains to equipment and specialty bulk items.
- Internally generated engineering data.

These are discussed in the following sections.

Project design data This includes the geographic location of the plant; its proximity to roads, railways, and waterways; local codes and regulations; topography; and climatic conditions. The project design data also specifies whether the project is within an existing facility or is a new site. This information is generally required during the project's plot plan development phase.

Vendor data All purchased equipment and specialty bulk items (e.g., pumps, compressors, air coolers, furnaces, control and safety valves, level instruments, strainers, and silencers) require preliminary vendor drawings for the development of piping layouts. Final certified drawings are usually not required until the detail phase.

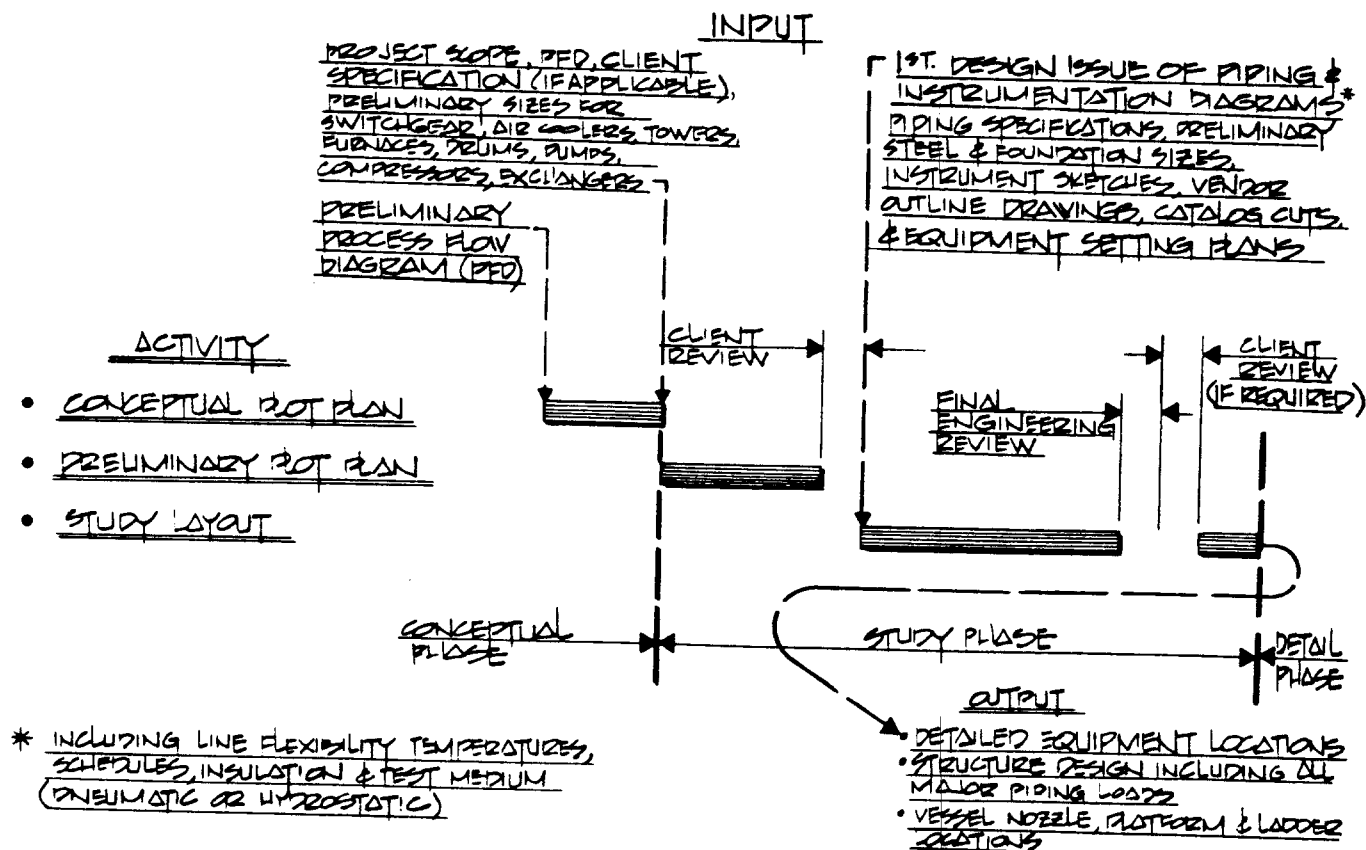
Internally generated engineering data This data is typically generated by the supporting disciplines within the designer's organization. An example of such information is shown in Exhibit 1-2. This information is eventually superseded by certified vendor drawings but is of sufficient quality and definition to use during the study phase of the project.

The Logic Diagram

The design of any processing plant is usually accomplished in three phases: conceptual, study, and detail. Conceptual designs are made when sketchy or minimal information is used to prepare an abstract arrangement of a plot plan or an equipment and piping layout. Preliminary, or study phase, designs are made with unchecked or uncertified data to design a facility in sufficient detail so that the documents produced can be used for detail design, confirmation of purchased equipment, and the purchase of bulk materials. In the detail phase, all designs are finalized. The designs use such checked data as steel and concrete drawings, hydraulics and certified vendor drawings for equipment, valves, and instruments.

The major activities of the plant layout designer to achieve an optimum plant configuration take place

EXHIBIT 1-3 Logic Diagram

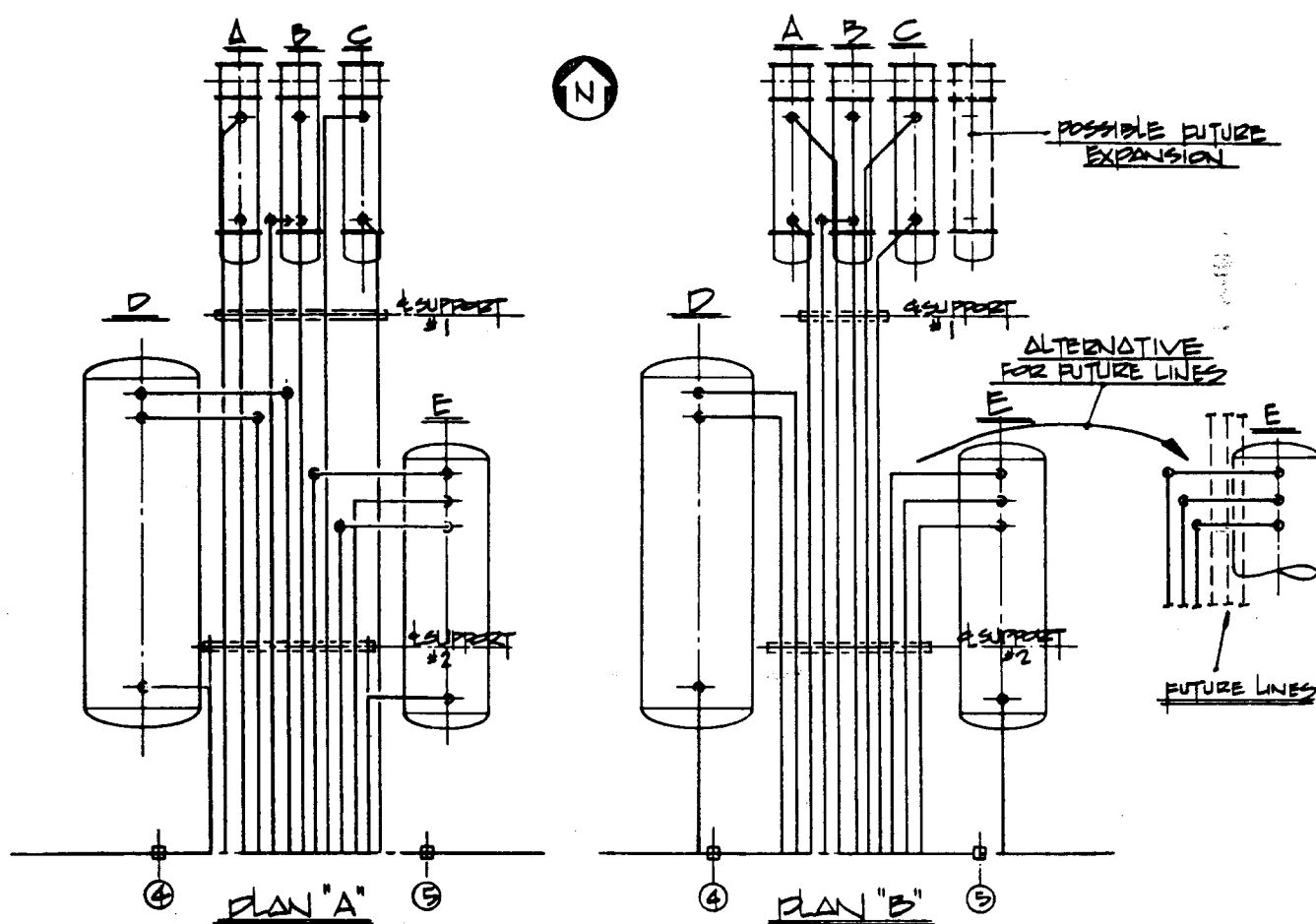


during the study phase of a project. The diagram shown in Exhibit 1-3 outlines the sequence of these activities, along with the principal input required and output generated. Although project schedules often dictate variations in this approach, it is intended to be an optimum condition for the most effective use of staff time. The study phase can make or break a project. Working out of sequence is acceptable within reason, but if it is overdone, a project will never recover during the detail phase. The ideal situation for speed and quality is to do the job right the first time.

BASIC LAYOUT PHILOSOPHY

Each plant layout designer develops an individual layout philosophy. Although conditions (e.g., client specifications, schedule constraints, and availability of information) may change significantly among projects, the designer's style remains consistent. One basic rule to remember is to avoid designing one line at a time—that is, routing a line from one piece of equipment to another before thinking about the next one. Although it is possible to complete an area design using this

EXHIBIT 1-4 Plan View Layout



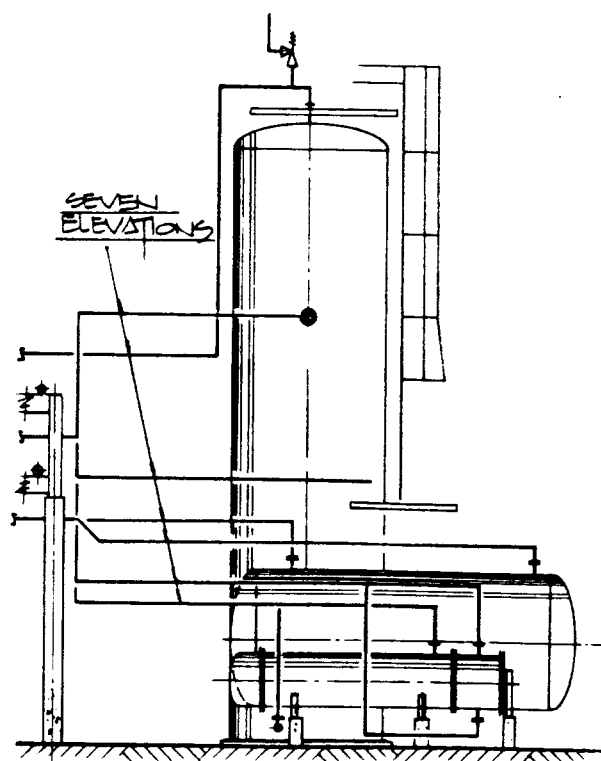
approach, the result is a lack of consistency.

An overview of all the piping within a given area should be completed before the designer proceeds with the final arrangement. This can be achieved through close review of the piping and instrumentation diagrams and freehand sketching of major piping configurations to ensure that the piping will be routed in an orderly manner.

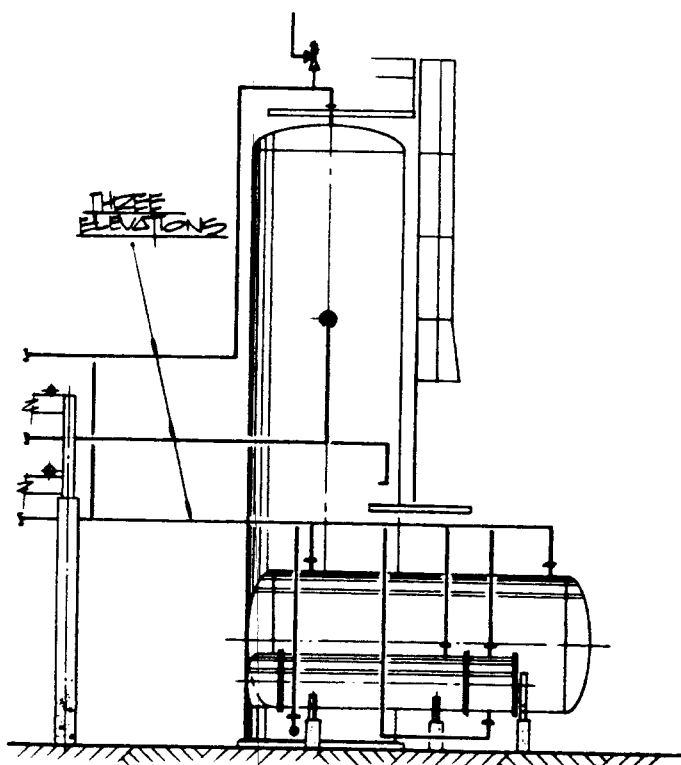
Plan View Layout

Both arrangements shown in Exhibit 1-4 are workable piping layouts for the given equipment. The design in plan A is the one-line-at-a-time approach. Along with requiring more pipe fittings and steel in support 1, it lacks consistency. Plan B was developed as a whole unit. Lines running to the nozzles on drums D and E

EXHIBIT 1-5 Elevation Layout



EXCESSIVE ELEVATIONS



PREFERRED DESIGN/MINIMUM ELEVATIONS

are on the outside of the pipe rack and peel off first with flat piping turns. The lines to exchangers A, B, and C are located to the center of the rack and can also peel off in most cases.

This approach saves fittings and requires a shorter steel beam to support the piping. It should be noted that the use of flat turns in piping is not recommended if there is a likelihood of future expansion in an area. The alternative to accommodate future piping running north at the same elevation is to change elevation for the piping running east and west to the drums. Al-

though it is not always necessary to plan for future expansion, it can often be done with very little additional effort and cost. Each area should be thought through on a case-by-case basis.

Elevation Layout

Exhibit 1-5 shows two workable piping layouts. The key difference is that the arrangement on the left shows piping running at too many elevations. With a little effort, this can be corrected, as shown in the

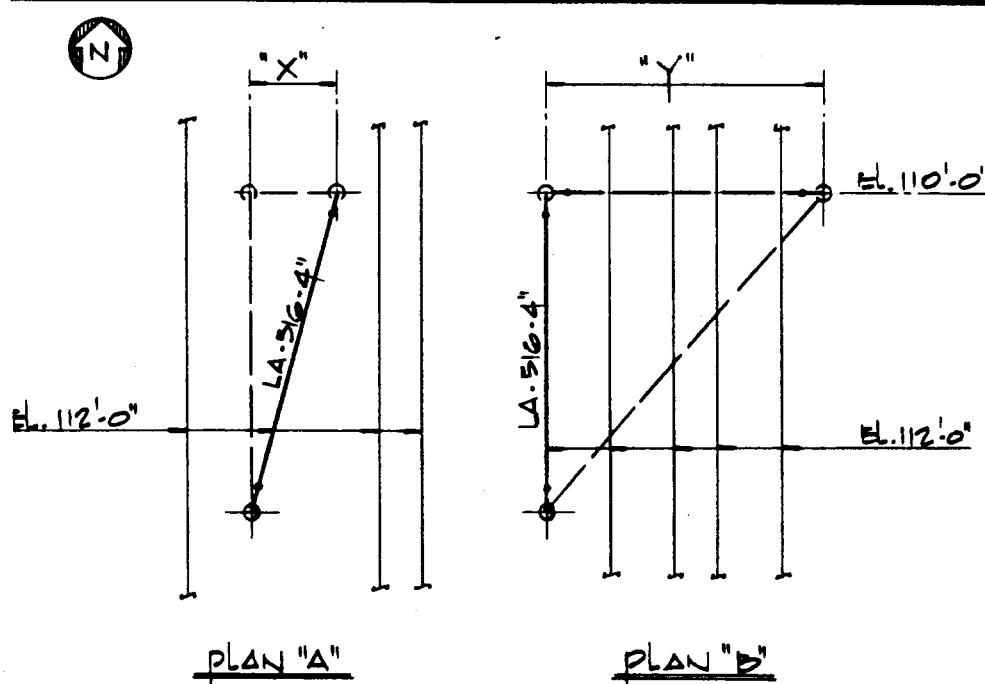


EXHIBIT 1-6
Diagonal Piping Runs

right-hand view. Adding support steel for this preferred design would require only minimal effort. The view on the left, however, would require additional engineering time and additional steel cost.

Diagonal Piping Runs

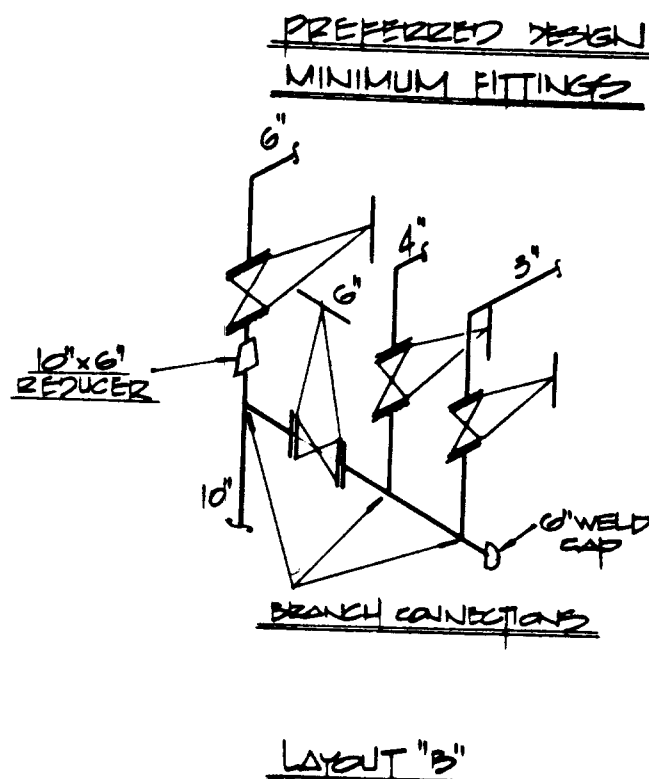
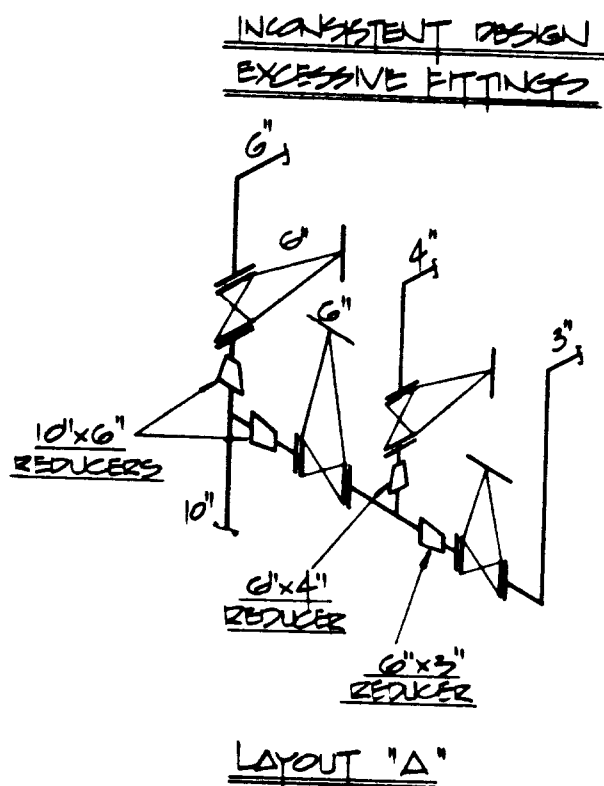
When lines are run in a congested area, a basic rule to follow is to change the elevation to avoid interference with other lines when lines are to be routed perpendicular to most adjacent piping. The arrangement shown in plan A of Exhibit 1-6 has a minimal offset dimension, X . Running the line at the same elevation is acceptable if it does not block the passage of a large number of other lines. In plan B, dimension Y would interfere with too many lines and should run at a dif-

ferent elevation, as shown. There is no absolute rule, except that judgment should be used to produce a neat and orderly layout as well as to occasionally save pipe fittings when possible.

Valve Manifolds

The layout of valve manifolds is another opportunity to exercise consistency of design. Layout A of Exhibit 1-7 uses an excessive number of fittings and indicates a lack of proper planning. With a little thought and extra effort, a less expensive and more practical design can be generated, as shown in layout B. Certain piping specifications may restrict the use of branch connections in lieu of reducers, but this option should be considered if at all possible.

EXHIBIT 1-7 Valve Manifolds



Use of Space

The effective use of plant real estate provides plant operations and maintenance personnel with the maximum amount of room in a plant, which in most cases can be very congested. Exhibit 1-8 shows some typical misuses of valuable real estate.

For example, the steam trap assembly shown on the left is commonly designed in the engineering office. This arrangement for a thermodynamic steam trap is spread out over an area of approximately 27 in (690 mm) in length. Although this area may not seem excessive for one trap assembly, it can be avoided completely by installing the trap and strainer in the vertical leg of the piping, as shown on the right. An additional drain may be required, but this arrangement should be considered as a space-saving alternative. The steam tracing manifold in the left-hand sketch is another common engineering office approach that wastes valuable plant space. If a vertical manifold that is supported from the column is used, additional space is available for other piping systems or operator access.

The client must live with the plant long after the engineering and construction phases are over. The operators will be walking through the facility each day and will be continually reminded of who took the time and effort to plan the project thoroughly, and they will

keep that in mind when the next expansion is planned.

ABBREVIATIONS, STANDARDS, AND TERMINOLOGY

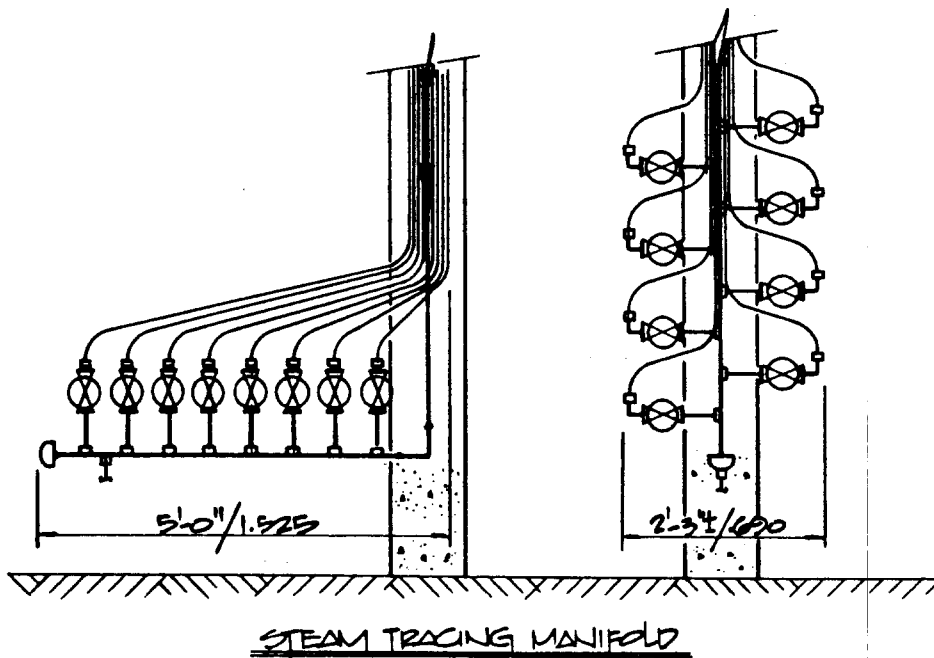
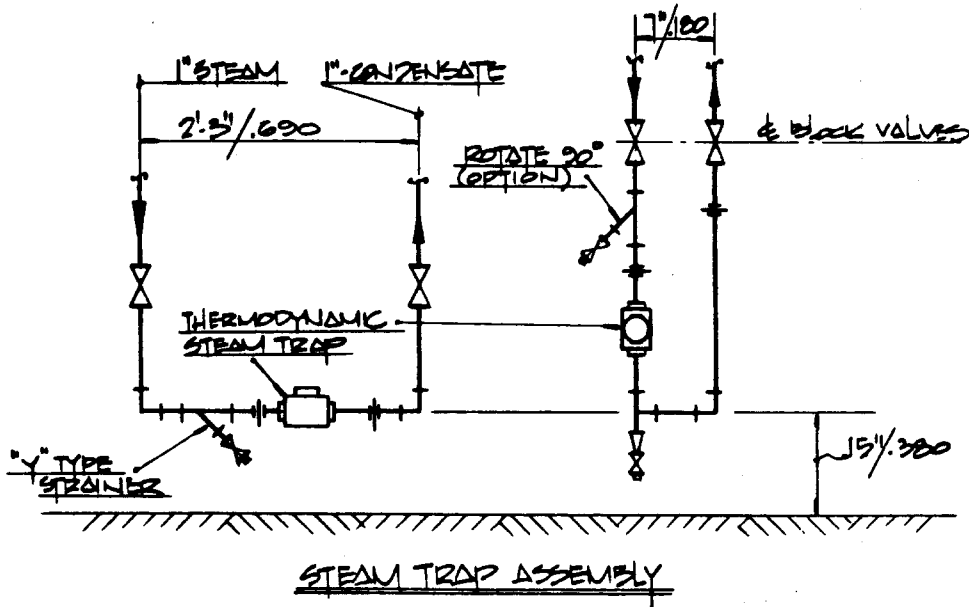
This section defines and summarizes the abbreviations, standards, and terminology used throughout this book.

Abbreviations

The following abbreviations are used in text and illustrations:

- AG—Above ground.
- ANSI—American National Standards Institute.
- ASME—American Society of Mechanical Engineers.
- BBP—Bottom of baseplate.
- BL—Battery limit.
- CL—Centerline.
- EL—Elevation.
- IRI—Industrial Risk Insurers.
- N—North.

EXHIBIT 1-8
Space Use



- OD—Outside diameter.
- Φ —Diameter.
- NFPA—National Fire Protection Association.
- NPSH—Net positive suction head.
- OSHA—Operational Safety and Health Act.
- PFD—Process flow diagram.
- P&ID—Piping and instrumentation diagram.
- POS—Point of support.
- TL—Tangent line.
- TOS—Top of steel.
- TYP—Typical.
- UG—Underground.

Codes and Standards

This book refers to the following codes and standards, which cover the stated areas:

- ANSI/ASME B31-3—Chemical plant and petroleum refinery piping.
- ANSI/ASME B31-4—Petroleum pipeline.
- ANSI/ASME B31-8—Gas transmission pipeline.
- NFPA 30—Tank storage.
- NFPA 58—Liquefied petroleum gas storage and handling.
- NFPA 59A—Liquefied natural gas storage and handling.
- OSHA 1910-24—Fixed stairs.
- OSHA 1910-27—Fixed ladders.

Terminology

The terminology used in text and illustrations is defined in the following sections.

Process flow diagram This document schematically shows all major equipment items within a plant and how they are linked together by piping, ducts, and

conveyors. It shows equipment numbers, flow rates, and operating pressures and temperatures and is used to prepare the mechanical flow diagrams (i.e., piping and instrumentation diagrams). It is also used to prepare conceptual and preliminary plot plans.

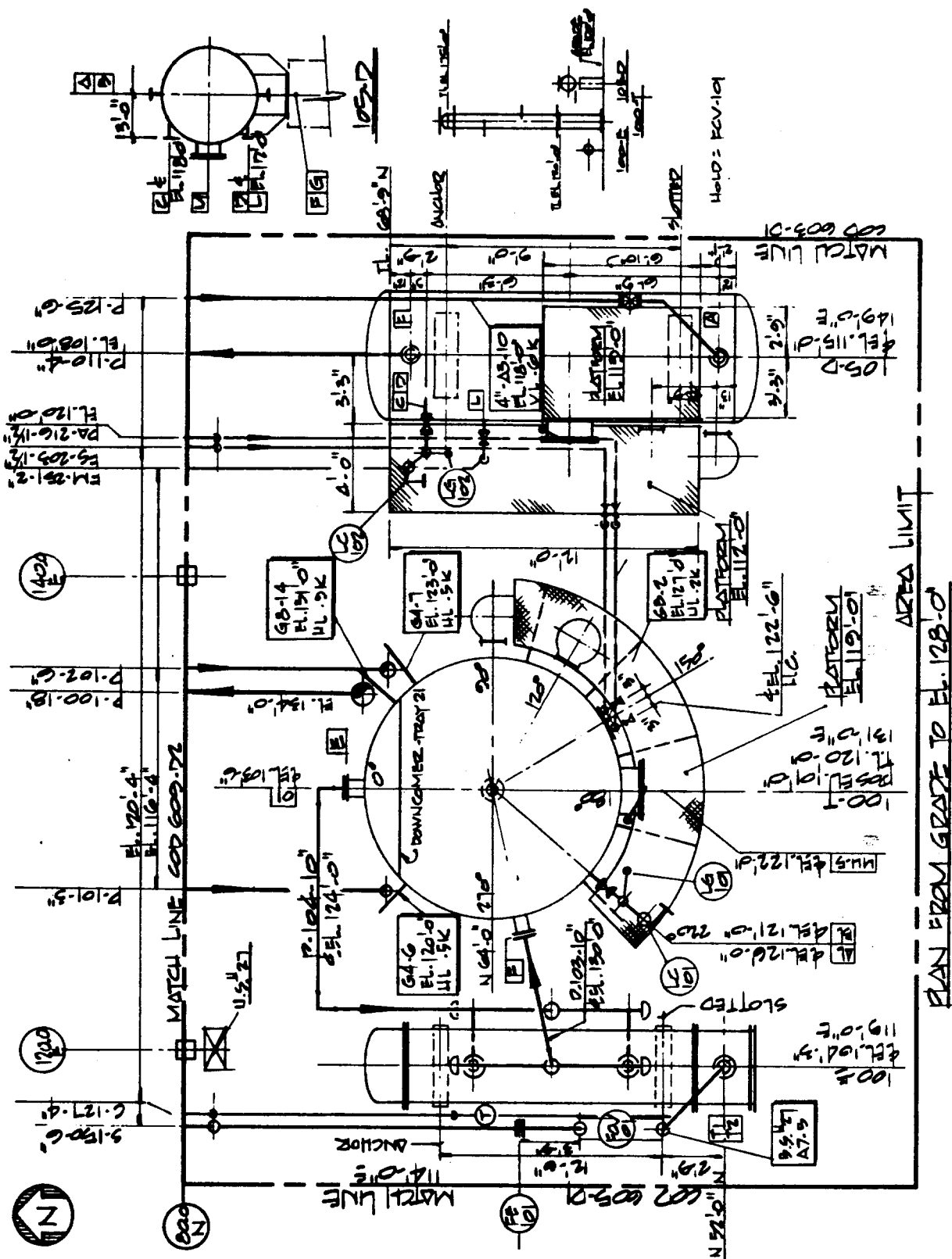
Equipment list An itemized accounting list by class of all equipment to be used on a project, this document gives the equipment item numbers and descriptions and is generally furnished by the client or project engineering.

Piping and instrumentation diagrams These documents schematically show all process, utility, and auxiliary equipment as well as piping, valving, specialty items, instrumentation and insulation, and heat tracing requirements.

Piping specification This document lists the type of materials to be used for pipes, valves, and fittings for each commodity in a plant. This listing is based on pressure, temperature, and the corrosive nature of the flow medium. It also describes pipe wall thicknesses, how branch connections are made, and itemized stock codes that are used for ordering materials.

Line run This is the physical route a pipe takes between any two points as set by the plant layout designer.

Planning study or layout drawing This is an orthographic piping plan. It is usually not a finished document, nor is it deliverable to a client. This drawing shows all equipment in a given area to scale and includes major process and utility piping systems, significant valving, and instruments. It notes exact equipment locations and elevations, all nozzles, platform and ladder requirements, and any pipe support data that affects the design of equipment or structures by other disciplines. Exhibit 1-9 is a typical example of a planning study.



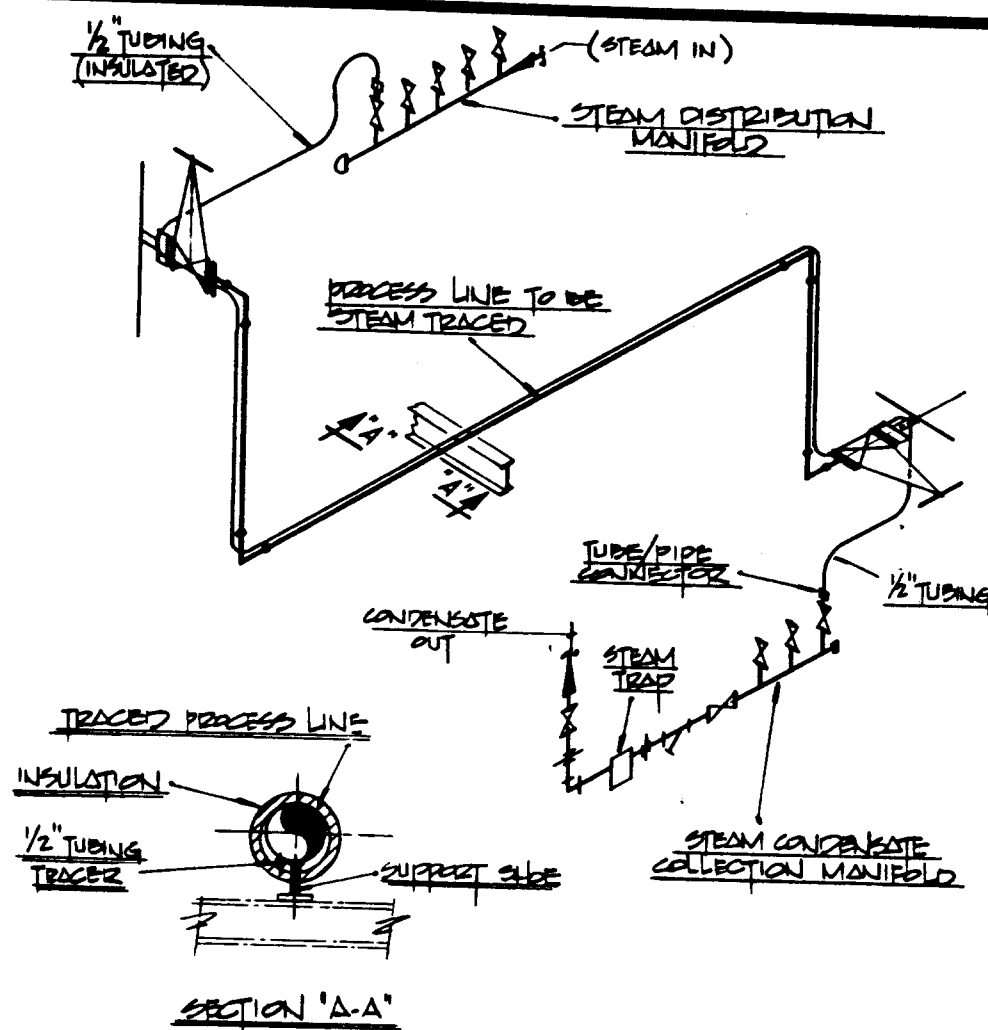


EXHIBIT 1-10
Steam-Traced Line

Heat tracing In many processes, equipment, instruments, and piping systems require externally applied heat. This heat may be applied by electrical tracing leads attached to the item or line or through a small bore pipe or tubing that carries steam or other heating media (e.g., hot oil). An example of a steam-traced line is shown in Exhibit 1-10.

Inline This term refers to a component that is placed either inside or between a pair of flanges as opposed to one attached to a piece of pipe or equipment. An example of inline instrumentation is shown in Exhibit 1-11.

Header block valves These valves isolate branch lines that are not usually provided with permanent access for plant operations personnel.

Header This line is the primary source of a commodity used by numerous pieces of equipment or service

points in a plant. An example of a header arrangement is shown in Exhibit 1-12.

Branch The individual piping leads between headers and users are also illustrated in Exhibit 1-12.

Maintenance Equipment and its components require routine maintenance for continued reliability and safe operation. A plant layout designer must provide unobstructed space for service equipment and personnel to access and remove components without removing unrelated equipment and piping.

Operation Valves, instruments, and many types of equipment require frequent attention for operation. These items must be accessible without impairing the safety of plant personnel.

Safety The layout of any facility must enable plant personnel to exit a potentially hazardous area without

EXHIBIT 1-11
Inline Instrumentation

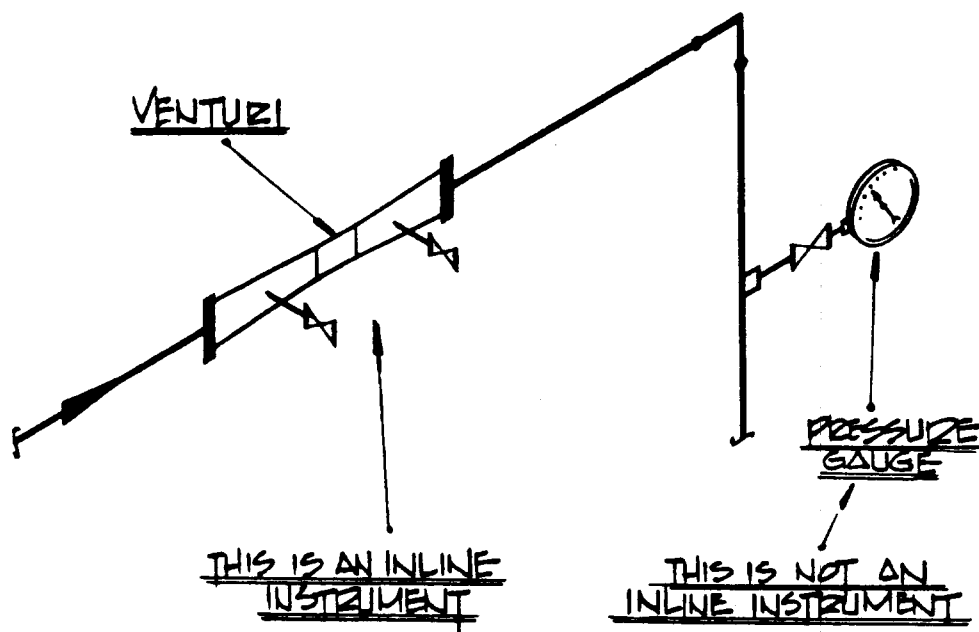
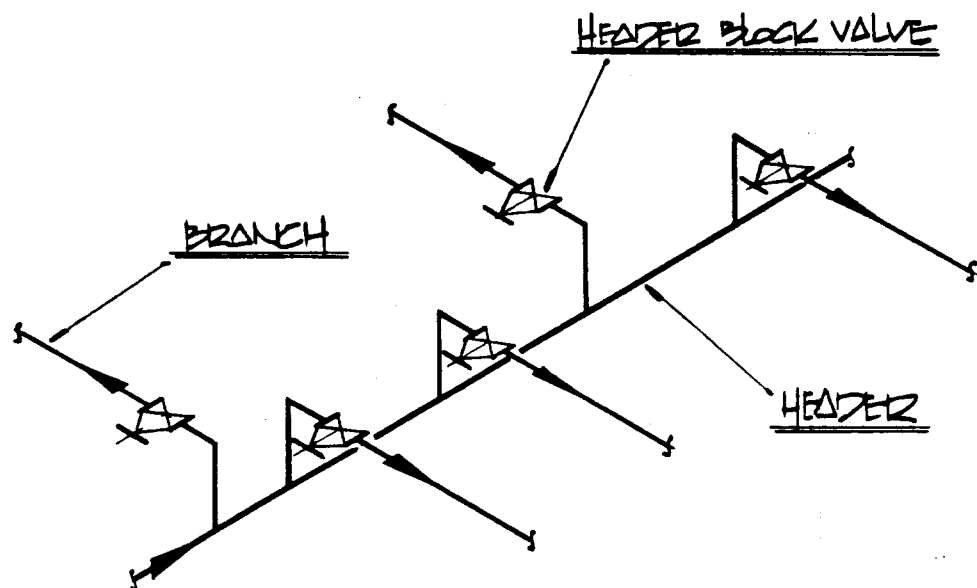


EXHIBIT 1-12
Header-Branch-Header
Block Valve



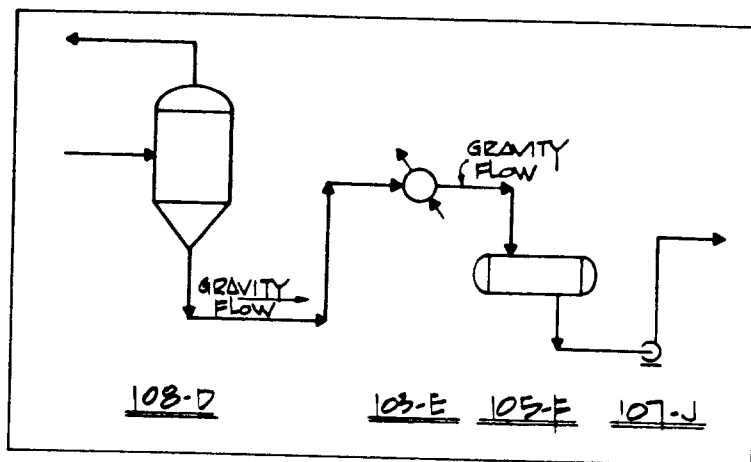
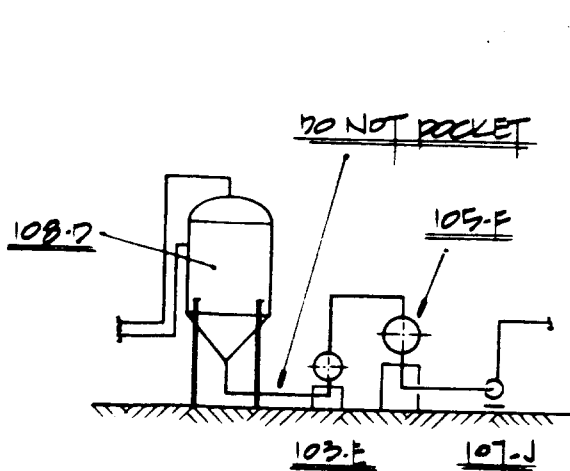
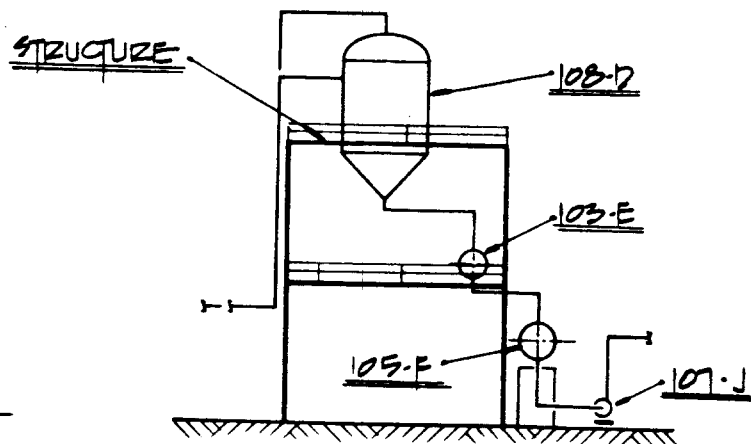
injury. Planning for safety includes adding roadways to provide access for fire fighters and equipment; strategically placing fire detectors and hydrants around the process unit; adding sufficient ladders and stairways at structures to meet OSHA requirements; locating furnaces with fired burners away from potential sources of gas leaks; and setting the height and location of vents to prevent injury to operating personnel.

Cost-effective Developing the most inexpensive layout may not translate into the most cost-effective design for the life of the plant. A cost-effective design is

the result of a balanced consideration of initial cost, safety, and the long-term effects of a design on operations and maintenance.

An example of cost-effectiveness is the layout of steam-driven gas compressors. Although a grade-mounted installation is initially less expensive to install, maintenance on such arrangements often requires the dismantling of all major piping systems. This can prolong plant downtime and translates into lost revenue for the client. Careful consideration should be given to all factors before the initially lowest-cost solution is chosen.

EXHIBIT 1-13 Gravity Flow

PIPING & INSTRUMENTATION DIAGRAMINCORRECT APPLICATIONGRAVITY FLOW DESIGN

Gravity flow When pockets must be avoided in a given piping system, the line is labeled "gravity flow" on the piping and instrumentation diagram. This often results in locating equipment in elevated structures instead of at grade, as shown in Exhibit 1-13.

Open systems An open system is one in which the contents of a line are discharged and not recovered. Examples of this include a relief valve discharging into the atmosphere and a steam trap discharging onto the ground or into an open drain.

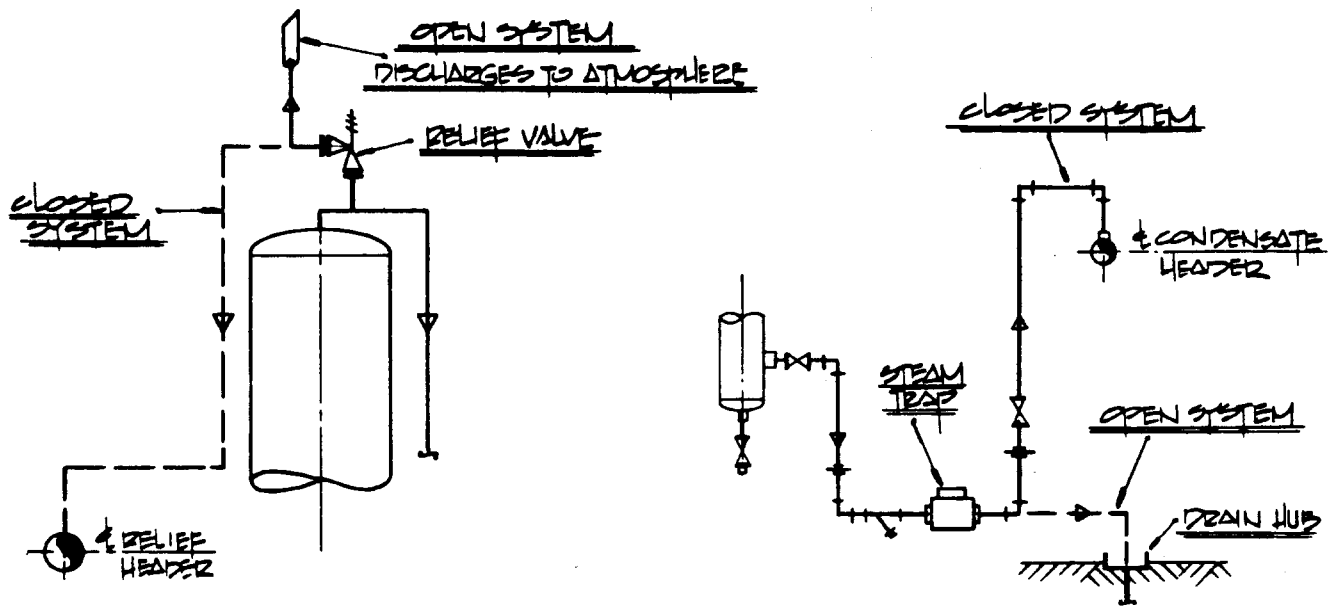
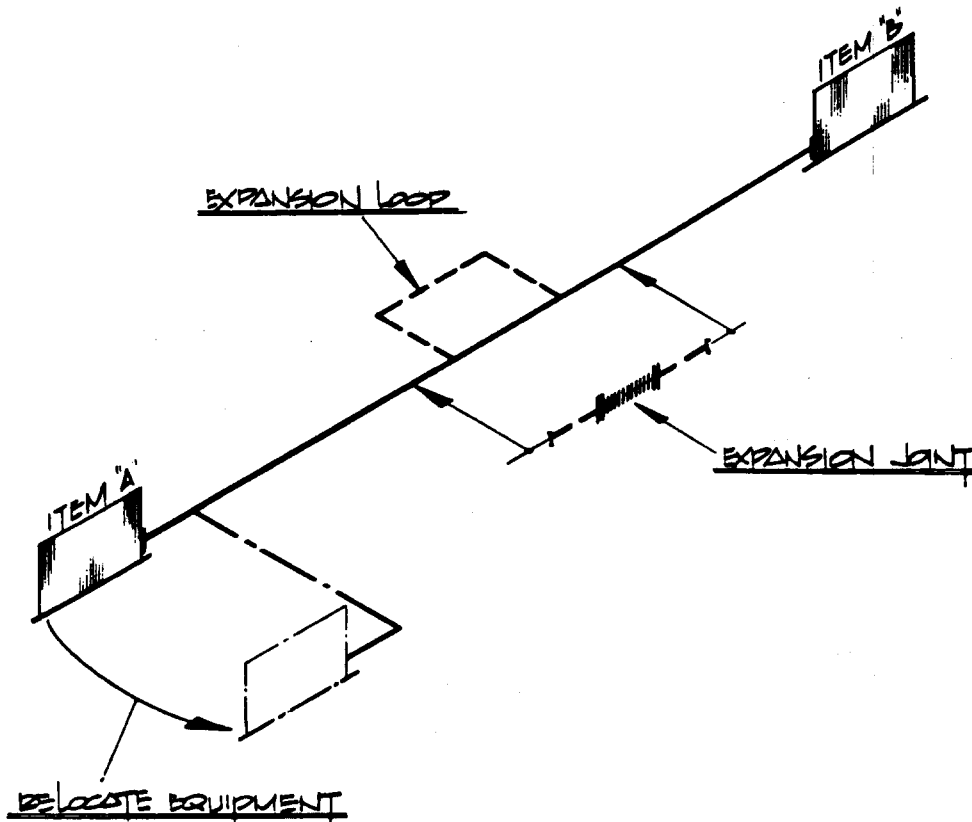
Closed systems A closed system is one in which the contents of relief systems or steam trap condensates are recovered. Examples of open and closed systems are shown in Exhibit 1-14.

Flexibility Every piping arrangement must be sufficiently flexible to allow each line to thermally expand or contract without overstressing the pipe or equipment. Exhibit 1-15 illustrates several methods to meet this flexibility requirement, including:

- Relocating equipment to build flexibility into the inherent design of the line.
- Adding an expansion loop.
- Adding an expansion joint (but only if a loop will not suffice).
- Reducing the schedule (i.e., wall thickness) of the pipe if possible.

The designer should thoroughly review all possible

EXHIBIT 1-14 Open and Closed Systems

EXHIBIT 1-15
Line Flexibility

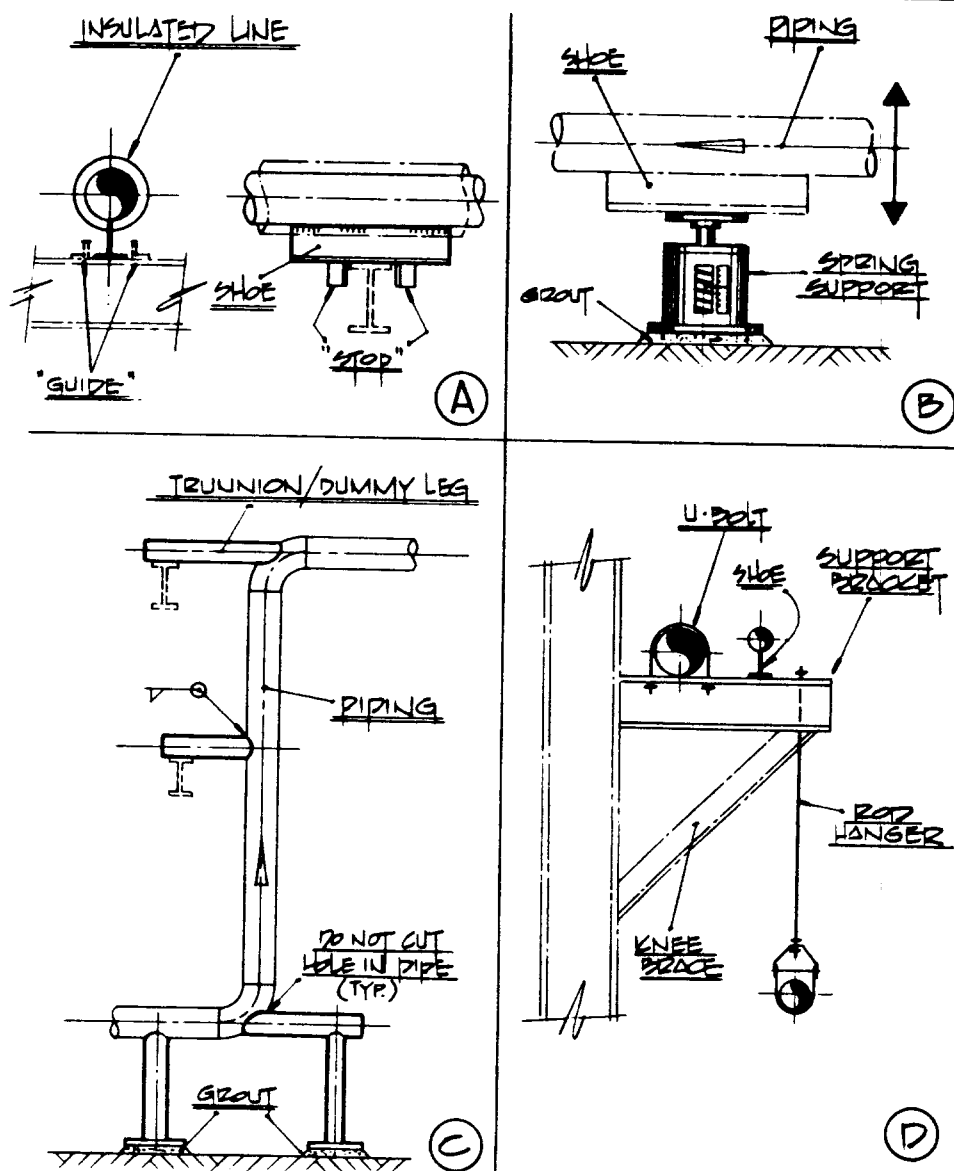


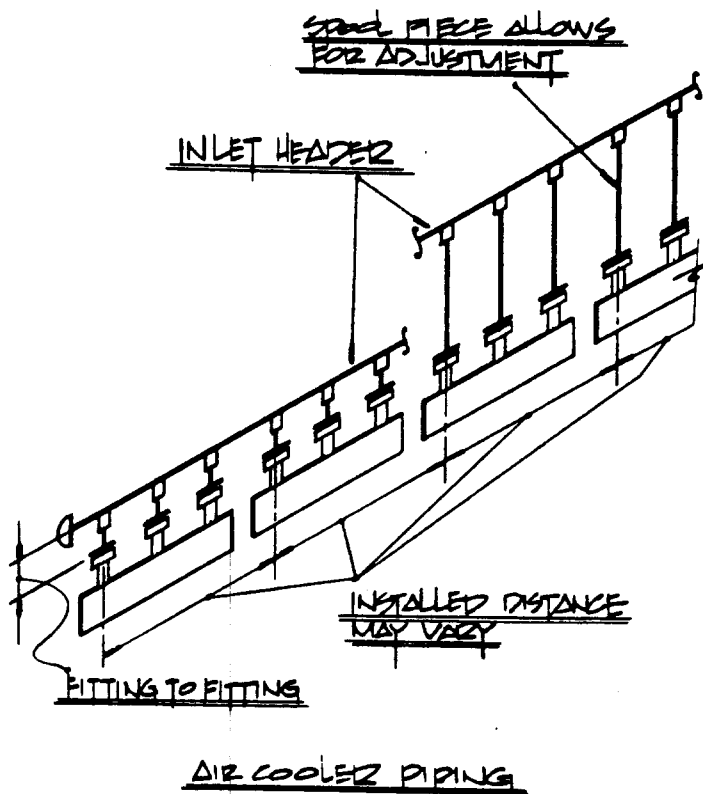
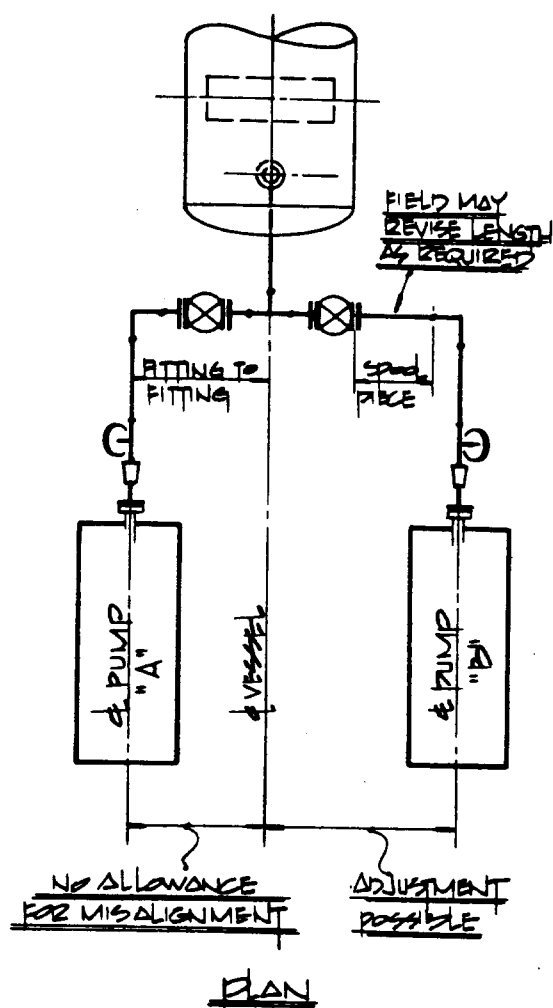
EXHIBIT 1-16
Typical Pipe Supports

solutions with the project stress engineer before proceeding with any of these methods.

Pipe supports These steel members are attached to a pipe to hold it in place during operation. Supports are available in many shapes and sizes and range from those that hold a line firm enough to permit no movement to those that allow movement in any direction. Some typical pipe supports are shown in Exhibit 1-16 and include:

- Pipe shoes—These insulated lines are usually supported on shoes fabricated from structural shapes (e.g., T-sections or wide flanges). A standard shoe height is 4 in (100 mm).
- Spring supports—These lines move at the point of support as a result of thermal expansion or contraction and are generally supported by springs. Designed for specific pipe loads and movements, they maintain a support under a line throughout its range of movement.
- Trunnions and dummy legs—These supports are used for many applications and are welded to the outside of the pipe without cutting a hole into it.
- Brackets—This type of support may be welded to structural members or certain pieces of equipment. It may have a cantilever design or knee bracing for supporting heavy loads. Lines may be U-bolted, guided, or hung by rod hangers from the bracket or may rest on shoes.

EXHIBIT 1-17 Constructibility Planning



A plant layout designer should make every effort to know and understand the pipe support requirements of the area being worked on so that an optimum layout from a piping and a pipe support point of view can be developed.

Constructibility Spending additional time and effort during the engineering phase of a project is often justified if it reduces initial construction staff time or decreases the potential for costly rework on piping layouts. Two examples of constructibility are shown in Exhibit 1-17. The suction piping of pump A is arranged fitting to fitting and does not allow the construction contractor any way to make an adjustment to a misalignment between the centerline of the vessel and the

pump. Although the piping configuration is basically correct, it ignores the constructibility of the overall layout. Adding a spool piece to pump B permits any adjustment that construction may require.

The fitting-to-fitting arrangement at the air cooler inlet header poses a similar problem. Installation of large air coolers often makes it impossible for a prefabricated piping configuration to be bolted to the nozzles, unless a spool piece of reasonable length is included in the layout. Heat may be applied to the problem branch lines so they can be recentered on the nozzles. The fitting-to-fitting configuration does not permit this flexibility to the constructor. Once again, the constructibility factor should be considered.

Plant Layout Specification

Specification, as used in industrial terminology, means the constraints under which a component should be designed and manufactured. Almost everything that is purchased, constructed, or designed is governed by specifications. Specifications encourage uniformity and improve quality throughout all industries. For the plant layout designer, specification is an essential tool of the trade. Ignorance of or failure to comply with the guidelines set in the project specification could be costly and could affect the quality of the design. Specifications set the requirements for plant equipment arrangement, operation, maintenance, and safety in the process plant layout and detail the requirements for compliance with national codes and regulations.

THE COMPONENTS OF SPECIFICATION

This chapter defines what is included in the specification. The plant layout designer must be aware of all the specification components and how to work effectively with the specification.

Modifications

Any revisions, exceptions, or addenda to the specification should be highlighted in the project documentation. Except for small skid-mounted units, all clearances and accesses for operation and maintenance on equipment furnished as a regular part of a proprietary package should be in accordance with the requirements of the specification.

Terms

Operator access is the space required between components or pairs of components to permit walking, operating valves, viewing instruments, climbing ladders or stairs, and safely exiting the unit in an emergency.

Maintenance access is the space required to service

equipment in place or to remove the unit equipment or portions of equipment for off-site repair.

Equipment includes every component associated with the process plant (e.g., pumps, towers, heat exchangers, and compressors).

Equipment Arrangement

General plant arrangement must be consistent with prevailing atmospheric and site conditions as well as with local codes and regulations. Equipment must be grouped within common process areas to suit independent operation and shutdown. Equipment within process and off-site areas must be arranged to accommodate operational and maintenance access and to meet the safety requirements listed in Exhibit 2-1. Unless required for common operation or safety, equipment is to be located in process sequence to minimize interconnecting piping.

Process units, buildings, and groups of off-site areas (e.g., tank farms) are serviced by auxiliary roads for maintenance and fire fighting. Equipment location must facilitate in-place maintenance by mobile equipment. Process equipment must be enclosed in shelters only when required by extreme climatic conditions or client preferences.

In general, piping, power, and instrument cables are to be carried on overhead pipe racks in process units and utility plants and in grade sleepers in off-site areas.

Equipment Elevations

Equipment should generally be elevated a minimum height from grade to suit process, operational, and maintenance requirements. Horizontal drums, shell and tube exchangers, and furnaces must be supported from grade by concrete piers. Vertical vessels (e.g., towers and reactors with attached skirts) and baseplate equipment with pumps should be supported at grade by concrete foundations.

EXHIBIT 2-1 Equipment Spacing

Key:

- A Can be reduced to a minimum of 200' by increasing height of flare
- B Boilers, power generators, air compressors
- C Monitor locations should be selected to protect specific items of equipment
- D Greater than 500° F
- E Less than 500° F
- F The diameter of the largest tank
- G Double the diameter of the largest tank
- H Maximum 250'; minimum will vary
- J Blast resistant
- M Minimum to suit operator or maintenance access
- NA Not applicable

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	FLARE	ADMINISTRATION BUILDINGS	MAIN PLANT SUBSTATION	FIRE PUMPS & STATION	TRUCK & RAIL LOADING	UTILITY PLANTS	COOLING TOWERS	ATMOSPHERIC STORAGE TANK	LOW PRESSURE STORAGE TANK	HIGH PRESSURE STORAGE TANKS	MAIN PLANT THROUGH ROADS	BOUNDARIES & PUBLIC ROADS	FIRE HYDRANTS & MAINS	MAIN PIPEWAYS	MAIN PLANT CONTROL HOUSE	PROCESS UNIT BATTERY LIMIT	PROCESS UNIT SUBSTATION	HYDROCARBON COMPRESSORS	DESALTERS	REACTORS	HEAT EXCHANGERS	PROCESS PUMPS ABOVE AUTO IGNITION	PROCESS PUMPS BELOW AUTO IGNITION	TOWERS, DRUMS	AIR COOLERS	PIPE RACKS	PROCESS UNIT CONTROL HOUSE	FIRE HEATERS	UNIT ISOLATION VALVES	EQUIPMENT HANDLING NON-FLAMMABLE
2	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
3	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
4	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
5	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
6	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
7	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
8	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
9	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
10	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
11	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
12	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
13	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
14	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
15	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
16	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
17	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
18	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
19	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
20	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
21	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
22	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
23	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
24	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
25	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
26	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
27	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
28	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
29	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
30	NA	M	NA	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M

Notes:

Exhibit 2-1 highlights the recommended safety distances between equipment associated with refinery, chemical, and petrochemical plants.

This exhibit should be read in conjunction with national and local codes and regulations. Exceptions to this exhibit should be by client specification only.

Dimensions shown are to the face of equipment and are minimum.

Fixed fire water sprays should be provided over equipment that handles flammable materials and operates at temperatures greater than 500° F (260° C) and over equipment that handles light hydrocarbons with a vapor pressure greater than 65 psi (3.5 kg/cm) at 100° F (38° C) or a discharge pressure greater than 500 psi (35 kg/cm) that is located directly beneath air-cooled exchangers.

a. English Measurement

Large vacuum or crude towers with swagged bottom sections and compressors that are to be elevated for operational needs must be supported from concrete structures. Equipment that must be elevated for process requirements (e.g., shell and tube overhead condensers) must be supported in structures. When practical, air coolers should also be supported from

overhead pipe racks. Equipment elevations must be in accordance with Exhibit 2-2.

Roads, Paving, and Railroads

Process plants are to be serviced by roads adjacent to process units, utility plants, materials-handling and

EXHIBIT 2-1 Equipment Spacing (Cont)

Key:

- A Can be reduced to a minimum of 61 m by increasing height of flare
- B Boilers, power generators, air compressors
- C Monitor locations should be selected to protect specific items of equipment
- D Greater than 260° C
- E Less than 260° C
- F The diameter of the largest tank
- G Double the diameter of the largest tank
- H Maximum 75 m; minimum will vary
- J Blast resistant
- M Minimum to suit operator or maintenance access
- NA Not applicable

OFF-SITE
PROCESS UNIT

FLARE
ADMINISTRATION BUILDINGS
MAIN PLANT SUBSTATION
FIRE PUMPS & STATION
TRUCK & RAIL LOADING
UTILITY PLANTS
COOLING TOWERS
ATMOSPHERIC STORAGE TANK
LOW PRESSURE STORAGE TANK
HIGH PRESSURE STORAGE TANKS
MAIN PLANT THROUGH ROADS
BOUNDARIES & PUBLIC ROADS
FIRE HYDRANTS & MONITORS
MAIN DRIVEWAYS
MAIN PLANT CONTROL HOUSE
PROCESS UNIT BATTERY UNIT
PROCESS UNIT SUBSTATION
HYDROCARBON COMPRESSORS
DESALTERS
REACTORS
HEAT EXCHANGERS
PROCESS PUMPS ABOVE AUTO IGNITION
PROCESS PUMPS BELOW AUTO IGNITION
TOWERS, DRUMS
AIR COOLERS
UNIT PIPE RACKS
PROCESS UNIT CONTROL HOUSE
FIRE HEATERS
UNIT ISOLATION VALVES
EQUIPMENT HANDLING
NONFLAMMABLE

FLARE
ADMINISTRATION BUILDINGS
MAIN PLANT SUBSTATION
FIRE PUMPS & STATION
TRUCK & RAIL LOADING
UTILITY PLANTS
COOLING TOWERS
ATMOSPHERIC STORAGE TANK
LOW PRESSURE STORAGE TANK
HIGH PRESSURE STORAGE TANKS
MAIN PLANT THROUGH ROADS
BOUNDARIES & PUBLIC ROADS
FIRE HYDRANTS & MONITORS
MAIN DRIVEWAYS
MAIN PLANT CONTROL HOUSE
PROCESS UNIT BATTERY UNIT
PROCESS UNIT SUBSTATION
HYDROCARBON COMPRESSORS
DESALTERS
REACTORS
HEAT EXCHANGERS
PROCESS PUMPS ABOVE AUTO IGNITION
PROCESS PUMPS BELOW AUTO IGNITION
TOWERS, DRUMS
AIR COOLERS
UNIT PIPE RACKS
PROCESS UNIT CONTROL HOUSE
FIRE HEATERS
UNIT ISOLATION VALVES
EQUIPMENT HANDLING
NONFLAMMABLE

b. Metric Measurement

loading areas, and groups of off-site equipment that require access for maintenance and fire fighting. An adequate road network and parking facility should be provided at administration buildings, the main plant control room, firehouses, and warehouses. Access ways or secondary roads must be provided within process units and utility plants so that equipment can be removed for off-unit repair and chemicals and catalysts can be loaded and unloaded. Roads must be ramped over piping at intersections with grade-level sleepers.

Paving within process units and utility plants should also encompass all equipment, unit control room areas and the area beneath the main pipe rack. Unless required for maintenance reasons, paving need not

extend to auxiliary roads.

Off-site area paving must be provided at groups of equipment (e.g., pump slabs and metering stations) but not at tank farms, inside diked areas, under pipe racks, or in areas alongside roads, except when required for maintenance. These unpaved areas are not surfaced. Unpaved areas within the battery limits of process units and utility plants must be graded and surfaced with crushed stone or a similar material. Except for floors in control and switchgear buildings, all indoor and outdoor paving must be sloped for drainage.

Curbs and walls are to be used in process units and utility plants to contain spills from equipment using acid and other dangerous chemicals. Earthen dikes

EXHIBIT 2-2
Equipment Elevations

Item	Support Reference	Open Installation		Enclosed Installation	
		ft	mm	ft	mm
a Process Units and Utility Plants					
Grade paving, floors	High point	100'	100,000	100'6"	100,150
	Low point	99'6"	99,850	100'2"	100,050
Vertical vessels	Bottom of base ring or legs	100'6"	100,150	101'	100,300
	POS				
Tankage	Bottom POS	101'	100,300	101'6"	100,450
Horizontal vessels	Bottom of saddles £ EL.	As required for NPSH or for operation and maintenance			
Pumps, blowers, packaged units	Bottom of baseplate	100'6"	100,150	101'	100,300
Independent lubricated compressors	Bottom of baseplate £ shaft	As required for lube oil return piping or surface condensers			
Motor-driven reciprocating compressors	Bottom of baseplate £ shaft	As required for clearance at pulsation bottles and piping			
Furnaces, wall- or roof-fired	Bottom of floor plate POS	104'	101,200	NA	NA
Furnaces, floor-fired	Bottom of floor plate POS	108'	102,400	NA	NA
Vertical reboilers	Bottom of lugs POS	As required to suit structure or related tower			
Pipe racks	Top of steel	As required to suit clearances for operation and maintenance access			
b. Off Site					
Grade paving, floors	High point	9"	230	1'3"	380
	Low point	3"	75	9"	230
Vertical vessels	Bottom of base ring or legs	1'3"	380	1'9"	530
	POS				
Storage tanks	Top of berm or bottom of tank POS	1'	300	NA	NA
Horizontal vessels	Bottom of saddles £ EL.	As required for NPSH or for operation and maintenance			
Pumps, blowers, packaged unit	Bottom of baseplate	1'3"	380	1'9"	530
Cooling towers, clarifiers, clear wells	NA	As required		NA	NA
Grade pipe sleepers	Top of steel	1'	300	NA	NA

For ease of height reference and calculations, all elevations refer to 100 ft for projects using English measurements and 100,000 mm for projects using metric measurements. These datums correspond to the site elevation highlighted in the project design data specification.

Dimensions shown in *b (Off Site)* are heights above high point of grade.

All concrete support elevations shown for equipment include an allowance for grout.

All dimensions shown are minimum.

must be built in off-site areas to retain spills from storage tanks. Dikes, curbs, and walls used to contain tank spills must be able to accommodate the volume of the largest tank in the area. When calculating the size of enclosure, the designer must consider the displacement volume of all other tanks (i.e., to the height of the dike) as well as an allowance for freeboard.

Railroad systems that are designed for in-plant operation and that intersect or form part of the main line are to conform with standards and practices of the main-line railroad or appropriate authority. Road, paving, and railroad dimensions and clearances should be in accordance with the minimum dimensions shown in Exhibit 2-3.

Item	Description	Dimensions		EXHIBIT 2-3 Roads, Paving, and Railroads
		ft	mm	
Main plant roads	Width	24'	7,300	
	Headroom	22'	6,700	
	Inside turning radius	22'	6,700	
Secondary plant roads	Width	16'	4,800	
	Headroom	14'	4,300	
	Inside turning radius	10'	3,000	
Minor access roads	Width	10'	3,000	
	Headroom	11'	3,400	
	Inside turning radius	8'	2,450	
Paving	Distance from outside edge of equipment to edge of paving	4'	1,200	
Railroads	Headroom over railroads, from top of rail	22'	6,700	
	Headroom over dead ends and sidings, from top of rail	12'	3,600	
	Clearance from track centerline to obstruction	8'6"	2,600	
	Centerline distance between parallel tracks	13'	4,000	
	Distance between centerline of track and parallel above ground and underground piping	23'	7,000	
	Cover for underground piping within 23 ft (7,000 mm) of track centerline	3'	900	

Platforms, Ladders, and Stairs

Platforms are to be provided at all elevated equipment and at controls that are beyond reach from grade for manual operation and maintenance.

Stairways must be provided to lead to service levels in structures, buildings, compressor house decks, and furnaces that require frequent access by plant operations personnel. Storage tanks larger than 15 ft (4,500 mm) in diameter and higher than 20 ft (6,000 mm) also require stairs for access. Ladders must be provided for vessel platforms, secondary service levels in structures, and furnaces and at storage tanks with the dimensions previously mentioned. Escape ladders must also be provided from service levels so that no point on a platform is horizontally more than 75 ft (22,500 mm) in walking distance from a main or secondary exit. Side exit ladders are preferred. Flare stacks need only be provided with a single continuous ladder for tip inspection and access to the top maintenance platform. Handrails should be installed on open sides of all platform areas and stairways. Ladders that extend more than 20 ft (6,000 mm) above grade must have safety cages. Self-closing gates at ladder openings on all platforms are also required.

Vertical vessels (e.g., towers or reactors) should generally have circular platforms supported by brackets from the side of the vessel. Platform, ladder, and stairway dimensions and clearances should be in accordance with those shown in Exhibit 2-4. (Unless otherwise noted, dimensions shown are minimum.)

EXHIBIT 2-4 Platforms, Ladders, and Stairs

Item	Description	Dimensions	
		ft	mm
Platforms	Headroom	7'	2,100
	Width of walkways (grade or elevated)	3'	900
	Maximum variance between platforms without an intermediate step	9"	230
	Width at vertical vessels	3'	900
	Distance between inside radius and inside of platform on vertical vessels	10"	250
	Maximum distance of platform or grade below centerline of maintenance access	5'	1,500
	Maximum length of dead ends	20'	6,000
Ladders	Width of ladders	1'6"	450
	Diameter of cage	2'4"	710
	Extension at step-off platforms	4'	1,200
	Distance of bottom hoop from grade or platform	8'	2,400
	Distance between inside radius of vertical vessels to centerline of ladder rung	1'2"	350
	Maximum vertical rise of uninterrupted ladder run	30'	9,150
	Maximum slope from vertical axis	15°	
Stairs	Toe clearance	8"	200
	Width (back-to-back of stringer)	2'6"	750
	Maximum vertical one-flight rise	18'	5,500
	Maximum angle	50°	
	Headroom	7'	2,100
	Width of landings	3'	900

Maintenance

Adequate clearance must be provided adjacent to or around equipment and controls that require in-place servicing or that require removal from their fixed operational location for repair.

If equipment is located within shelters, suitable facilities (e.g., trolley beams or traveling cranes) must be provided to lift and relocate the heaviest items. Drop areas must exist within shelters that use fixed handling facilities. There should also be drop areas for vertical equipment that must be lowered to grade. There must be adequate area at all shell and tube exchangers for rodding or tube bundle removal and at furnaces for coil removal. Exhibit 2-5 highlights some of the principal maintenance activities and handling devices associated with a conventional operating plant.

Plant Operation

There must be clear access at grade and at elevated platforms so that operation of the plant can proceed in a safe and unrestricted manner. Valves and instruments are to be placed so that they can be operated or viewed but do not impede access at grade and elevated walkways.

Operating valves that cannot conveniently be located below a centerline elevation of 6 ft 9 in (2,050 mm) from grade or platform must have chain operators, extension stems, or motor operators. Except for battery limit valves, all unit isolation valves must be located at grade. Exhibit 2-6 highlights the minimum requirements for operator access to controls.

Above-Ground Piping

With the exception of pipeline pumping stations, sewers, and most cooling water systems, piping is generally run above grade in process plants. When located below ground, process piping that has protective heating or that requires inspection and servicing should

be located in trenches.

In process units and utility plants, piping to equipment must run overhead to meet operator and maintenance clearances. Short runs of piping (e.g., pump suction), however, may run at grade, where they do not obstruct access ways. Piping in such off-site areas as tank farms must run approximately 18 in (450 mm) above grade and must provide adequate access to controls and maintenance areas by walk-over stiles. Off-site pipe racks must be located adjacent to storage tank dikes. Within diked areas, piping must run by the most direct route unless limited by flexibility and tank settlement. Piping serving a tank or tanks in a common area must not run through adjoining diked areas.

All insulated piping that passes through dikes and all piping passing under roads or railroads must be enclosed in metal pipe sleeves. Uninsulated piping passing through dikes should be coated and wrapped but not sleeved. Piping systems must facilitate the removal of equipment without removing the associated piping and controls.

Piping systems are to be arranged with sufficient flexibility to reduce any excessive stresses and, when possible, to accommodate expansion without using expansion bellows. Line spacing should be based on anticipated line movements under regular operating conditions.

The top of stacks and continuously operating vents that discharge hazardous vapors must be positioned at least 10 ft (3,000 mm) above any platform within a horizontal radius of 70 ft (21,000 mm) from the vent or stack. Intermittent vents that discharge hazardous vapors into the atmosphere are to be located a minimum of 10 ft (3,000 mm) above any platform within a horizontal radius of 35 ft (10,500 mm) from the vent.

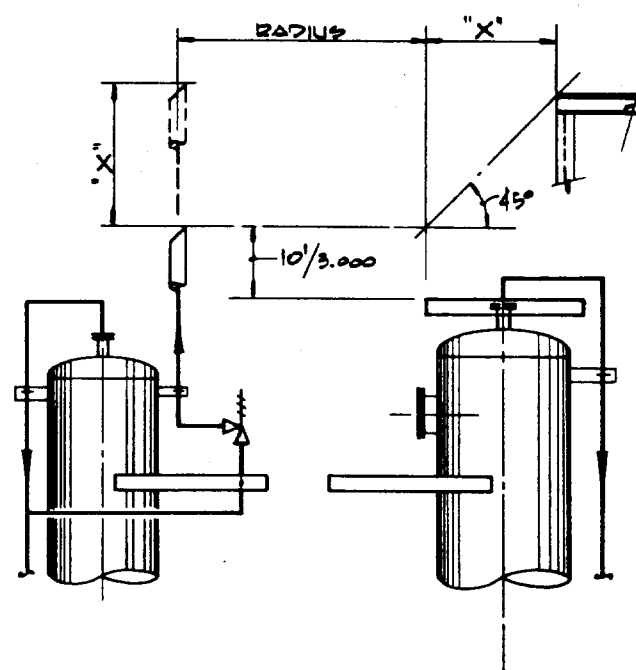
The vertical distance may be reduced for vents and stacks discharging into the atmosphere by the same distance that a platform is outside the safety radius from the vent or stack, as illustrated in Exhibit 2-7. Nonhazardous vapors (e.g., air or steam) must be directed away from personnel.

Item	Activity	Handling Device	EXHIBIT 2-5 Maintenance Requirements
Vertical vessels	Maintenance access cover removal	Maintenance access davit	
	Relief and control valve removal	Top head davit	
	Catalyst loading and unloading	Mobile crane	
	Vessel internal removal	Top head davit or mobile crane	
Exchangers	Cover removal (horizontal)	Hoist trestle with load up to 2,000 lb (900 kg) or mobile crane	
	Bottom cover removal (vertical)	Hitch points	
	Top cover removal (vertical)	Mobile crane	
	Bundle removal (horizontal)	Mobile crane and extractor	
	Bundle removal (vertical)	Mobile crane	
	Rodding	Manual	
	Air cooler tube removal	Mobile crane	
	Plate removal (plate exchanger)	Manual	
Pumps, compressors	Motor or largest component removal (housed)	Trolley beam or traveling crane	
	Motor or largest component removal (open installation)	Mobile crane or hoist trestle with load up to 2,000 lb (900 kg)	
	Vertical pumps	Mobile crane	
Furnaces	Coil removal	Mobile crane	
Miscellaneous	Filter removal	Manual or hoist trestle	
	Strainer removal	Manual	
	Relief valves, 4 to 6 in and larger	Davits, hitch points, or mobile crane	
	Blinds, blanks, figure-8s, and valves, more than 300 lb (135 kg)	Hoist trestle	
	Small components, 300 lb (135 kg) and less	Manual or hoist trestle	

EXHIBIT 2-6 Operator Access to Controls

Item	Platform or Grade	Fixed Ladder
Maintenance access	Yes	No
Level controls	Yes	No
Motor-operated valves	Yes	No
Sample connections	Yes	No
Blinds and figure-8s	Yes	No
Observation doors	Yes	No
Relief valves	Yes	No
Control valves	Yes	No
Battery limit valves	Yes	No
Valves, 3 in and larger	Yes	No
Hand holes	Yes	Yes
Valves, smaller than 3 in	Yes	Yes
Level gauges	Yes	Yes
Pressure instruments	Yes	Yes
Temperature instruments	Yes	Yes
Vessel nozzles	No	No
Check valves	No	No
Header block valves	No	No
Orifice flanges	No	No

EXHIBIT 2-7 Atmospheric Vents



Plot Plans

The plot plan is one of the key documents produced during the engineering phase in any processing facility. It is used to locate equipment and supporting infrastructure and to establish the sequence of major engineering and construction activities. Plot plans are used by almost every engineering group within a project task force from estimating and scheduling through construction. The plot plan is developed by the plant layout designer, usually at the proposal stage of the project, and remains the responsibility of the designer throughout construction. Similar process units engineered for two clients may look vastly different for various reasons, including available real estate, soil and climate conditions, and client philosophy on operation, maintenance, and safety. For these reasons, standardization of process unit plot plans is difficult. Nevertheless, as most operating facilities use common equipment (e.g., shell and tube heat exchangers, pressure vessels, pumps, and compressors), it is possible to apply a few basic rules that suit most clients and processes and that enable the plant layout designer to approach the task of arranging the equipment and supporting facilities in an orderly manner.

THE PLOT PLAN IN THE PROCESS UNIT

This chapter highlights the general requirements for process unit plot plan arrangement. It identifies the information required to locate operating equipment and supporting facilities to suit operator and maintenance access, constructibility, process operation, safety, and cost-effective design.

DEFINITION

The process unit plot plan is an arrangement drawing that highlights the equipment and supporting facilities (e.g., pipe racks and buildings). These are required for a given process integrated within a common battery

limit area, usually designed for independent operation and shutdown. The final plot plan identifies all the components by designated numbers and shows, to scale, the basic shapes of the equipment and supporting facilities, locating them in both the vertical and the horizontal planes. Generally, the arrangement is shown in the plan with elevated views furnished only for clarity (e.g., in the vertically structured plant). Plot plans developed with three-dimensional CAD modeling have the advantage of producing multiple plans, elevations, and isometric views with no additional effort. The plot plan is used for the functions discussed in the following sections.

Piping design The plot plan is used to produce equipment arrangement studies that facilitate the interconnection of above- and below-ground process and utility piping systems and to estimate piping material quantities.

Civil engineering The plot plan is used to develop grading and drainage plans, holding ponds, diked areas, foundation and structural designs, and all bulk material estimates.

Electrical engineering The plot plan is used to produce area classification drawings, to locate switchgear and the incoming substation and motor control center, to route cables, and to estimate bulk materials.

Instrument engineering The plot plan is used to locate analyzer houses and cable trays, assist in the location of the main control house, and estimate bulk materials.

Systems engineering The plot plan is used to facilitate hydraulic design, line sizing, and utility block flow requirements.

Scheduling The plot plan is used to schedule the orderly completion of engineering activities.

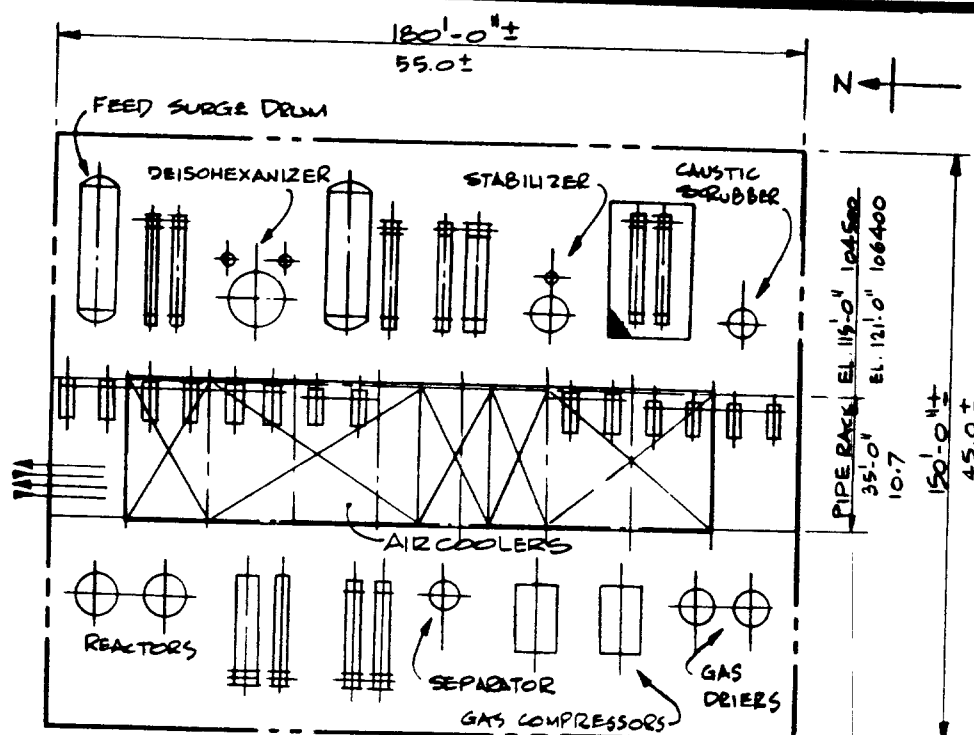


EXHIBIT 3-1
Sample Proposal Plot
Plan

Construction The plot plan is used to schedule the erection sequence of all plant equipment, which includes rigging studies for large lifts, constructibility reviews, marshaling, and lay-down areas throughout the entire construction phase.

Estimating The plot plan is used to estimate the overall cost of the plant.

Client use The plot plan is used for safety, operator, and maintenance reviews and to develop an as-built record of the plant arrangement.

PLOT PLAN DEVELOPMENT

Developing a plot plan is not an exact science, because the arrangement of the plant must be set at the beginning of the project before all equipment requirements and configurations are finalized and before all of the mechanical problems associated with the design are solved. Plot plan arrangement is a reflection of the designer's ability to anticipate mechanical problems and provide the necessary access for operation and maintenance as well as the designer's general experience with plant layout requirements. The intended goal is to produce a safe, cost-effective operational plant, which will probably remain in use for at least 25 years. Therefore, it is important that any errors in

arrangement be recognized and eliminated during the plot plan development phase of the project because they can be costly to correct once the plant is in operation.

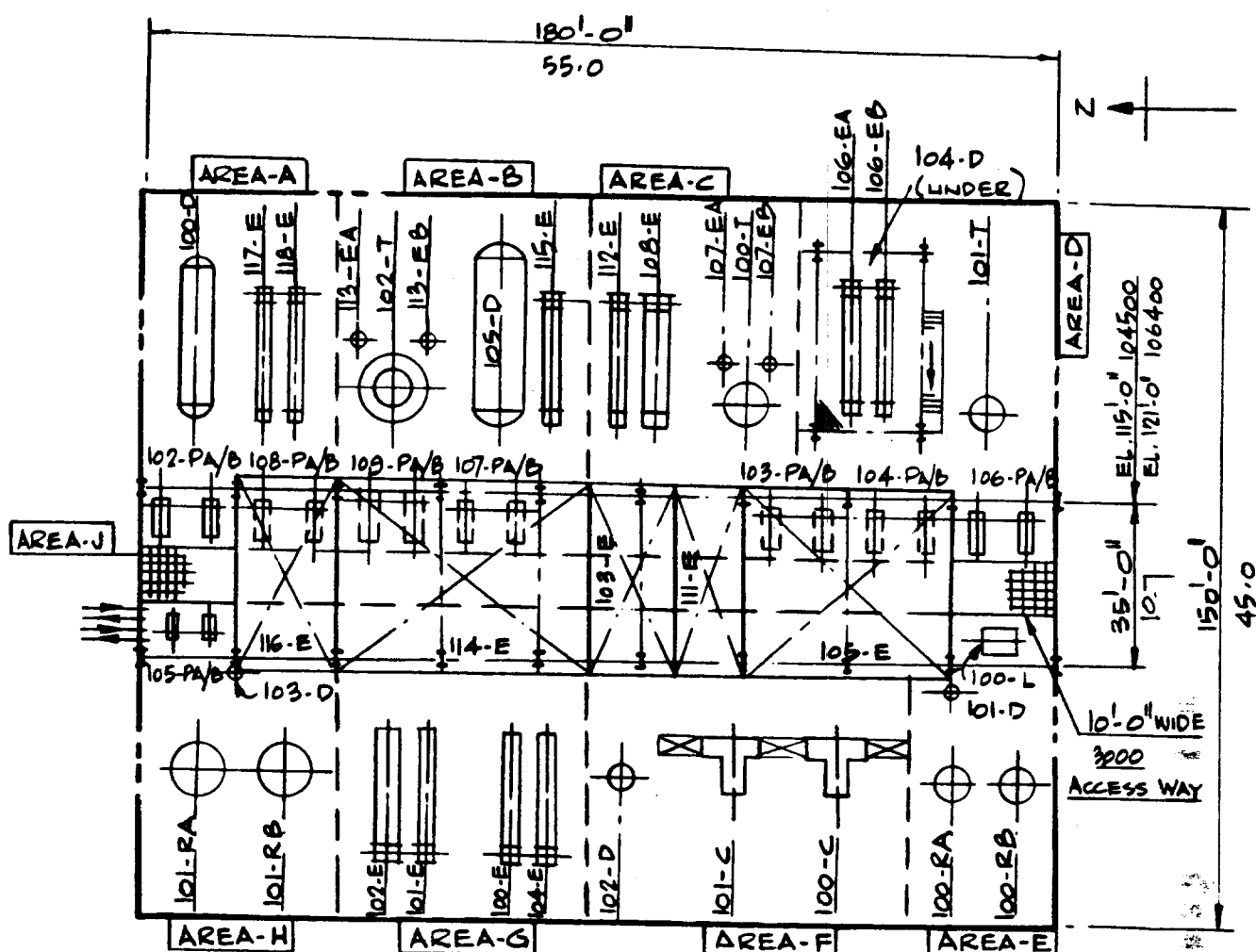
Plot plans are generally developed in stages, from the initial concept to the fully dimensioned document at the construction issue stage.

The proposal plot plan, shown in Exhibit 3-1, is developed during the estimate phase of the project and is used to estimate bulk materials. It is also included in the proposal as a representation of the unit arrangement to the prospective client. The proposal plot plan is based on limited information and generally indicates only the principal items of equipment, main supporting facilities, and overall dimensions.

After contract award, the proposal plot plan is updated to suit the latest information and is reviewed and approved by the client. This document becomes the basis for the plant layout phase of the project and is called the planning plot plan. A sample planning plot plan is shown in Exhibit 3-2. On completion of the plant layout phase—when all the equipment has been sized and is in the best position to suit the project requirements and when all access roads, buildings, and pipe racks have been located—the plot plan is finally issued for construction. This is illustrated in Exhibit 3-3 as the construction plot plan.

To develop a plot plan, the designer must assemble the information discussed in the following sections.

EXHIBIT 3-2 Sample Planning Plot Plan



The equipment list This document lists all the items of equipment and buildings by number and description to be included within the unit battery limits. A sample equipment list is given in Exhibit 3-4.

The process flow diagram The process flow diagram is one of the most important documents required by the designer to position equipment. It indicates flow rates, temperatures, and pressures and how the various pieces of equipment are interconnected. The process flow diagram generally does not show utility equipment (e.g., drives, surface condensers, and injection packages). These can be obtained from the equipment list. The process flow diagram does not always show the true representation of the equipment. A shell and tube exchanger shown as a single item could turn out to be two or more shells for a large load. Exhibit 3-5 shows a process flow diagram that incorporates the items in the sample equipment list.

The block flow diagram The block flow diagram shows all primary interconnecting lines between process units, utility plants, and storage facilities. Although not absolutely essential, it is a useful document for equipment location.

Specifications Similar to the plant layout specification discussed in Chapter 2, this document highlights maintenance, operator access, clearances, and equipment spacing.

Process design data The process design data gives site information on a map or an overall existing plot plan. The existing plot plan, or site map, shows such geographic details as roads, railroads, rivers or sea-shore, land contours, and inhabited areas. It also indicates the location and extent of real estate available for the new facility or expansion. The process design data indicates weather conditions (e.g., average seasonal

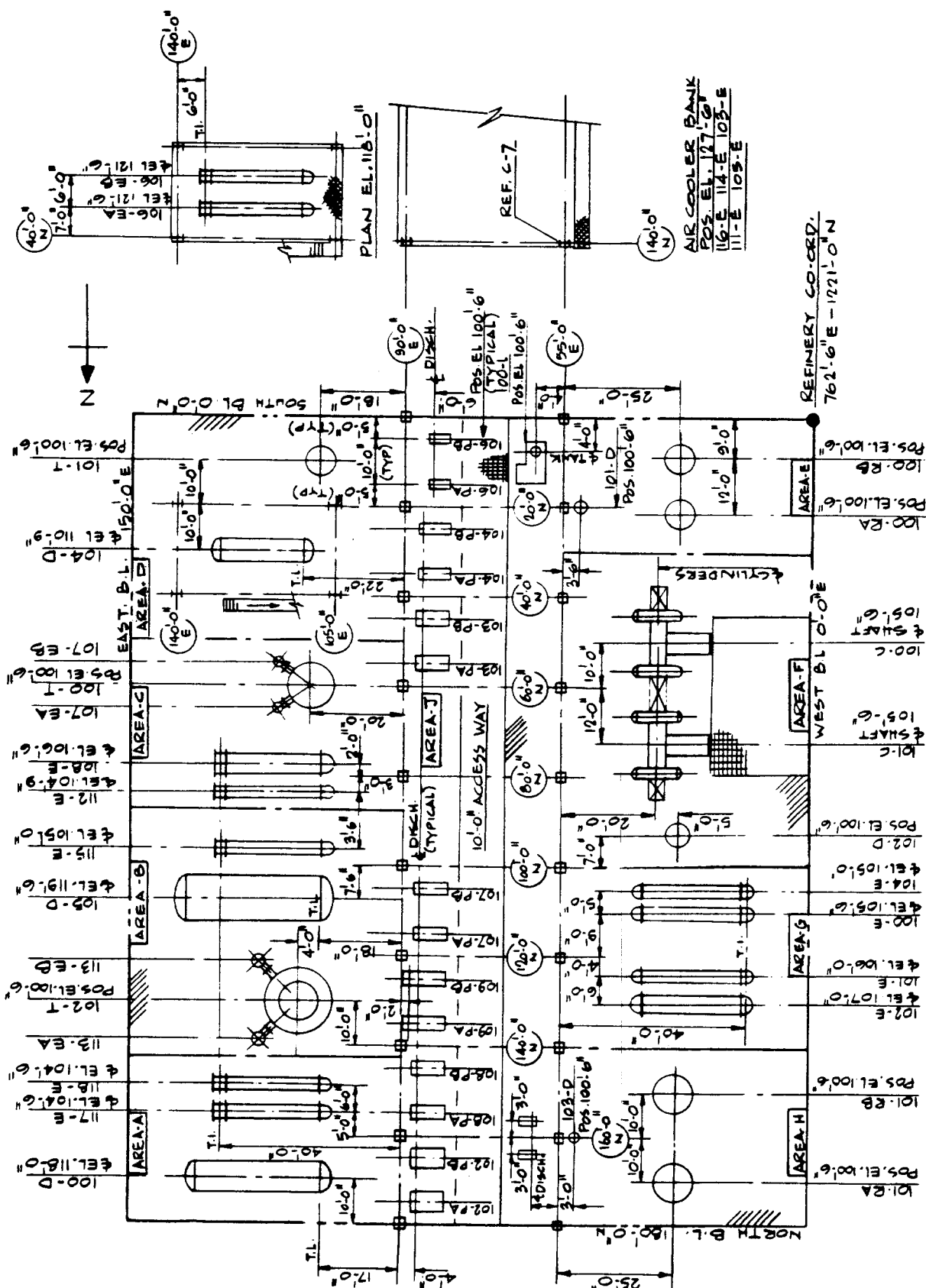


EXHIBIT 3-4 Sample Equipment List

Item	Description
Furnaces	
101-F	Charge furnace
Exchangers	
101-E	Stripper reboiler
102-E	Stripper feed/effluent exchanger
103-E	Stripper overhead trim condenser
104-E	Reactor effluent trim cooler
105-E	Stripper overhead condenser
106-E	Reactor effluent cooler
107-E/A to H	Combined feed exchangers
108-E	Surface condenser
109-E	Product cooler
Pumps	
101-PA	Charge pump
101-PB	Spare charge pump
102-P	Water injection pump
103-PA	Stripper bottoms pump
103-PB	Spare stripper bottoms pump
104-PA	Stripper reflux pump
104-PB	Spare stripper reflux pump
105-PA	Condensate pump
105-PB	Spare condensate pump
Towers	
101-T	Stripper
Reactors	
101-R	Reactor
Drums	
101-D	Feed surge drum
102-D	Recycle compressor suction drum
103-D	Make-up compressor suction drum
104-D	Water injection drum
105-D	Stripper reflux drum
Compressors	
101-C	Recycle compressor
102-CA	Make-up compressor
102-CB	Spare make-up compressor
Miscellaneous	
101-CL	Lube oil console
101-L	Corrosion inhibitor injection system
101-H	Compressor house
101-HL	Overhead traveling crane

temperatures, rainfall records, and prevailing winds). It also gives the plant elevation datum and reference coordinates for plant location.

Equipment sizes At this phase of the project, the equipment sizes for the plant are furnished by the supporting groups on the basis of preliminary information and cover such general items as floor space requirements (e.g., for a pump of known size) or a shell and tube exchanger with only the tube diameter and length given. As the project progresses, equipment configurations and sizes become firm and the plot plan is updated accordingly. Exhibit 3-6 lists sample information that must be supplied.

Materials of construction A materials specialist marks up a process flow diagram identifying special or critical piping materials (e.g., alloy and large heavy wall piping). The diagram assists the plant layout designer in optimizing equipment locations to suit the most economic piping runs.

TYPES OF PLOT PLANS

Plot plans are often referred to by their process (e.g., an ammonia plant or hydrotreater unit) rather than by the type of configuration of the equipment layout. In terms of equipment arrangement, process unit plot plans can basically be divided into two configurations: the grade-mounted horizontal inline arrangement seen in most refinery facilities, and the structure-mounted vertical arrangement found in many chemical plants.

The Grade-Mounted Horizontal Inline Arrangement

The horizontal inline unit is usually located within a rectangular area, with equipment placed on either side of a central pipe rack serviced by auxiliary roads.

EXHIBIT 3-5 Sample Process Flow Diagram

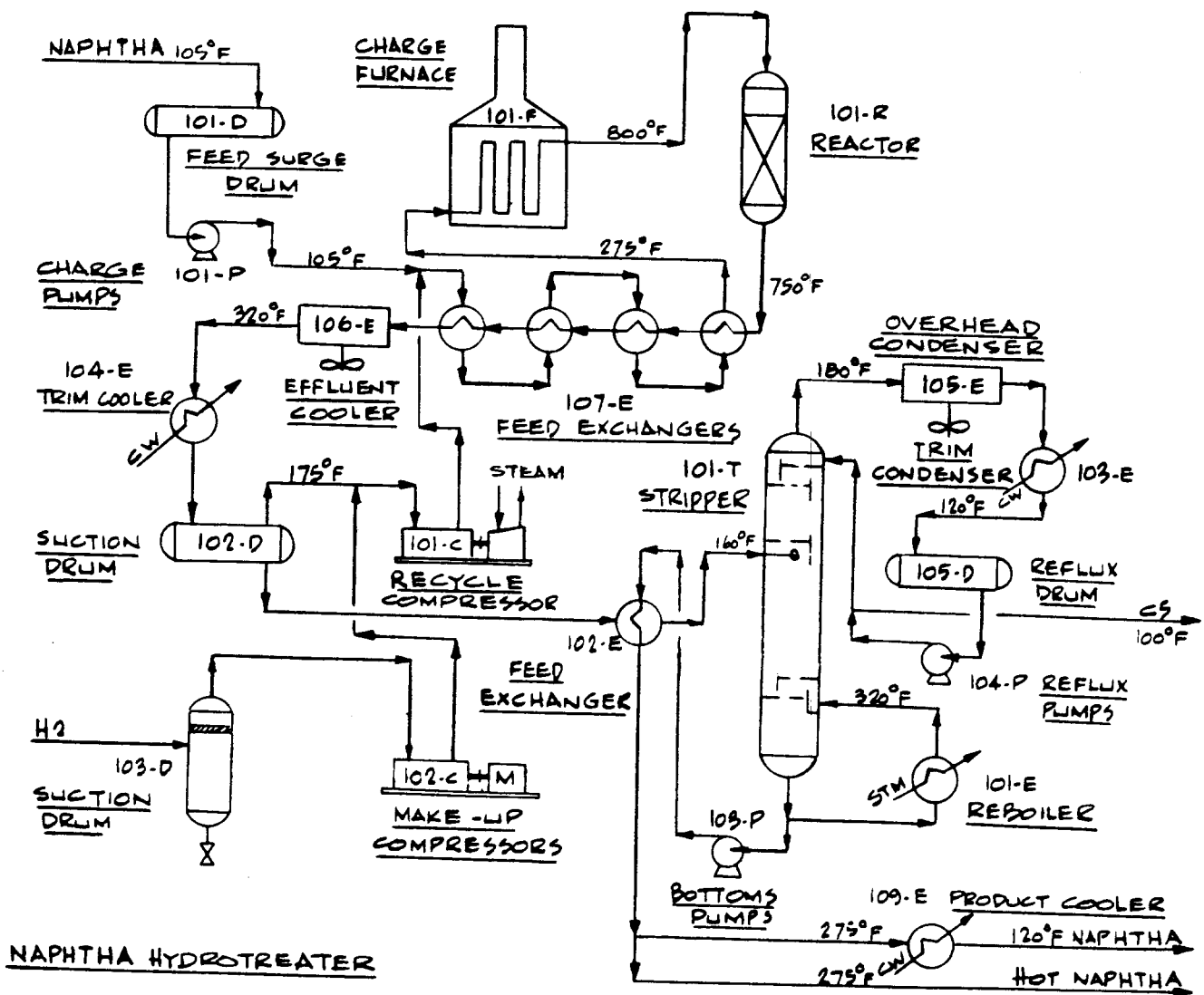


EXHIBIT 3-6 Floor Space Sizes

Exchangers		
Item	Bundle Diameter	Length
101-E	36 in (915 mm)	20 ft (6,100 mm)
102-E	30 in (750 mm)	20 ft (6,100 mm)
103-E	30 in (750 mm)	20 ft (6,100 mm)
104-E	24 in (610 mm)	20 ft (6,100 mm)
105-E (A/C)	30 ft (9,150 mm)	40 ft (12,200 mm)
106-E (A/C)	30 ft (9,150 mm)	20 ft (6,100 mm)
107-E (8 shells)	36 in (915 mm)	24 ft (7,300 mm)
108-E	60 in (1,500 mm)	15 ft (4,600 mm)
109-E	30 in (750 mm)	20 ft (6,100 mm)
Pumps		
Item	Length	Width
101-Pa/b	5 ft (1,500 mm)	2 ft 6 in (750 mm)
102-P	2 ft 6 in (750 mm)	1 ft 3 in (380 mm)
103-Pa/b	4 ft 6 in (1,370 mm)	2 ft (610 mm)
104-Pa/b	4 ft (1,220 mm)	1 ft 6 in (450 mm)
105-Pa/b (vertical)	1 ft 6 in (450 mm)	1 ft 6 in (450 mm)

The principal advantage of this arrangement is that the equipment is generally located at grade, which makes this type of plant easier to construct and more accessible for maintenance and operation. The disadvantages are the amount of real estate required and the long runs of cabling, utility, feed, and product piping required to service the unit. Exhibit 3-7 shows a typical horizontal inline plot plan arrangement.

The Structure-Mounted Vertical Arrangement

The structure-mounted vertical arrangement has equipment located in a rectangular multilevel steel or concrete structure. The structure can be several bays long and either open-sided or fully enclosed, to suit either client preference or climate conditions. Piping

and cabling usually enter and exit the structure at one level and gain access to each floor by chases or are supported from the outside members. Operators usually gain access to each level by stairs or by elevator. Equipment maintenance is usually accomplished through the use of hitch points, trolley beams, or traveling cranes. An adequate area must be provided around each item along with a clear drop zone at grade for equipment removal. The structure is serviced by access roads.

The advantages of this type of arrangement are the small amount of real estate required for the plant and the ability to house the facility to suit process requirements or climate conditions. The disadvantages are in the operator and maintenance access and in the construction of the plant. Exhibit 3-8 shows a typical structure-mounted vertical plot plan arrangement.

EQUIPMENT LOCATION

Various requirements dictate the location of equipment and supporting facilities within the conventional operating plant, and many factors must be considered when the designer is locating equipment. They are discussed in the following sections.

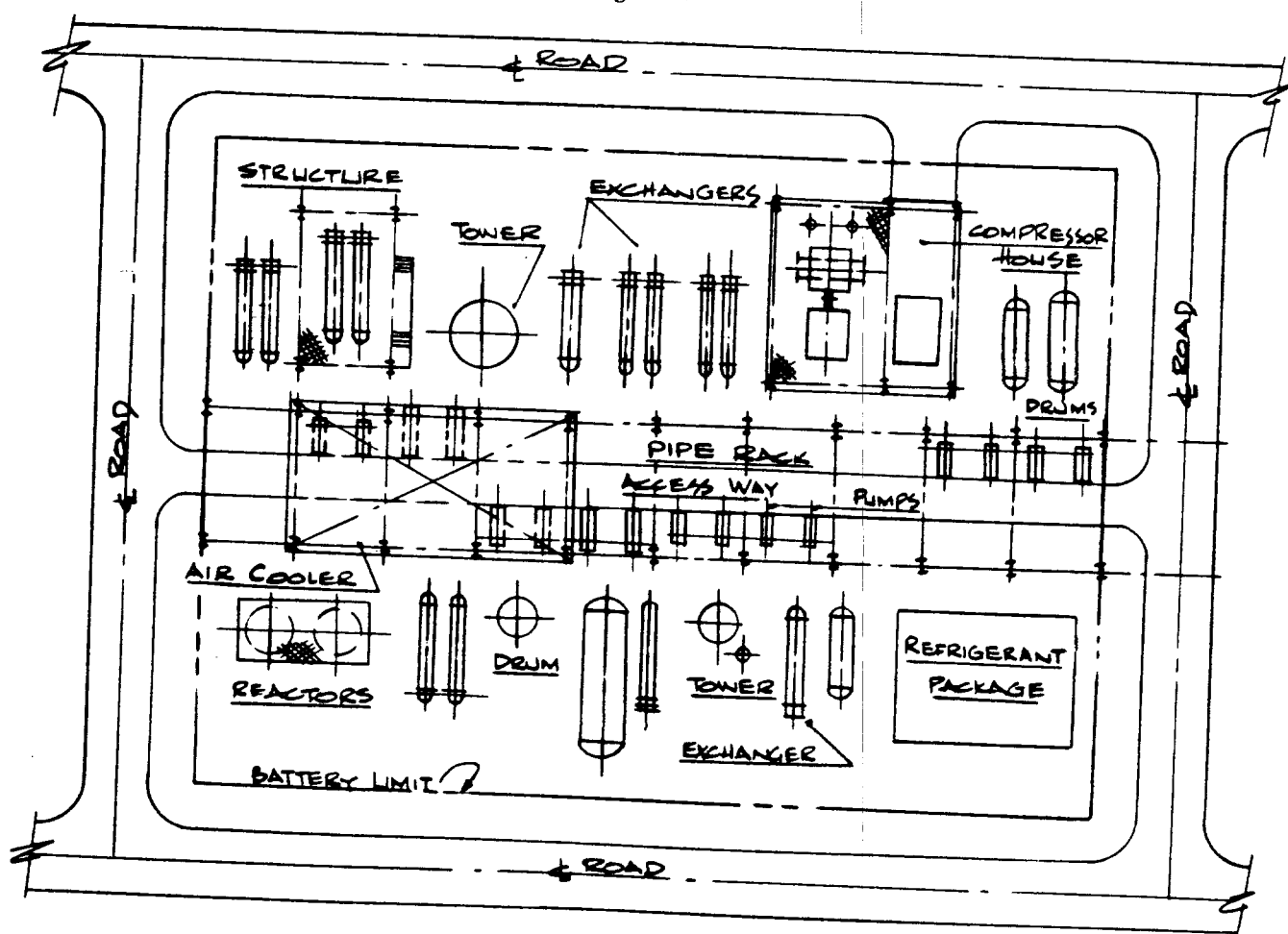
Plant Layout Specification

This document highlights spacing requirements for equipment and access widths and elevation clearances for operator and maintenance access. A typical plant layout specification can be found in Chapter 2. The sample specification shown in Exhibit 3-9 highlights the safety spacing requirements around a process furnace.

Economic Piping

The major portion of the piping within most process units is used to interconnect equipment and support controls between equipment. To minimize the cost of

EXHIBIT 3-7 Grade-Mounted Horizontal Inline Arrangement



this bulk material, equipment should be located in process sequence and close enough to suit safety needs, access requirements, and piping flexibility. The sequential interconnection of the unit is shown on the process flow diagram. The first step is to identify the alloy or heavy wall piping. The diagram should then be subdivided into smaller groups of process-related equipment. These groups should contain an assembly

of related equipment and controls that function as a subsystem within the main process unit. The components within the subsystem should be arranged to suit the most economic piping runs, and the whole assembly should be positioned within the plot area to provide the most economic interconnection between related process subsystems. Exhibit 3-10 shows a process flow diagram divided into subsystems, an ar-

EXHIBIT 3-8 Structure-Mounted Vertical Arrangement

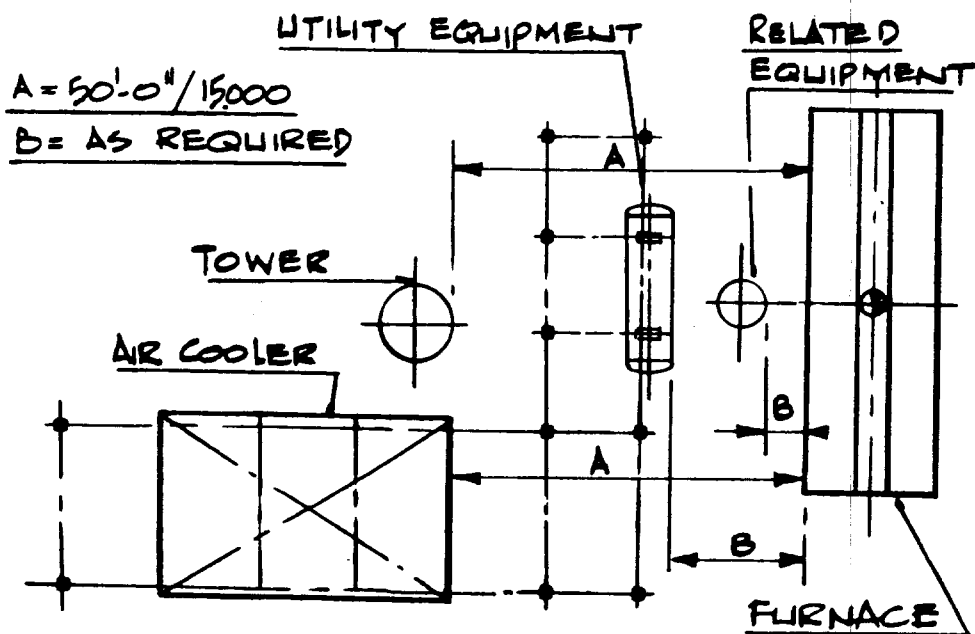
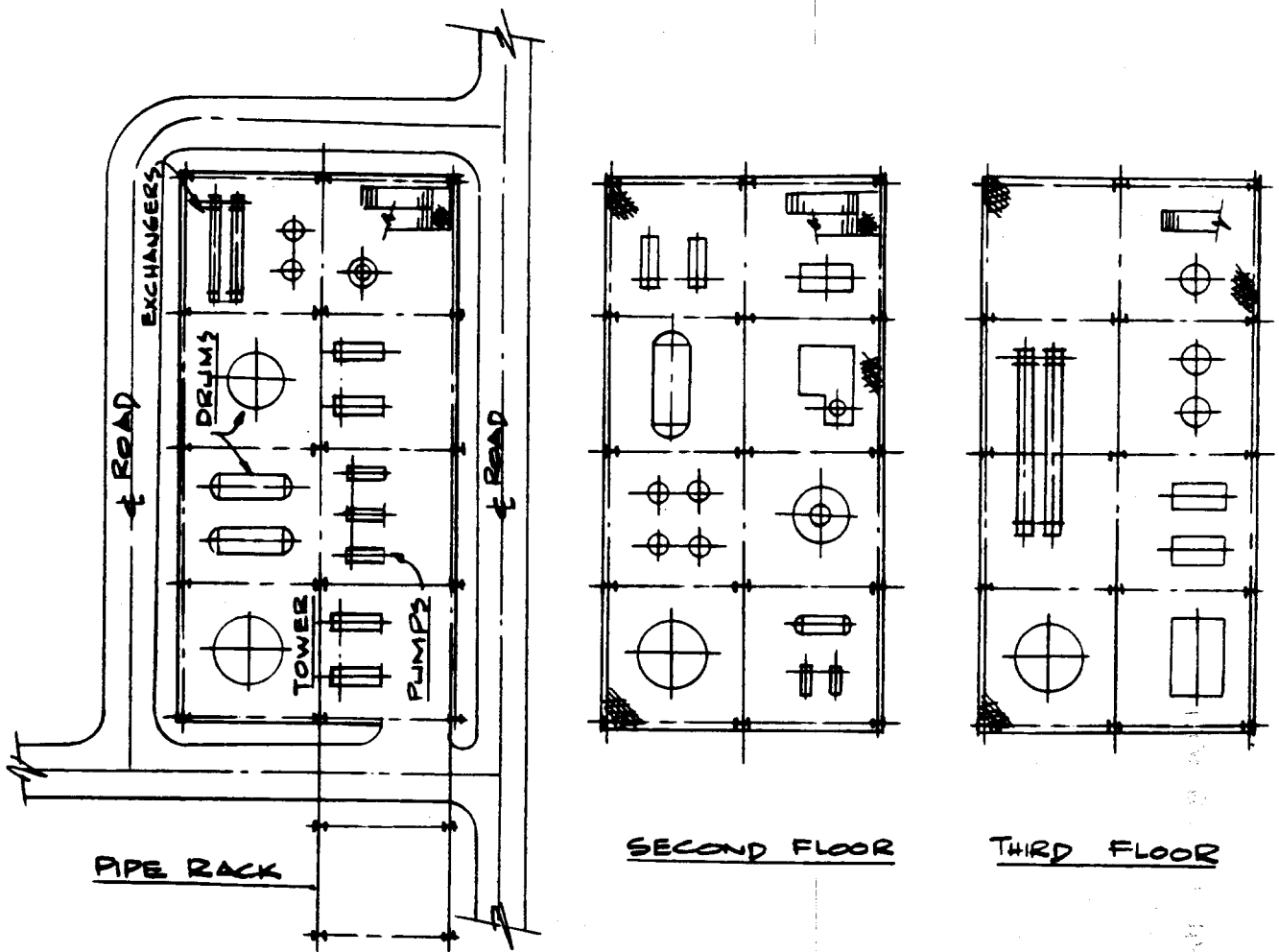
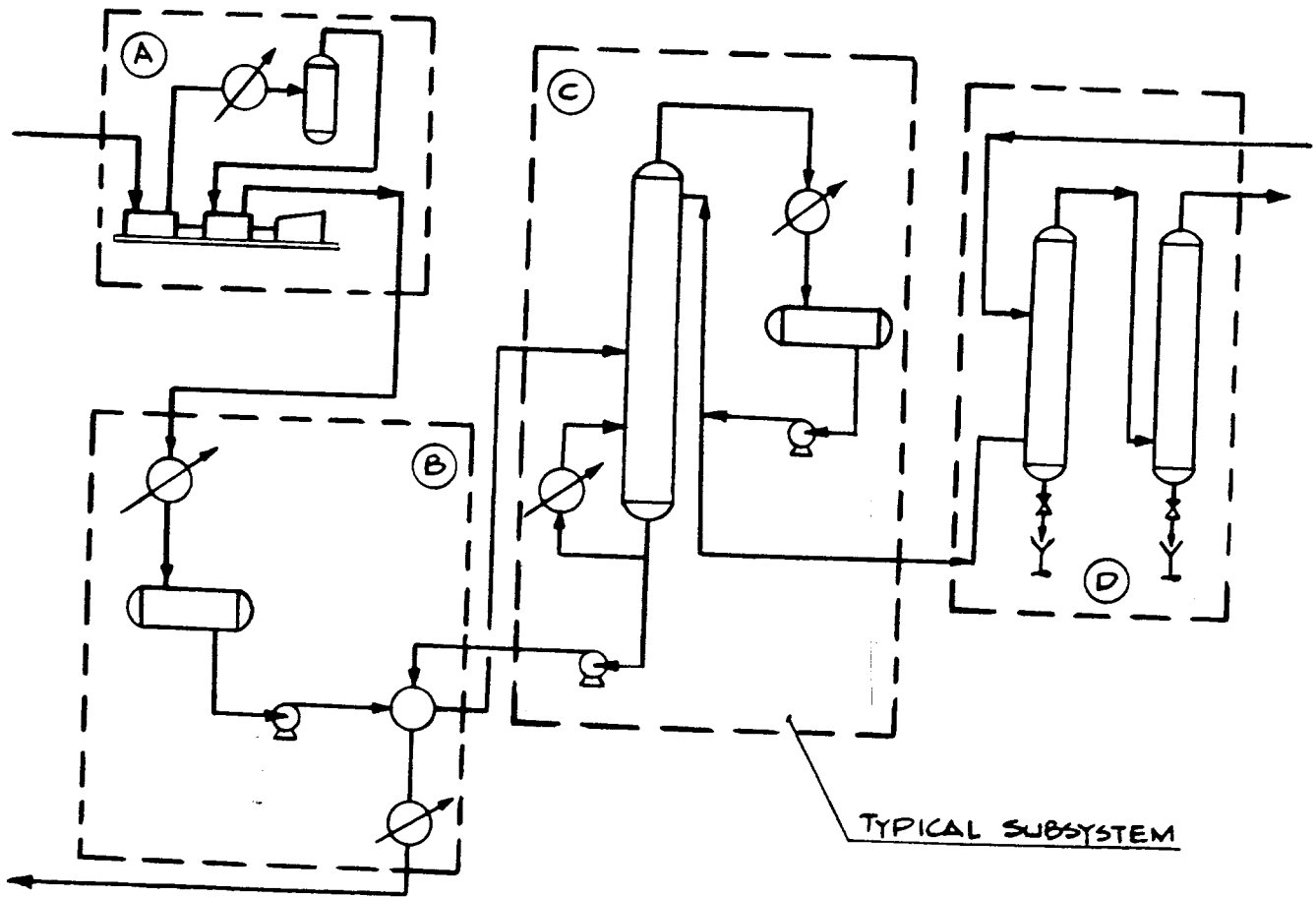
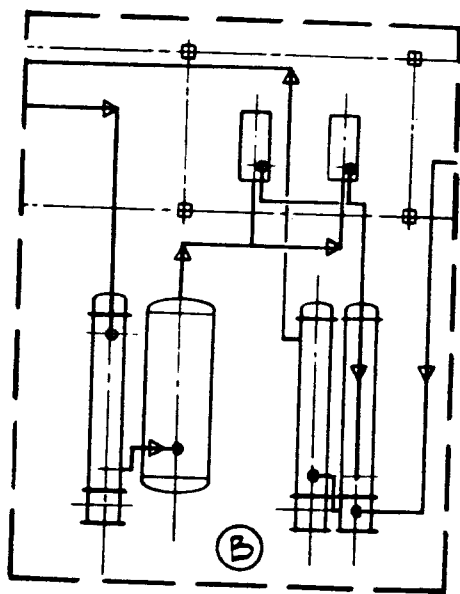
EXHIBIT 3-9
Sample Plant Layout
Specification for Safety
Spacing Requirements

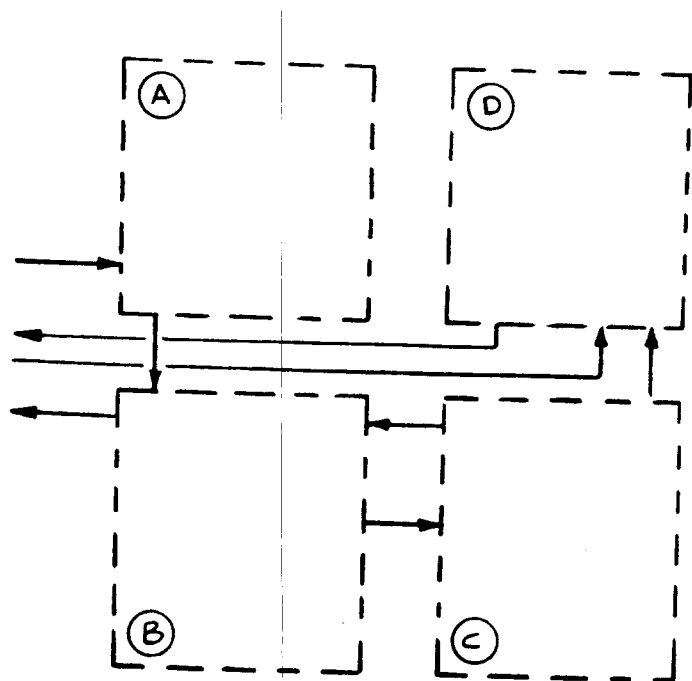
EXHIBIT 3-10 Planning Piping with a Process Flow Diagram



a. Subdivided Process Flow Diagram

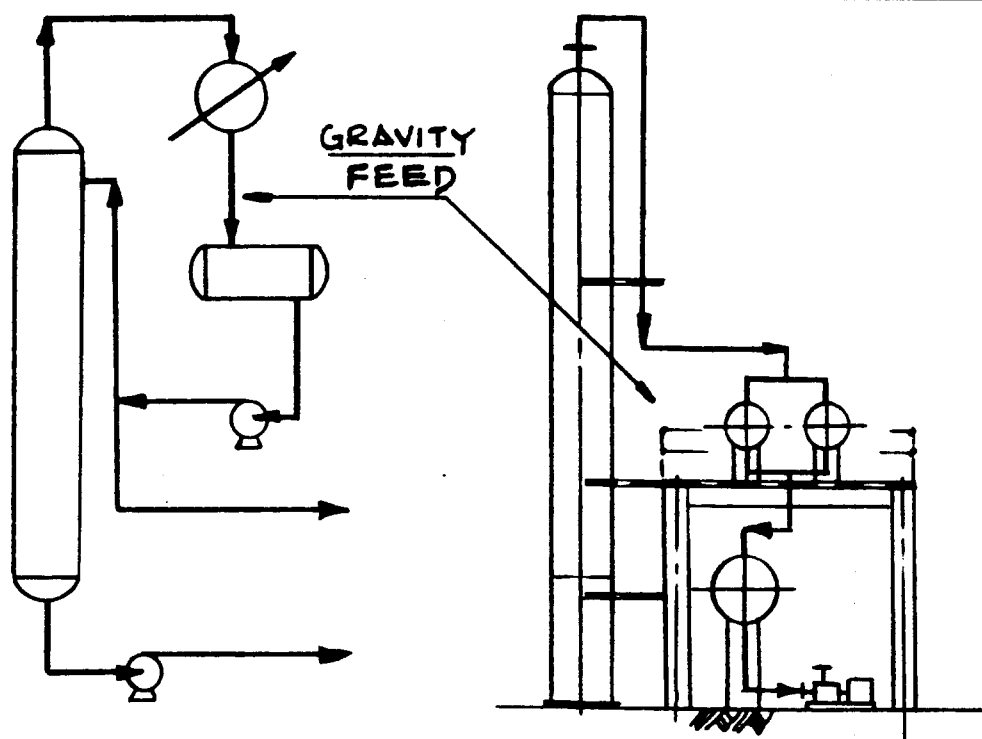


b. Subsystem Arrangement



c. Interconnection of Subsystems

EXHIBIT 3-11
Typical Gravity
Feed Arrangement



range of a subsystem, and the interconnection of a group of subsystems.

Process Requirements

Equipment often must be located in a specific position to support the plant's process operation (e.g., for pressure drop, line pocketing, and gravity feed). The plant layout designer must be familiar with the process because the process flow diagram rarely indicates this information. It is recommended that the designer discuss these requirements with the process engineer before proceeding with the plant arrangement. Exhibit 3-11 shows the effects of an arrangement with a gravity feed process requirement.

Common Operation

Equipment that requires continuous operator attention or shares common utility and maintenance facilities should be located in the same area. For example, compressors generally require 24-hour operator attention. Compressors with condensing steam turbine drives often share the same surface condenser and are located in a compressor house using a common fixed handling facility (e.g., an overhead traveling crane). Although this arrangement is often more expensive in terms of piping components, the use of common facilities (e.g., the surface condenser, building, and equipment-handling facilities) makes up the difference in

cost. Exhibit 3-12 shows a typical compressor area arrangement.

Real Estate Availability

Generally, most new process units are built within an existing facility in which a piece of land is dedicated to the new expansion. Older process units, which have undergone many expansions, often leave a less-than-desirable piece of real estate for the next new facility. This can be a problem for inline horizontal arrangements but is less so for vertical structure arrangements, which require less ground space. When an inline arrangement is constructed, it is recommended that parts of the unit be located in elevated structures with related equipment located adjacent to it if the process permits. For an already-elevated plant, adjustments can be made in the overall size of the structure and extra floors can be added. Care must be taken to adjust usual plant configurations to suit minimum space requirements so that the plant is not too difficult to maintain. Exhibit 3-13 shows an arrangement before and after it has been adjusted to suit minimum space requirements.

Equipment Sizes

Ideally, all the different types of equipment within the process unit would be the same size. This rarely occurs, however, and the plant layout designer often

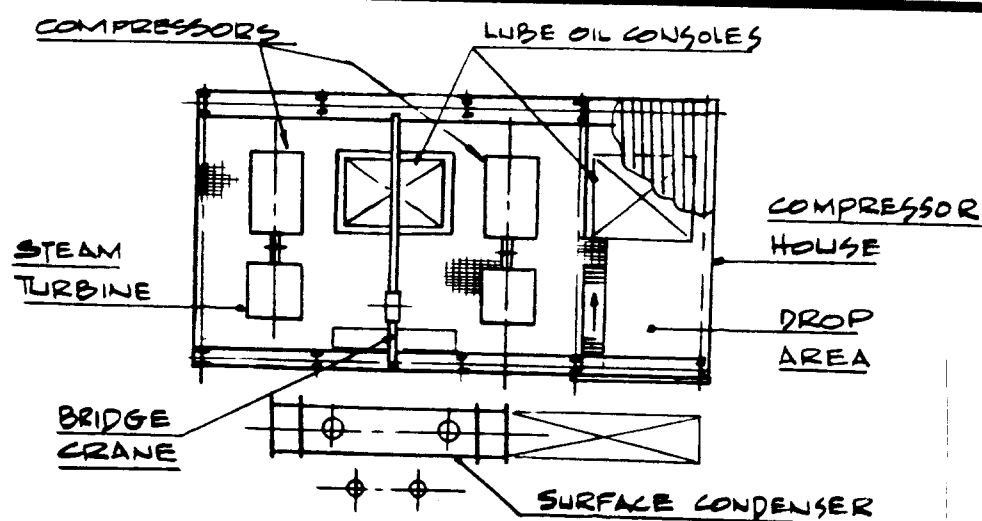
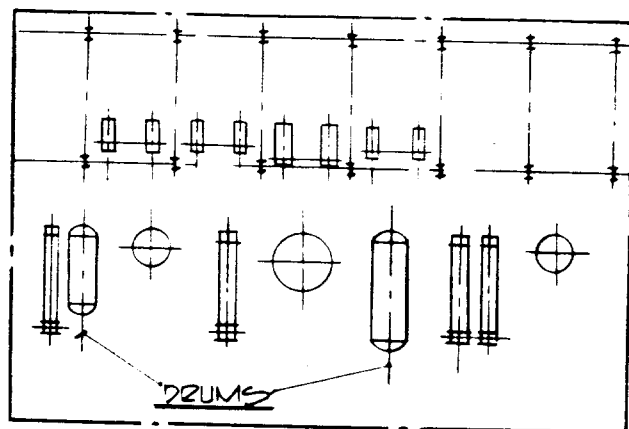
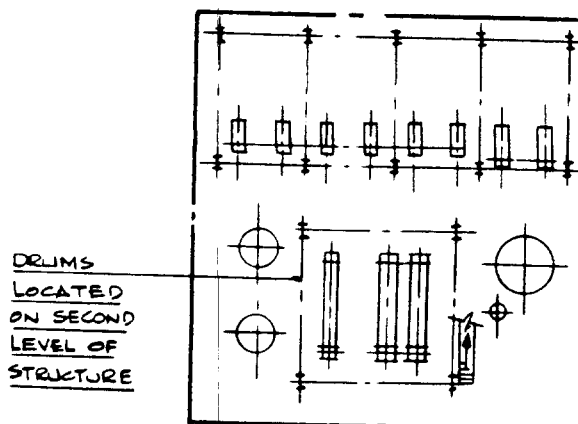


EXHIBIT 3-12
Typical Compressor Area
Arrangement

EXHIBIT 3-13 Floor Space Comparison

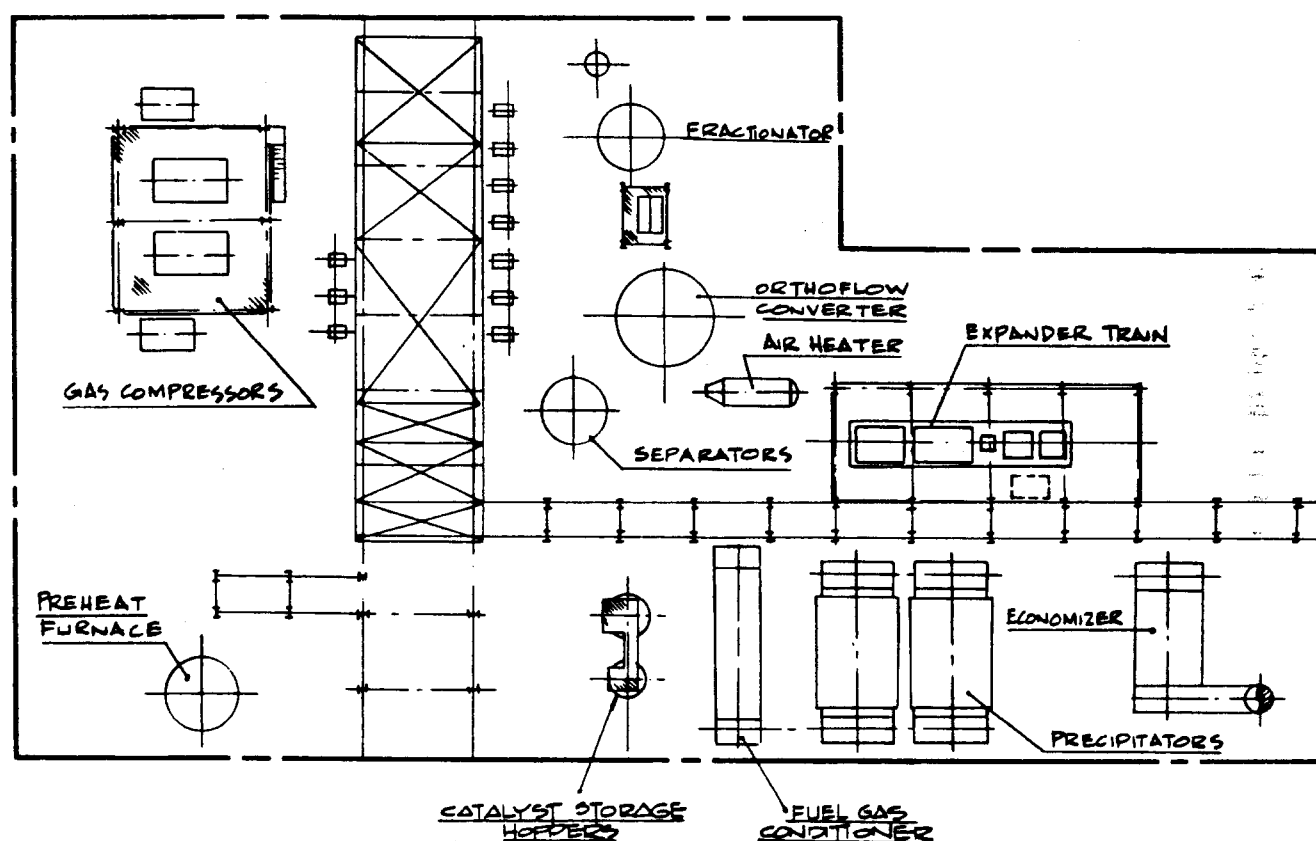


a. Before Minimum Space Adjustment



b. After Minimum Space Adjustment

EXHIBIT 3-14 Fluid Catalytic Cracking Unit Plot Plan



struggles to place a large, cumbersome piece of equipment into an area while retaining the aesthetics of the unit. Generally, most plants are dominated by conventional rectangular and circular equipment of a reasonable size. Some processes, however, require much larger and more awkwardly shaped items (e.g., an orthoflow converter and expander train in a fluid catalytic cracking unit, as displayed in Exhibit 3-14, a reformer furnace in an ammonia unit, or a waste heat recovery system in a large cogeneration plant). In these situations, the designer should place these items

first and plan the remainder of the unit around them.

Whether the planned plant is an inline arrangement or housed in a structure, the plant layout designer must make provisions for operator and maintenance access. The designer must review the items of equipment that are included in the process and plan for their operation and maintenance requirements. For example, towers must be located in a position to allow for the removal of internals, reactors require space for catalyst loading and unloading, shell and tube exchangers require space for bundle removal, and rotat-

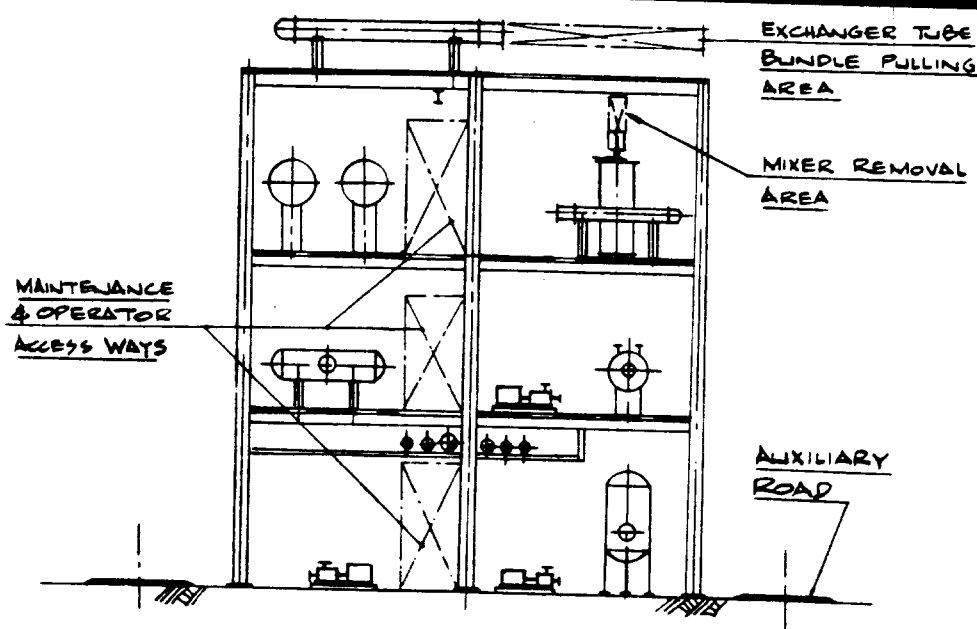


EXHIBIT 3-15
Typical Access
Requirements in a
Vertical Arrangement

ing equipment needs space for drive and casing removal.

All these aspects of the equipment design add to the floor space requirements of the plant. Equipment that requires servicing during regular operation or planned shutdown periods should be accessible from the auxiliary roads or internal access ways. From the project specification, the plant layout designer should determine operator access requirements and the devices to be used for servicing before proceeding with the plant arrangement. Exhibit 3-15 shows typical access requirements in a vertical arrangement, and Exhibit 3-16 displays an inline arrangement.

Underground Facilities

There are a variety of underground facilities that could affect the positioning of equipment. Depending on

soil conditions, the foundations for the equipment are either piled or spread footings. Spread footing foundations require more space than piled applications, and care should be taken to locate equipment so that enough space exists between equipment for the foundations of larger items. In certain cases, equipment can be supported on a common foundation. Depending on the project specification, instrument and electrical cabling can be located above or below grade. If located below grade, adequate space should be designated during the plot plan development stage. Underground piping is another factor that the designer must consider when locating equipment. Most process units are serviced by an underground oily water sewer, storm sewer, and fire water system and a chemical drainage system if required. In addition, the unit cooling system could be positioned below ground. All of these facilities require plot space, and it is recom-

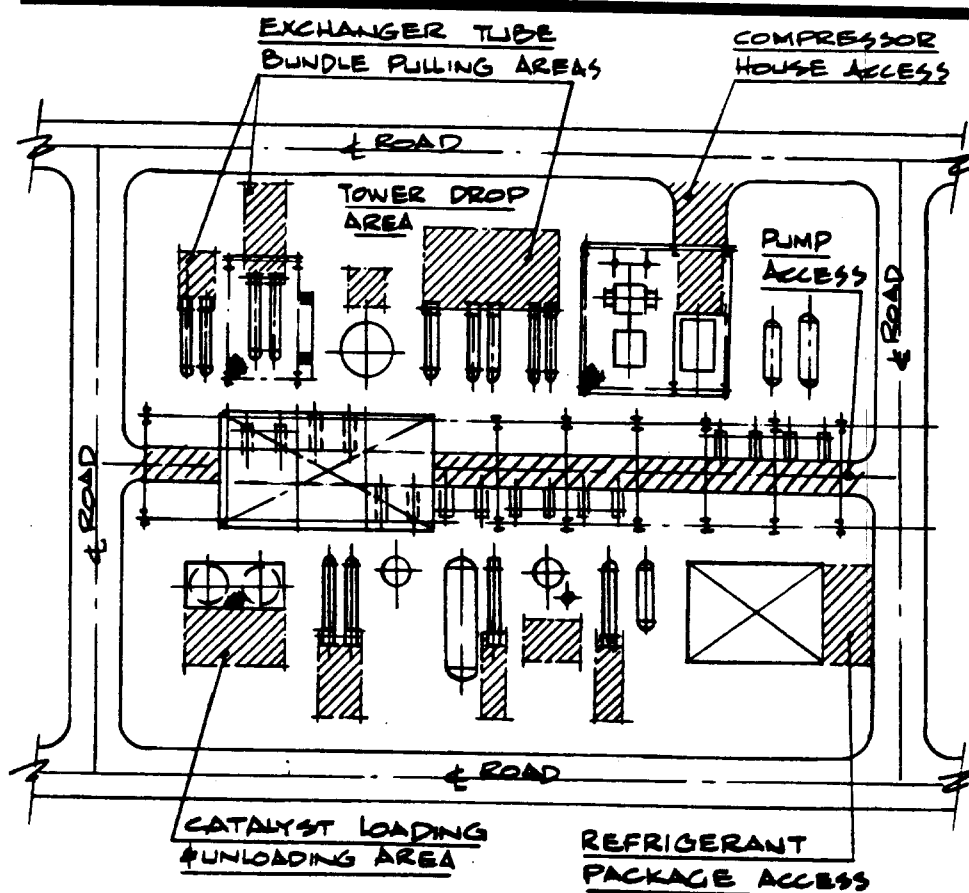


EXHIBIT 3-16
Typical Access
Requirements in an
Inline Arrangement

mended that the plant layout designer investigate what facilities are to be positioned below ground before proceeding with the equipment arrangement. Exhibit 3-17 shows a typical elevation through a unit below ground.

Climate Conditions

Weather conditions could influence the location of equipment. In a severely cold climate, equipment should be housed; this can be done by encasing

the whole unit, as depicted in Exhibit 3-18, or by individually housing groups of equipment (e.g., compressors or pumps), as illustrated in Exhibit 3-19. For individual housing, consideration must be given to locating equipment out of process sequence to minimize cost.

The wind can influence the location of such equipment as furnaces, compressors, control houses, cooling towers, and stacks. Furnaces or other fired equipment should be located so as not to allow flammable vapors to constantly drift. Smoke from stacks or vapors

EXHIBIT 3-17
Typical Underground
Elevations

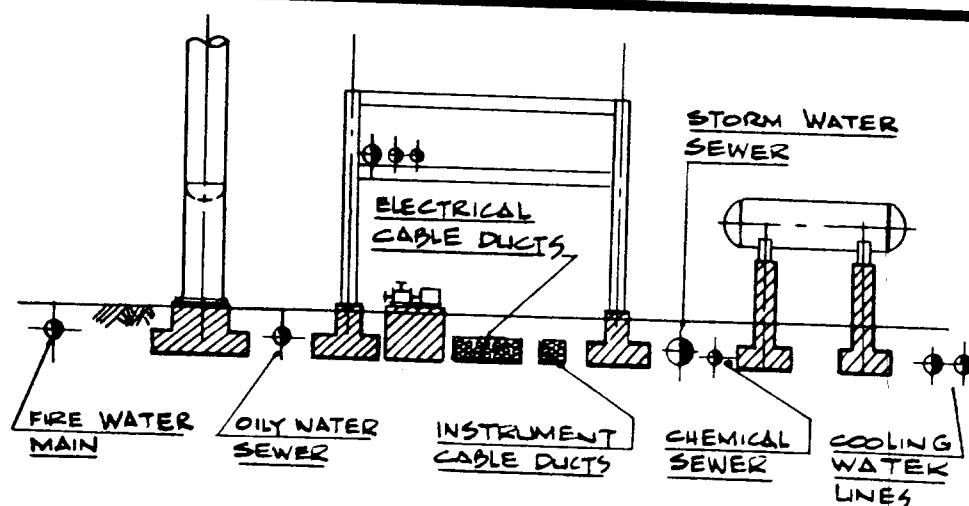
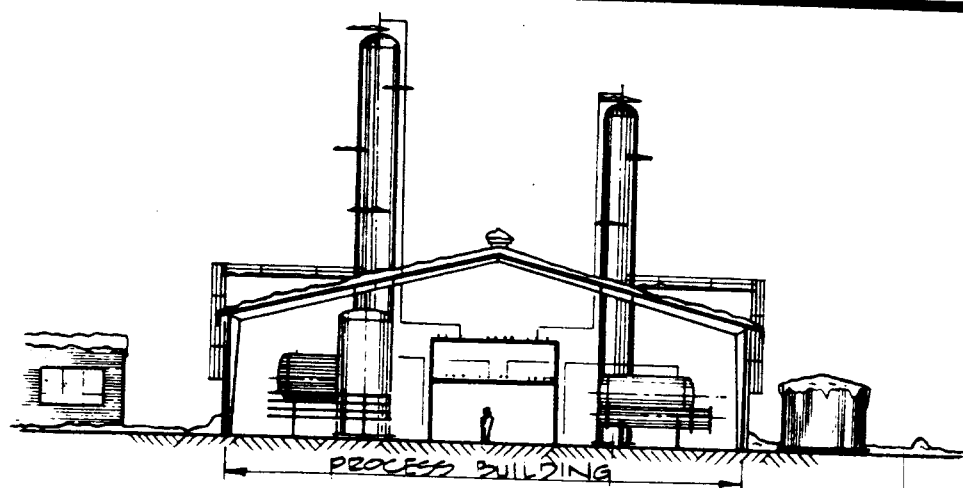


EXHIBIT 3-18
Total Unit Encasement



from cooling towers should not be in the direct path of main operating areas (e.g., compressor houses, control rooms, and structures).

PIPE RACKS

Generally, most inline plant arrangements are furnished with a central pipe rack system that acts as the main artery of the unit supporting process interconnection, feeds, product and utility piping, instrument and electrical cables, and, sometimes, air coolers and drums. Usually, the pipe rack is made of structural steel, either single level or multilevel, to suit the width and capacity of the unit it is serving. The pipe rack bays are usually spaced at 20-ft (6,000-mm) centers. The width is determined by such factors as the quantity of piping and cabling to be carried on the main run of the pipe rack (with an allowance for future expansion), the equipment and access way located beneath the pipe rack, or the equipment (if any) supported above the pipe rack. The layout that results in the most economical design should be chosen.

At the estimate stage, when most plot plans are developed, the pipe rack width is specified on the basis of limited information: process flow diagrams usually are not available to accurately work out the exact requirements. Using the process flow diagram, the designer can prepare a line routing diagram on a print of the preliminary plot plan, similar to the instructions given in Chapter 11. This establishes the main process lines supported in the pipe rack for equipment interconnection, feed, and production. An allowance of 20% of the main lines should be added to the total for unknowns. The pipe rack width can be adequately sized on the basis of approximate line sizing, utility piping, and insulation requirements by the process system engineer; cable tray require-

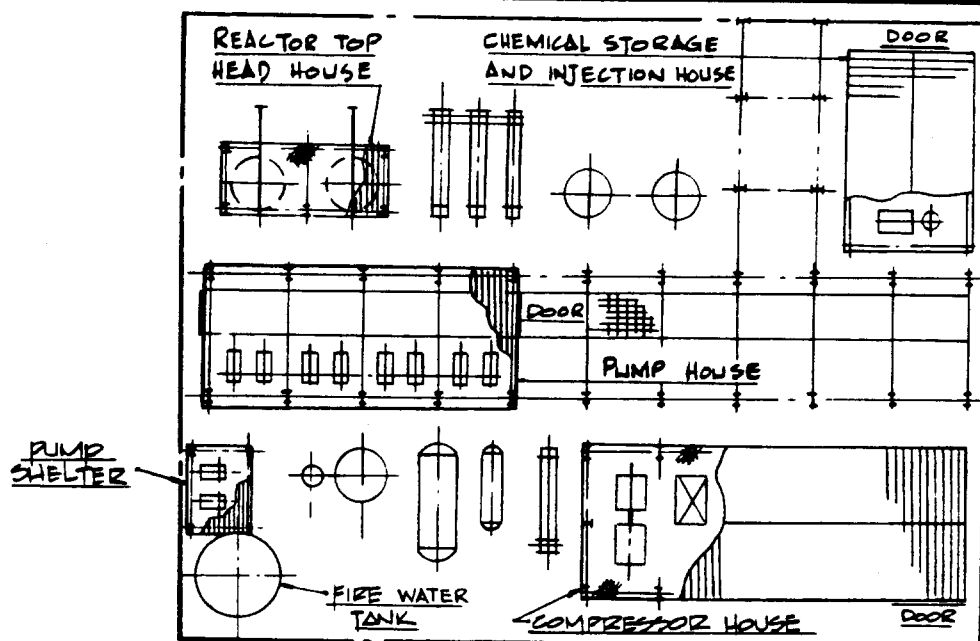


EXHIBIT 3-19
Individual Equipment
Houses

ments by the electrical and instrument engineers; and a 20% future piping allowance. Most typical units require a two-level pipe rack with a width of 20 ft (6,000 mm) to 40 ft (12,000 mm). If the total requirements exceed 80 ft (24,000 mm), an extra level should be introduced.

After establishing the pipe rack width to suit the piping and cable requirements, the designer must check the design for the accommodation of air cooler support, if specified, and pumps and access ways beneath the pipe rack. The air cooler is specified by tube bundle length and is established at the estimate stage of the project. It can overhang the rack width equally on either side. An air cooler with a 40-ft (12,000-mm) tube bundle length can be adequately supported on a pipe rack that is 35 ft (10,500 mm) wide. Pumps may be located beneath pipe racks on either side of an access way that is 10 ft (3,000 mm) wide.

The bottom support elevation of the main pipe rack is dictated by the maintenance and piping clearance beneath the pipe rack, with additional levels spaced at 6-ft (1,800-mm) intervals. On projects with very large diameter piping, increasing this dimension to suit clearance requirements should be considered when pipe direction is changed. External clearances (e.g., over main roads or intersections with off-site pipe racks) need close attention. Exhibit 3-20 shows a typical pipe rack elevation.

Pipe rack configurations are dictated by the equipment layout, site conditions, client requirements, and plant economy. The ideal situation would be a straight-through arrangement, with process feeds and utilities entering one end of the unit and products and disposals exiting the other end. The final layout of the pipe rack to meet the specific requirements of the project could result in a variety of configurations (e.g.,

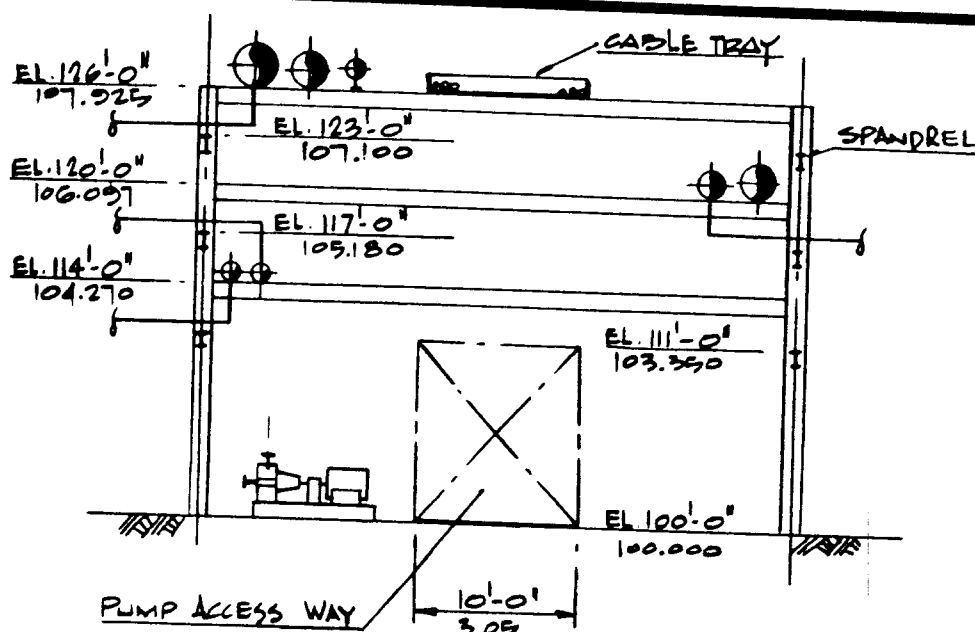


EXHIBIT 3-20
Typical Pipe Rack
Elevation

a T, L, or U shape), as shown in Exhibit 3-21. Changes of direction in pipe racks must be accommodated by changes in elevation and are usually equally spaced about the midpoint of the main pipe rack elevations to suit required clearances.

Pipe racks within vertically structured or housed facilities cannot be defined as easily as for inline arrangements, because the equipment is usually located on several levels. The vertical units are usually fed by conventional pipe racks at established elevations entering the structure at a designated area. Once inside the structure, piping should be routed in an orderly manner according to economic, constructibility, and support requirements. Exhibit 3-22 displays a typical process structure.

ROADS, ACCESS WAYS, AND PAVING

For maintenance and safety, the principal access to and from most process units is by auxiliary roads. Ideally, the unit battery limits should be positioned 50 ft (15,000 mm) from the centerline of the main plant roads. This allows adequate space for ditch drainage and firefighting facilities and avoids obstructing roads when such items as heat exchanger tube bundles are removed. Access ways or spur roads should be provided within the unit for access to items that require servicing or for components that require removal for off-site repair. Clearance according to project specification should be provided over roads and ac-

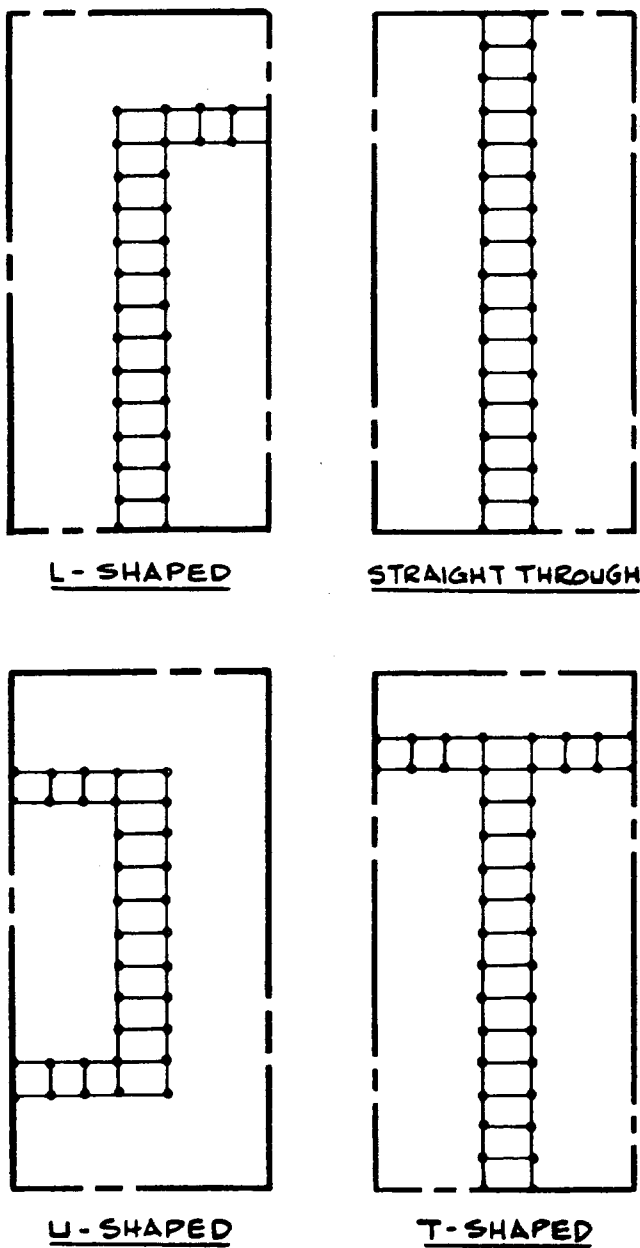
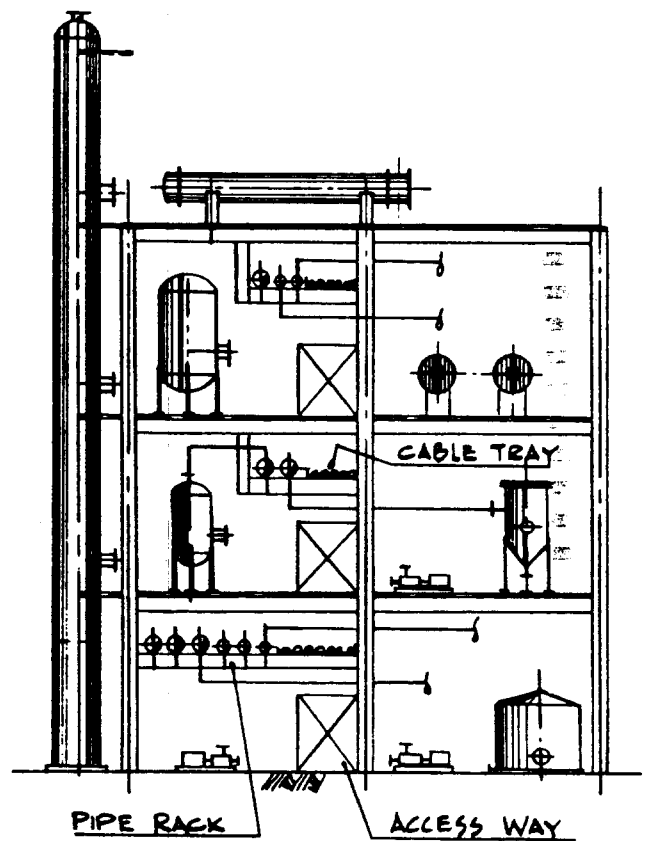
cess ways for mobile equipment access. Most clients require that the equipment areas, the area beneath the pipe rack, and the areas around buildings be paved with concrete for housekeeping. Exhibit 3-23 illustrates a typical process unit road and paving arrangement.

BUILDINGS

Apart from buildings that house equipment (e.g., compressor houses), it is often necessary to position control houses, substations, analyzer houses, and operator shelters within the process unit battery limits. Administration buildings and warehouses are generally located away from process unit areas. Control houses and substations are usually located at the edge of the unit adjacent to a plant road, 50 ft (15,000 mm) from the operating equipment. As seen in Exhibit 3-24, analyzer houses and operator shelters should be located next to the equipment that they service.

EQUIPMENT SPACING

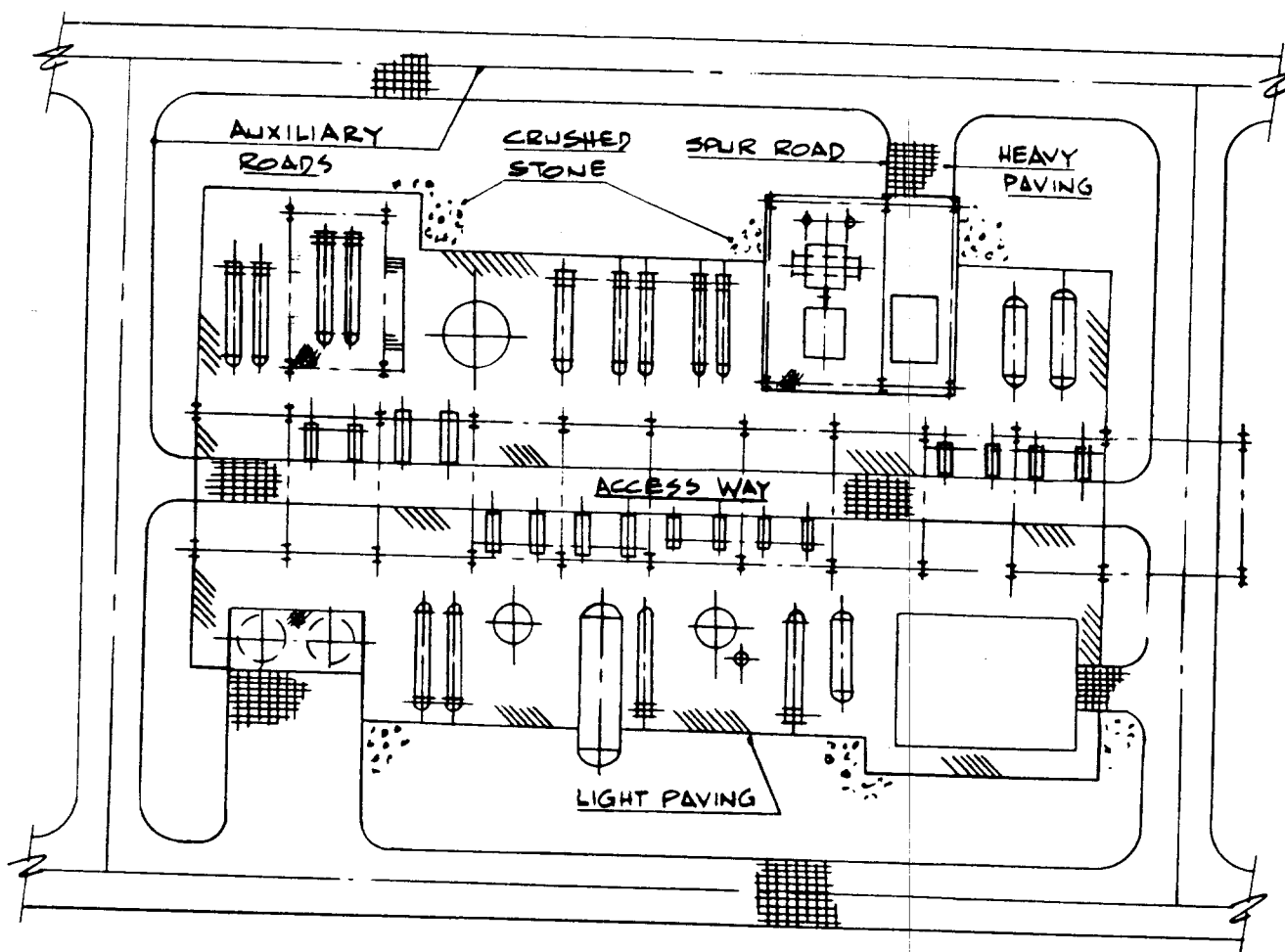
The previous sections have outlined the information required to locate equipment and the general content of the typical process unit. At this stage, the plant layout designer should prepare a sketch of the unit configuration and a line run to confirm that the equipment is positioned for the most favorable piping interconnection. The line run can be prepared by dia-

EXHIBIT 3-21 Pipe Rack Configurations**EXHIBIT 3-22** Typical Pipe Rack in a Vertical Arrangement

graming the principal process piping, as shown on the process flow diagram, onto a print of the plot plan arrangement sketch.

The final step in the plot plan arrangement is to space equipment and supporting facilities for operator and maintenance access, safety, piping flexibility and support, and platforming requirements. At this stage, the layout designer must rely on experience because the final information is not available for calculating

EXHIBIT 3-23 Typical Process Unit Road and Paving Arrangement



exact distances between equipment or solving unforeseen mechanical problems. The spacing of the components within the unit is an important exercise—it finalizes real estate requirements for the facility and assists in the pricing of the plant. It is also used as the basis for the plant layout design.

Before spacing the equipment, the layout designer

should review the sketched arrangement of the unit to confirm the exact requirements needed for safe and orderly operation of the plant. Consultation with process engineers is recommended to obtain general line sizing requirements for control spacing allowances. At this stage, the designer should be completely familiar with the project specification requirements for safety

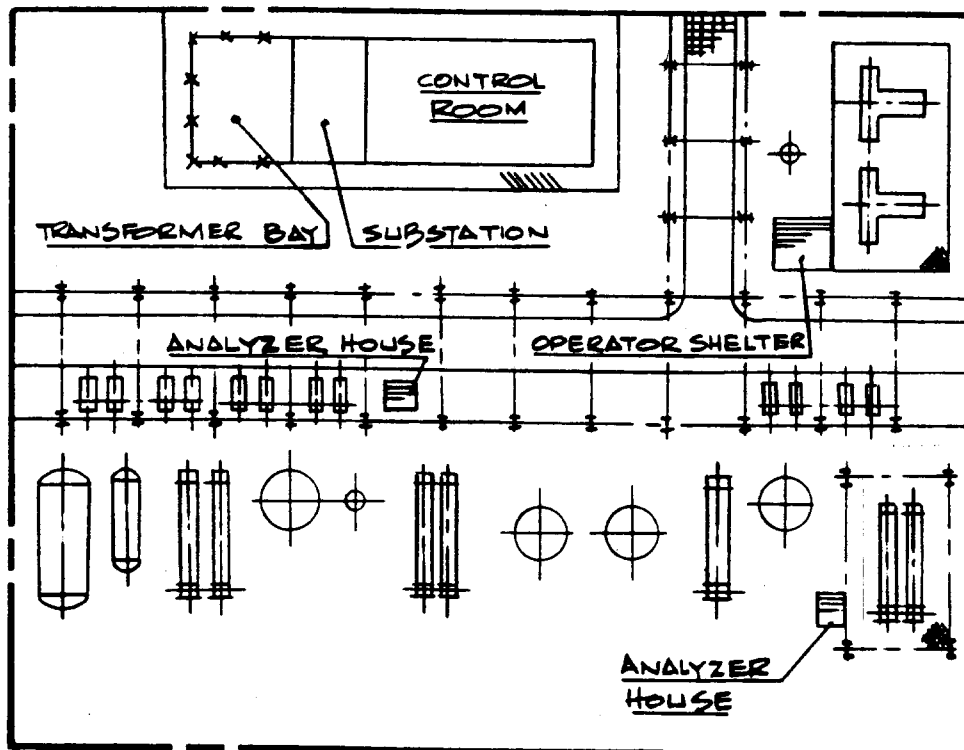


EXHIBIT 3-24
Building Locations

and for operator and maintenance access.

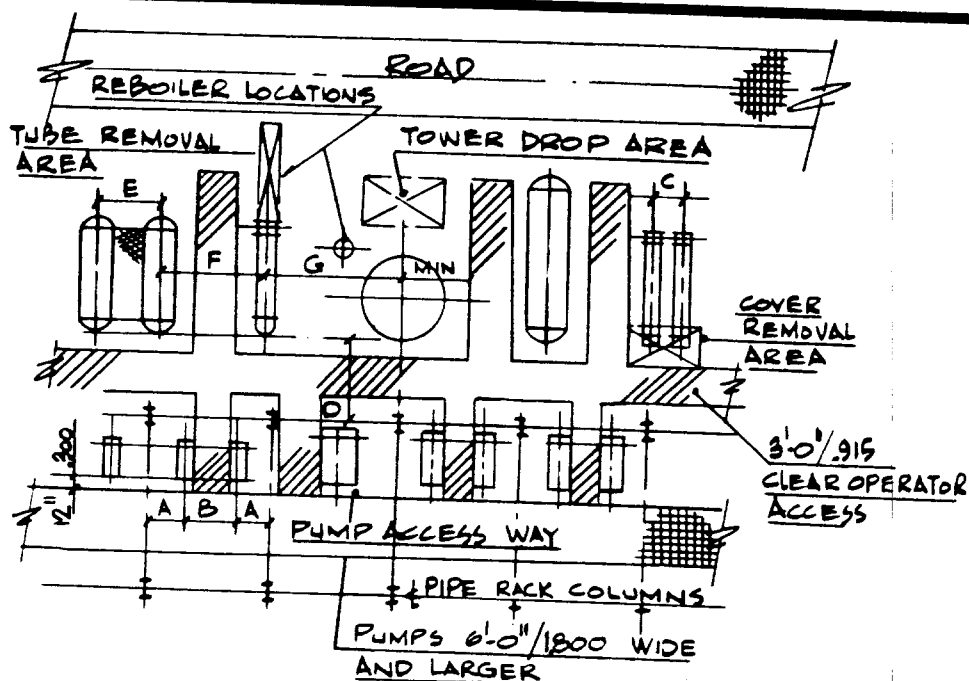
In a typical tower area, depicted in Exhibit 3-25, the tower and such related equipment as drums and heat exchangers are located adjacent to the main pipe rack, with maintenance access from the auxiliary road. The associated pumps are located beneath or adjacent to the pipe rack and are serviced by a central access way. Shell and tube heat exchangers can be located as single items or in pairs. If the process permits, they can be supported vertically or located in structures to meet gravity feed requirements. Vertical reboilers should be supported from their related towers. Multiple shell heat exchangers operating in series or in parallel may be stacked three high if size permits. Pumps beneath the pipe rack may, if size permits, be

paired in each bay.

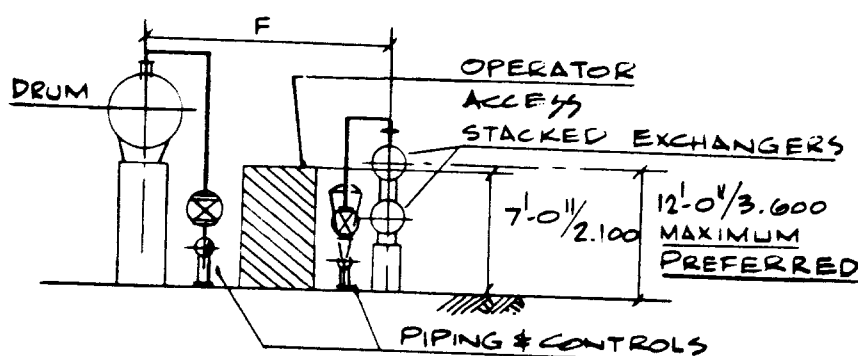
Compressors and their related equipment are usually located in one area for common operation and servicing adjacent to the main pipe rack and the auxiliary road. The suction drum for the machine should be positioned for flexibility in the piping and to accommodate orifice run requirements. If the compressor is driven by a condensing turbine, a surface condenser and condensate pumps are required. If servicing one machine, the condenser may be located beneath the turbine. If it services two or more, the condenser must be located adjacent to the machines it services. In both cases, space must be provided for condenser tube bundle removal.

The condensate pumps are usually vertical pumps

EXHIBIT 3-25
Typical Tower Area
Spacing



A =	5'-0" 1.500
B =	10'-0" 3.000
C =	1/2 DIAMETER EXCHANGER FLANGES + 18" .450
D =	8'-0" 2.400 TO 10'-0" 3.000
E =	1/2 DRUM DIAMETERS + 4'-0" 1.200
F =	1/2 DRUM DIAMETER + 1/2 EXCHANGER DIAMETER + 3'-0" .915 OPERATOR ACCESS + 3'-0" .915 FOR PIPING AND CONTROLS
G =	MINIMUM FOR FLEXIBILITY



and should be located as close to the condenser as possible to suit flexibility in the piping and vertical removal space. The lube oil console should be located as close to the compressor as possible with operator access on all sides of the skid, with space to remove the cooler tube bundle, filters, and pumps. Interstage coolers, if needed, should be located adjacent to the

compressor and suction drum. Adequate space should be provided around the compressor and turbine for the installation of a platform and staircase. If the facility is housed, a drop area must be provided. Exhibit 3-26 illustrates a typical compressor area arrangement. Air coolers, shown in Exhibit 3-27, are generally supported from the central pipe rack adjacent to their

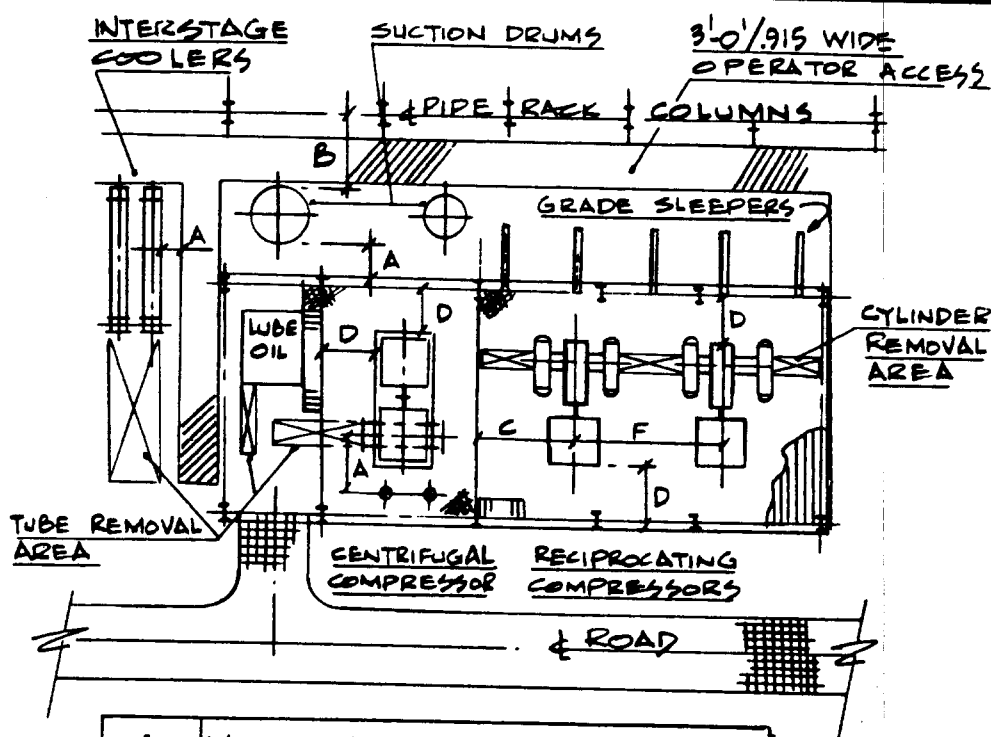


EXHIBIT 3-26
Typical Compressor Area
Spacing

A =	MINIMUM
B =	8'-0" / 2400
C =	CYLINDER REMOVAL + 12" / 300
D =	6'-0" / 1800 MINIMUM
F =	2 x C + 18" / 450

related equipment and are serviced by platforms at the header boxes and beneath the air coolers for motor maintenance. Care should be taken to position air coolers to allow flexibility for interconnecting piping. A poorly positioned overhead condenser could result in additional large overall diameter piping and expensive supports. Unless furnished with fixed fire water sprays, pumps containing hydrocarbons and operating higher than autoignition conditions should not be

located directly beneath air coolers. Space should be available on the plot plan for maintenance access by mobile cranes for removal of air cooler tube bundles.

Furnaces should be located at a safe distance and upwind from unrelated equipment containing hydrocarbons. Steam drums or deaerators can be located as required for operation and maintenance. Reactors can be located closer to furnaces than other equipment containing hydrocarbons, as long as adequate space is

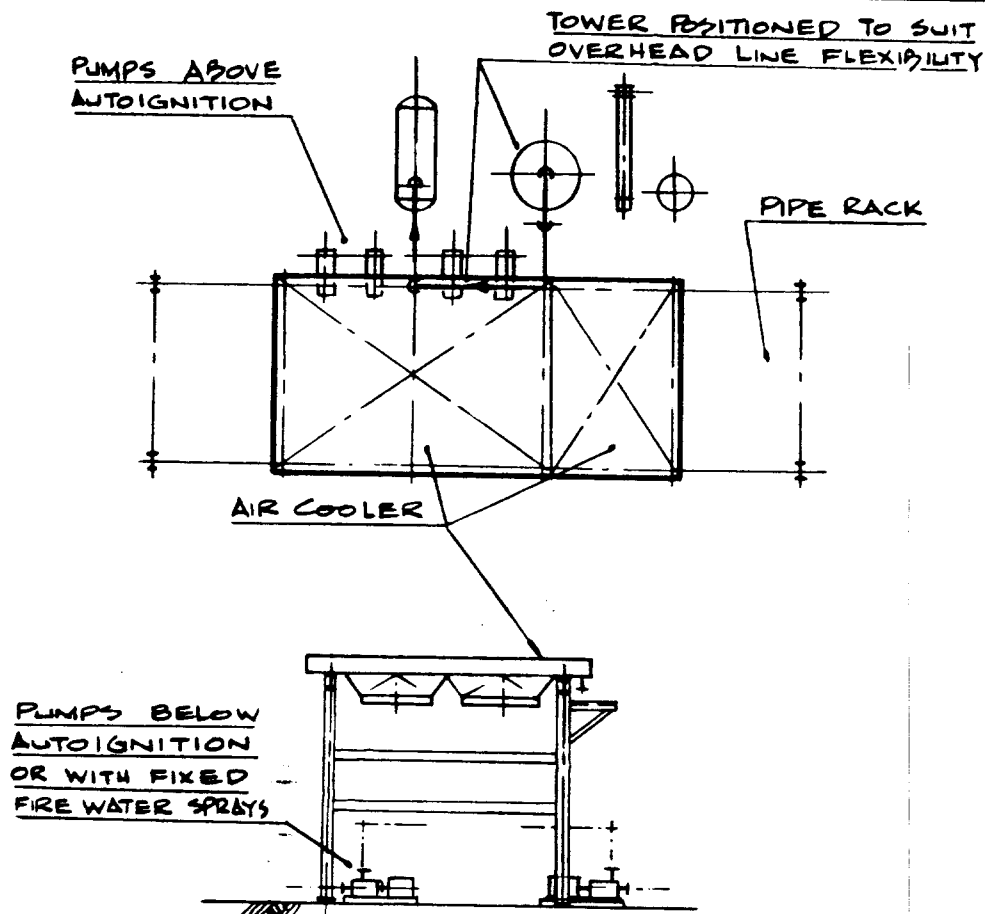


EXHIBIT 3-27
Typical Air Cooler
Spacing

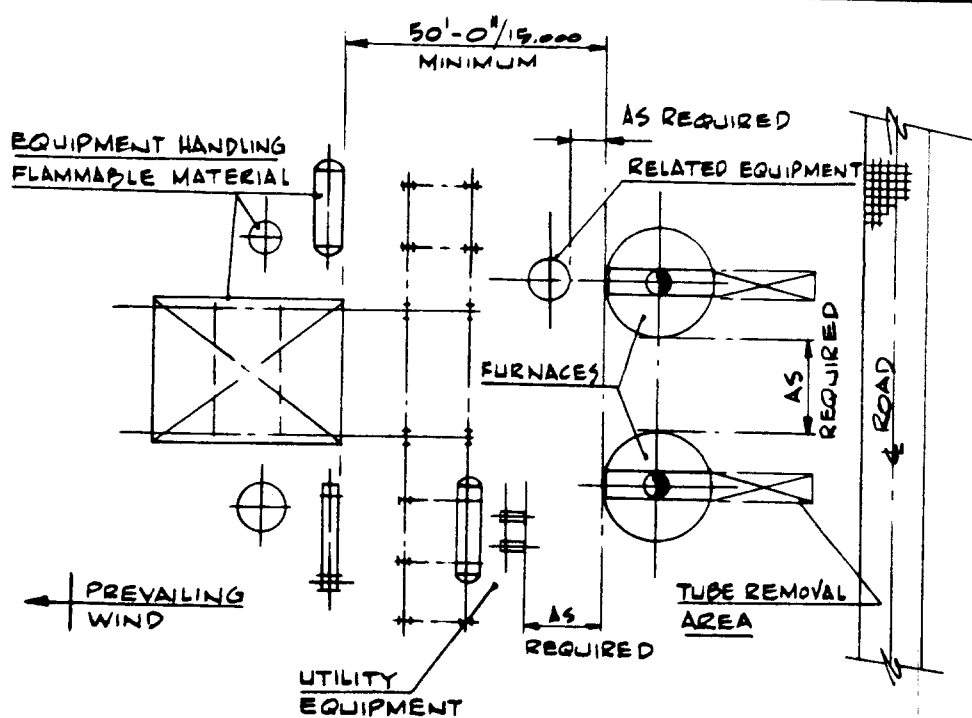
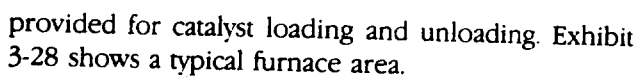


EXHIBIT 3-28
Typical Furnace Area
Spacing



SAMPLE PLOT PLAN ARRANGEMENT

The following illustrated examples show the various steps in arranging a naphtha hydrotreater unit and identify the process subsystems within the process flow diagram (Exhibit 3-29), the initial arrangement

sketch of the unit (Exhibit 3-30), the line run check (Exhibit 3-31), and the final plot plan arrangement (Exhibit 3-32).

This chapter has highlighted some of the principal features involved in the arrangement of process equipment with regard to operation, maintenance, constructibility, safety, and economics. Subsequent chapters deal with the needs of each equipment item in more detail, thereby offering greater insight to proper equipment location on a plot plan.

EXHIBIT 3-30 Initial Arrangement Sketch

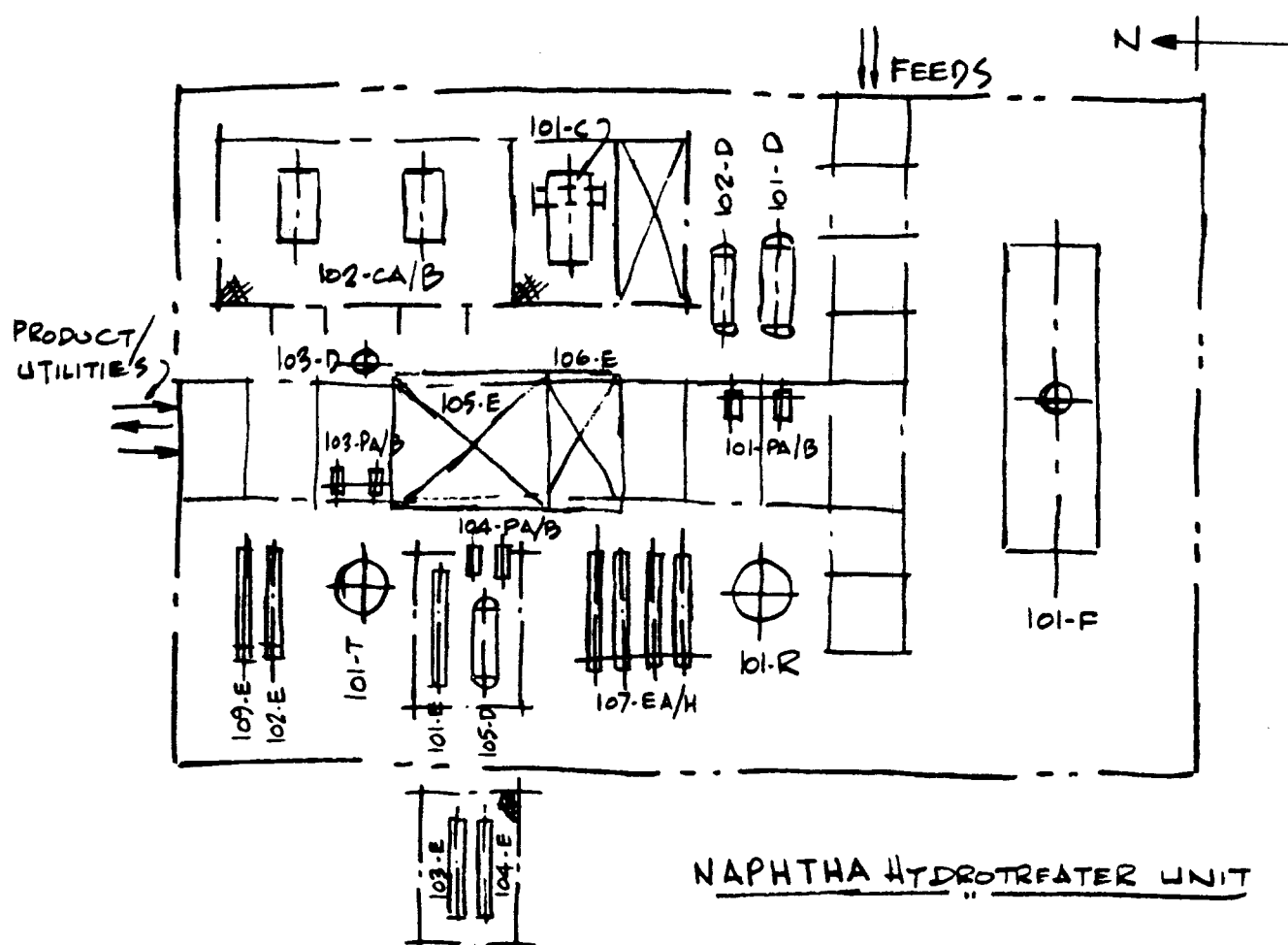


EXHIBIT 3-31 Line Run Check

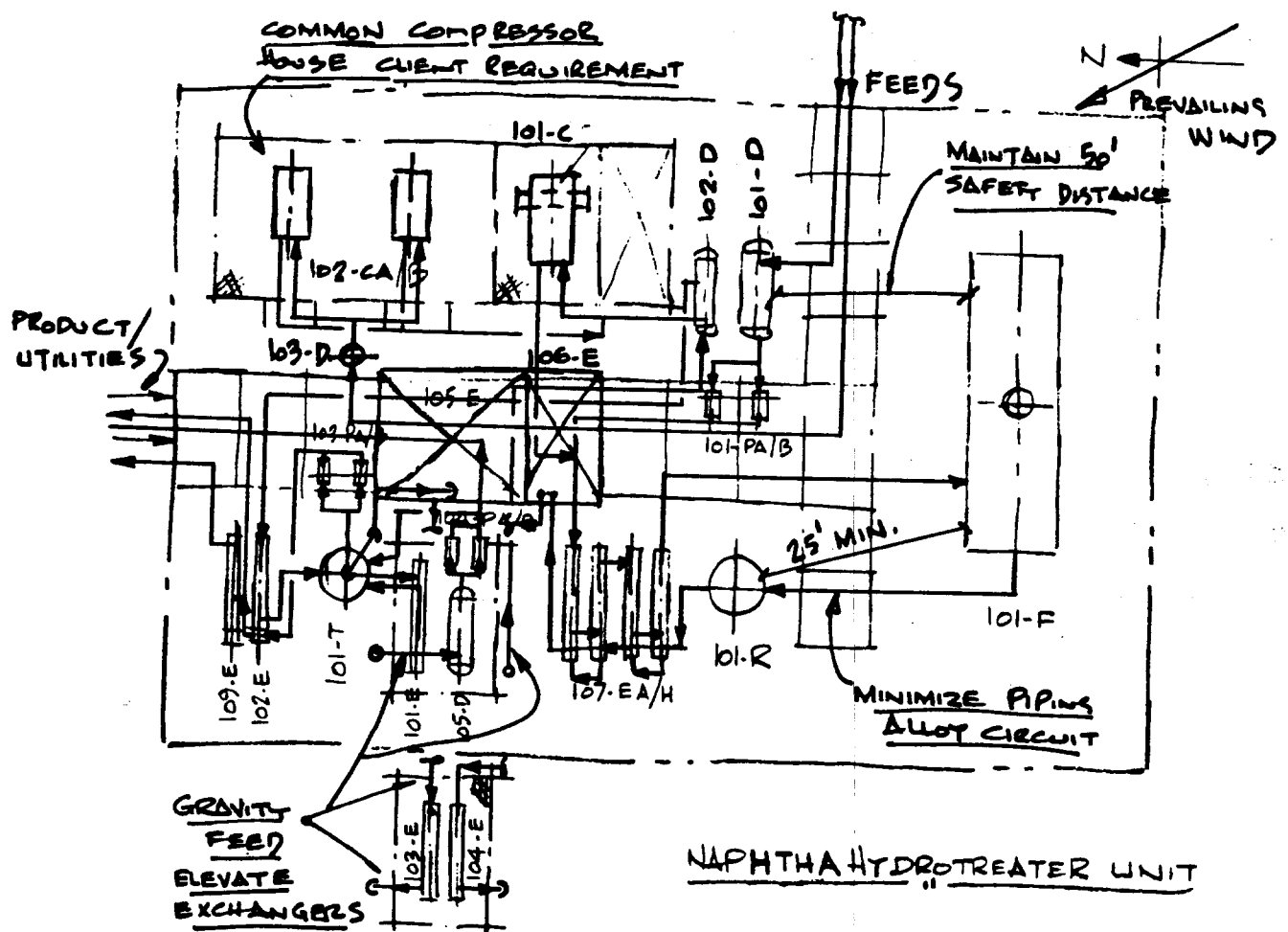
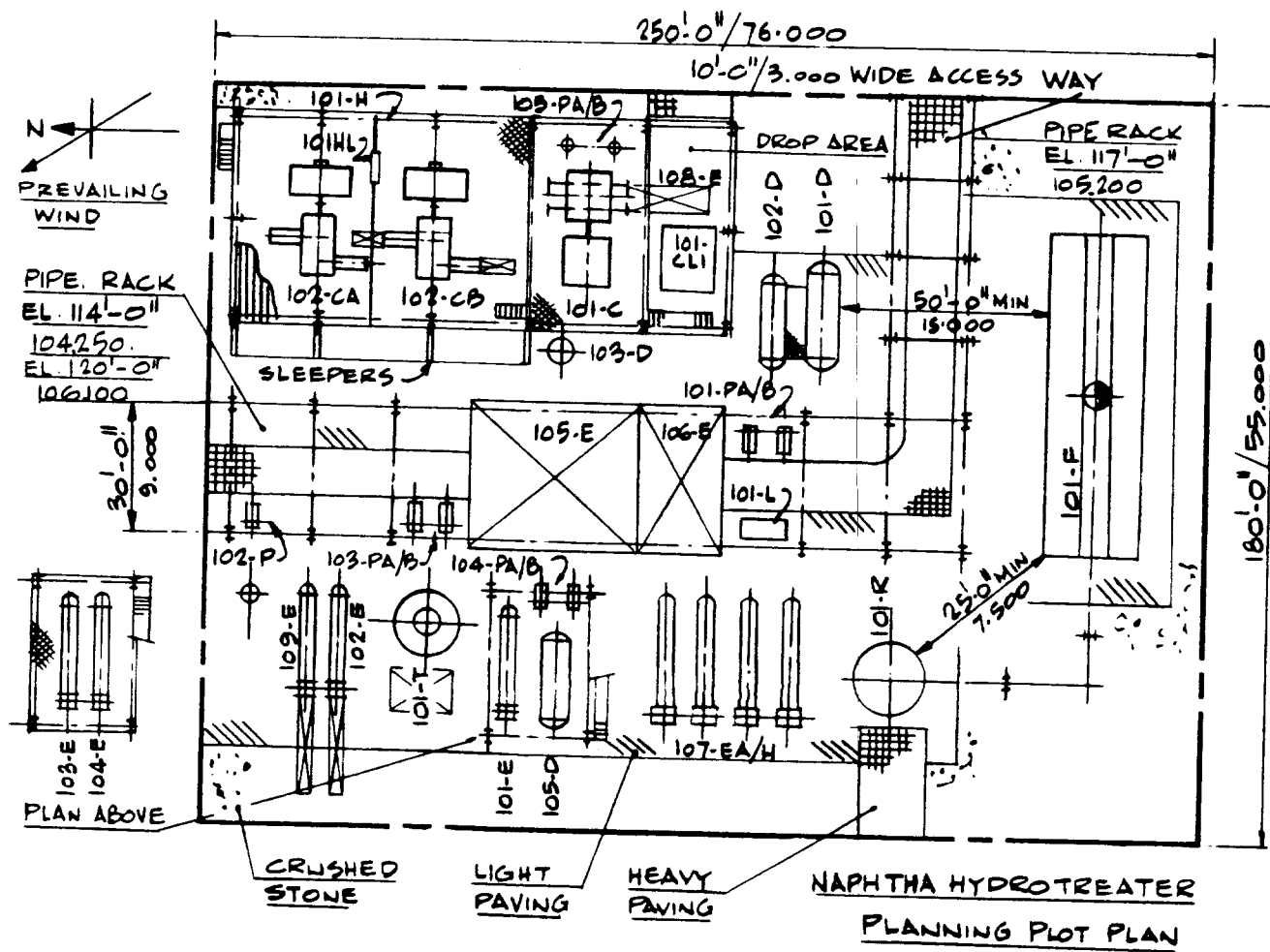


EXHIBIT 3-32 Final Plot Plan Arrangement



Compressors

Compressor machines are used to increase the pressure of a gas by mechanically reducing its volume within its case. Air is most frequently compressed, but natural gas, oxygen, and nitrogen are also compressed. Positive-displacement, centrifugal, and axial compressors are the three most common types used in process facilities and pipeline stations. They can handle large volumes of gas in relatively small equipment and may have a variety of drives (e.g., electric motors and steam or gas turbines).

This chapter focuses on the two most common types of compressors—centrifugal and positive displacement, also known as reciprocating. Centrifugal machines can be single stage or multistage. High-speed impellers increase the kinetic energy of the gas, converting this energy into higher pressures in a divergent outlet passage called a diffuser. Large volumes of gas are compressed to moderate pressures in centrifugal machines. Positive-displacement, or reciprocating, compressors can also be single stage or multistage. They are usually of the reciprocating piston-type and are the only compressors that can compress gas to extremely high pressures. Centrifugal and reciprocating

compressors are available in many sizes and physical configurations. These machines, which can be used with a variety of auxiliary equipment, are usually driven by steam or gas turbines or by electric motors.

Exhibit 4-1 shows a surface condenser mounted directly below the turbine. This arrangement is used when the condenser is designed to service only one steam turbine. The arrangement shown in Exhibit 4-2 is generally used when several turbines are exhausting into one condenser. Exhibit 4-3 shows the various compressor systems and their reciprocals.

AUXILIARY EQUIPMENT

Centrifugal and reciprocating compressors and their drives require a variety of auxiliary equipment to support their operation. The equipment for these compressors is described in the following sections.

Lube oil consoles Compressor bearings receive lubricating oil from the lube oil console (Exhibit 4-4). These consoles may either stand alone or be mounted

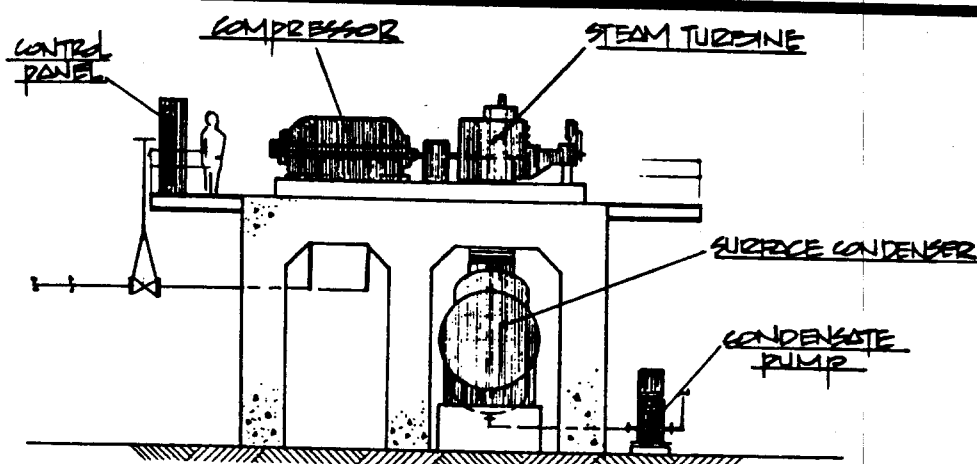


EXHIBIT 4-1
Elevated Centrifugal
Compressor with a Single
Condensing Steam
Turbine Drive

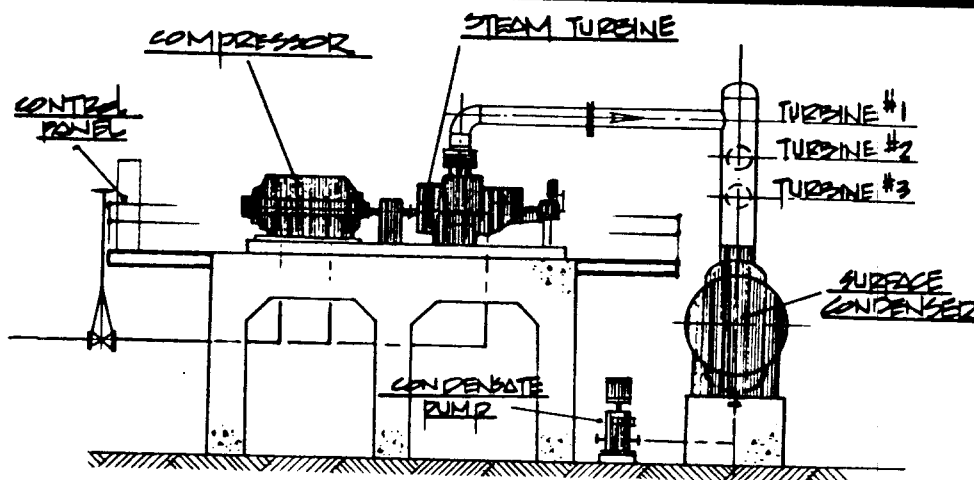


EXHIBIT 4-2
Elevated Centrifugal
Compressor with
Multiple Condensing
Steam Turbine Drives

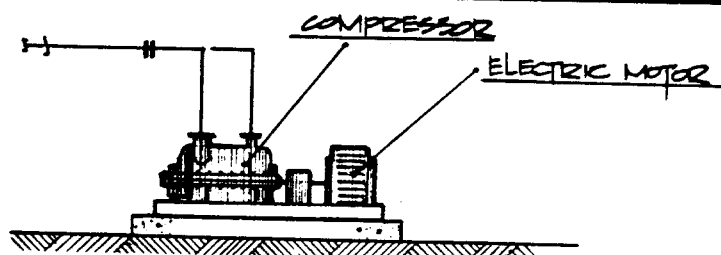
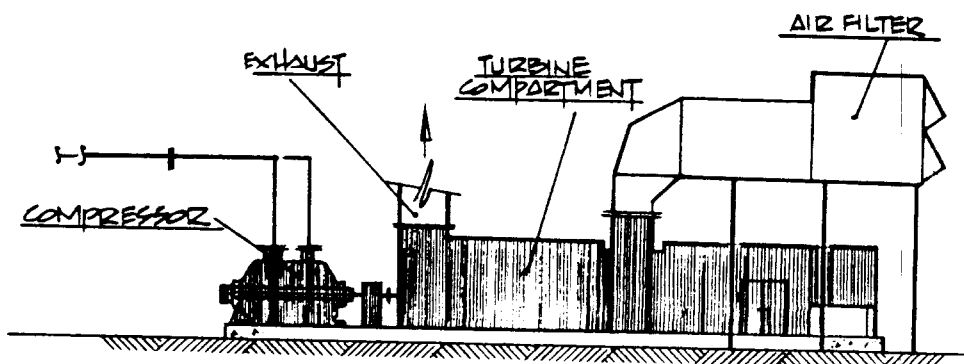


EXHIBIT 4-3
Types of Compressor
Systems

**a. Grade-Mounted Centrifugal Compressor
with Electric Motor Drive**



**b. Grade-Mounted Centrifugal Compressor
with Gas Turbine Drive**

directly onto the compressor frame.

Seal oil consoles The hydraulic seals, located at the outer ends of the compressor shaft, receive oil from the seal oil console (Exhibit 4-5). The seal oil equipment may be configured as a console or may be designed as individual pieces of equipment.

Surface condensers Surface condensers (Exhibit 4-6) reduce gas or vapor to a liquid by removing heat. Once sufficient heat is eliminated, liquefaction occurs.

Condensate pump The condensate pump (Exhibit 4-7), which is usually vertical, removes the condensate from the hot well in the surface condenser. Condensate forms during liquefaction in the condenser and is collected in the hot well.

Air blowers Usually motor driven, these centrifugal fan machines (Exhibit 4-8) deliver fresh air to cool the internally housed electric motors. Although this air is delivered to the motor through ducts, its exhaust may be sent directly into the compressor house or to the

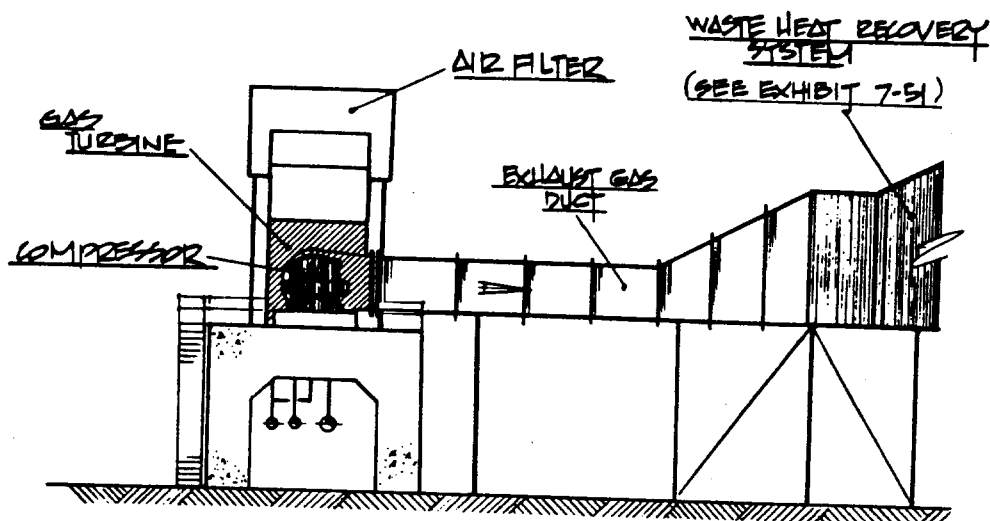
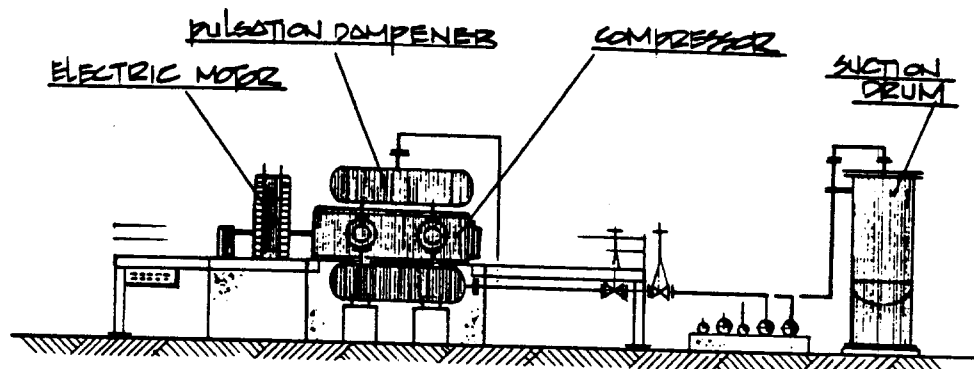
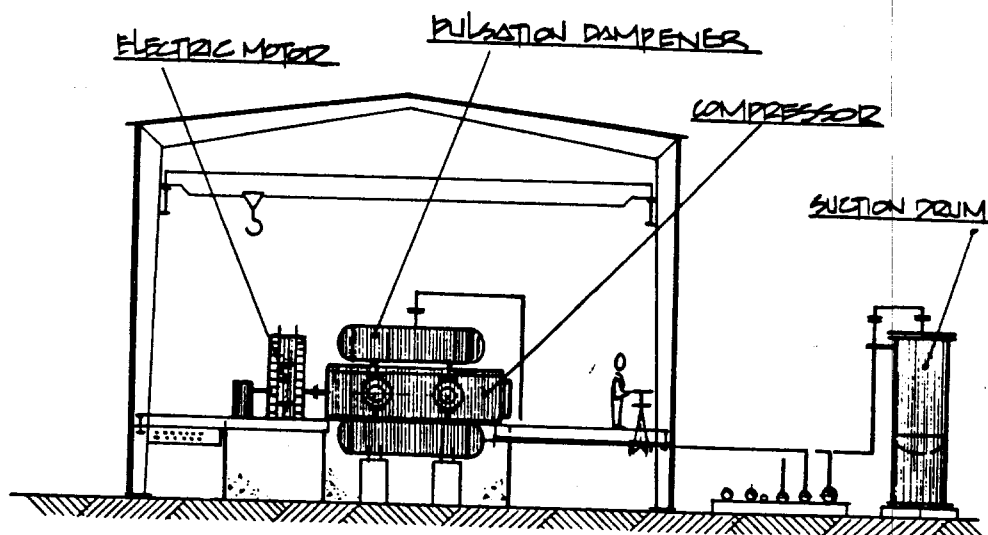


EXHIBIT 4-3
Types of Compressor
Systems (Cont)

**c. Elevated Centrifugal Compressor with Gas Turbine Drive
and Waste Heat Recovery System**



**d. Reciprocating Compressor with Electric Motor Drive:
Outdoor Installation**



**e. Reciprocating Compressor with Electric Motor Drive:
Indoor Installation**

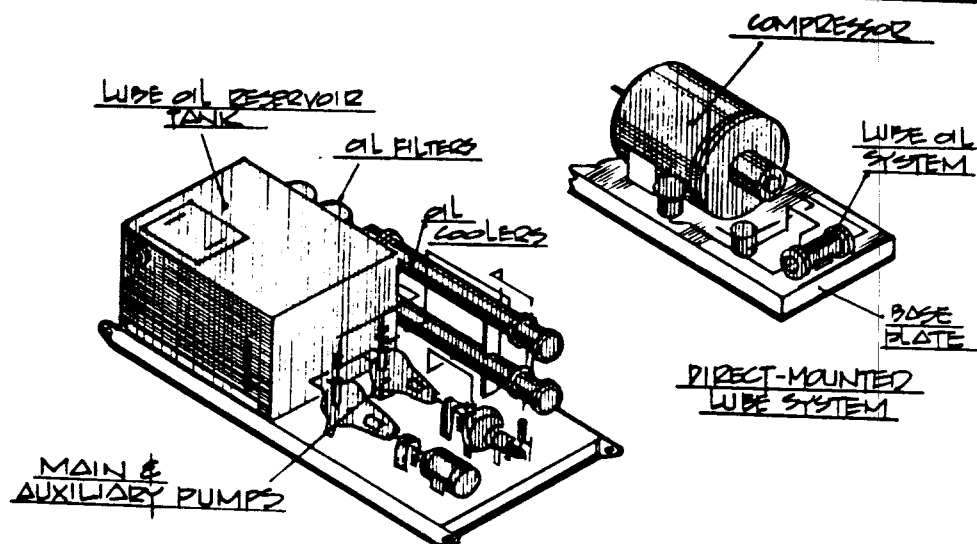


EXHIBIT 4-4
Lube Oil Console

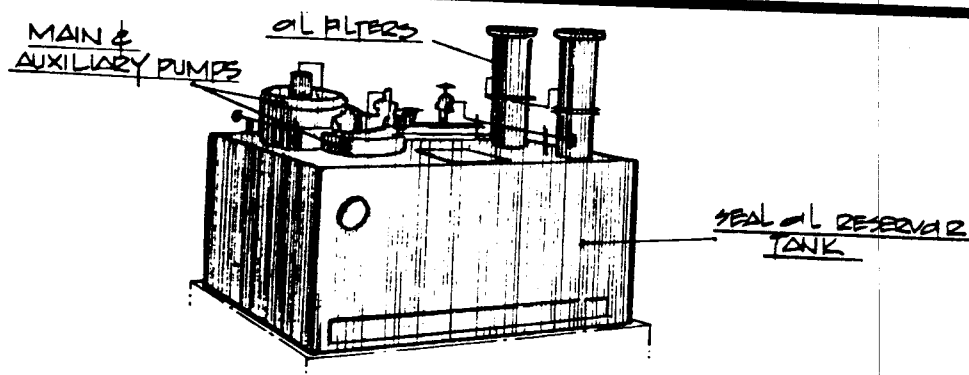


EXHIBIT 4-5
Seal Oil Console

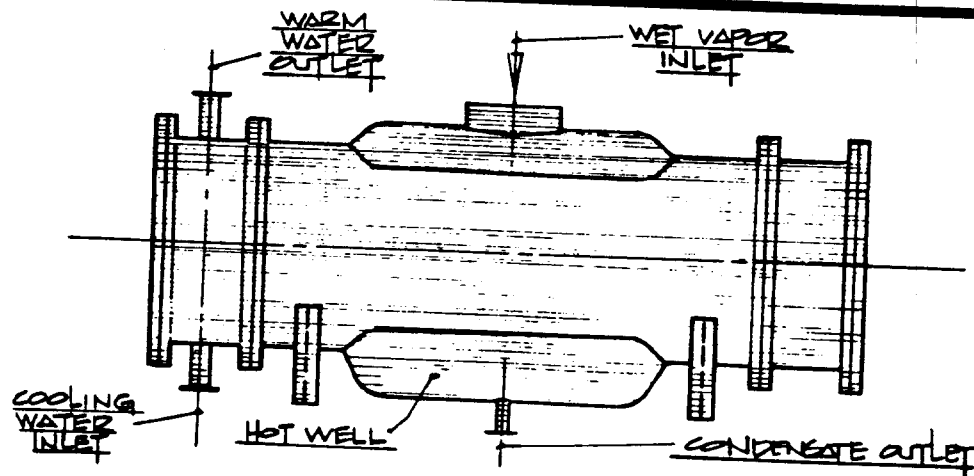


EXHIBIT 4-6
Surface Condenser

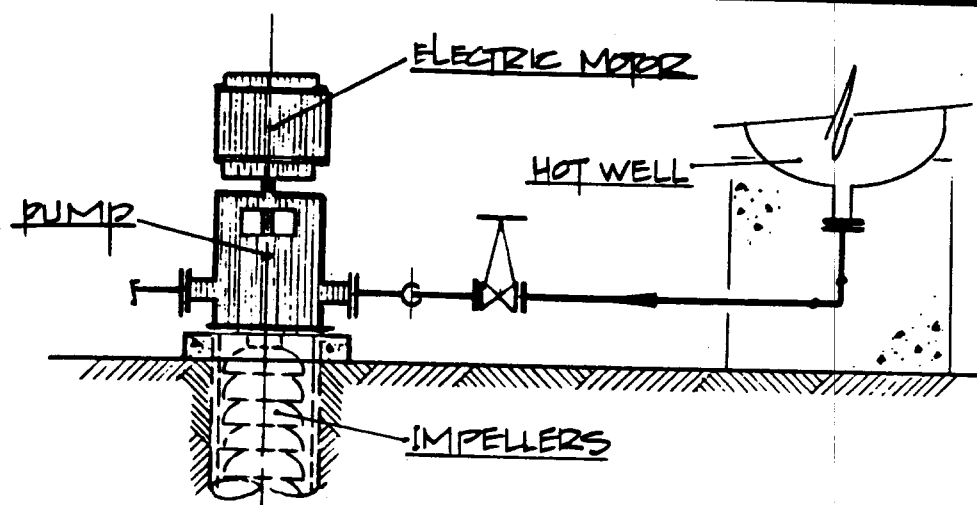


EXHIBIT 4-7
Vertical Condensate
Pump

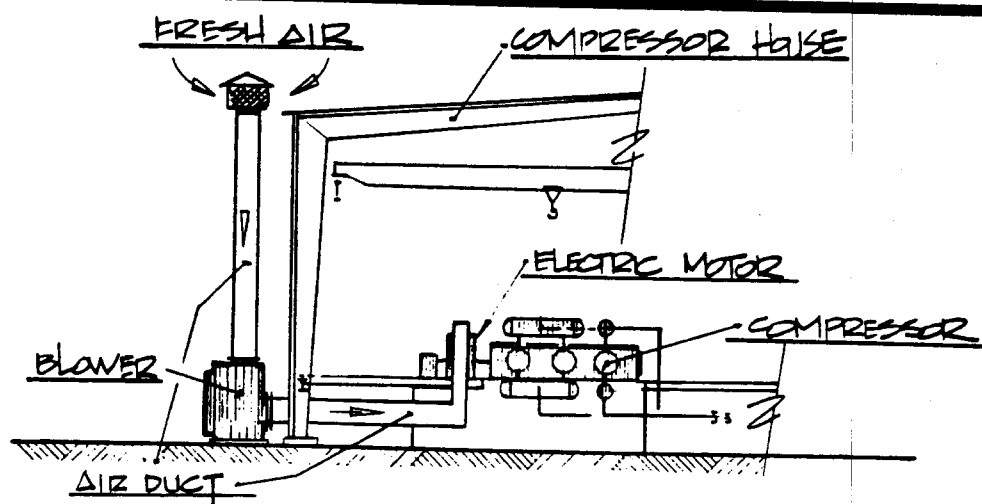


EXHIBIT 4-8
Air Blower

outside in similar ducts. Not all electric motors within houses require this cooling facility.

Inlet air filters Gas turbines require large amounts of clean filtered air for operation. The filters (Exhibit 4-9) can be extremely large. When positioning a gas turbine-driven compressor, the plant layout designer should be aware of the possible variations in orientation of the inlet and outlet ducting, as shown in Exhibit 4-10.

The optimum inlet ducting arrangement shown in Exhibit 4-10 is in a parallel plane with the gas turbine, which is at point A in the exhibit. Sometimes, however, the available space adjacent to the gas turbine and air filter does not permit this optimum arrangement, and alternative layouts must be considered. Additional turns and length to the inlet ducting can degrade the machine's efficiency and overall economics.

If other air inlet duct schemes (e.g., B, C, D, or E) in Exhibit 4-10 are considered, a brief study should be conducted to obtain an agreement by all principals, including the equipment engineer, the engineering manager, the vendor, and the client. The exhaust gas duct has a theoretical 180° discharge orientation range but is usually set at the left, top, or right side, shown as F, G, and H in Exhibit 4-10.

Waste heat system Waste heat systems (Exhibit 4-11) take hot exhaust gas from gas turbines and put high outlet temperatures, ranging from 800° to 1,200° F (426° to 650° C), to use in various ways. Through convection, it may be used to generate steam or to heat oil, which may be used as a heating medium.

Compressor suction drum/knockout pot Because compressors require dry gas that is free of foreign

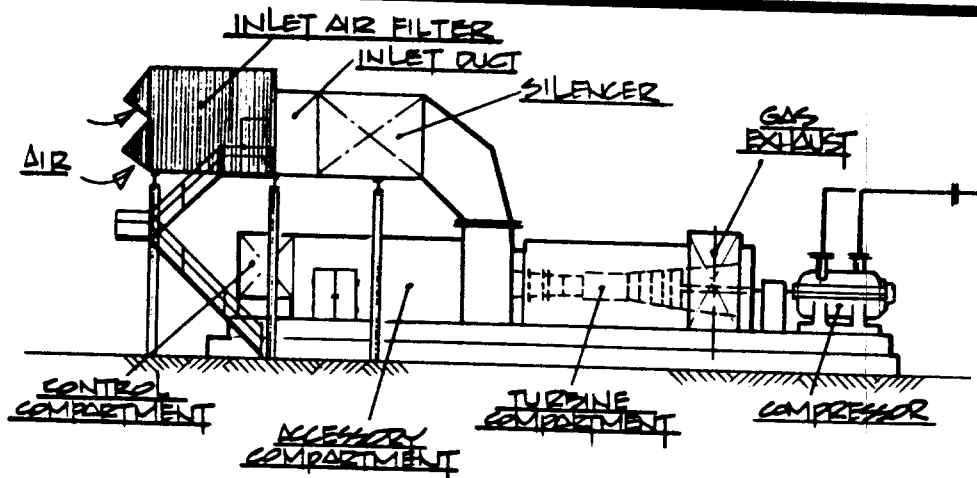


EXHIBIT 4-9
Inlet Air Filter

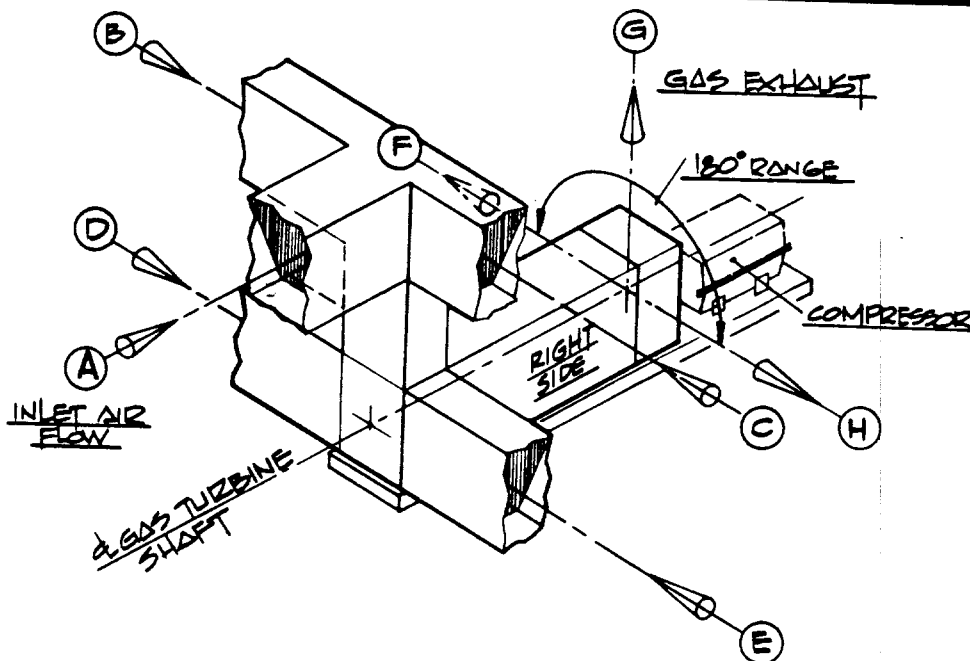


EXHIBIT 4-10
Variations in Inlet and
Outlet Ducting

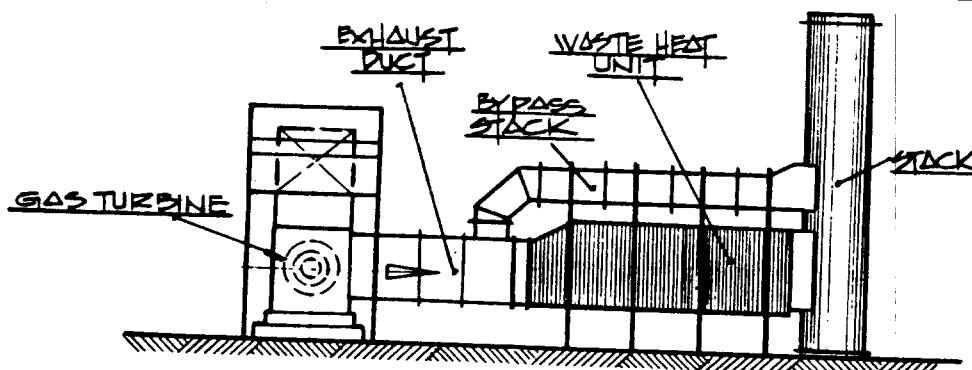


EXHIBIT 4-11
Waste Heat System

particles, it is necessary to pass the inlet gas through a suction drum or knockout pot (Exhibit 4-12). This vessel removes moisture and particles from the gas by passing it through a demister screen, which is located just below the outlet nozzle.

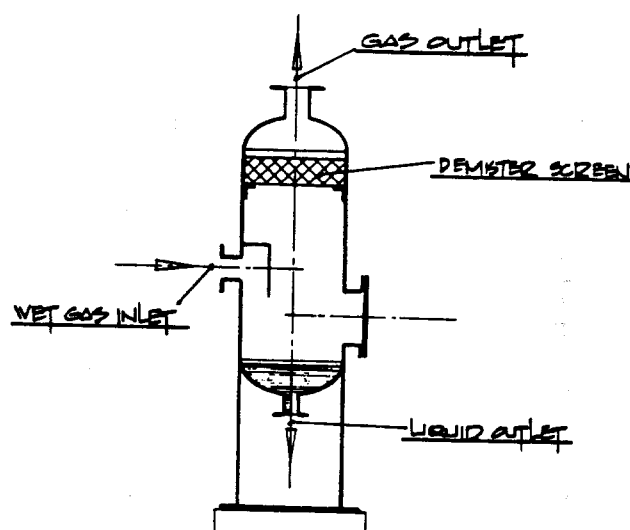
Pulsation dampener/volume bottles The negative effects of vibration on the life of reciprocating compressors and associated piping can be minimized by the use of pulsation dampeners (Exhibit 4-13). The pulsation dampeners are sized by the compressor vendor and are mounted directly onto the cylinder nozzles. Higher pressure on the outlet side, which is subject to greater pulsation and vibration, is usually on the bottom of the cylinder. It can be held down more easily because it is located close to grade. Volume bottles are also used to reduce vibration. They are located downstream of the discharge pulsation dampener and are similar to snubbers but do not have such internals as baffles or choke tubes.

CENTRIFUGAL COMPRESSORS: NOZZLE ORIENTATIONS

Horizontal Split-Case Compressors

The selection of a single-stage or multistage horizontal split-case compressor may depend on the design of the compressor or preference of the nozzle location to suit a particular layout. If a grade-mounted compressor is planned, the side or top orientation may be selected, whereas the bottom connections are generally used for elevated compressors. During maintenance, the top half of the compressor case is removed by lifting it vertically and away from the bottom assembly. This configuration is used for chemical, petrochemical, industrial and process air, refrigeration, and high-volume and low- to medium-pressure gas service applications. Exhibit 4-14 shows the variations of a horizontal split-case compressor.

EXHIBIT 4-12 Compressor Suction Drum/Knockout Pot



Vertical Split-Case Compressors

Exhibit 4-15 illustrates how this application can come with top or bottom orientations on the nozzles. Layout preference dictates the selection. Removal of the rotor assembly is through the front end of the compressor, away from the driver; the compressor vendor supplies the removal distance to the plant layout designer. This design is used for catalytic reforming, gas conversion and repressurizing, processing services, refrigeration, and high-pressure, low-volume or high-volume, low-pressure gas service applications. More than one compressor case may be hooked up in tandem (see Exhibit 4-16).

TYPES OF COMPRESSOR DRIVES

Electric motor From a layout standpoint, electric motors require the least amount of information to

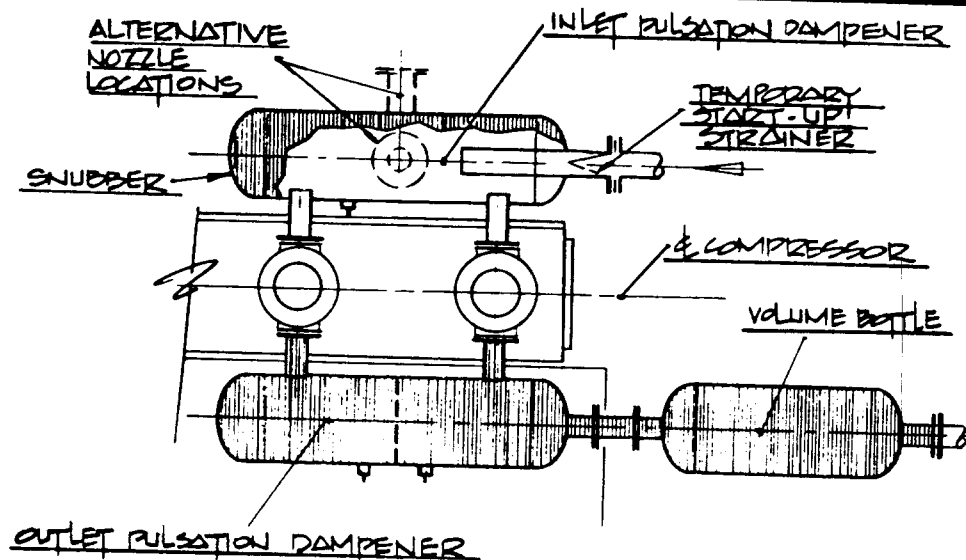


EXHIBIT 4-13
Pulsation Dampeners/
Volume Bottles

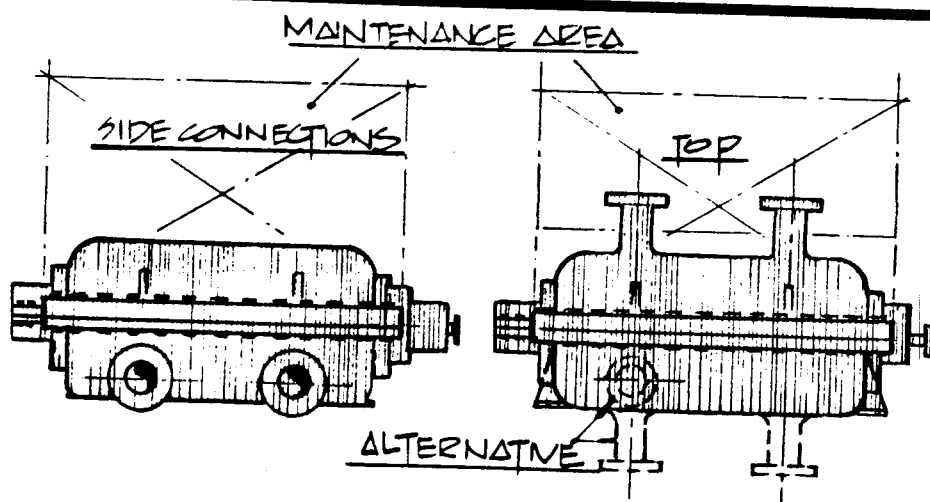
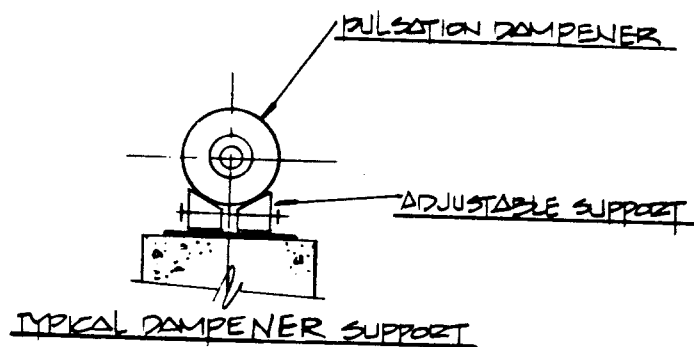
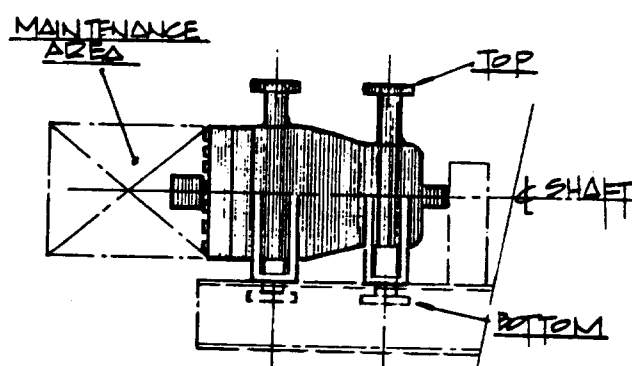
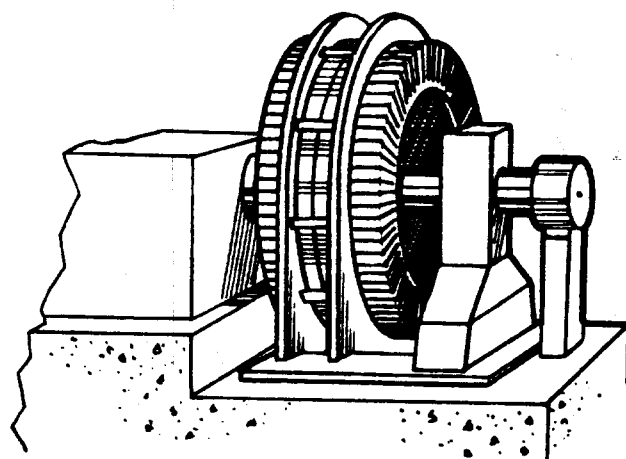


EXHIBIT 4-14
Single-Stage or Multistage
Horizontal Split-Case
Compressor

EXHIBIT 4-15 Vertical Split-Case Compressor

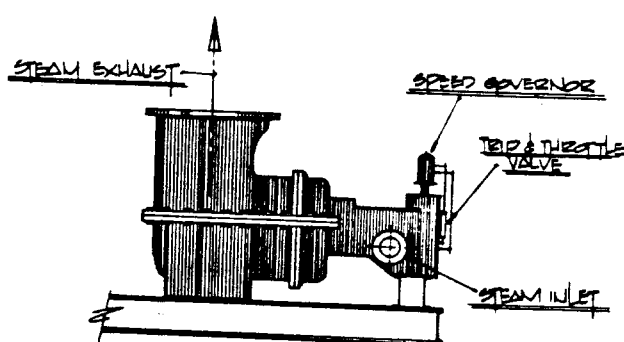
support a comprehensive design adequately. Information is needed regarding the motor's physical dimensions, largest component, weight to be maintained, and special cooling requirements, if any. Exhibit 4-17 shows a typical electric motor.

Steam turbine There are two kinds of steam turbines—back pressure and condensing. Back-pressure turbines are driven by high-pressure steam and do not require surface condensers. Condensing turbines are usually driven by low-pressure steam. Steam turbines are currently popular because they can convert large amounts of heat energy into mechanical work very efficiently. The propulsion force is applied directly to the rotating element and not through a series of links and cams. The steam turbine also has a low vibration level and few moving parts that require maintenance. Finally, the turbine's range of speed is very wide—some vendor turbines are rated from 1 to 100,000 horsepower. Noncondensing turbines are physically smaller than comparable condensing units because fewer stages are needed to let down steam that has a lower heat drop. A typical steam turbine is shown in Exhibit 4-18.

EXHIBIT 4-16 Tandem Arrangement**EXHIBIT 4-17** Electric Motor

Gas turbine Selection of gas turbines, like any other drive system, is based on economics. The availability of gas in such remote areas as deserts and offshore platforms makes it a prime source of power in these locations. Gas turbines are used in various applications, including gas transmission, gas lift, liquid pumping, gas reinjection, and process compressors. Air is compressed in the gas turbine by the centrifugal compressor and is discharged into a reverse flow annular combustor in which fuel is injected through nozzles. The transition duct directs the hot gas into a gas gener-

EXHIBIT 4-18 Steam Turbine

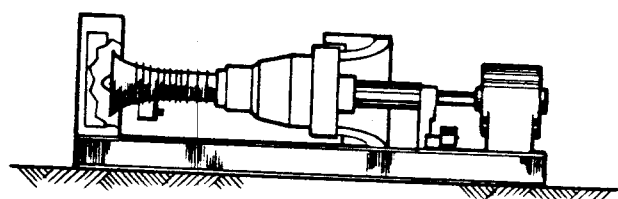


ator turbine, which in turn drives the compressor. The hot gas is ducted into a power turbine and discharged through an exhaust diffuser. The exhaust gas, which generally ranges between 800° and 1,200° F (426° to 650° C), is often used for steam generation and for hot oil systems. Exhibit 4-19 shows a typical gas turbine.

LUBE OIL SYSTEM

The primary function of the lube oil console is to supply clean, cool lubricating oil to the bearings of the compressor and its driver. The console is a package of equipment, which is supplied by the compressor vendor and usually includes an oil reservoir, two pumps (a primary and a spare), two filters or filter elements in a duplex-type arrangement, coolers, and associated controls. A typical lube oil console is shown in Exhibit 4-20. When placing a lube oil console around a compressor, the designer must adhere to clearance requirements for operation and maintenance of the unit. First, there should be sufficient room to remove the cooler tube bundle. Second, the space required to pull the filter elements must be considered—there can be no physical obstruction over the filters that

EXHIBIT 4-19 Gas Turbine



might restrict their removal. Third, when the unit will be exposed to severely cold temperatures, a heating coil is placed below the tank that requires maintenance and must be pulled clear of the tank. Exhibit 4-21 shows a typical lube oil console piping and instrumentation diagram, and Exhibit 4-22 illustrates a typical drain line routing from the compressor to the lube oil reservoir tank.

SEAL OIL SYSTEM

The seal oil system supplies oil to the hydraulic seals of the compressor, which are located at the outer ends of the shaft, at a constant temperature and pressure. The oil escaping the low-pressure side of the seal returns to the reservoir and is recirculated. Oil escaping through the high-pressure side passes through sour oil traps to the seal oil degassing tank.

There are two types of seal oil systems: gravity and pressurized. The gravity-feed seal oil system reservoir is mounted above and in view of the compressor, whose elevation is set by the compressor vendor. The sour oil traps can be integral with the lube oil console skid or located on a separate skid. The pressurized seal oil system is a pump-around facility whose components are integral to the lube oil console skid or mounted on a separate skid. If components are mounted on a separate skid, placement must accommodate seal oil console operation and maintenance,

EXHIBIT 4-20
Lube Oil Console
Maintenance

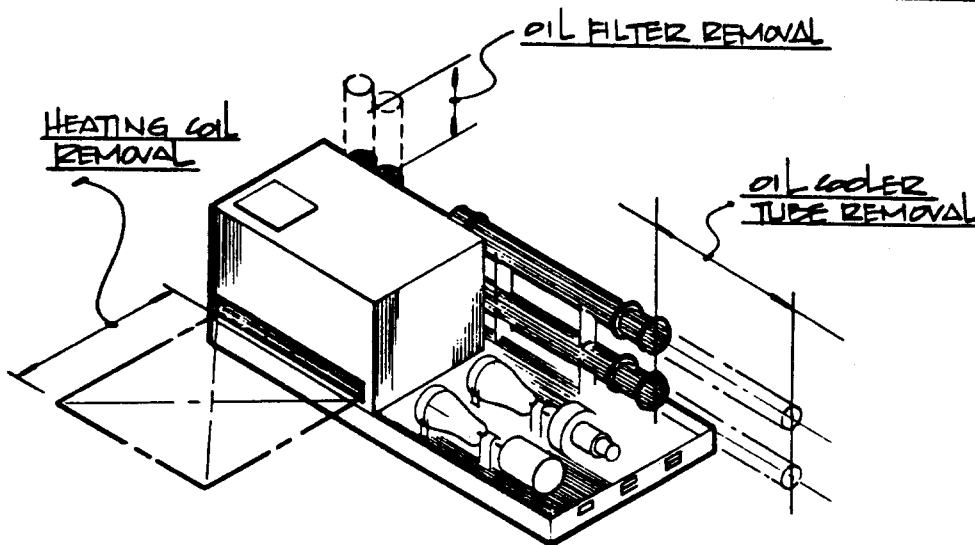


EXHIBIT 4-21
Lube Oil Console Piping
and Instrumentation
Diagram

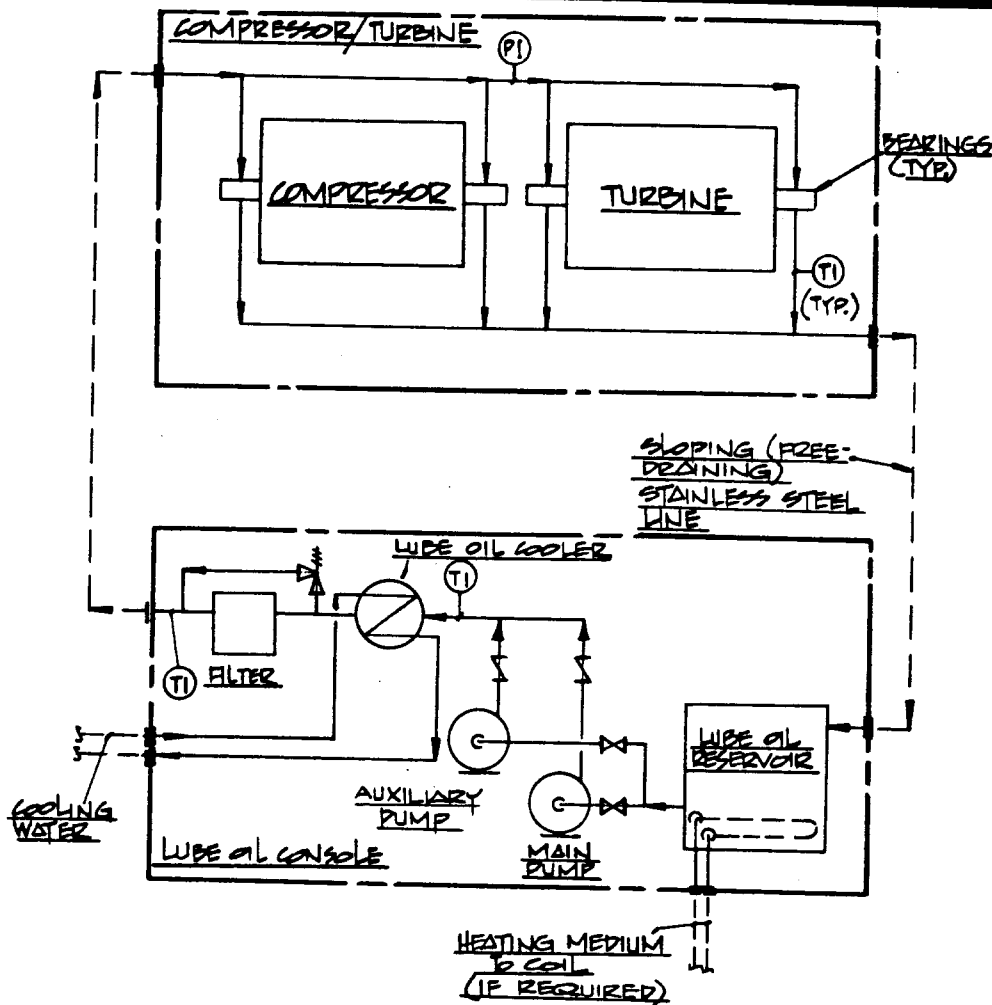


EXHIBIT 4-22
Lube Oil Drain Routing

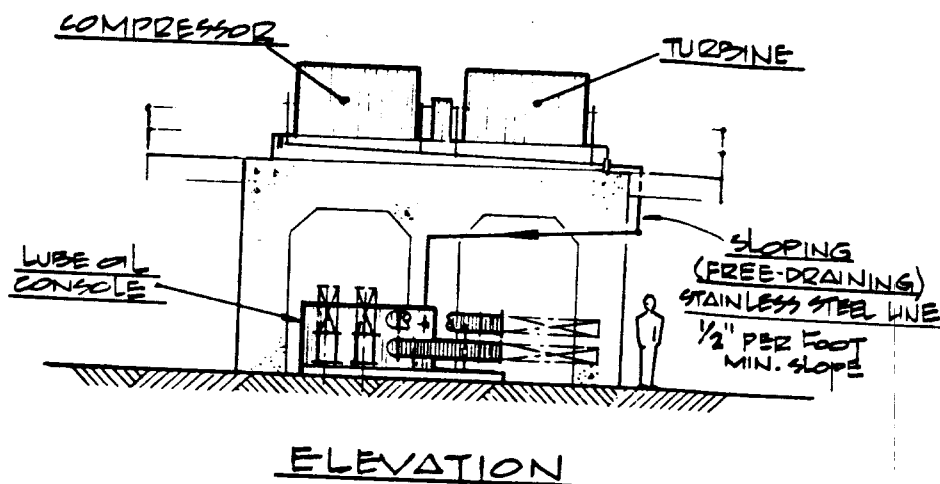
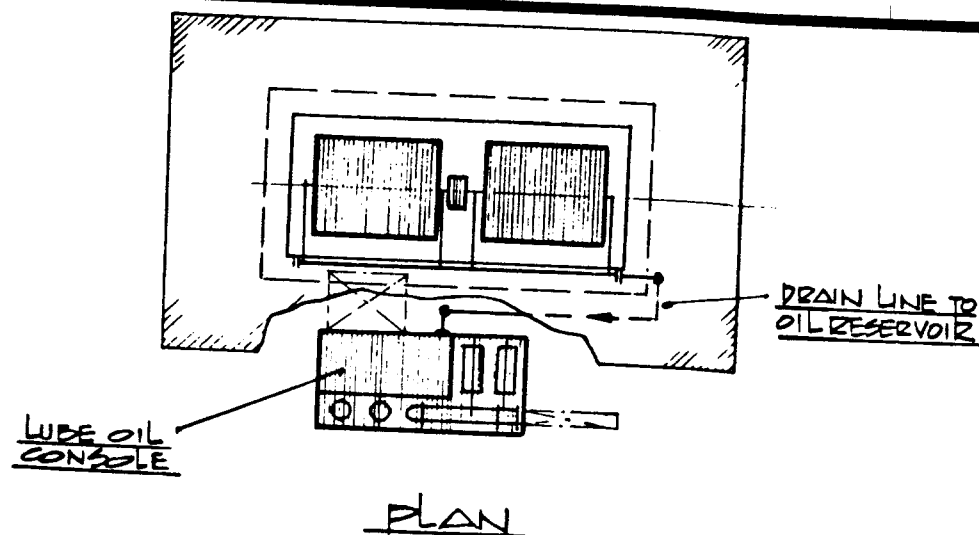


EXHIBIT 4-23 Seal Oil Tank Location

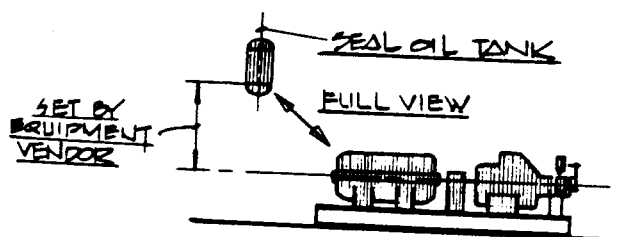


Exhibit 4-23 shows a seal oil tank location, and Exhibit 4-24 shows a general piping and instrumentation diagram of a seal oil console.

SURFACE CONDENSERS AND AUXILIARY EQUIPMENT

Surface condensers are used in conjunction with condensing steam turbines that drive large centrifugal compressors. As depicted in Exhibit 4-25 the exhaust steam enters the top of the condenser and passes through the shell, which is filled with tubes. Cold water is pumped through the tubes while hot exhaust steam passes around the outside. Hot water, called condensate, results and collects in the hot well at the bottom of the condenser.

Exhibit 4-26 shows a piping arrangement typically

as with the lube oil console. On some compressor systems, a gland condenser is required; it should be located close to the compressor. Systems engineering supplies information regarding the elevation and other requirements of a seal oil loop. Seal oil facilities are not required for reciprocating compressors. Ex-

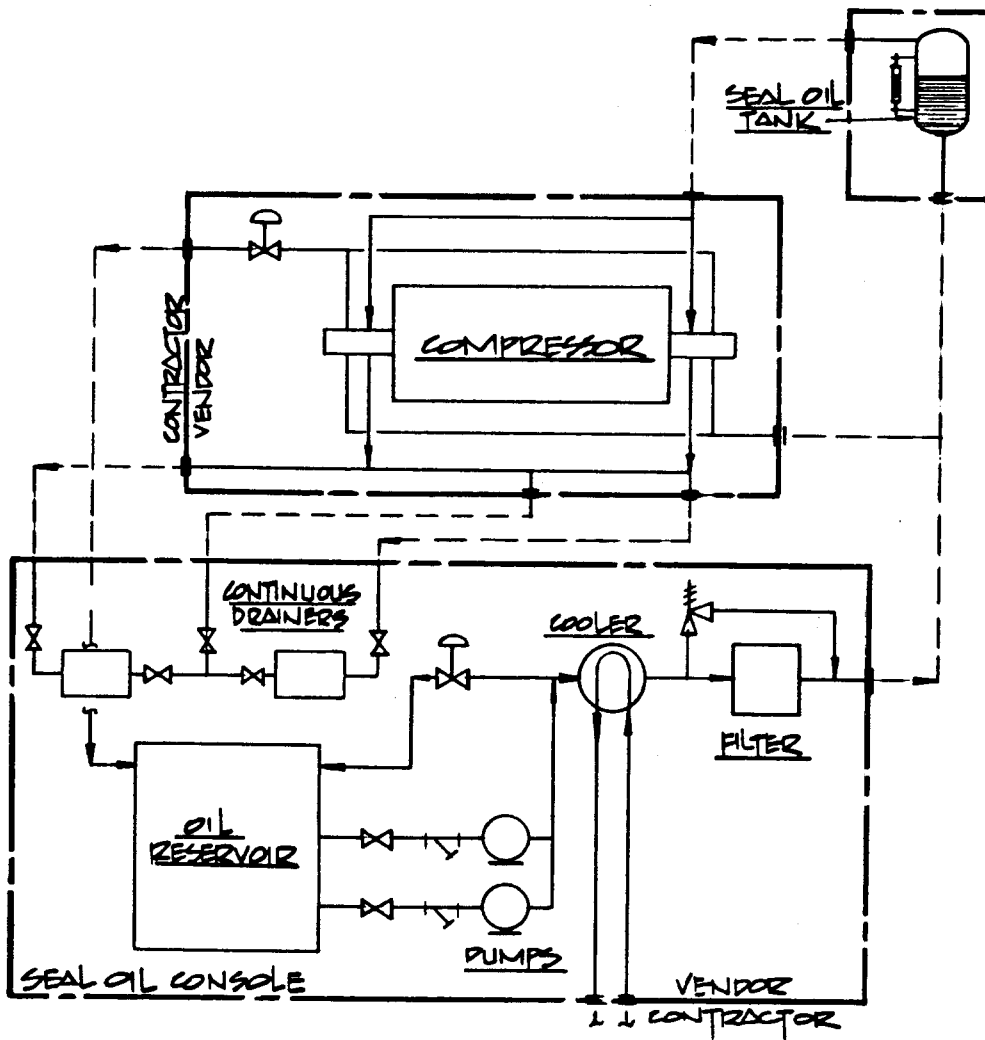


EXHIBIT 4-24
Seal Oil Console Piping
and Instrumentation
Diagram

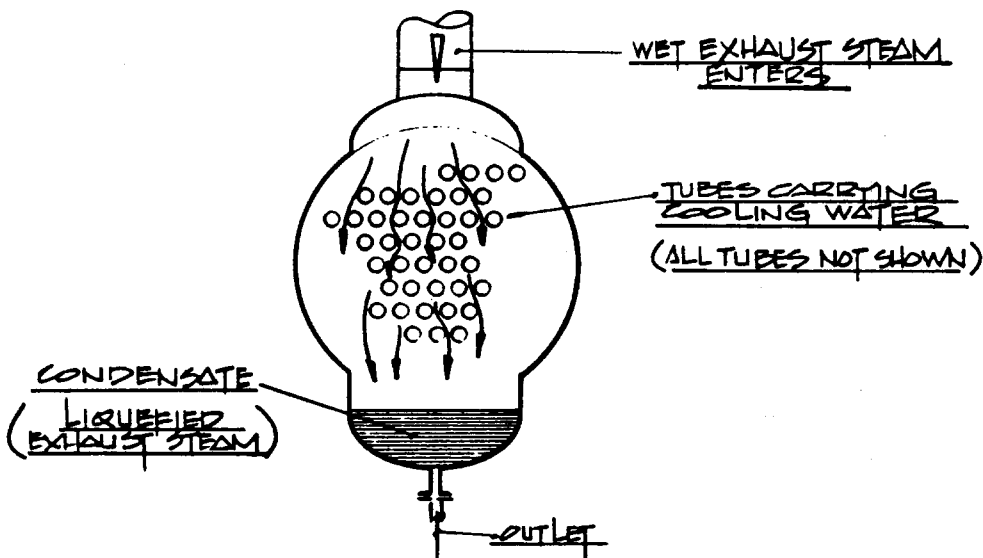


EXHIBIT 4-25
Basic Condenser
Operation

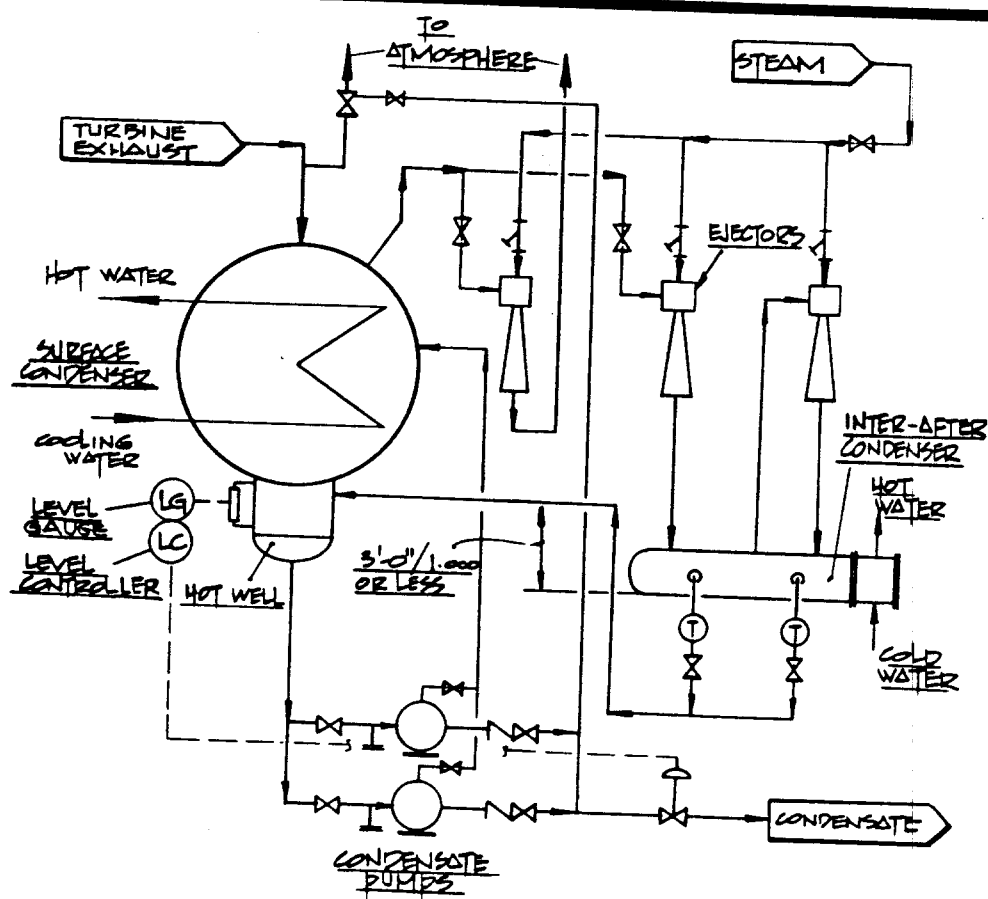


EXHIBIT 4-26
Surface Condenser and
Auxiliary Equipment

found around surface condensers. The condensate that collects in the hot well is pumped out and used in the generation of steam elsewhere in the plant. A level controller, which is mounted on the side of the hot well, activates the control valve downstream of the pumps when the condensate reaches a specific level in the hot well. A wet vapor vent is run from the pump casing back to the condenser shell to be liquefied. A line connected to the exhaust system inlet is vented to

the atmosphere through a safety valve. Condensate is piped downstream of the valve and creates a water seal on the valve to maintain the vacuum pressure in the system. Ejectors pull additional wet vapor from the condenser. As steam is fed into the end of the ejector, the low-pressure wet vapor is sent to the inter-after condenser, where additional liquefaction takes place through convection with cold water. When the steam trap is filled with condensate, it opens and the higher

pressure on the inter-after condenser sends the condensate back to the hot well in the surface condenser.

Equipment Location and Elevation

Exhibit 4-27 illustrates how primary process considerations govern the elevation of the surface condenser and some of its auxiliary equipment. Because a pump is needed to remove the condensate from the hot well, the pump net positive suction head (NPSH) must be satisfied to operate satisfactorily. Vertical pumps are generally used in this application because the NPSH requirement is calculated from the bottom of the lower impeller for vertical pumps, compared with the centerline of the inlet nozzle for horizontal pumps. Setting the elevation of the inter-after condenser, usually located to the side of the surface condenser, can be done with fewer restrictions. The bottom of the inter-after condenser shell must not be more than 3 ft (900 mm) below the condensate return nozzle on the side of the hot well. The plant layout designer is then free to set the elevation as high as necessary.

COMPRESSOR MAINTENANCE

Compressor installations and most other equipment may be located either in open areas of the plant or in structures that have a roof only or a curtain wall or are completely enclosed. For the plant layout designer, client preference and climate conditions are the two primary considerations that determine the inclusion of compressor shelters. The fact that machines may be either elevated or grade mounted creates a variety of maintenance problems for the plant layout designer.

Compressor Maintenance Versus Economics

Although operation and safety are important and must be incorporated in the design of any facility, mainte-

nance and economic factors must also be considered when in a compressor area plan. When dealing with a horizontal split-case centrifugal compressor, the plant designer must determine whether the compressor should be elevated or grade mounted. Although a grade-mounted machine sits on a relatively low concrete pad, with its lube oil console close by, this arrangement also has its price. Suction and discharge piping enters and exits the compressor case from the top, which means that piping must be removed to perform general maintenance on horizontal split-case machines. When a condensing turbine is used as the driver for such a machine, the exhaust piping, which is also run overhead, must be removed. The support steel required for top-connected compressors is generally more extensive, and it must be placed so that maintenance of the machine is not hindered.

For an elevated compressor with condensing turbine drive, the compressor suction and discharge (with single stage or multistage) and the exhaust outlet on the turbine remain in place during general maintenance. Although an elevated structure requires a greater initial capital expenditure, the on-stream time over the life of the plant will be greater because of shorter maintenance turnaround and shorter downtime.

Maintenance Impact on Shelter or Structure Size

Exhibit 4-28 illustrates how compressor maintenance affects the size of the shelter or structure. Although operational access often determines floor space requirements, the height of a compressor house is strictly a function of maintenance. Consequently, the size of the maintenance area must permit the largest single item to pass unobstructed from one end of the building to the other and should be set as close to the operating level as possible. The centerline elevation of the hook that allows all items to pass through the maintenance area must be set. The hook elevation,

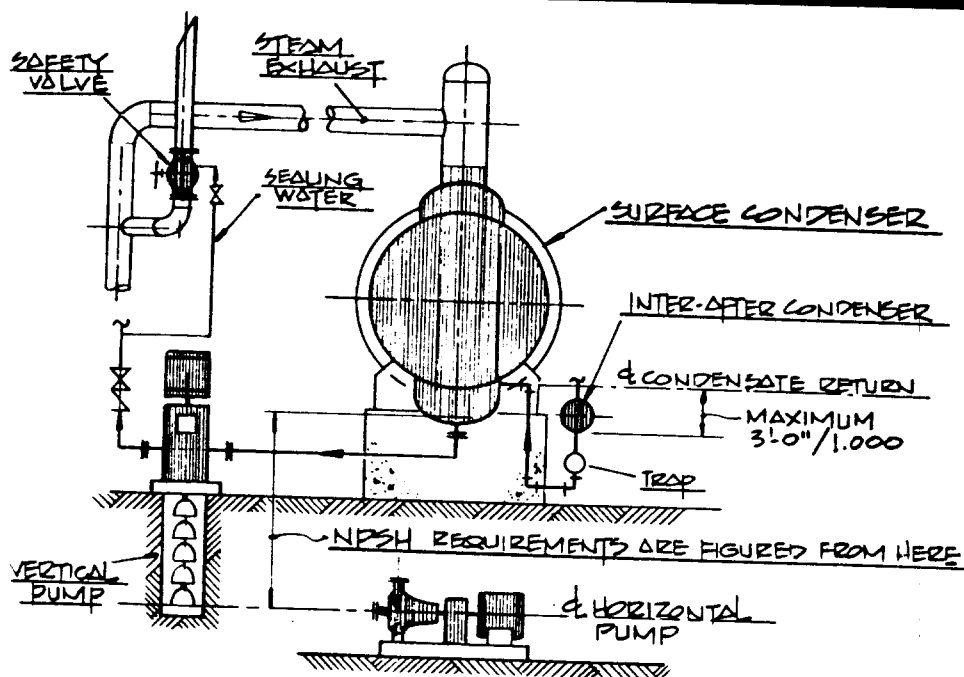


EXHIBIT 4-27
Surface Condenser
Elevation

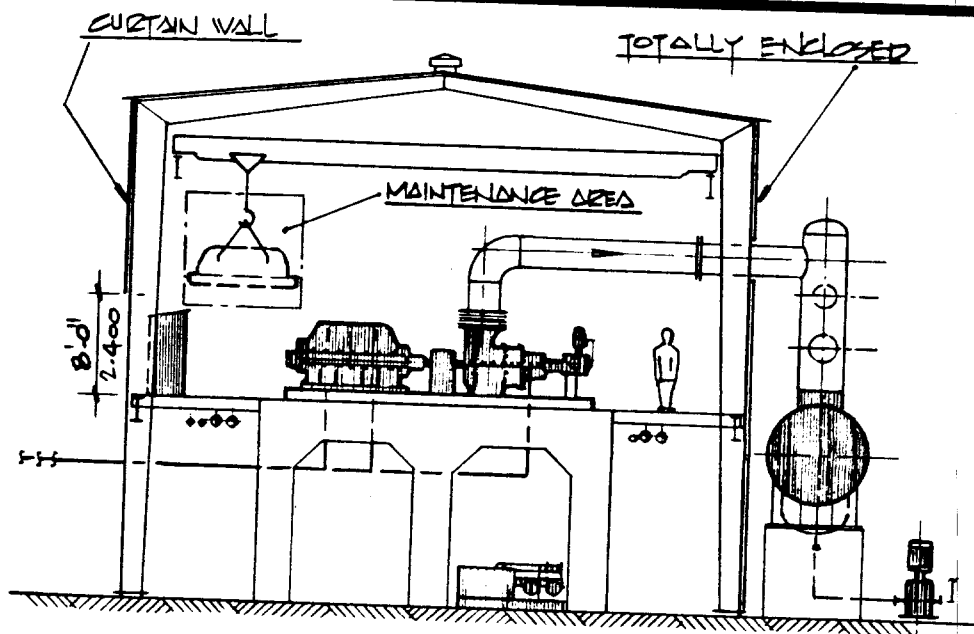


EXHIBIT 4-28
Elevated Compressor

A curtain wall is usually a four-sided structure with all four sides open 8 ft (2.6 m) above the operating floor.

Totally enclosed structures usually have siding on all four sides from grade level up. This generally is done in severe climates.

All maintenance is handled by a traveling crane. A clear area is reserved during the layout stage to allow the largest piece to be removed without dismantling any piping system, if at all possible.

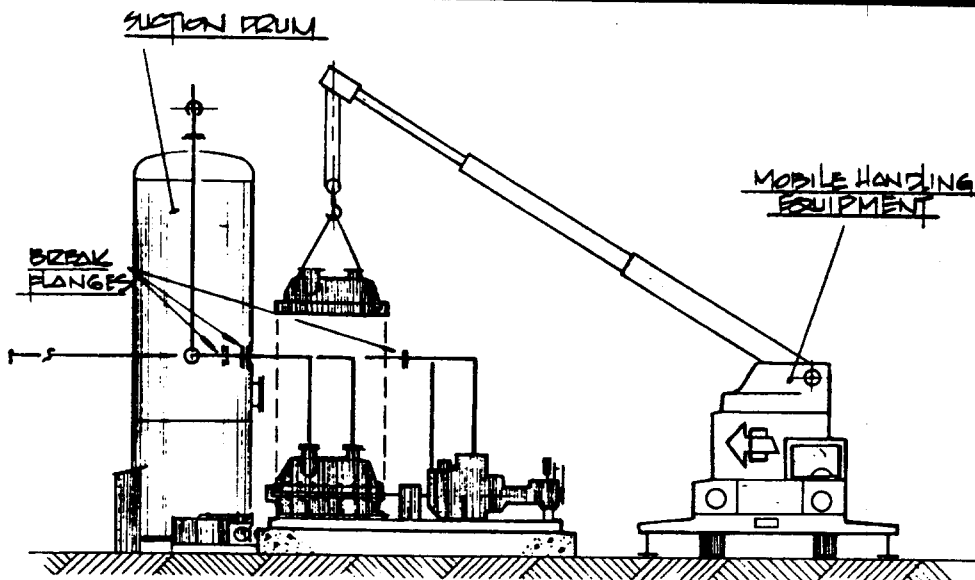


EXHIBIT 4-29
Grade-Mounted
Centrifugal Compressor:
No Shelter

plus the maximum lifted load, determines the depth of the trolley beam. The elevation of the building's eave is then set by allowing sufficient space for the traveling crane to traverse the length of the building as well as for its routine maintenance.

Maintenance Considerations for No Shelter

When developing a compressor layout that does not require a structure or shelter, the designer must allow adequate room for mobile handling equipment to lift an item, raise it to clear all obstructions (including fire hydrants, monitors, and light poles), and back away or swing it to where it can be placed on another vehicle. Exhibit 4-29 illustrates a grade-mounted centrifugal compressor with no shelter.

This installation is usually the easiest to maintain because all the components may be removed with mobile equipment. If possible, the engineering con-

tractor should be informed of the type of mobile equipment the client will use, as well as its lifting capacity, to develop the optimum compressor layout. For top-connected horizontal split-case compressors, break flanges must be provided in the piping to allow the removal of the top half of the compressor case.

The installation in Exhibit 4-30 is an open-sided structure with a roof. Component removal may be accomplished by mobile equipment or a traveling crane. Adequate room must be planned for removing the largest component both in the level I (grade-mounted) and level II (elevated) installations.

The compressor arrangement in Exhibit 4-31 is a curtain wall structure with four sides, open from the operating level to a height of 8 ft (2,400 mm). This arrangement is often found in temperate climates. Maintenance is accomplished with a traveling crane. The drop zone for the equipment may be within or outside the shelter; if the drop zone is outside the shelter, removable panels must be furnished and iden-

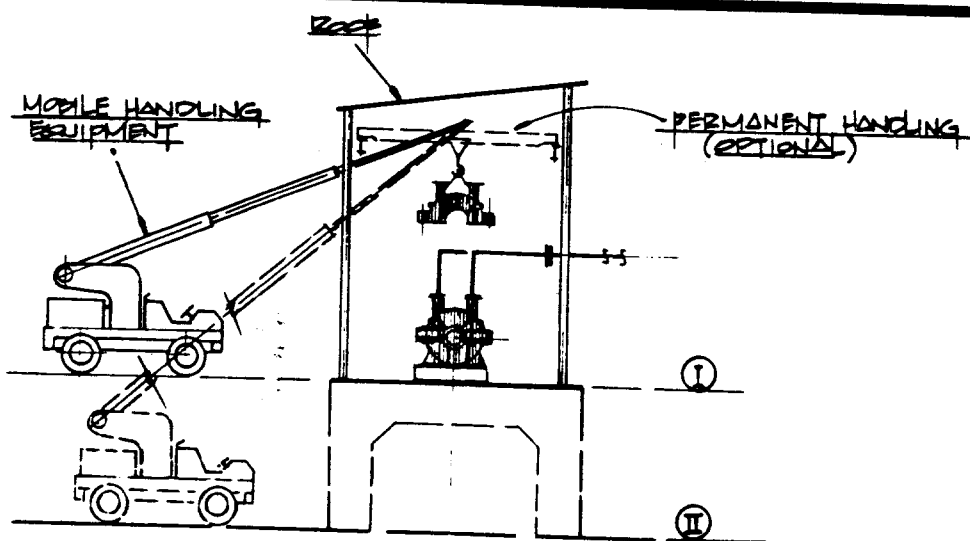
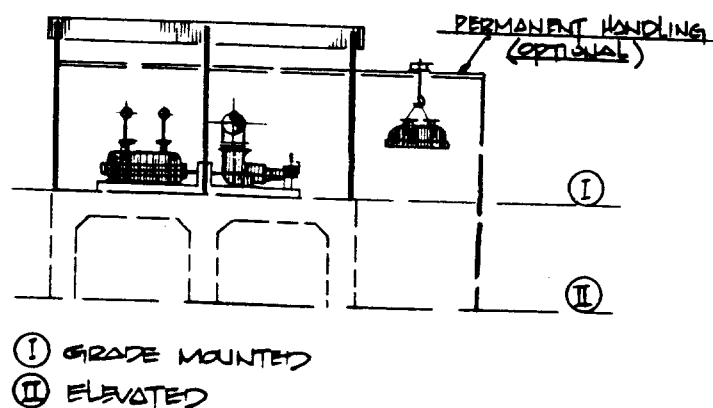


EXHIBIT 4-30
Grade-Mounted or
Elevated Centrifugal
Compressor:
Open-Sided Structure



tified on the layout drawings.

The arrangement in Exhibit 4-32 is an open elevated installation. Component removal may be accomplished with mobile equipment or a traveling gantry, which rides on two rails along either side of the machine. A structure must be provided to carry the rails out to the equipment drop zone.

The arrangement illustrated in Exhibit 4-28 is for an elevated multicompressor structure; it can be equipped with a curtain wall or totally enclosed. A clear area must be planned early in the layout stage to permit any machine to be maintained without disturbing the piping or components of the other compressors. The maintenance sequence for a multicompres-

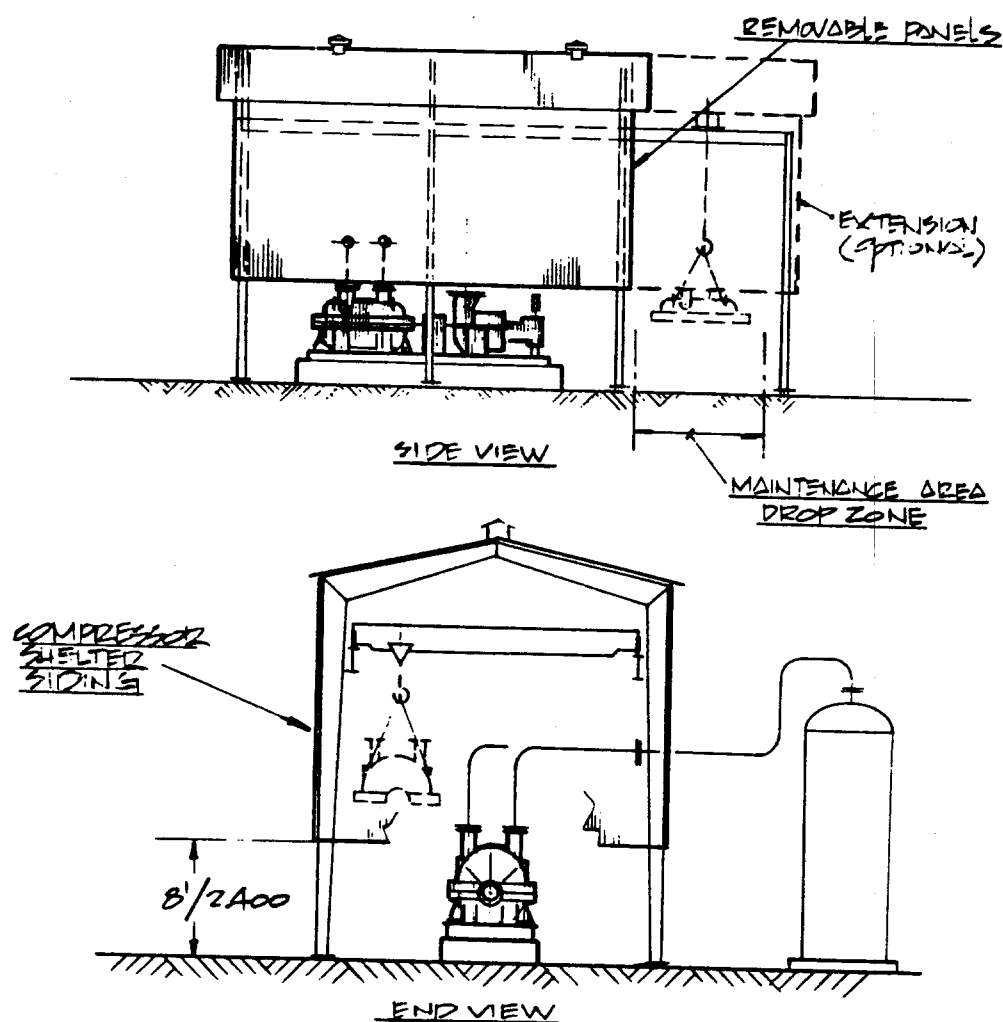


EXHIBIT 4-31
Grade-Mounted
Compressor:
Curtain Wall Shelter

sor arrangement is shown in Exhibit 4-33 and is detailed as follows:

- The component is lifted by the traveling crane and is passed through the clear maintenance area.
- It is brought to the drop zone above the operating floor level.

- The item is lowered to grade, where maintenance may be performed, or set on a flatbed truck for removal.
- The clear area allows the mobile equipment to travel to and from the drop zone.

If the client prefers to maintain the component on the

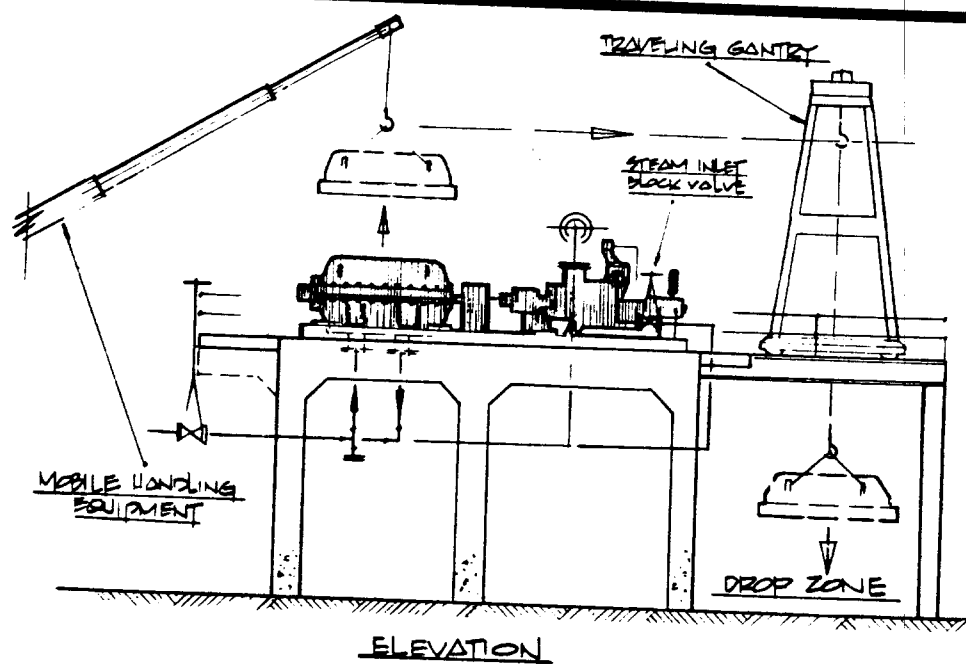


EXHIBIT 4-32
Elevated Centrifugal
Compressor: No Shelter

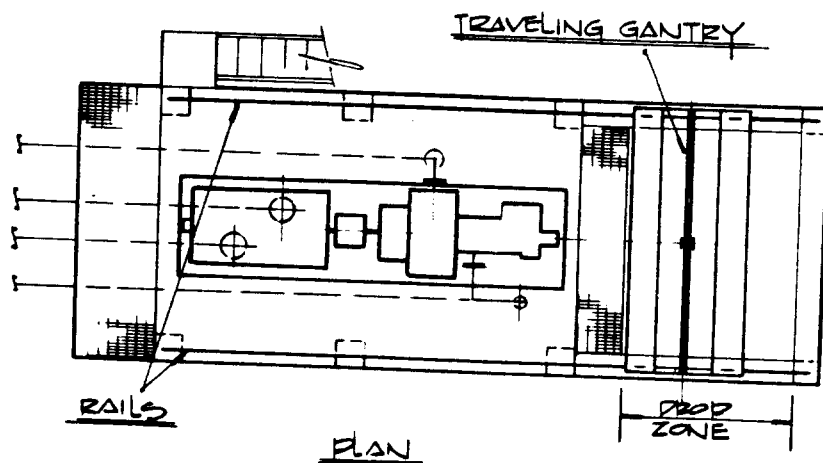
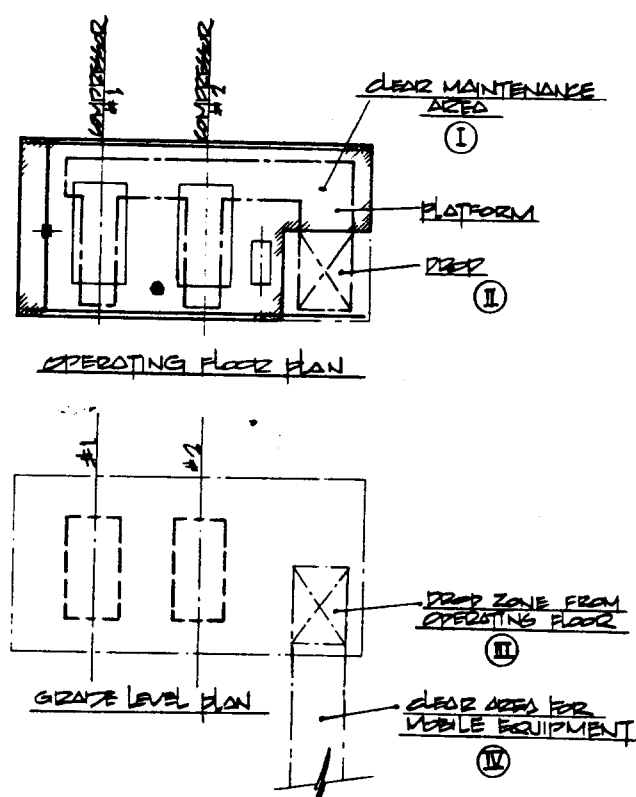


EXHIBIT 4-33 Maintenance Sequence



- I. Piece to be maintained is lifted and passed through this area.
- II. It is then brought to the drop zone area.
- III. The piece is lowered to grade or onto a vehicle for removal from the compressor structure.
- IV. The clear area allows the vehicle to pass free of any obstruction (e.g., equipment, piping, fire monitors, and light poles).

Some maintenance may be done on the operating floor, but the floor must be designed accordingly.

operating deck level, an adequate area must be provided and the structural engineers must be notified of the size and weight of the largest item that will be set onto the deck.

Maintenance of reciprocating compressors for open and enclosed installation is shown in Exhibit 4-34. Although it is common to use permanent handling facilities (e.g., traveling cranes) for enclosed installations, another option is available. If the structural engineers provide removable panels in the roof, mobile equipment may be used to facilitate component removal.

Another important feature regarding reciprocating compressor maintenance is shown in Exhibit 4-35. A clear area must be provided in line with each compressor cylinder to permit cylinder removal during the maintenance cycle. The area between two machines must be common for both cylinders.

COMPRESSOR ARRANGEMENT AND LOCATION

No Shelter

Because many acceptable variations of a centrifugal compressor area are possible, the version presented in Exhibit 4-36 must be explained. Briefly, the area includes three centrifugal machines with separate lube oil consoles (driven by condensing steam turbines), two inter-coolers, three suction drums, a surface condenser, and two vertical condensate pumps. Because there are three condensing steam turbines operating at low steam pressure, minimizing the length of the exhaust line to the surface condenser should be one of the first goals a layout designer considers. The surface condenser is located just to the south of the compressor operating platform. The lube oil console for compressor 1 is located to the west of the surface condenser, which permits the return line to drain to the oil reservoir without obstruction. Consequently, the area directly east of the surface con-

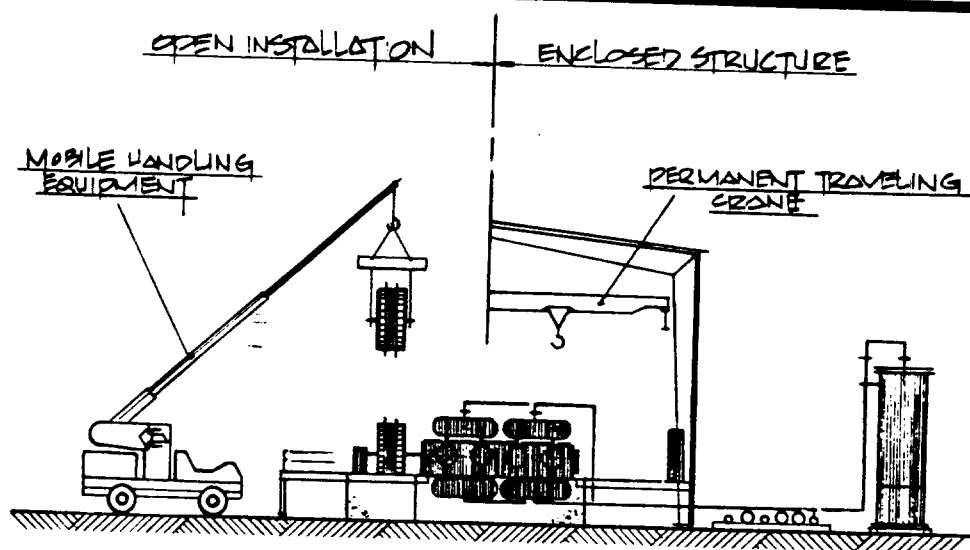


EXHIBIT 4-34
Reciprocating
Compressor: Open
Installation/Enclosed
Structure

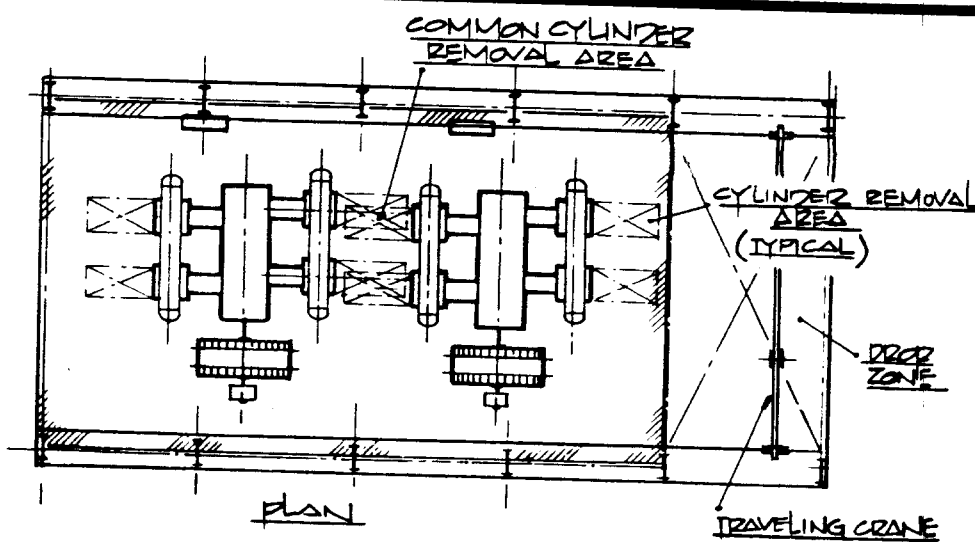


EXHIBIT 4-35
Planning for Cylinder
Removal

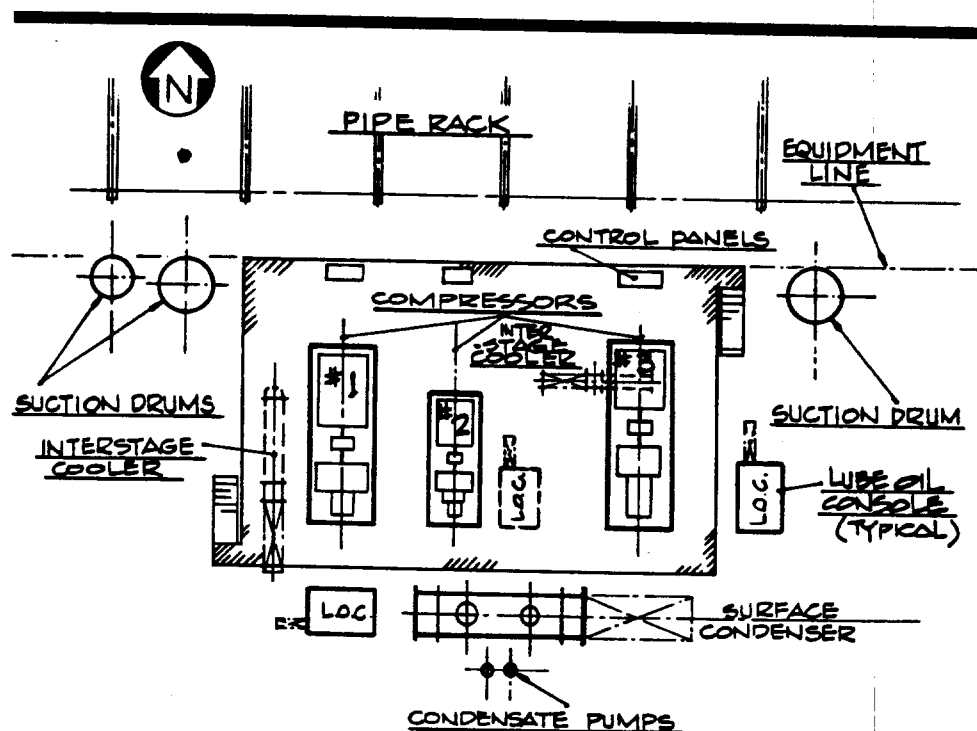


EXHIBIT 4-36
Centrifugal Compressor
Area: No Shelter

denser can be used to pull the tube bundle.

The vertical condensate pumps are located just to the south of the condenser and should straddle the centerline of the hot well outlet nozzle. The distance between the condenser and the pumps is dictated by pump operation and maintenance requirements as well as piping flexibility.

The suction drums for compressors 1 and 2 are located along the equipment line just to the west of the operating platform. Often, the outlet line of the suction drum to the compressor suction nozzle requires a flow meter with straight run lengths upstream and downstream. This arrangement permits the natural configuration of the line to satisfy the meter flow requirements.

The intercooler for compressor 1 is located at grade below the platform, with clear access to the

south for tube removal. The lube oil console for compressor 2 is located just to the east of the compressor at grade level below the operating platform. If there is insufficient room to maintain the console, removable grating must be provided at the operating platform level, which prohibits any other use for this area.

Compressor 3 has an inter-cooler mounted directly below the machine, which is supplied by the vendor. Again, ample access must be provided for tube removal. The lube oil console for compressor 3 is located just outside and clear of the operating platform to the east. Again, a free-draining oil return line to the console must be provided. The suction drum for compressor 3 is on the equipment line to the east of the operating platform.

Access to the operating platform is by two stairways at opposite ends of the area, allowing emergency exit.

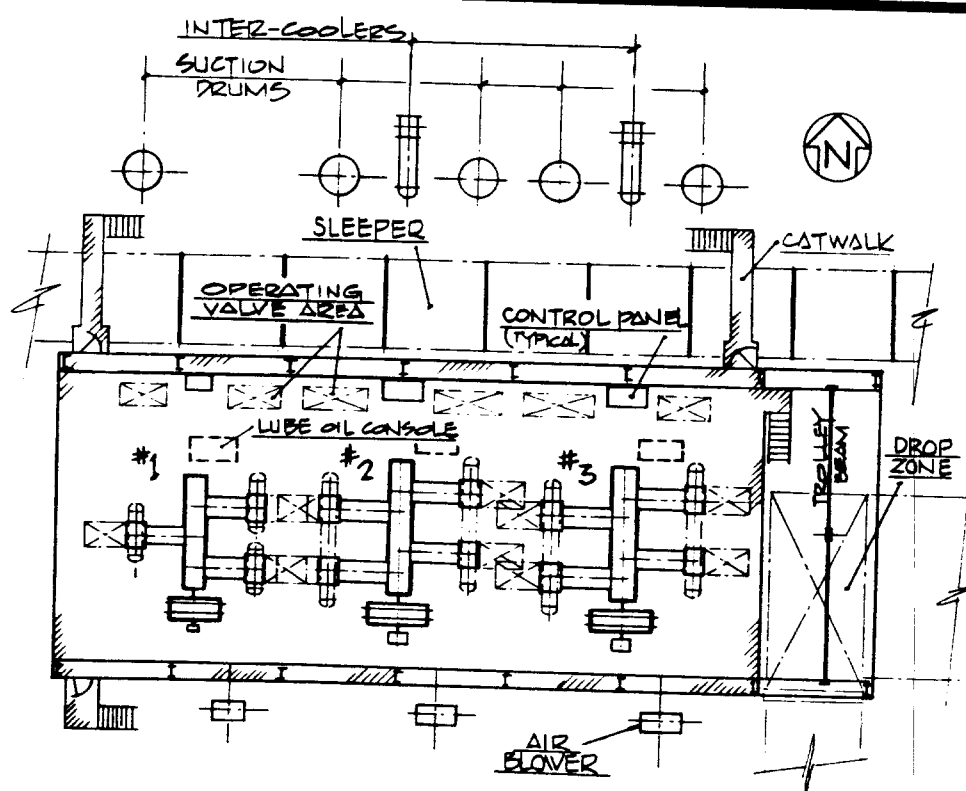


EXHIBIT 4-37
Reciprocating
Compressor Area: Totally
Enclosed Structure

Each machine has a control panel that is placed along the north edge of the operating platform. Because there is no shelter over this particular area, all major maintenance is handled by mobile equipment.

Enclosed Structure

The arrangement shown in Exhibit 4-37 consists of three electric motor-driven-reciprocating compressors as well as air blowers, suction drums, inter-coolers, control panels, and one lube oil console. Because the compressors are two different sizes, the electric motors have been lined up to permit the power-supply conduit to run straight east and west, regardless of

whether it runs directly below the operating platform or below grade.

Compressor 1 has three cylinders with a separate lube oil console that is located directly to the north, below the operating platform. A removable section of the platform should be provided for maintenance above the unit. This area must be kept clear of any obstruction.

Compressors 2 and 3 are identical four-cylinder machines that have integral lube oil consoles mounted directly onto the compressor frame. Each compressor has a control panel located along the north wall.

An area along the north compressor wall is reserved for the valve stems, which are located below

the floor and extend to a distance of approximately 3 ft (1,000 mm) above the platform floor. A sleeper runs east and west outside the north wall for all compressor piping, which vibrates a great deal because of reciprocating compressor operation and therefore must be run as close to grade as possible. If the operating valves are located outside the building, a catwalk should be provided to allow access during operation. The suction drums and inter-coolers are located across from the sleeper area.

In a totally enclosed building, all compressor maintenance is handled by traveling crane. The operating floor stops one bay before the east wall, which allows for a drop zone for maintenance. Mobile equipment must be brought into this area from the south or east. Roll-up doors are generally provided for this purpose.

Each of the three electric motors requires air from the outside to cool the motors. Electric motors within buildings do not always require this type of cooling.

Access to the operating area of this structure is accomplished by stairway and doors along the north wall both at the west end and close to the east end and on the south wall at the west end. An additional stairway at the east end permits operators or maintenance personnel to enter the drop zone or to access the area under the operating floor.

ELEVATIONS OF MACHINES

This section deals with the problems that must be addressed when the elevations of both centrifugal and reciprocating compressors are set. When separate lube oil consoles are used, a free-draining line from the machine to the lube oil reservoir must be maintained.

Centrifugal Compressors

The type of driver and associated equipment items as well as the straight run requirements of the compres-

sor inlet piping are the major factors that set the final elevation of the machines. Exhibits 4-38 and 4-39 illustrate the following:

- Arrangement A shows bottom-mounted nozzles.
- Arrangement B shows top-mounted nozzles.
- Arrangement C shows a surface condenser mounted directly below the turbine, which is common when only one turbine is being serviced.
- Arrangement D shows a top nozzle that allows the exhaust steam line to run to a surface condenser servicing multiple turbines, as shown in Exhibit 4-2.

By selecting compressor arrangement A or B and placing its match line against the turbine match-line arrangement C or D, a designer can review the governing criteria for setting machine elevations (see Exhibit 4-40). In addition, consideration must be given to miscellaneous equipment (e.g., as shown in arrangement A of Exhibit 4-38).

Reciprocating Compressors

Reciprocating machines are located as close to grade as possible because of the extreme vibration in the piping system. This minimum elevation is established by the following steps that describe Exhibit 4-41:

1. Sleeper—Usually set at 12 to 18 in (300 to 450 mm) above grade.
2. Header size—Established on the piping and instrumentation diagram.
3. Minimum distance required to enter the header with the largest line to and from the compressor.
4. The pulsation dampener—Designed by the compressor vendor.
5. Minimum clearance required between the dampener and floor steel.
6. Maximum depth of floor steel—Set by the structural engineer.

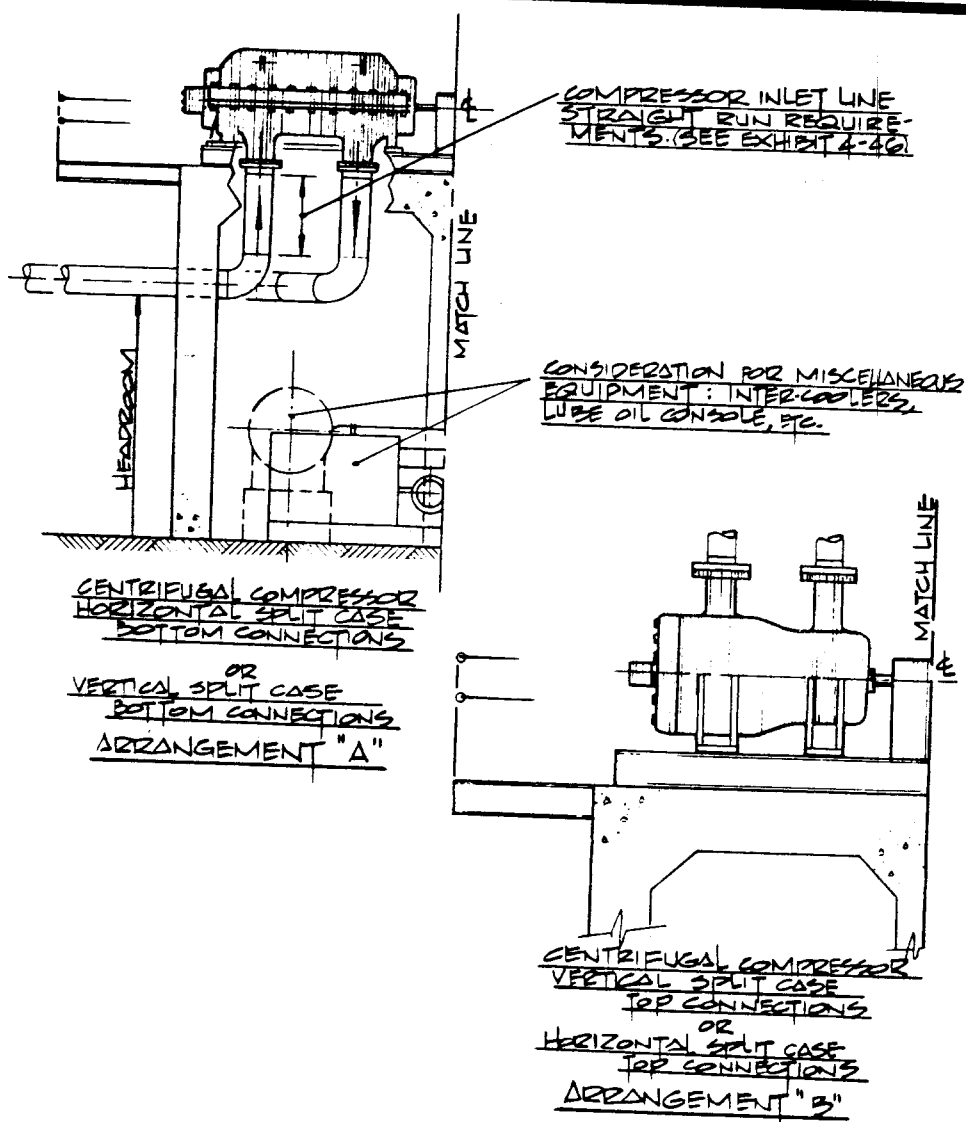
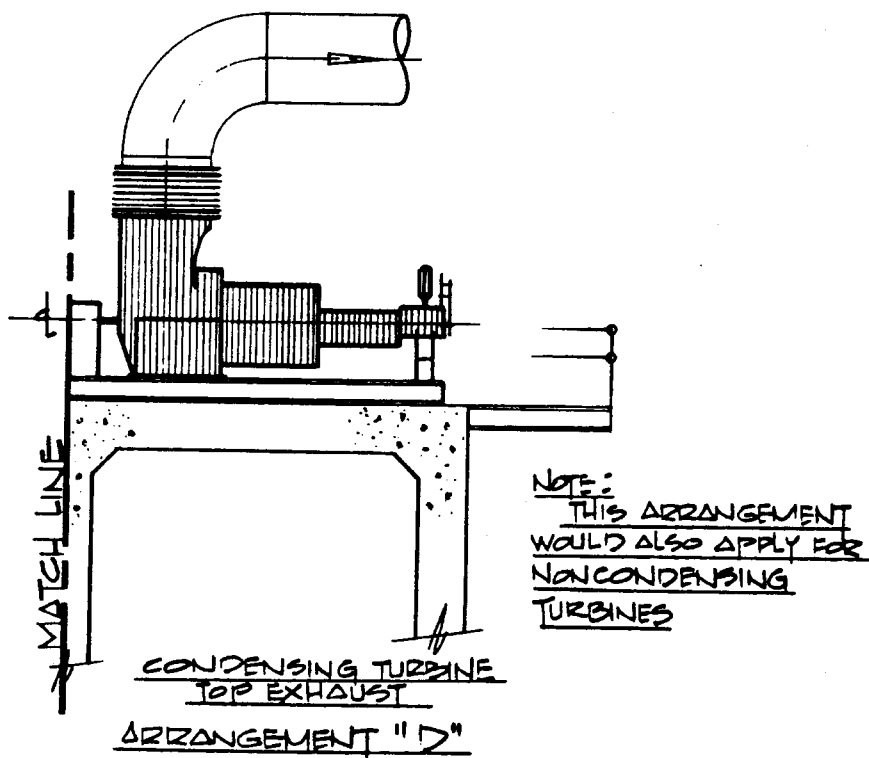
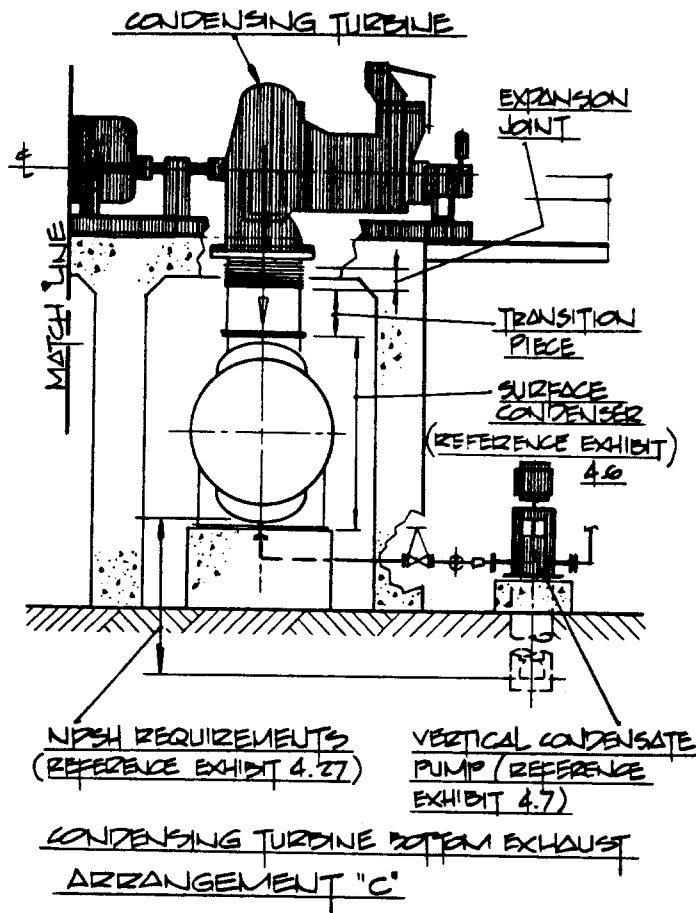


EXHIBIT 4-38
Setting Elevations of
Centrifugal Compressors

EXHIBIT 4-39
Setting Elevations of
Steam Turbines



Compressor Arrangement	Drive Arrangement	Elevation Governed By	Remarks
A	C	C	
A	D	A	
A	Electric motor	A	Motor not shown
B	C	C	
B	D	NA	Usually grade-mounted arrangement
B	Electric motor	NA	Usually grade-mounted arrangement, motor not shown

EXHIBIT 4-40
Criteria for Setting
Machine Elevations

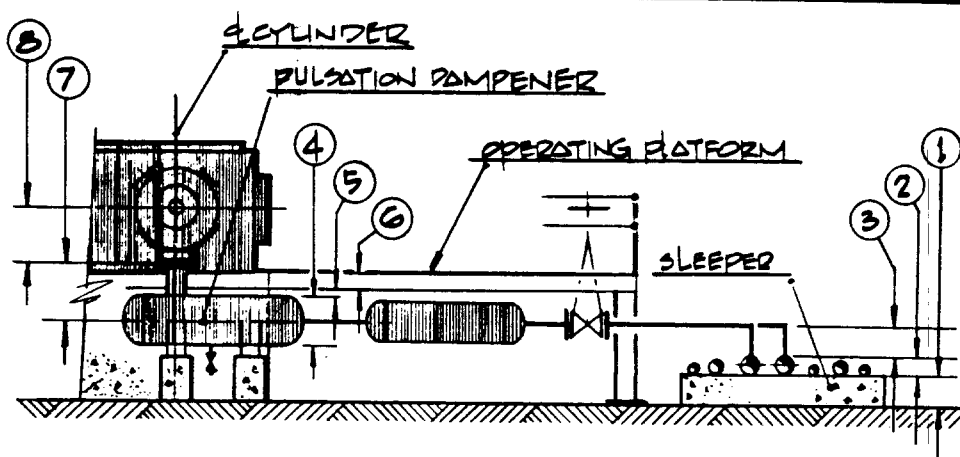


EXHIBIT 4-41
Setting Elevations of
Reciprocating
Compressors

7. Dimension from the centerline of the dampener to the face of the nozzle—Set by vendor.
8. Bottom of the compressor baseplate to the centerline of the compressor shaft—Set by the vendor.

INTER- AND AFTER-COOLERS

Inter-coolers Coolers are primarily used to reduce the operating temperature within a compressor circuit, which allows the use of a smaller machine with fewer cylinders. These coolers may vary in size and type (e.g., shell and tube, air coolers, and U-tube) and

should be located as close to the compressor as practical. In some reciprocating compressor arrangements, the coolers may be mounted on and directly over the compressor by the vendor, but they are usually located by the engineering contractor close to the machine or stage suction drum. Exhibit 4-42 shows a centrifugal compressor with its inter-cooler and inter-connecting piping between stages as supplied by the vendor. Exhibit 4-43 shows a reciprocation compressor with all components, including the inter-cooler, supplied separately by the contractor. Further reference to this can be seen in Exhibit 4-36, where the intercooler to compressor 1 is mounted separately at

grade, parallel to the compressor shaft. The inter-cooler to compressor 3 is mounted at grade, perpendicular to the centerline of the shaft, and is supplied by the vendor.

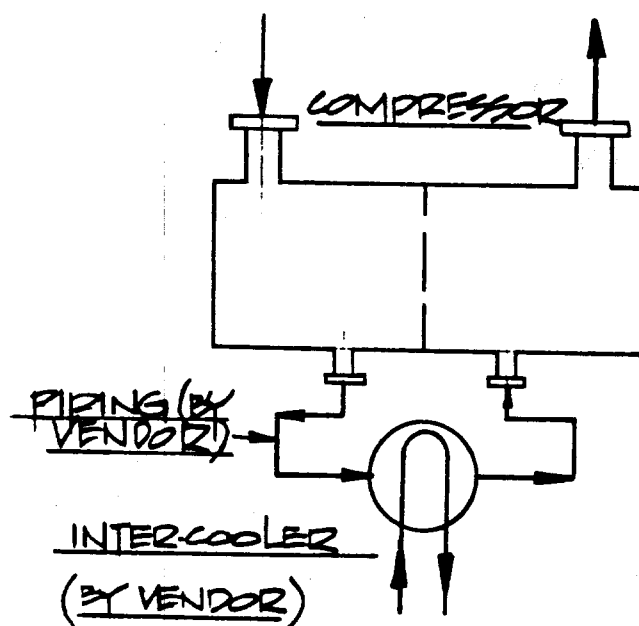
After-coolers After-coolers are used to reduce the operating temperature of the gas when it leaves the compressor, whether it continues through additional process equipment or enters a pipeline in which it must have a specific temperature. After-coolers may be located farther away from the compressor than shown in Exhibit 4-37 because the primary piping does not return to the cooler. Exhibit 4-44 shows a typical after-cooler piping and instrumentation diagram.

HOUSING AND PLATFORM REQUIREMENTS

When a compressor is covered—partially or totally enclosed by a shelter or structure—many elements determine how the layout must be approached. The factors to consider are:

- **Operation**—The plant operations personnel need room to walk safely around the machine. They must have access to valves, switches, and gauges and must be able to see all gauges, lights, and dials on the control panels.
- **Maintenance**—All principal components to be removed during major maintenance must be able to be lifted by the traveling crane, swung laterally to the clear area (designated in Exhibit 4-33), and removed from the building.
- **Climate conditions**—Installation in temperate climates may require only a roof that provides limited protection from the elements. In warmer climates, a curtain wall structure may be the right application. A curtain wall has a complete roof and four sides that are open from the operating level to a height of 8 ft (2,400 mm). The roof blocks the sun for most of the

EXHIBIT 4-42 Centrifugal Compressor with Inter-Cooler and Piping Between Stages

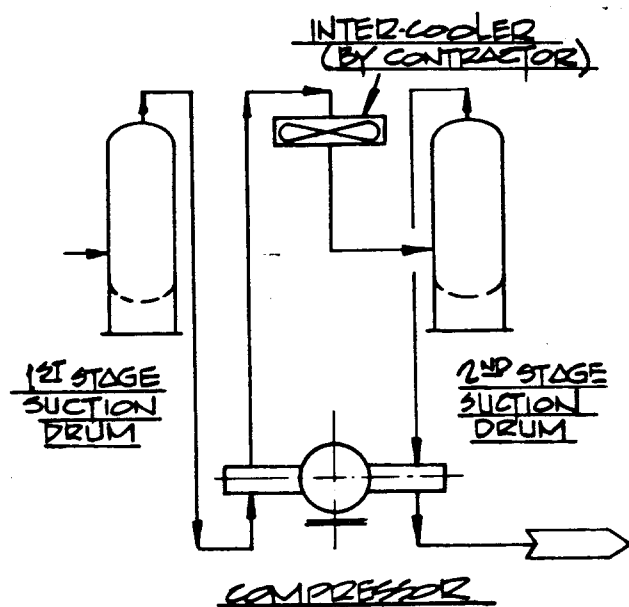


day while allowing cooler breezes to pass through the structure. This installation may also be used in areas with significant rainfall. Totally enclosed structures are usually provided in severely cold climates.

- **Safety**—The housing must have easy access throughout, ample ventilation as protection from potentially dangerous gas leaks, and a sufficient number of doors and stairways in the event of an emergency.
- **Economics**—The area inside the building should be large enough to satisfy all other factors and no larger, unless specifically requested by a client to accommodate future equipment within the structure.

Exhibit 4-45 shows how to size a building, regardless of what type of machine is used; the example is for

EXHIBIT 4-43 A Reciprocating Compressor with All Components

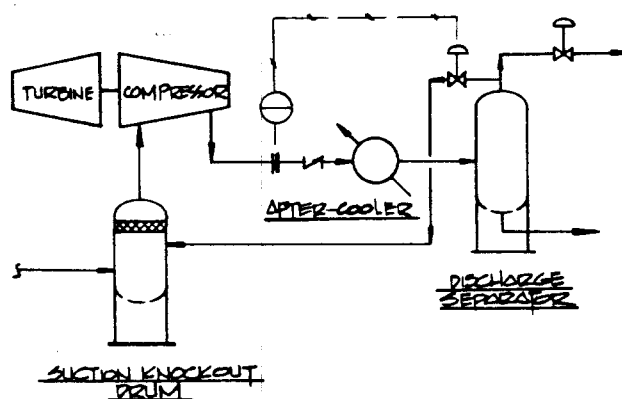


a centrifugal gas compressor. The elements to be sized are discussed in the following sections.

Floor elevation The operating floor elevation is established by making all standard allowances around and above equipment and providing the usual headroom below all horizontal piping runs and conduits, as shown by blocks E and F and Exhibit 4-45.

Building width The width of the building is established by first allowing space for the largest compressor train. There must be adequate room between the steam turbine, lube oil drain piping, and any miscellaneous piping that may be arranged along the adjacent wall, as shown by block C in Exhibit 4-45. At the com-

EXHIBIT 4-44 After-Cooler Piping and Instrumentation Diagram



pressor end, there must be sufficient room for the operators and any routine maintenance, as shown in block B. Although the operator must have access to the front of the control panel, it may also be necessary to allow access to the rear of the panel for maintenance, shown as clearance D.

Building elevation The elevation of the building is further established by determining the size of the clear maintenance area (shown as X by Y). This area must accommodate the largest single piece to be maintained at a minimum elevation above all operating floor requirements, shown as clearance A. The alternative maintenance area may be used if this area is clear throughout the length of the building.

Hook centerline elevation The layout designer determines the centerline elevation of the hook. The maximum lifted load must be supplied to the structural engineer or building contractor to furnish the correct traveling crane. The eave elevation is then set on the basis of the clearance of the crane selected.

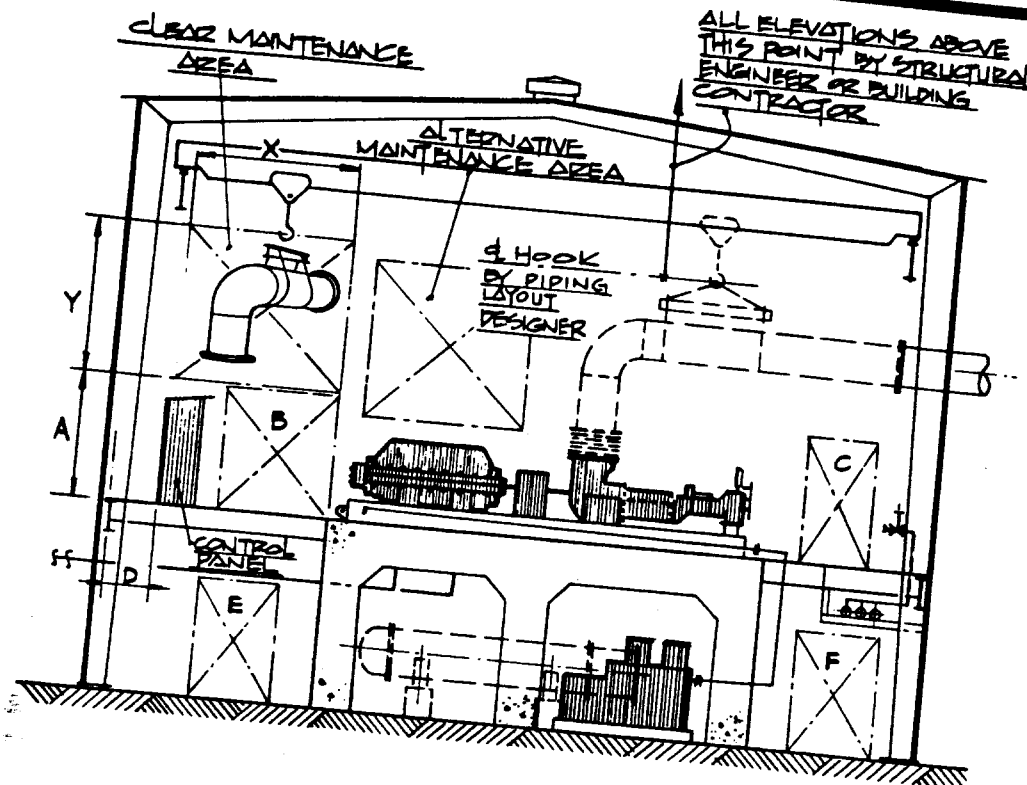


EXHIBIT 4-45
Compressor Shelter:
Sizing Criteria

GENERAL COMPRESSOR LAYOUT

This section highlights additional features to consider in the design of a centrifugal or reciprocating compressor layout. There are many ways to develop a compressor layout, but certain aspects of these machines dictate how best to approach a design that optimizes operation, maintenance, and safety while adhering to economic requirements.

Centrifugal Compressors: Inlet Piping

With higher compressor velocities and rotating speeds, the plant layout designer must give greater consideration to the compressor inlet line. The ASME power test code requires a minimum of three diameters of straight run piping between the elbow and the inlet nozzle. Often, however, such factors as gas velocities, molecular weight, and temperature must be considered for the optimum layout. An equipment engineer should be consulted at the outset to develop a base-case layout requirement. The preferred design is one in which the horizontal run is parallel to the compressor shaft, as shown in arrangement A of Exhibit 4-46. (In these examples, it is assumed that the compressor inlet size is 12 in and that the required L-dimension for this particular gas compressor is four diameters.) The compressor elevation can be affected

by the various layouts. Another factor that could influence straight run requirements is the need to inject wash water into the gas stream to clean compressor blades, as shown in Exhibit 4-47.

Suction Line Strainers

Compressor suction lines must be free of any foreign particles that could damage the internals of the machine. Strainers are installed in the inlet line between the block valve and the compressor inlet nozzle. After the unit has been on stream for some time, the strainers are normally removed. Should the strainer be the permanent type, a clean-out connection must be added to remove any trapped foreign matter during a shutdown of the compressor. Exhibit 4-48 illustrates two such applications.

Break-Out Flanges

All lines to a compressor that must be removed for maintenance of the compressor or strainer removal must have a set of flanges in the line in addition to the set at the compressor nozzle. Exhibit 4-49 shows one line with a built-in extra set of flanges at the shut-off valve and another line for which flanges must be added because there are no other flanges near the compressor case.

LINE SIZE = 12" L DIMENSION = 4 ϕ (DIAMETERS)

EXHIBIT 4-46
Compressor Suction
Configurations

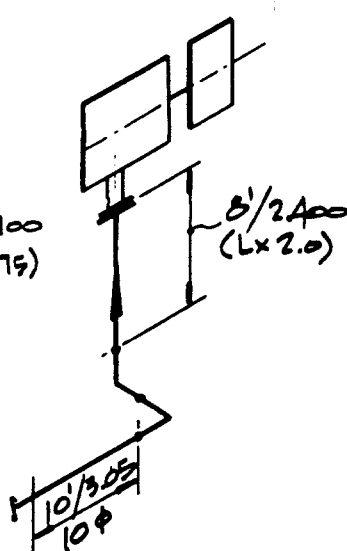
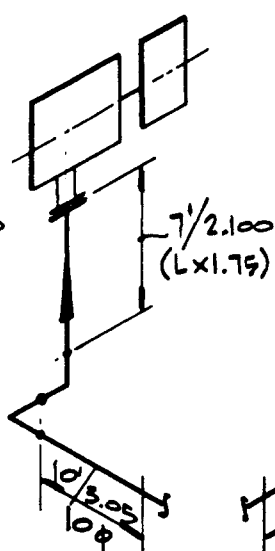
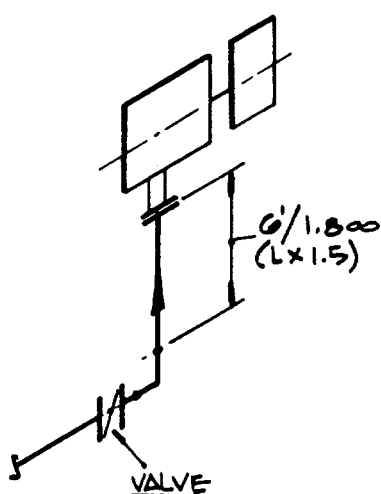
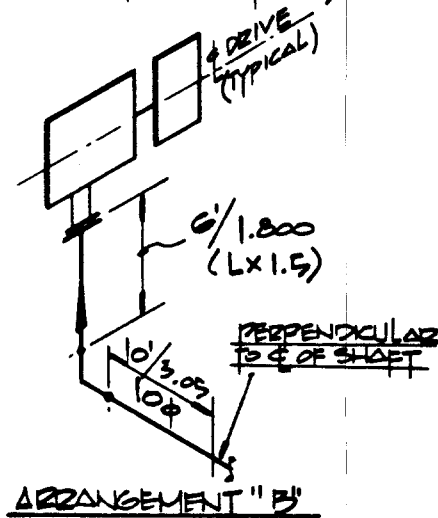
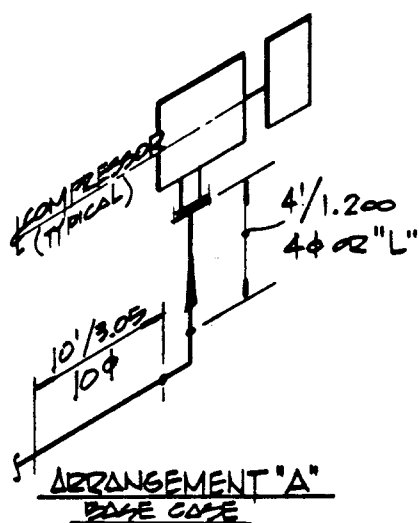
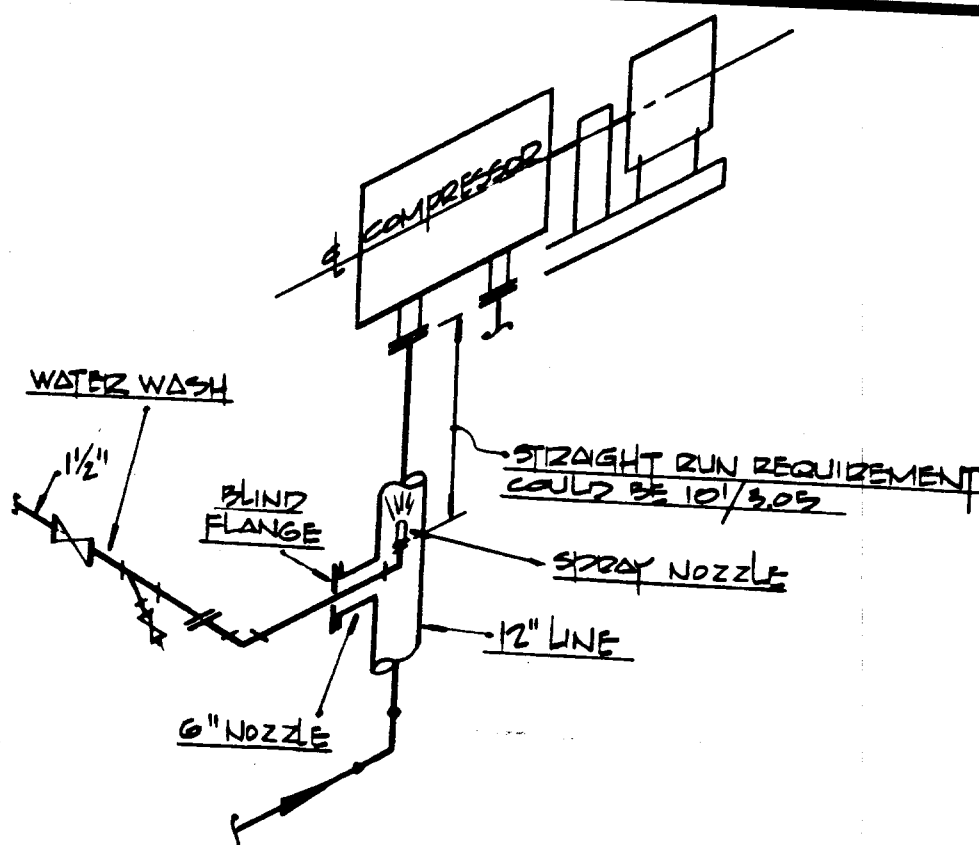


EXHIBIT 4-47
Wash-Water Injection



Miscellaneous Piping Connections

The plant layout designer must review both the engineering contractor and the vendor piping and instrumentation diagrams to ensure that all connections have been piped up by one or the other.

Primary operating valve accessibility All operating valves must be accessible to the operator from grade or the operating platform around the machine. Valves that are physically out of reach may be made

accessible through extension stems or chain operators. Exhibit 4-50 shows some of these variations.

High-Pressure Steam Inlet Piping

To streamline the high-pressure, high-temperature steam inlet piping to the turbine, the plant layout designer should review the compressor outline drawing to locate the neutral axis. At this point, the turbine is anchored to the steel frame. As depicted in Exhibit

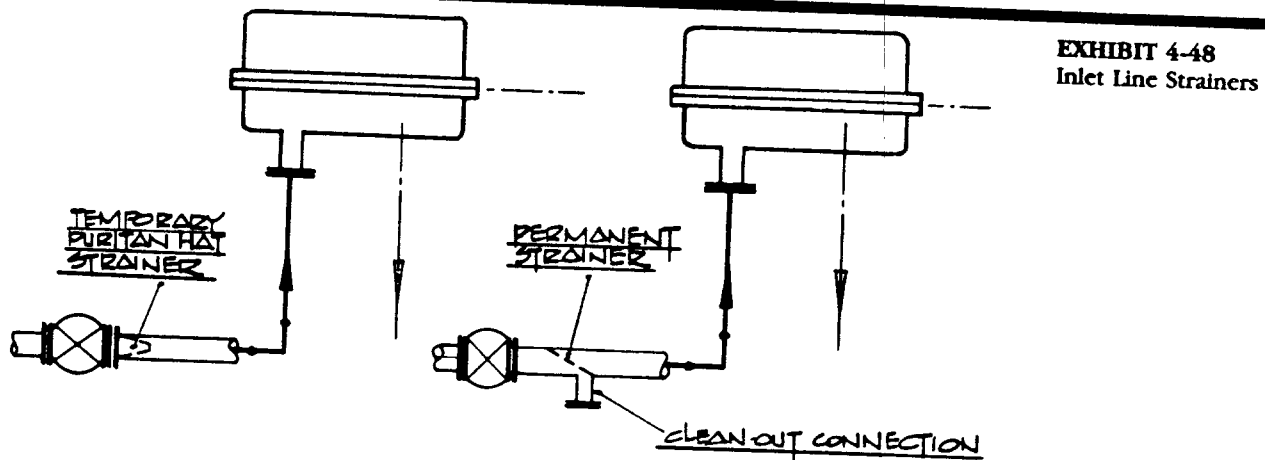


EXHIBIT 4-49 Maintenance Break-Out Flanges

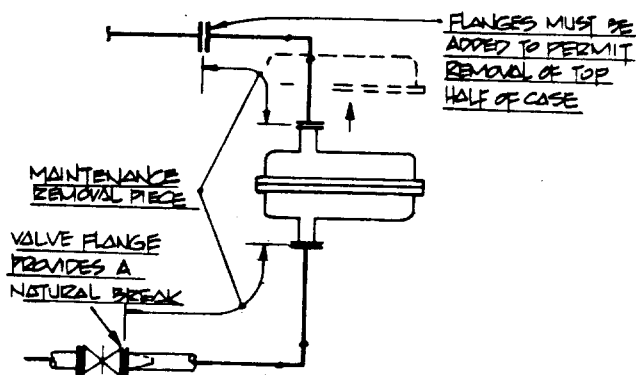


EXHIBIT 4-50 Operating Valve Accessibility

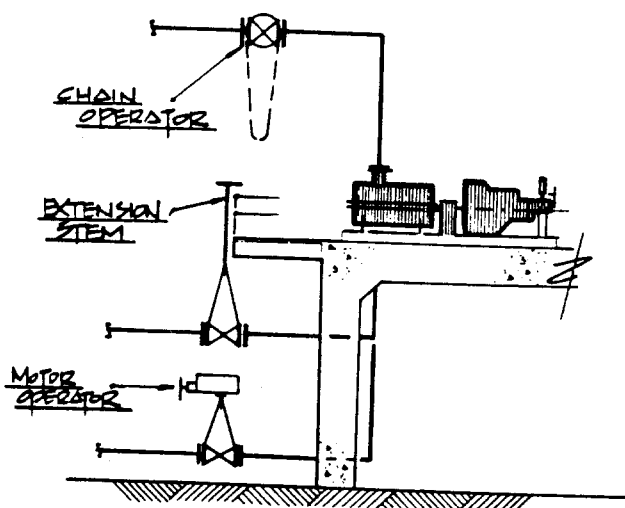
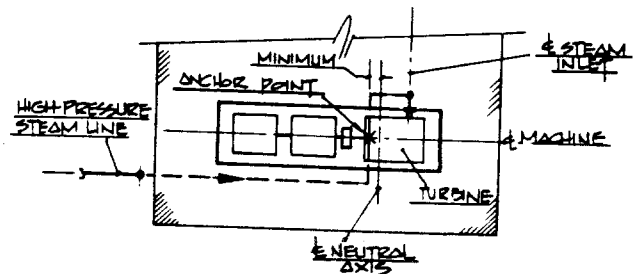


EXHIBIT 4-51 High-Pressure Steam Inlet Piping



4-51, locating the line anchor close to this point enables the designer to generate a layout with a minimum amount of leg, thereby satisfying the stress and flexibility requirements in this particular system.

Straightening Vanes

When the straight run on the inlet piping is less than desired, a straightening vane may be installed to smooth the flows and improve the compressor performance. These vanes must be in accordance with ASME or American Gas Association standards. If use of vanes can be tolerated, the length for any arrangement (as illustrated in Exhibit 4-46) can be divided by four.

Reciprocating Compressor Piping

Poorly designed reciprocating compressor piping causes pulsation that can reduce machine capacity and increase horsepower requirements. Line design should be simple and run as low to grade as possible to facilitate support. Once the compressor piping has been designed, the proposed configuration is subjected to an analog study that may be done by the

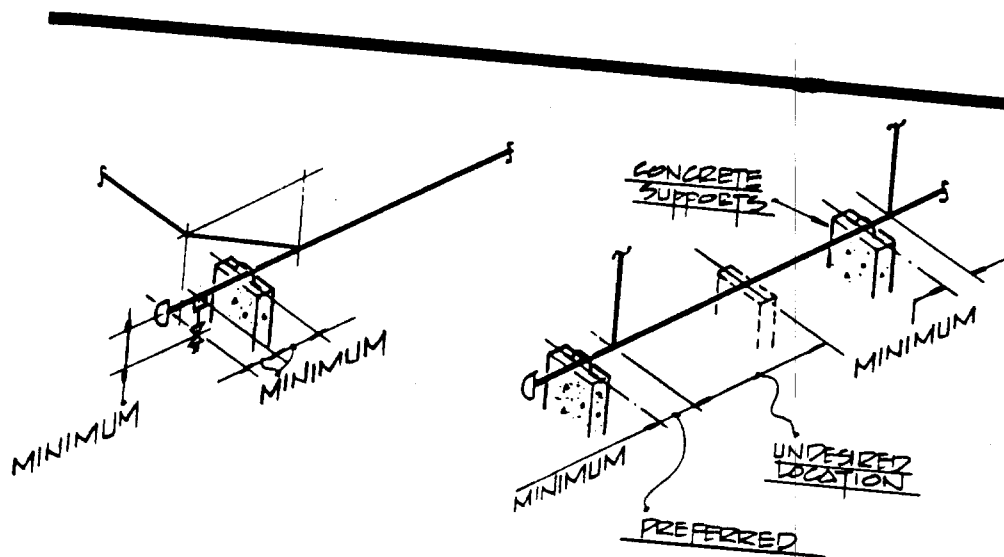


EXHIBIT 4-52
Compressor Line
Branches

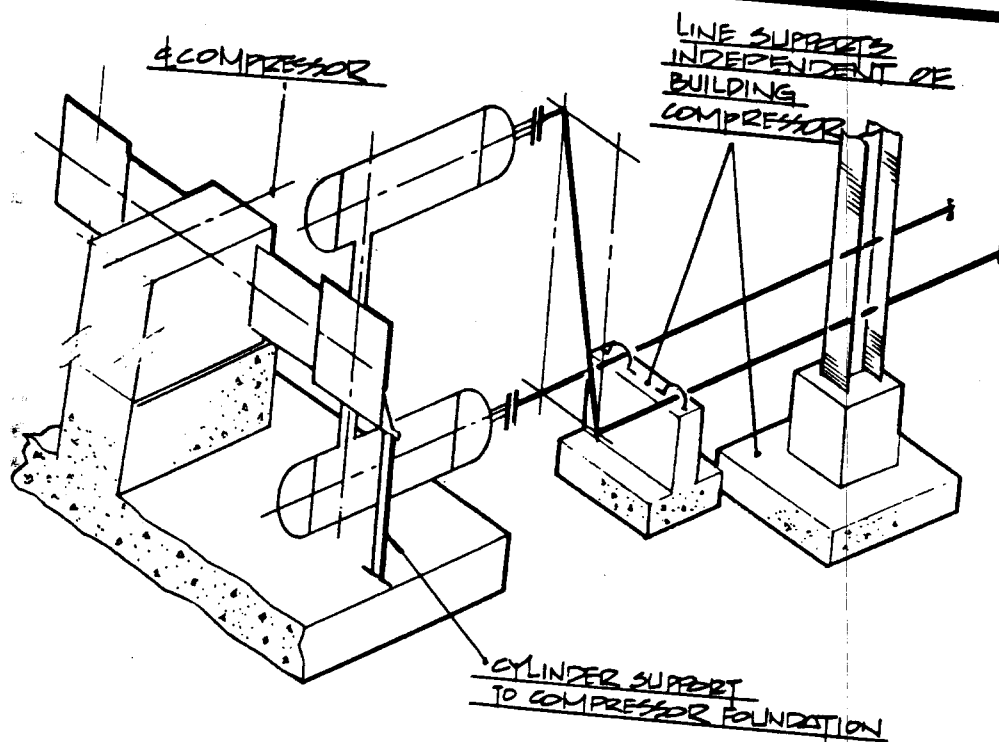


EXHIBIT 4-53
Compressor Supports

vendor or an independent testing laboratory. Simulated by electrical circuits, this analog study identifies potentially damaging acoustic or pulsation problems during the design phase of the project, eliminating higher repair and redesign costs at a later date.

Line Branches

All branches should be located close to a line support whenever possible. Any such connections should be

located on the top of the piping to minimize any potential liquid carry-over. Exhibit 4-52 shows typical branch connections.

Compressor Pipe Supports

Exhibit 4-53 illustrates how to minimize the transmission of damaging vibrations by isolating the line supports from adjacent compressor or building foundations, operating floor steel, or building framing.

Drain Piping

Ample drain piping must be provided on suction and discharge piping to avoid liquid carry-over into the cylinders. On multistage machines, care must be taken with the drain header system to avoid piping up a low-pressure drain into a high-pressure header. Doing so forces the higher-pressure liquids into the lower-pressure cylinders. Compressors have small amounts of gas leakage at the stuffing box, which is usually picked up in the distance piece between the cylinder and the crankcase. Gas-tight distance pieces are used for such hazardous materials as hydrogen. The piping and in-

strumentation diagram should be carefully reviewed to ensure that all vents and drains are properly designed.

This chapter has given the plant layout designer a variety of possible solutions to successfully develop a comprehensive compressor layout. Maximizing efficiency while minimizing original capital expenditures and ongoing maintenance costs is a demanding task. The close coordination and cooperation of equipment and system engineers, an understanding of the client's needs and preferences, and designer creativity are all necessary elements to achieve this goal.

Drums

Generally, drums are cylindrical hollow steel vessels used in process plants as intermediate containers that receive liquid from distillation and condensing equipment. Drums also collect liquid from vapor circuits and pump it to other process groups, disposal, or product storage. They are also used for chemical and catalyst storage, steam generation, and deaeration of boiler feed water. This chapter highlights the general requirements for drum plant layout and provides information required to locate nozzles, instruments, piping, and controls for platforming and operator and maintenance access.

TYPES OF DRUMS

The drums discussed in this chapter are process unit drums that are used for refluxing, surge, suction, and general liquid collection. Drums in these services can generally be divided into two categories: horizontally and vertically mounted. Drum internals are far less sophisticated than the components found inside the distillation tower and are limited to demister pads, baffles, vortex breakers, and distribution piping. Exhibit 5-1 shows a typical vertical compressor suction

drum, and Exhibit 5-2 shows a horizontal reflux drum.

When specified, steam drums and deaerators are usually furnished as a proprietary item. Layout is limited to confirmation of nozzle and support locations to suit piping and structural configurations and platforming for operator and maintenance access. Exhibit 5-3 illustrates a typical deaerator arrangement.

EXHIBIT 5-1 Typical Vertical Compressor Suction Drum

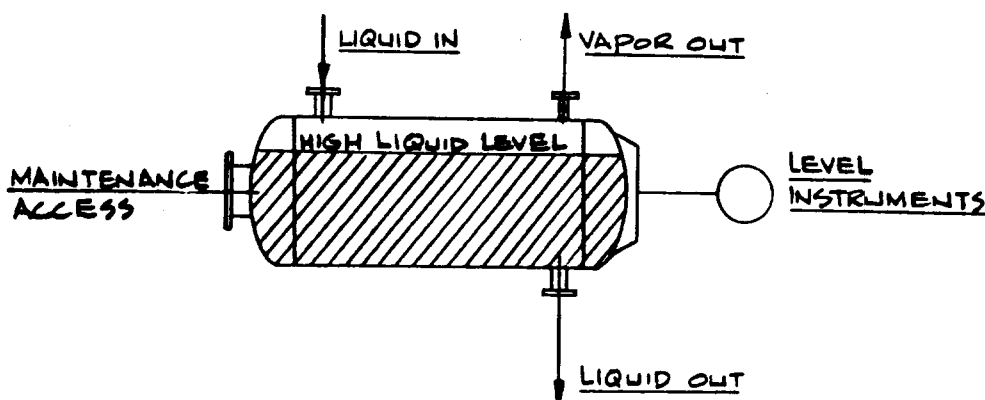
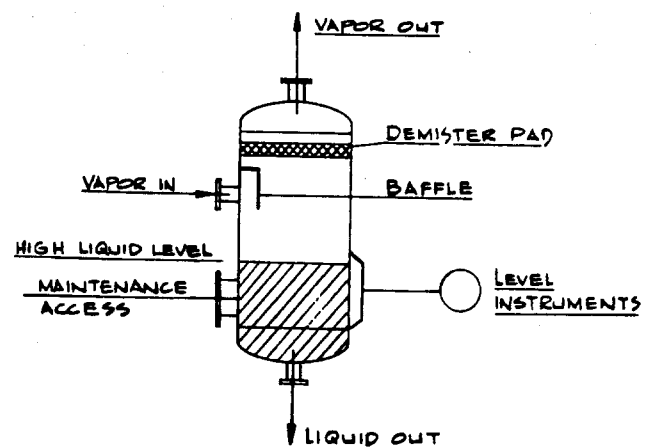
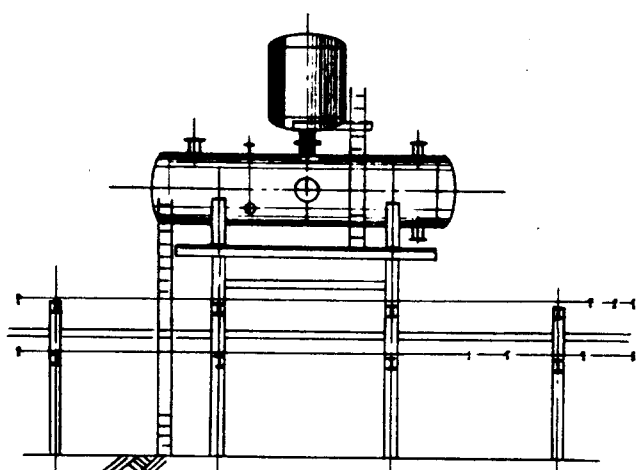


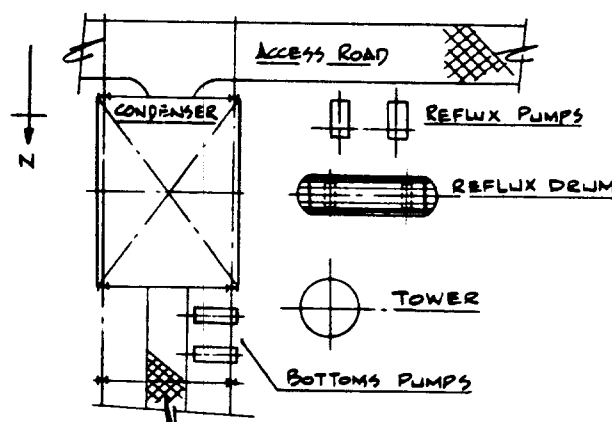
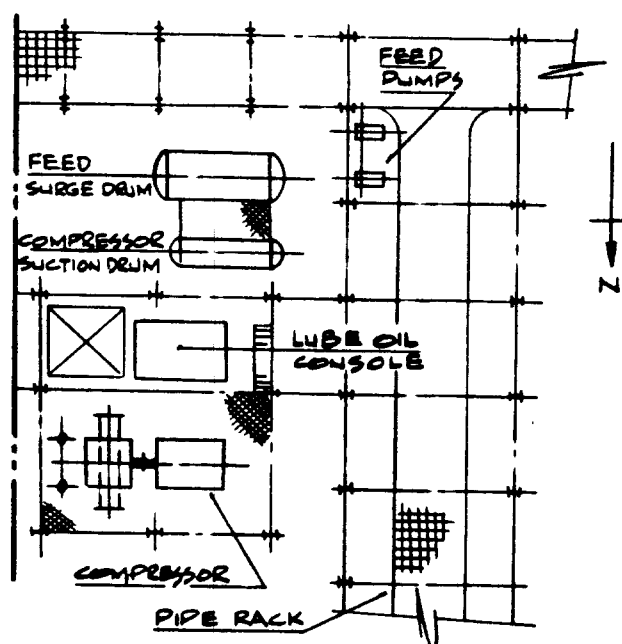
EXHIBIT 5-2
Typical Horizontal Reflux Drum

EXHIBIT 5-3 Typical Deaerator Arrangement

LOCATION OF DRUMS

Drums are located within a process unit either adjacent to related equipment (e.g., the reflux drum) or as a standalone operation (e.g., a condensate collection drum). When operating within process sequence of related items (e.g., pumps, condensers, and towers), the drum should be positioned to facilitate an orderly and economic piping interconnection between itself and those items.

Within the conventional inline process unit, drums and their related items are generally located on either side of a central pipe rack serviced by auxiliary roads for maintenance access. In certain cases (e.g., for flash drums and deaerators), drums can be located above the pipe rack. In chemical plants, drums are generally located at all levels of enclosed or open-sided structures. For example, Exhibit 5-4 shows the drum location in a tower reflux system, Exhibit 5-5 shows the typical location of feed surge and compressor suction drums, and Exhibit 5-6 shows the drum locations in an enclosed chemical plant structure.

EXHIBIT 5-4 Drum Location in a Tower Reflux System**EXHIBIT 5-5** Locations for Feed Surge and Compressor Suction Drums

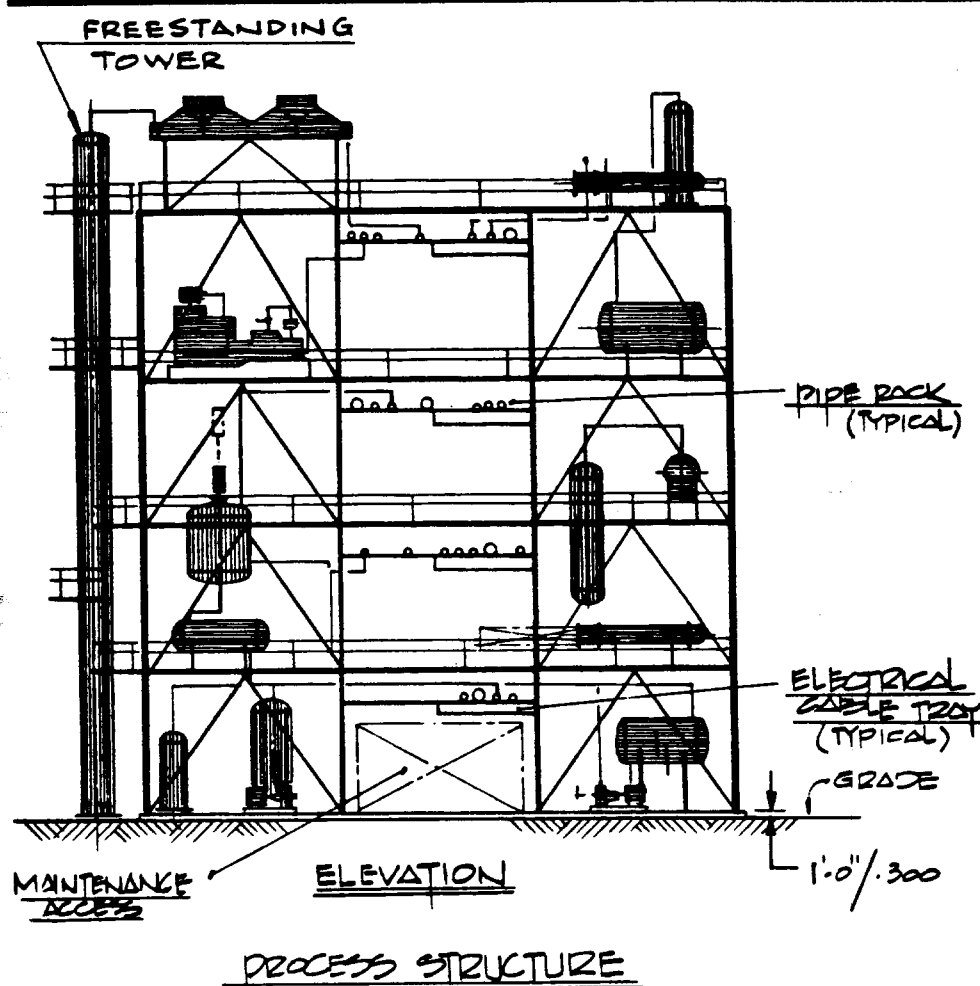


EXHIBIT 5-6
Drum Locations in an
Enclosed Chemical Plant
Structure

Elevation and Support

Similar to towers, drum elevations are dictated by the NPSH, as illustrated in Exhibit 5-7, minimum clearance, common platforming, and maintenance and operator access. Within structures, especially chemical facilities, drums could be elevated above the minimum requirements of accommodate floor space avail-

ability. Drums for chemical collection systems are generally located below ground in concrete pits, as shown in Exhibit 5-8.

Methods of support are influenced by the size and location of the drum. Similar to towers, large vertical drums are supported by skirts. If size permits, small vertical drums may be supported by legs, as shown in Exhibit 5-9, or by lugs if elevated within a structure, as

EXHIBIT 5-7 Net Positive Suction Head Elevation Requirements for a Horizontal Drum

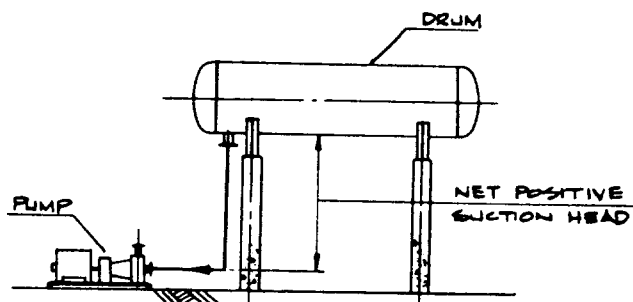


EXHIBIT 5-8 Elevation Requirements for an Underground Drum

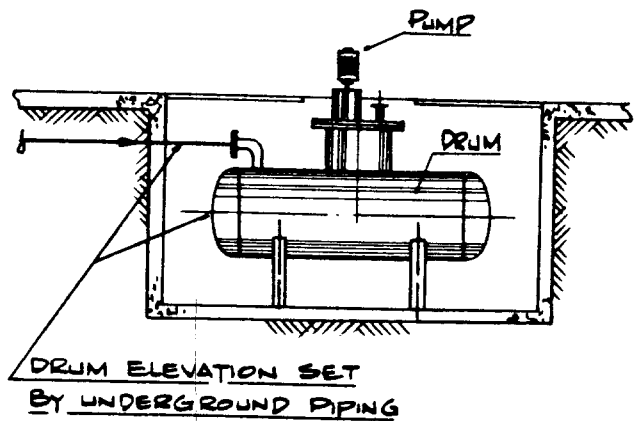


EXHIBIT 5-9 Sample Leg-Supported Drum

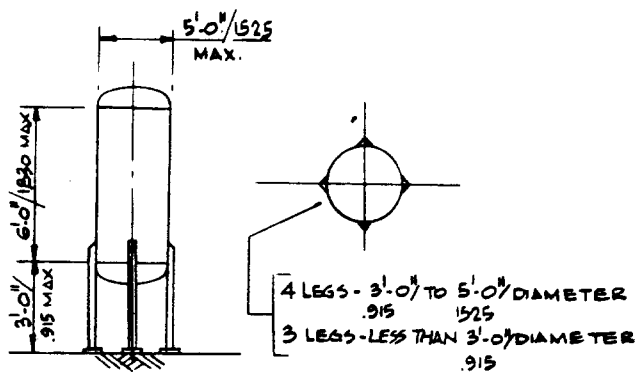


EXHIBIT 5-10 Sample Lug-Supported Drum

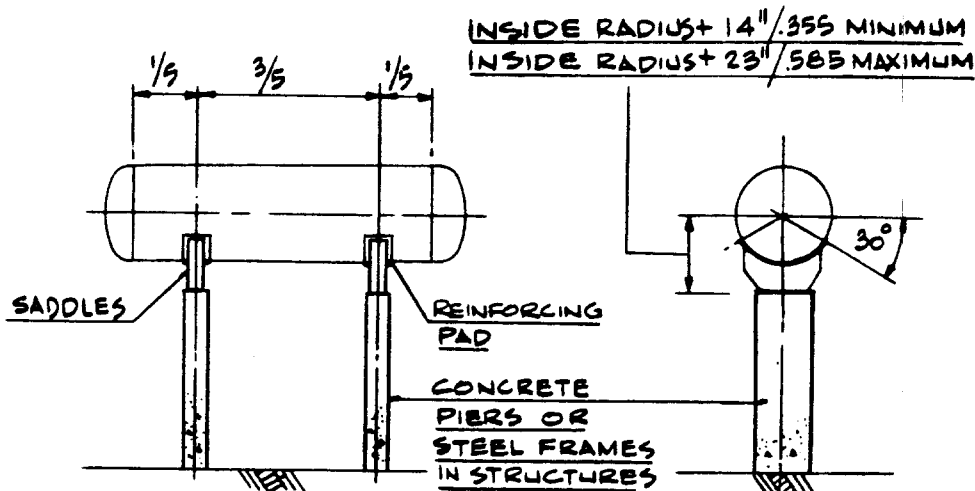
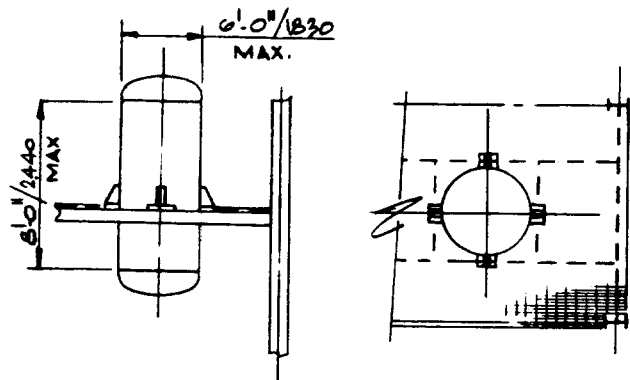
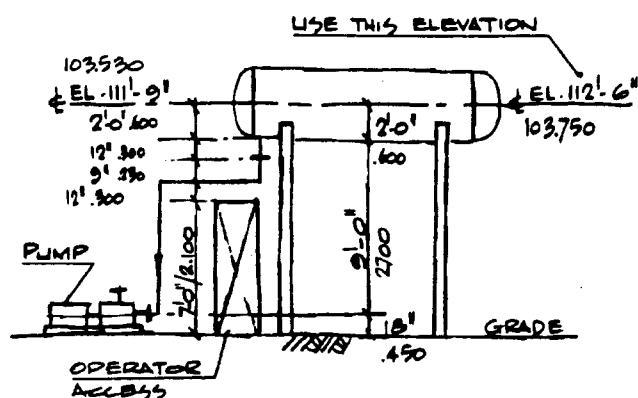


EXHIBIT 5-11
Sample Saddle-Supported Drum

EXHIBIT 5-12 Drum Elevation Sketch



shown in Exhibit 5-10. Horizontal drums are usually supported by saddles from concrete piers or steel frames if elevated within a structure, as illustrated in Exhibit 5-11. Leg-supported drums should not be used in reciprocating compressor circuits.

The first step in drum layout is setting the height of the drum. To do this, the plant layout designer requires the following information:

- Drum dimensions.
- Type of heads.
- Support details.
- NPSH requirements of pump.
- Bottom outlet size.
- Minimum clearances.
- Location.

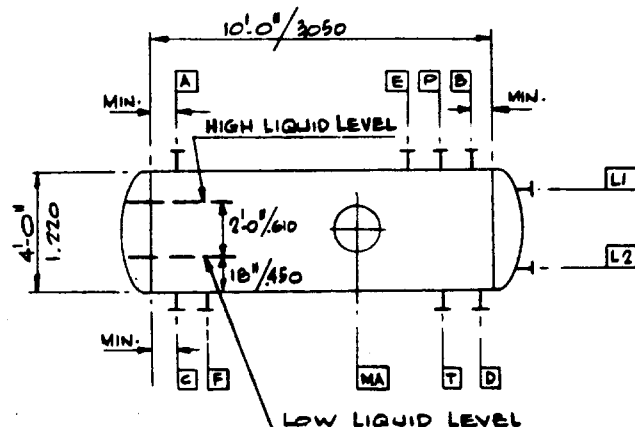
The centerline elevation of the drum, as illustrated in Exhibit 5-12, was set using the following listed information (it is recommended that a freehand sketch be used for this exercise):

- Drum dimensions—4-ft (1,220-mm) diameter by 10-ft (3,050-mm) length.
- Support details—Saddles and concrete piers.
- NPSH—9 ft (2,700 mm).
- Bottom outlet—4 in.
- Location—Freestanding.
- Minimum clearance—7 ft (2,100 mm).

NOZZLE LOCATIONS

Drum dimensions, nozzle sizes, and, if required, internals are shown on the process vessel sketch furnished by process engineering and included in the process

EXHIBIT 5-13 Typical Process Vessel Sketch for a Horizontal Drum



NOZZLE SUMMARY		
SYMBOL	SIZE	SERVICE
A	1 1/4" ISO RF	VAPOR OUT
B	6"	LIQUID IN
C	4"	LIQUID OUT
D	2"	DRAIN
E	1"	VENT
F	1"	STEAM OUT
MA	18"	MAINTENANCE ACCESS
L	2"	LEVEL
P	1"	PRESSURE
T	1"	TEMPERATURE

release package. Exhibit 5-13, shows a typical process vessel sketch for a horizontal drum. The following information is required in order to position drum nozzles:

- Process vessel sketch.
- Instrument vessel sketch.
- Piping and instrumentation diagrams.
- Plant layout specification.
- Nozzle summary.
- Insulation requirements.
- Plot plan.

Exhibit 5-14 depicts the preferred nozzle locations for horizontal drums.

The preferred location for level instruments is away from the turbulence at the liquid outlet nozzle. Although the vessel is provided with a vortex breaker, instruments should be set in the quiet zone of the vessel—for example, on the opposite side of the weir or baffle or near the vapor outlet end. Process nozzles should be located a minimum from the tangent line. Steam-out connections should be located at the end opposite the maintenance access and vent in the bot-

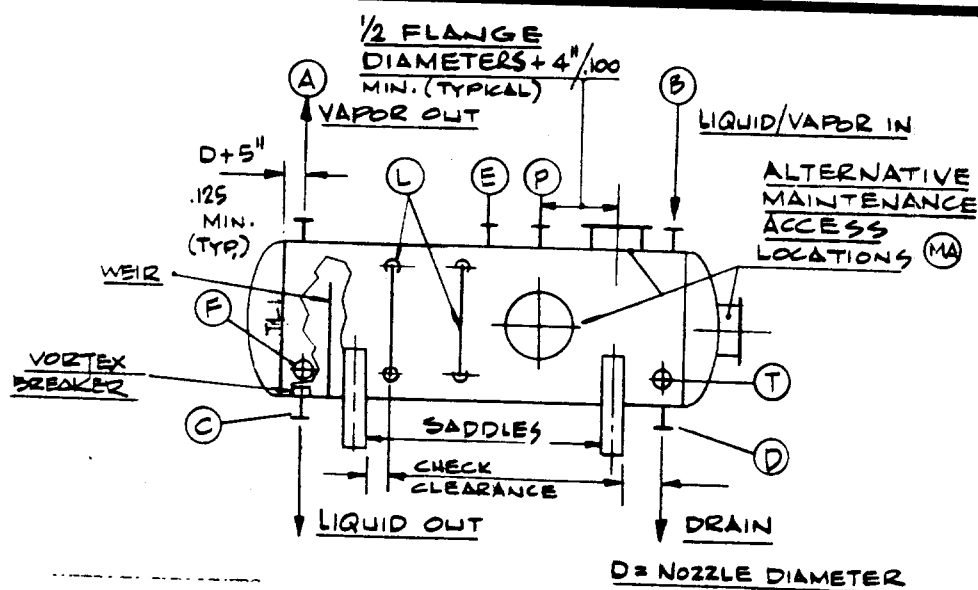
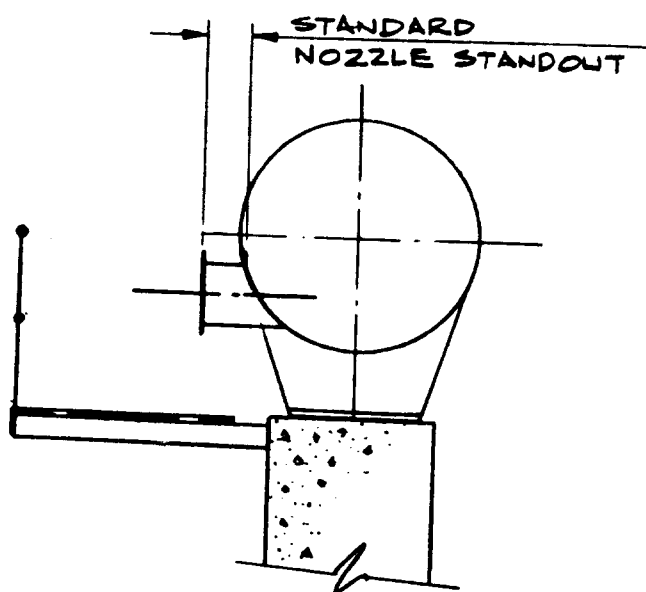


EXHIBIT 5-14
Preferred Nozzle
Locations for a
Horizontal Drum

EXHIBIT 5-15 Typical Hillside Nozzle



tom section of the drum. Pressure instruments should be located anywhere in the vapor space, preferably at the top section of the drum. Temperature instruments should be located anywhere in the liquid space, preferably at the bottom section of the drum. The vent connection should be located in the top section of the drum at the end opposite the steam-out connection. The drain should be located in the bottom section of the drum.

To facilitate specific elevation requirements for level instruments or positioning a maintenance access, nozzles may be located off the main axis. These nozzles are generally referred to as hillside nozzles. A typical hillside nozzle is shown in Exhibit 5-15. Tall vertical drum nozzles should be elevated and oriented using the tower subject as a guide. It should be noted, however, that nozzle locations are not restricted by internal components, as is the case for the distillation tower. More information on vertical drums is available in Chapter 10, Towers.

The nozzles shown in Exhibit 5-16 were positioned

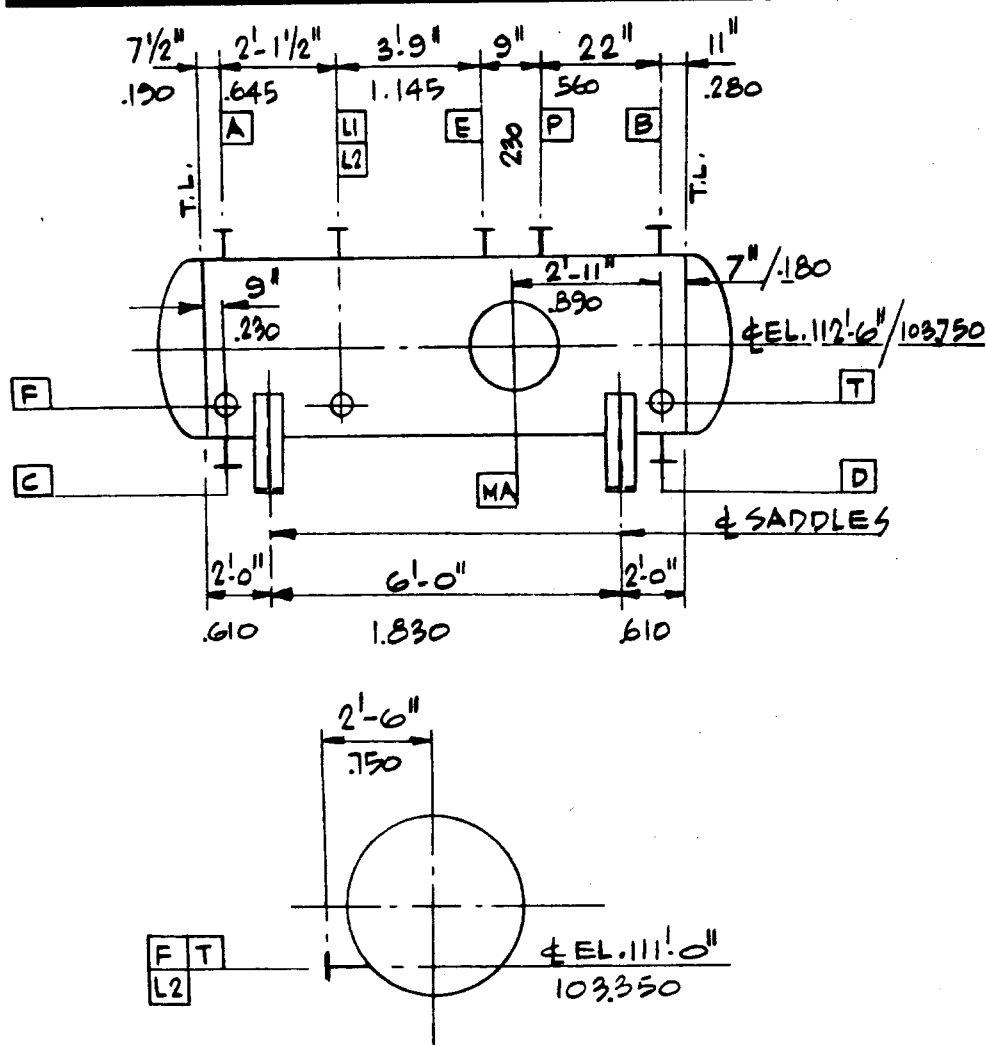


EXHIBIT 5-16
Sample Nozzle Locations
and Elevations

using the guidelines discussed in this chapter as well as other information contained in this book. The information required can be located as follows:

- Process vessel sketch—Exhibit 5-13.
- Instrument vessel sketch—Exhibit 5-29.
- Piping and Instrumentation Diagram (P&ID)—Exhibit 5-28.
- Nozzle summary—Exhibit 5-13.
- Plant layout specification—Chapter 2.
- Insulation—No requirements.
- Plot plan—Exhibit 5-4.

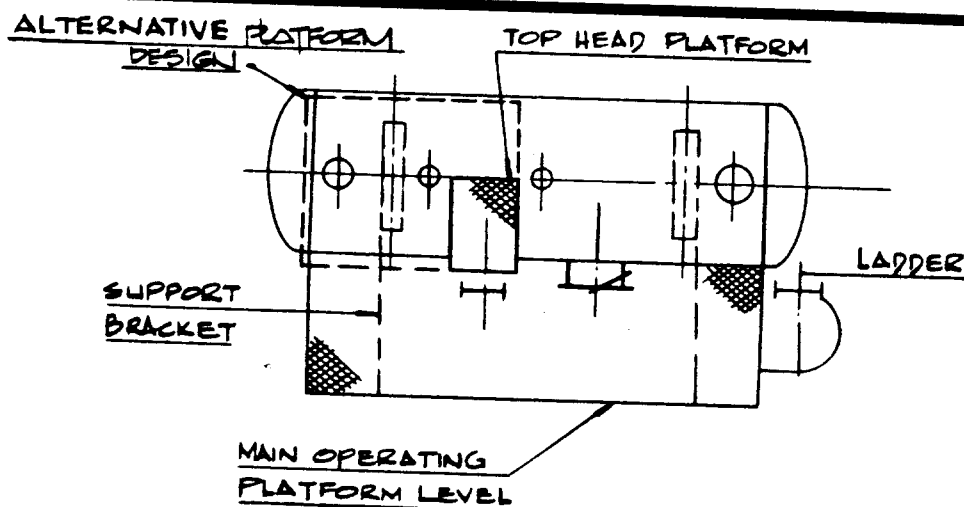
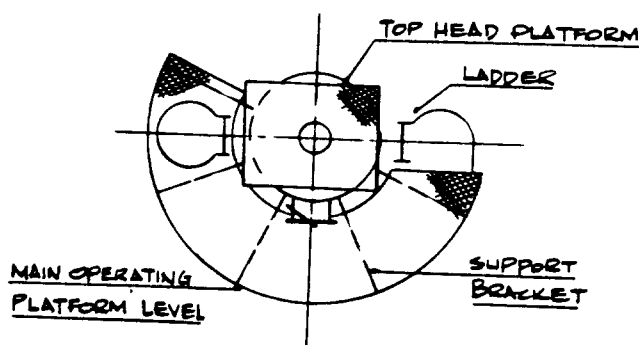


EXHIBIT 5-17
Platform Arrangement at
a Horizontal Drum

EXHIBIT 5-18 Platform Arrangement at a Vertical
Drum



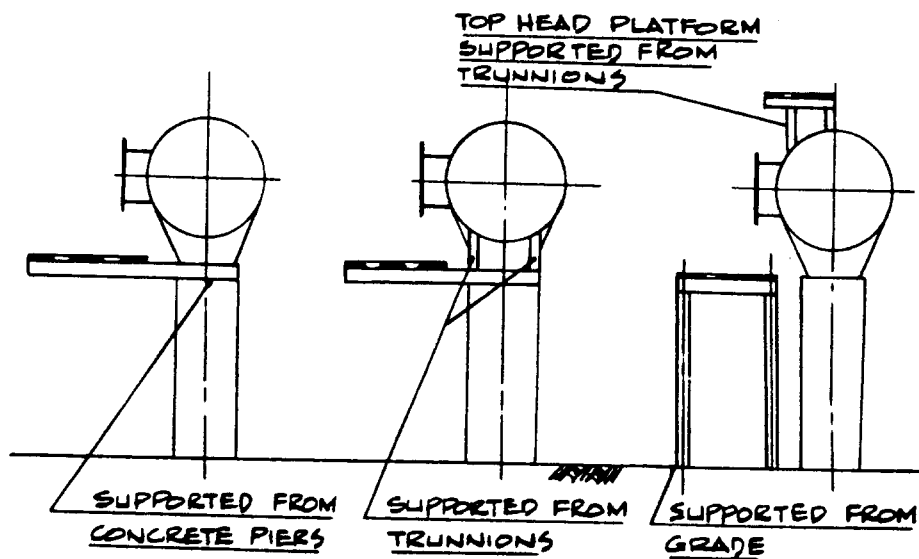
PLATFORM ARRANGEMENTS

Platforms are required at drums for access to valves, instruments, blinds, and maintenance accesses. Exhibit 5-17 illustrates a platform arrangement at a horizontal drum, and Exhibit 5-18 displays the arrangement for a vertical drum.

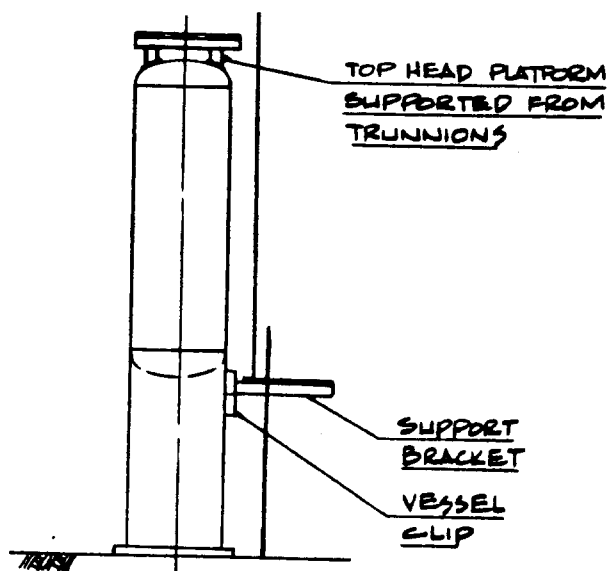
For tall vertical drums, platforms are usually circular and supported by brackets attached to the shell of the drum. Platforms at horizontal drums are usually rectangular and are supported by brackets attached to the concrete piers supporting the drum or trunnions attached to the shell of the drum, or by structural steel supported from grade. Drums located in structures, if size permits, use the structure floor for access to controls. Top head platforms on horizontal and vertical installations are supported by trunnions attached to the vessel head. Generally, access to freestanding drum platforms is by ladder. Typical drum platform arrangements are shown in Exhibit 5-19.

Platform elevations for drums are set by the items that require operation and maintenance. On tall vertical and high elevated horizontal drums, the platform elevations are determined by a maximum ladder run of 30 ft (9,150 mm). Exhibit 5-20 illustrates horizontal drum platform and ladder elevation requirements. Platform floor space requirements are dictated by operator access to controls, instruments, and maintenance accesses. Exhibits 5-21 and 5-22 show platform floor space requirements for horizontal and vertical

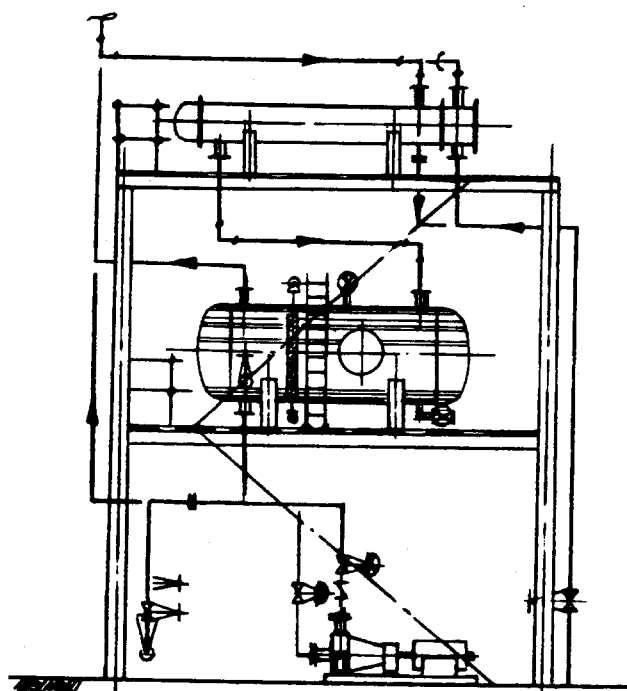
EXHIBIT 5-19 Typical Drum Platform Arrangements



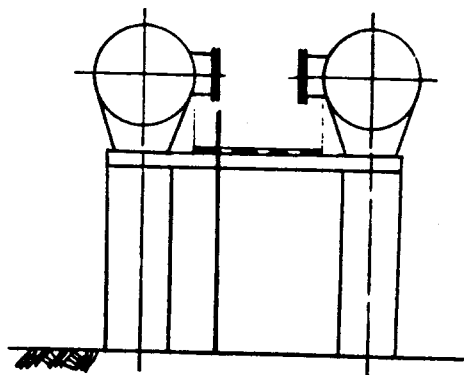
a. Horizontal Drum Platform Supports



b. Vertical Drum Platform Supports



c. Structure-Located Drum



d. Common Platform

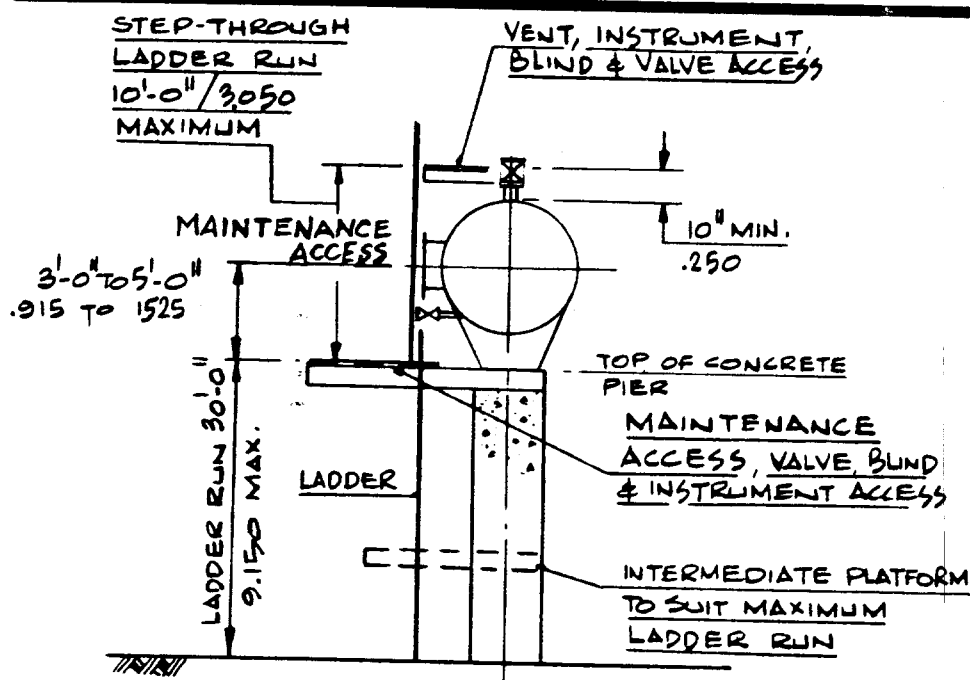


EXHIBIT 5-20
Horizontal Drum
Platform and Ladder
Elevation Requirements

installations. For tall vertical drums, platforms should be arranged using the tower subject as a guide; this is covered in Chapter 10.

Exhibit 5-23 depicts a horizontal drum platform arrangement that was designed using the guidelines in this chapter. This information can be found as follows:

- Process vessel sketch—Exhibit 5-13.
- Drum elevation—Exhibit 5-12.
- Plot plan—Exhibit 5-4.
- Type of support—Saddles and concrete piers.

PIPING ARRANGEMENTS

Piping at drums should be arranged in conjunction with nozzle locations, platform arrangements, and the

drums' location to related equipment. Piping should be positioned to facilitate the installation of supports, with sufficient flexibility to absorb any excessive stresses during operation. Piping at tall vertical drums should be arranged in accordance with the guidelines given in Chapter 10.

If required, piping at horizontal freestanding drums should be supported from the shell of the drum, the platform steel, or the concrete piers supporting the drum. Piping associated with drums located within structures should be supported from the structural steel. Exhibit 5-24 shows typical pipe supports at a horizontal drum, and Exhibit 5-25 shows a typical pump suction arrangement.

Relief valves that are open to the atmosphere on low elevated horizontal or vertical drums should be positioned to allow the discharge piping to be routed

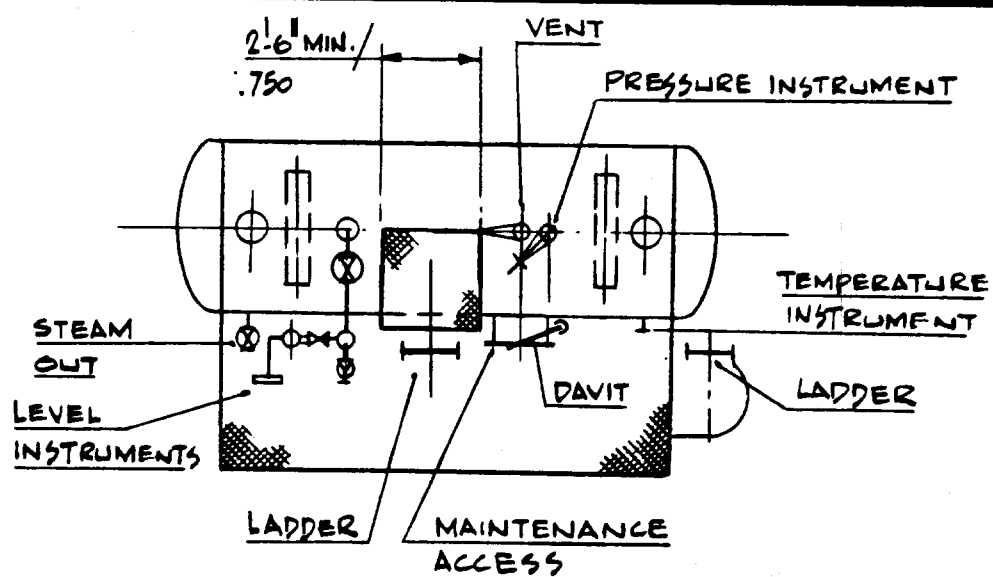


EXHIBIT 5-21
Horizontal Drum
Platform Floor Space
Area Requirements

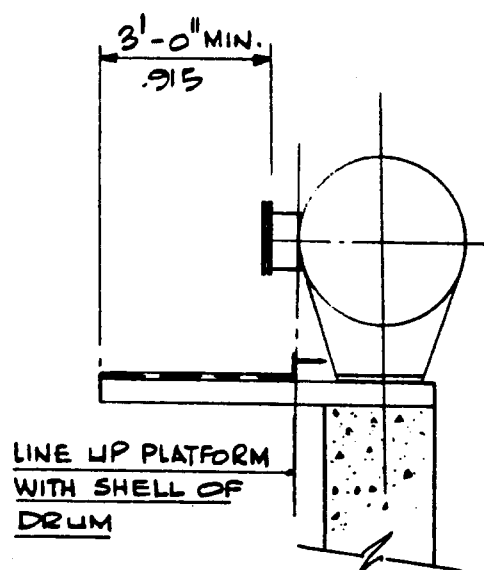


EXHIBIT 5-22 Vertical Drum Platform Floor Space Area Requirements

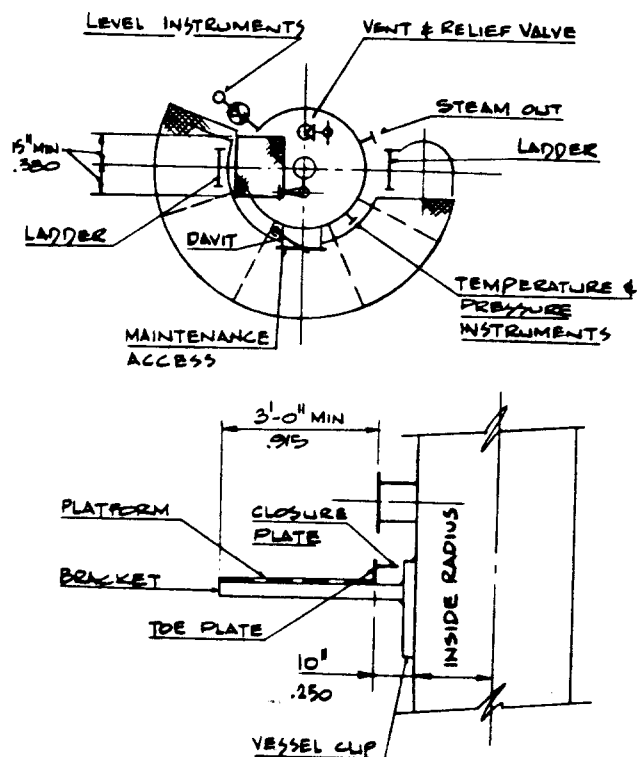


EXHIBIT 5-23 Horizontal Drum Platform Arrangement

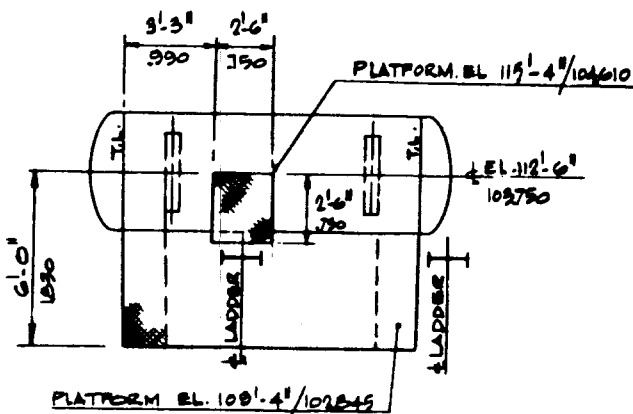


EXHIBIT 5-24
Horizontal Drum Pipe
Supports

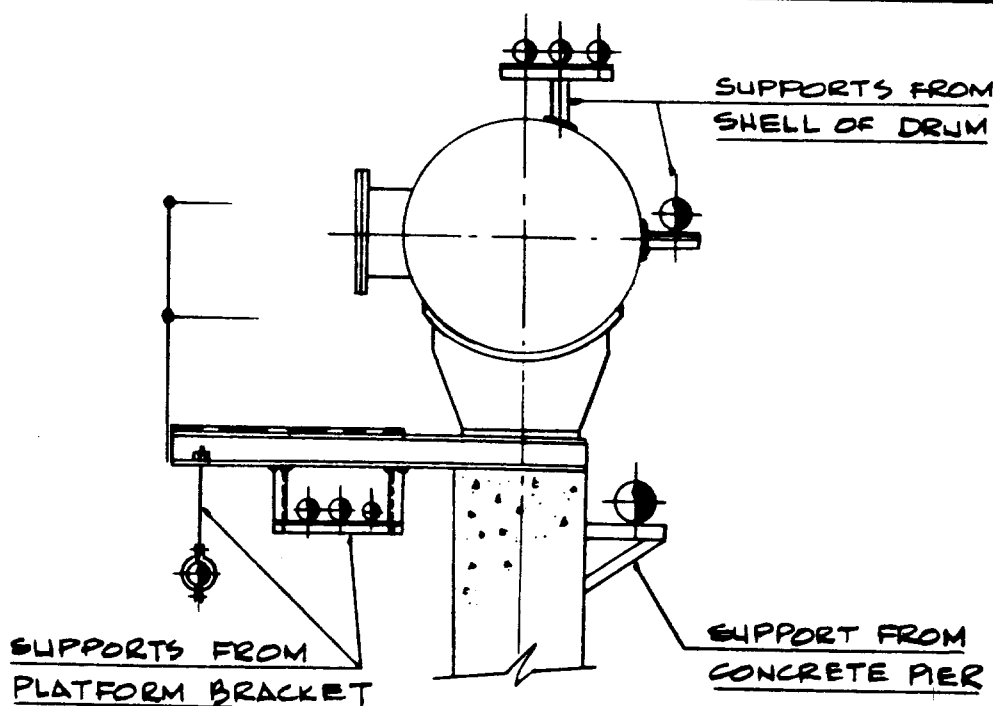
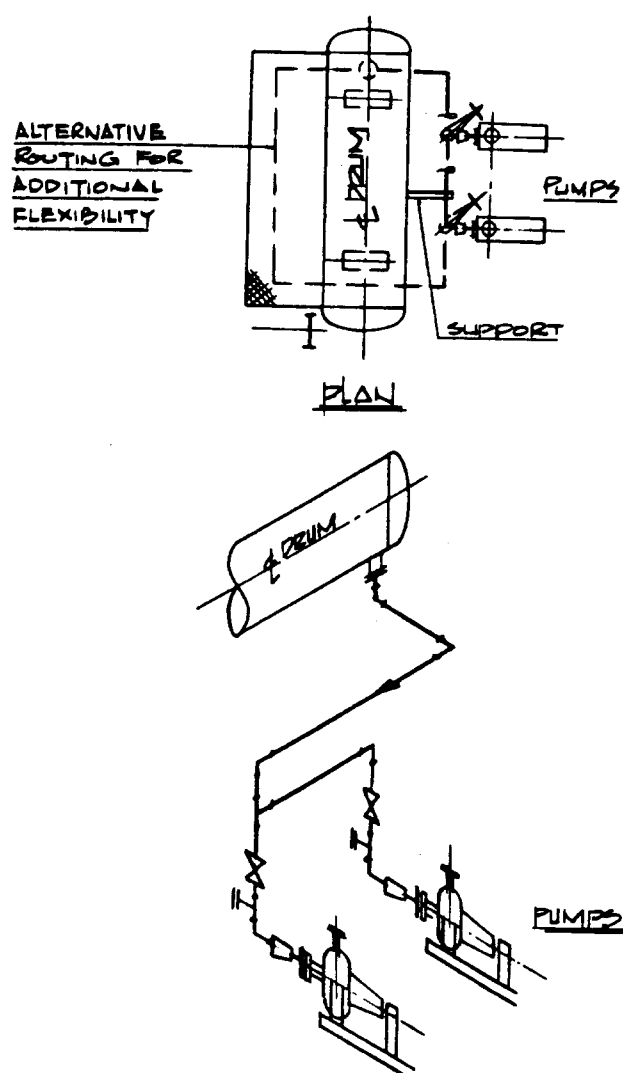
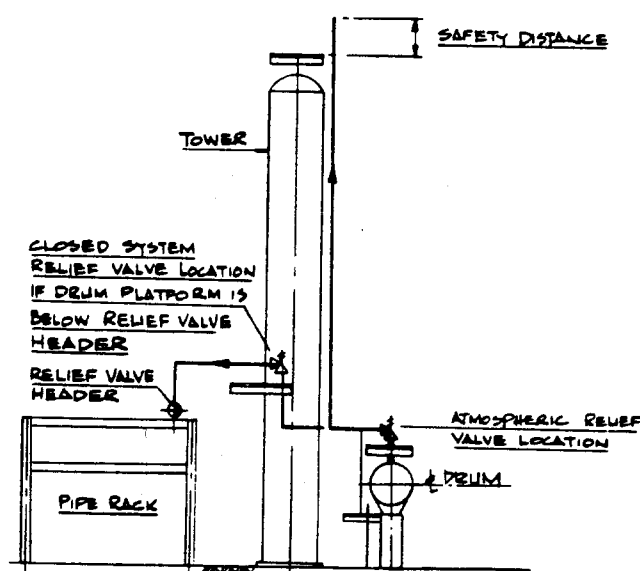


EXHIBIT 5-25 Pump Suction Arrangement

to a convenient, safe location. Closed system relief valves should be located at a convenient platform adjacent to the drum above the relief valve header. Relief valve inlet piping more than 20 ft (6,100 mm) long should be checked by the systems engineering group to determine whether the line size needs to be increased for pressure drops. Exhibit 5-26 shows typical arrangements for both systems.

The piping arrangement shown in Exhibit 5-27 was designed using the guidelines in this chapter. The requirements can be found as follows:

- Process vessel sketch—Exhibit 5-13.
- Nozzle locations—Exhibit 5-16.
- Instrument vessel sketch—Exhibit 5-29.
- P&ID—Exhibit 5-28.
- Equipment arrangement—Exhibit 5-4.
- Platform arrangement—Exhibit 5-23.

EXHIBIT 5-26 Relief Valve Systems

- Nozzle summary—Exhibit 5-13.
- Drum elevation—Exhibit 5-12.
- Plant layout specification—Chapter 2.

The sample piping and instrumentation diagram discussed in this chapter is illustrated in Exhibit 5-28.

DRUM INSTRUMENTATION

Level, pressure, and temperature instruments are used to control the operation of the drum and should be placed in a position for optimum operation and maintenance. Instrument requirements are usually highlighted on an instrument vessel sketch furnished by the instrument engineer assigned to the project. Exhibit 5-29 is a typical instrument vessel sketch.

Level controllers, switches, and gauges are either located individually or grouped from a common bridle or standpipe. The controller must be operable from grade or a platform; switches, gauges, and pressure and temperature connections may be operable from a ladder if no platform is available at the required elevation.

The instrument arrangement shown in Exhibit 5-30 was designed using the guidelines in this chapter as follows:

- Nozzle locations—Exhibit 5-16.
- Instrument vessel sketch—Exhibit 5-29.
- Platform arrangement—Exhibit 5-23.
- Piping arrangement—Exhibit 5-27.

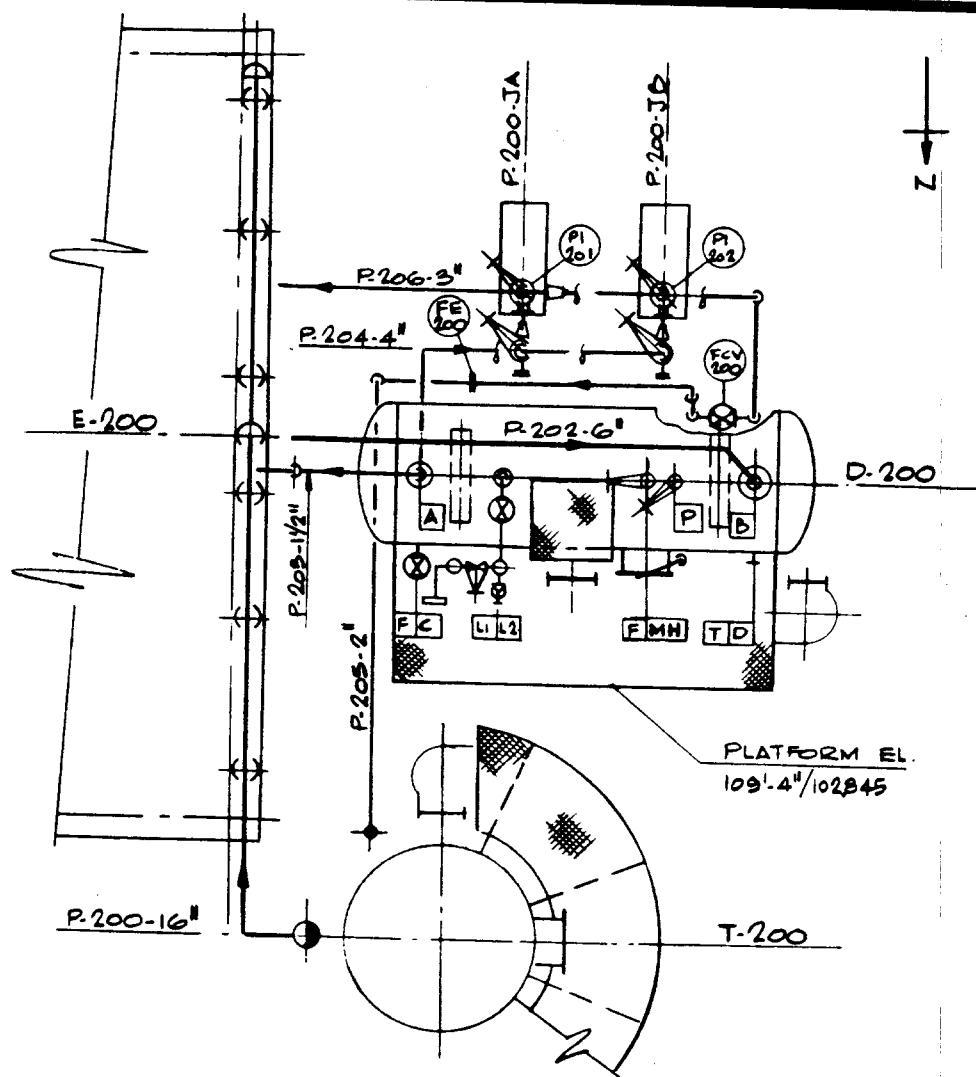


EXHIBIT 5-27
Sample Drum Piping
Arrangement

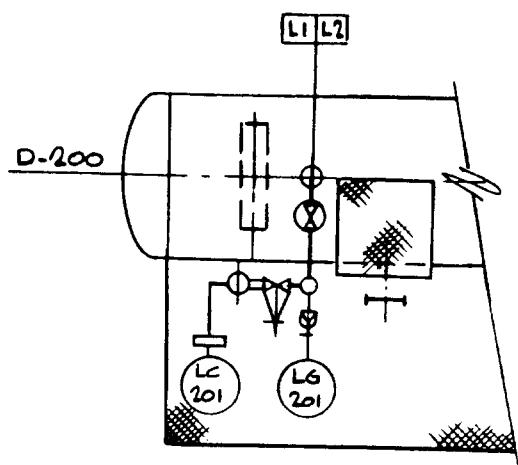


EXHIBIT 5-30
Instrument Arrangement

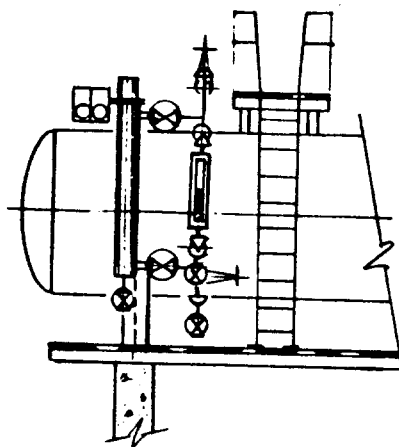


EXHIBIT 5-31 Sample Horizontal Drum Davit Arrangement

EXHIBIT 5-32 Drum with Mixer

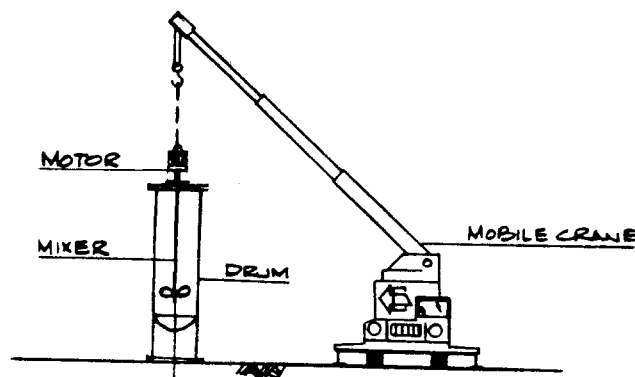
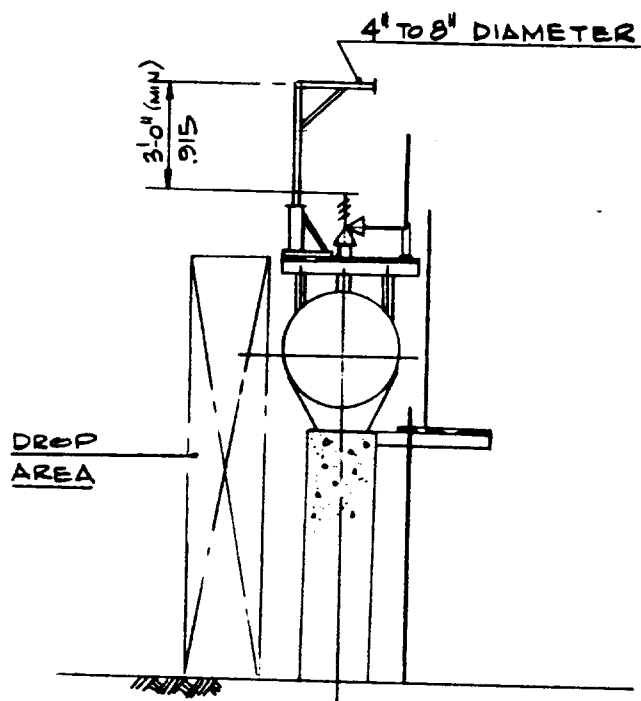
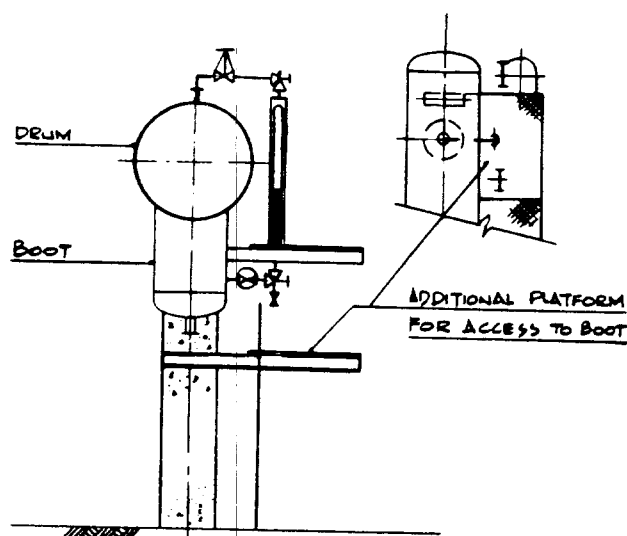


EXHIBIT 5-33 Typical Drum Boot Layout



MAINTENANCE

Maintenance of drums is limited to removal of such exterior components as large relief or control valves for off-site repair. Handling of these items can be achieved either by fixed davits or by mobile equipment. Davit arrangements for tall vertical drums should be in accordance with tower requirements. Davits are not usually furnished at horizontal drums; if

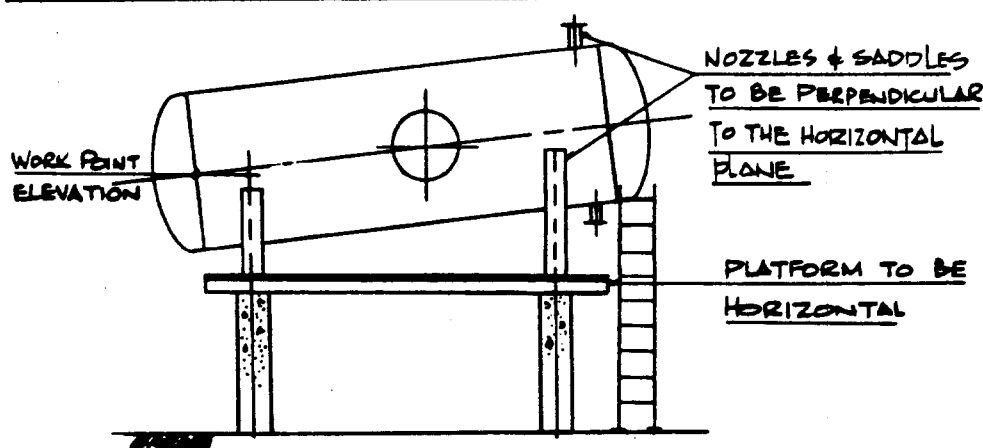


EXHIBIT 5-34
Sample Sloping Drum

required, they should be arranged in accordance with those in Exhibit 5-31.

Removal space should be provided above drums furnished with mixers. If the drum is located within a structure, a removable section of the floor above should be provided. Exhibit 5-32 illustrates a drum with a mixer.

FURTHER CONSIDERATIONS

For various process reasons, horizontal drums often are furnished with what appears to be a small vertical drum, called a boot, attached to the underside of the vessel. Because the boot is inaccessible to the main drum platforming, special consideration must be

given to the arrangement of additional platforming for access to the instrumentation on the boot. Exhibit 5-33 shows a typical drum boot layout.

In certain cases, drums must slope, as shown in Exhibit 5-34. If the nozzles are not perpendicular to the horizontal plane, all vertical piping runs from these nozzles must be calculated because they will be offset at an angle.

The dimensions, clearances, and guidelines highlighted in this chapter are an example of what can be used for drum arrangement. The plant layout designer should be familiar with company and client standards, however, before proceeding with drum layout and should coordinate the effort with such supporting groups as vessel, systems, process, and instrument engineering.

Exchangers

Heat exchangers are similar to pumps and vessels in that they are widely used in most process plants. The control of heat within any facility is an important part of plant operation, whether by direct application (e.g., in a furnace) or by heat interchange (e.g., in a shell and tube exchanger). The principal application of a heat exchanger is to maintain a heat balance through the addition or removal of heat by exchange with outside sources or between streams of two different operating temperatures.

This chapter highlights the general layout requirements for heat exchangers. It also identifies the infor-

mation required by the plant layout designer to locate, elevate, operate, and maintain the most common exchangers and to position the piping and controls associated with these items. The most common applications for heat exchangers, illustrated on a process flow diagram in Exhibit 6-1, are:

- Cooler—Cools process streams by transferring heat to cooling water, atmosphere, and other media.
- Exchanger—Exchanges heat from a hot to a cold process stream.
- Reboiler—Boils process liquid in tower bottoms us-

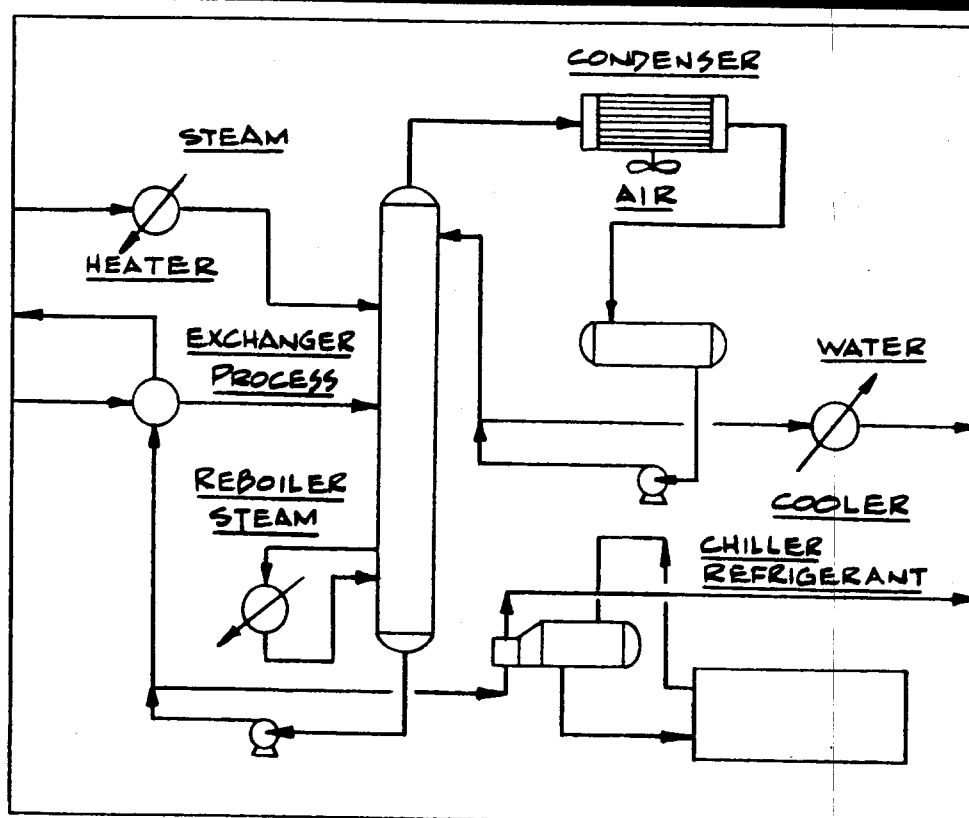
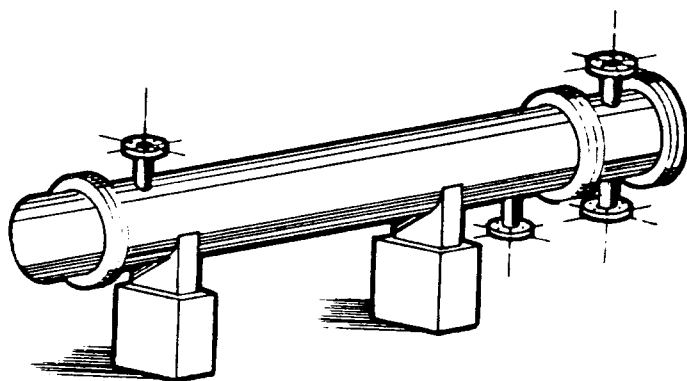
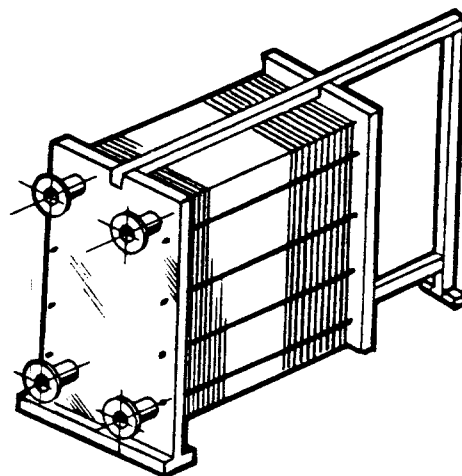


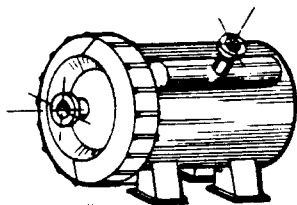
EXHIBIT 6-1
Exchanger Applications
Shown on a Process Flow
Diagram



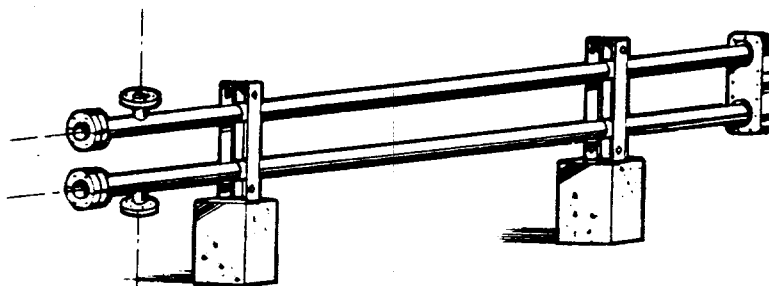
a. Shell and Tube Exchanger



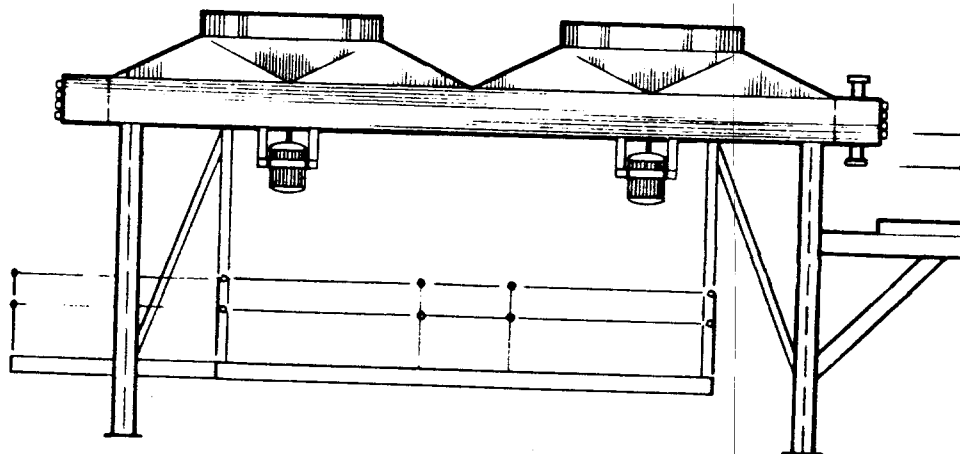
b. Plate Exchanger



c. Spiral Exchanger



d. Double Pipe Exchanger



e. Air Cooler Exchanger

ing steam, hot oil, or a hot process stream as the heating medium.

- Heater—Heats a process stream by condensing steam.
- Condenser—Condenses vapors by transferring heat to cooling water, atmospheric air, or other media.
- Chiller—Cools a process stream to very low temper-

atures by evaporating a refrigerant.

EXCHANGER CONSTRUCTION

The most common heat exchangers used in processing facilities are illustrated in Exhibit 6-2 and discussed in the following sections.

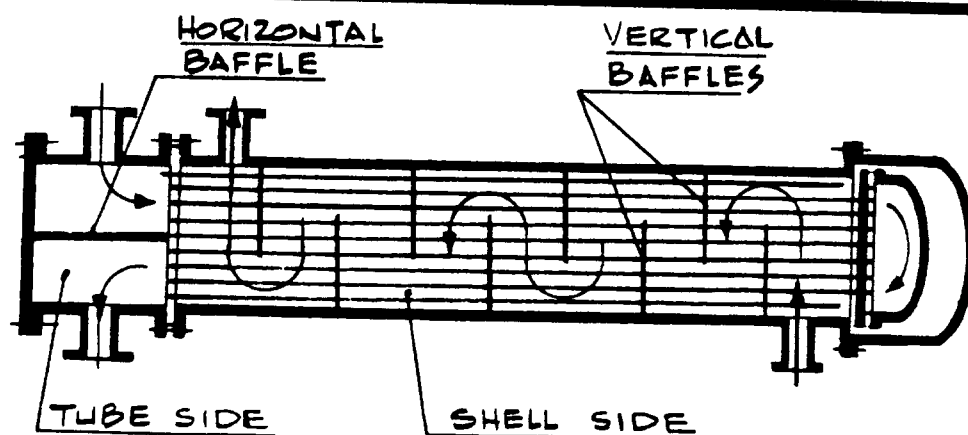
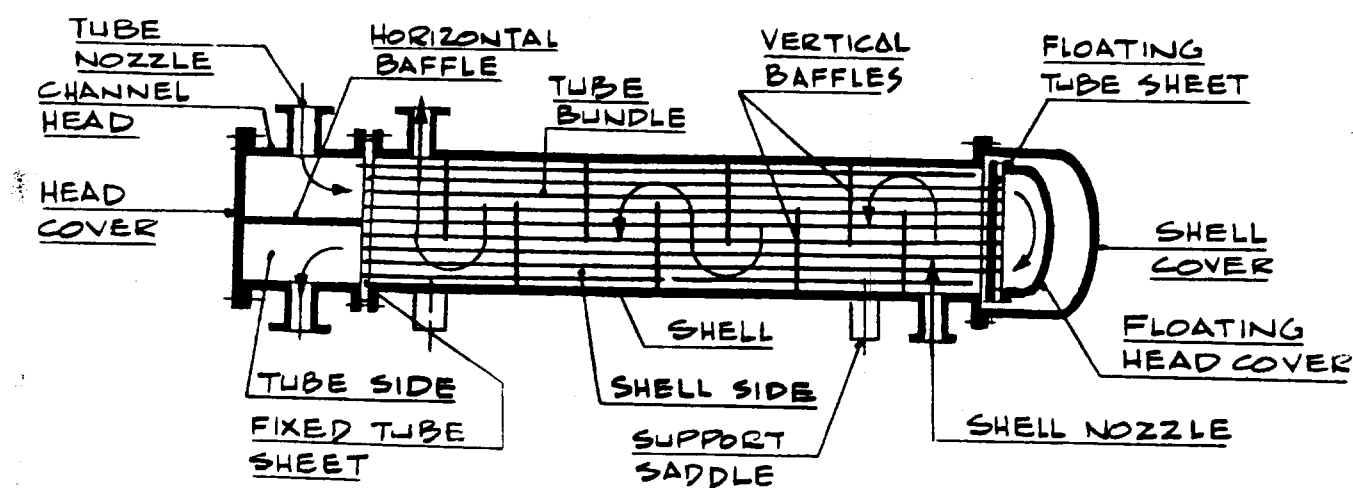


EXHIBIT 6-3
Sample of Tube and Shell
Exchanger Passes

EXHIBIT 6-4 Key Items for a Typical Shell and Tube Exchanger



Shell and Tube Exchangers

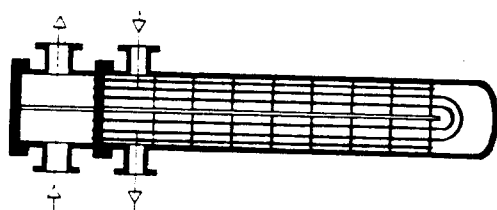
Shell and tube exchangers are elongated steel cylindrical vessels containing bundles of parallel tubes. Liquid passes through the inside of the shell over the exterior side of the tubes, with another liquid passing through the interior of the tubes, causing the necessary interchange of heat between the two liquids. The heads at the ends of the exchanger can be designed to accommodate several passes on the tube side. Multiple passes on the shell side can be achieved by installing baffles parallel to the tubes. Baffles may also be installed inside the shell, perpendicular to the tubes, to direct the liquid in the shell against the tubes. Multiple passes are used to increase the fluid velocity or to improve the flow path, causing increased heat recovery. Exhibit 6-3 shows an exchanger with two passes on the tube side and one on the shell side.

The shells of most heat exchangers are constructed of seamless pipe for small diameters and shaped

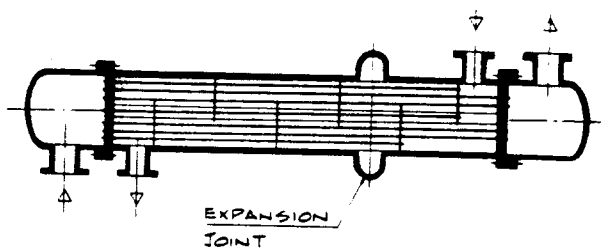
welded steel plates for the larger sizes. Tube bundle sizes can vary from 8 to 96 in (200 mm to 2,400 mm) in diameter and from 6 to 50 ft (1,800 mm to 15,000 mm) in length. The ends of the shell can be designed to accommodate welded, dished, or flanged shell covers as well as flanged or welded heads. Both the tube side and the shell side of the exchangers have inlet and outlet nozzles positioned to provide the required flow through the exchanger. The unit is supported at the shell by attached saddles for horizontal installations and by lugs for vertical arrangements. Tube bundles are made up of many small-diameter tubes that are expanded into tube sheets at each end of the bundle. One end is usually fixed; the other is allowed to float for expansion. For the more simplified U-tube arrangement, only one tube sheet is used, which is integrated with the channel head. Exhibit 6-4 shows a typical shell and tube exchanger identifying the key items of construction.

With many shells, shell covers, and head covers

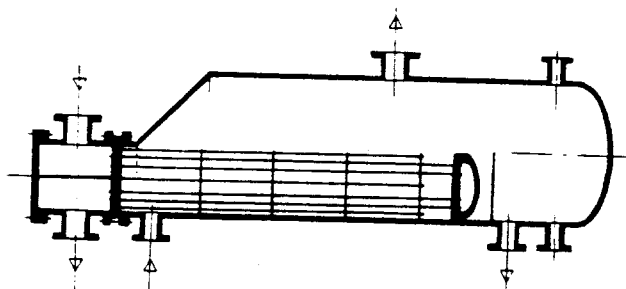
EXHIBIT 6-5 Typical Shell and Tube Exchanger Arrangements



a. U-Tube



b. Fixed Tube



c. Kettle

available, exchangers can be arranged in various combinations to provide a wide range of services. The U-tube, fixed tube, and kettle arrangements are illustrated in Exhibit 6-5.

Plate Exchangers

Plate exchangers, shown in Exhibit 6-6, are generally used in low-pressure, low-temperature applications and are made up of end covers, carrying bars, inlet and outlet nozzles, plates, and gaskets. The exchanger plates have spacing between them for liquid flow. A gasket, set into channels on the periphery of each plate, directs and contains the liquid flow distribution. Ports for inlet and outlet of both hot and cold liquids are stamped into the corners of each plate. When aligned, they form four distribution headers through the plate pack. Distribution of hot and cold liquids to alternate plate flow channels is achieved by the gasketing pattern around each port. When the liquid is intended to flow through to the next plate, the gasket is left intact around the port. Alignment is achieved by top and bottom carrying bars and slots in each plate. When completely assembled, the plate pack and gaskets are compressed by bolts between the two covers. Support is provided by the fixed end cover and carrying bar. The plate exchanger requires less installation and servicing space than do shell and tube arrangements of equivalent surface.

Spiral Heat Exchangers

Spiral heat exchangers are generally used in chemical plants and are of circular construction, consisting of an assembly of two long strips of plate wrapped to form a pair of concentric spiral passages. Alternate edges of the passages are closed, so that liquid flows through continuous channels. Removable covers are fitted to each side of the spiral assembly for access to the spiral plate. As shown in Exhibit 6-7, the inlet and outlet nozzles are integral to the plate housing and the covers. The unit is supported by legs attached to the plate

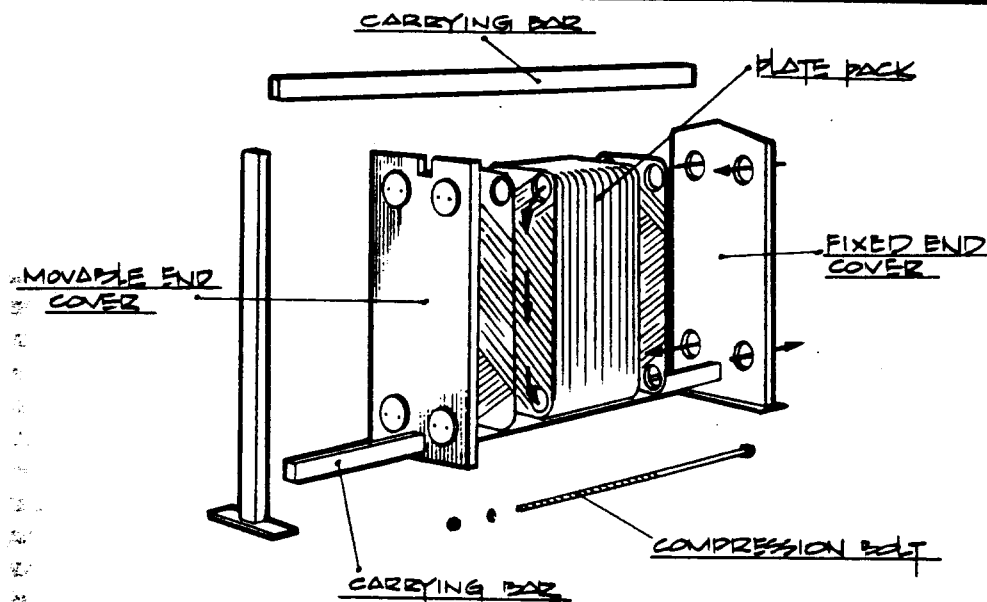
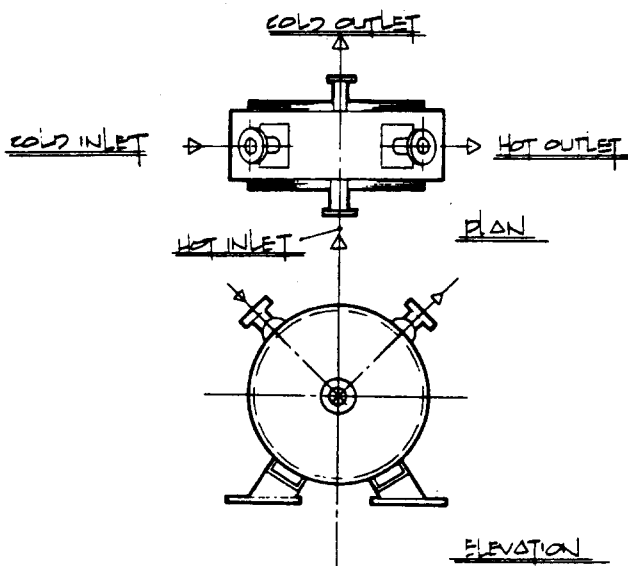


EXHIBIT 6-6
Plate Exchanger
Construction

EXHIBIT 6-7 Spiral Exchanger Construction



housing for horizontal installations and by lugs for vertical installations. Similar to the plate exchanger, the spiral exchanger is compact and requires less installation and servicing space than conventional exchangers of equivalent surface.

Double Pipe Exchangers

The double pipe, or fin-tube, exchanger is used when one liquid has a greater resistance to heat flow than another or when the surface area is small. In such cases, the addition of fins to the inner pipe evens out the resistance to heat flow of the two liquids. As shown in Exhibit 6-8, the double pipe exchanger consists of a pipe within a pipe; both pipes have a return bend at one end. The inner pipe is fitted with fins; the outer pipe acts as the shell. The shell nozzles are mounted vertically from the outer pipe, and the tube nozzles are directly welded to the inner pipe ends. The units are generally supported horizontally by brackets at-

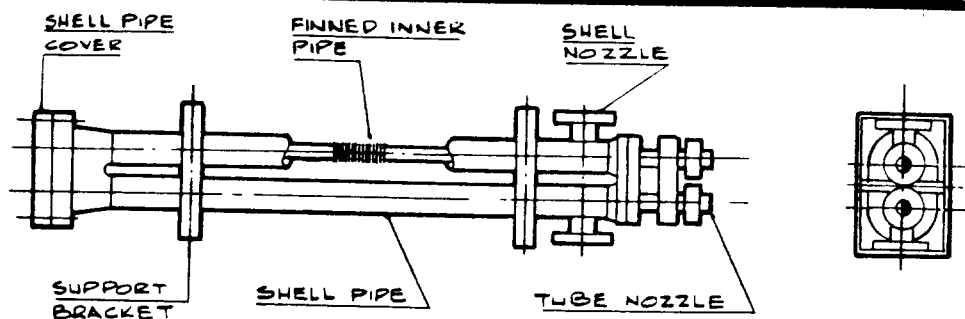


EXHIBIT 6-8
Double Pipe Exchanger
Construction

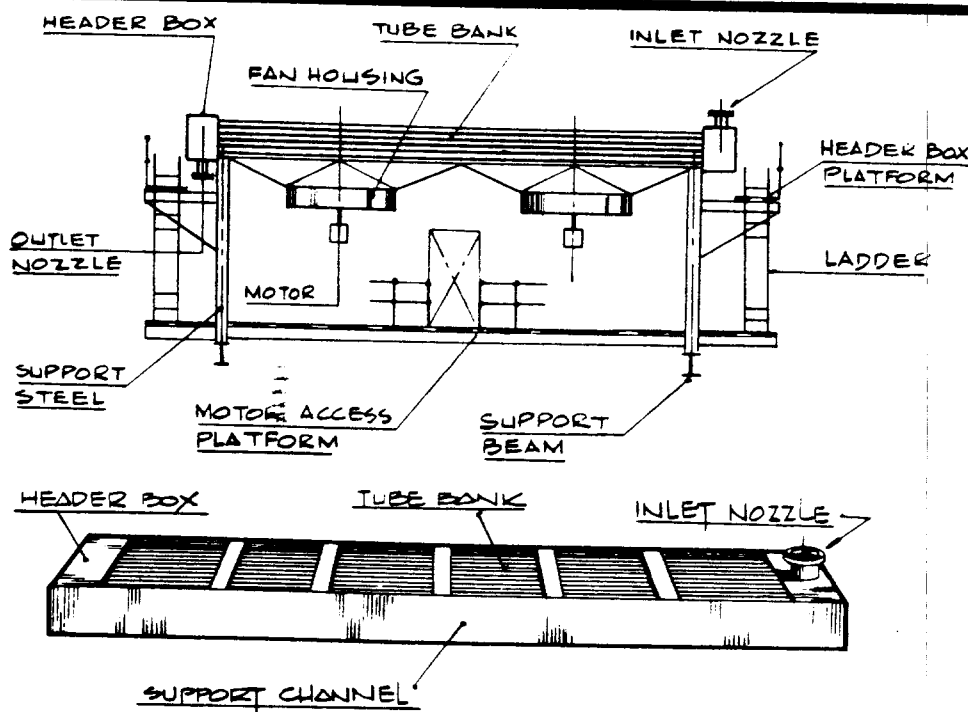


EXHIBIT 6-9
Air Cooler Exchanger
Construction

tached to a foundation or to the side of other equipment supports.

Air Cooler Exchangers

Air cooler units are entirely different from the previously mentioned arrangements in that the cooling agent used is circulating air instead of a liquid. As seen in Exhibit 6-9, an air cooler unit consists of fin-tube bundles with a header box attached to each end, supported horizontally by a steel frame or structure. For the single-pass arrangement, the inlet nozzles are mounted on the top of the header box; the outlet nozzles are at the opposite end and mounted on the bottom of the header box. For the double-pass arrangement, the outlet nozzles are located at the same end as the inlet nozzles. For additional surface area, more passes can be added or additional units can be

installed and located side by side.

Air is circulated by multiblade propeller-type fans that provide forced or induced drafts. Fans can be supplied with either adjustable-speed or variable-pitch blades. The fan blade pitch can be changed to vary the air-flow rate to compensate for rising or falling air temperatures. Air coolers supplied with multiple fans may be operated with some of the fans shut down. Dampers, baffles, and bypasses can also be used to further control liquid outlet temperature. For elevated installations, platforms are generally furnished for access to header boxes and motors.

EXCHANGER LOCATION AND SUPPORT

Heat exchangers are located within the conventional process unit plot area, close to related equipment, to

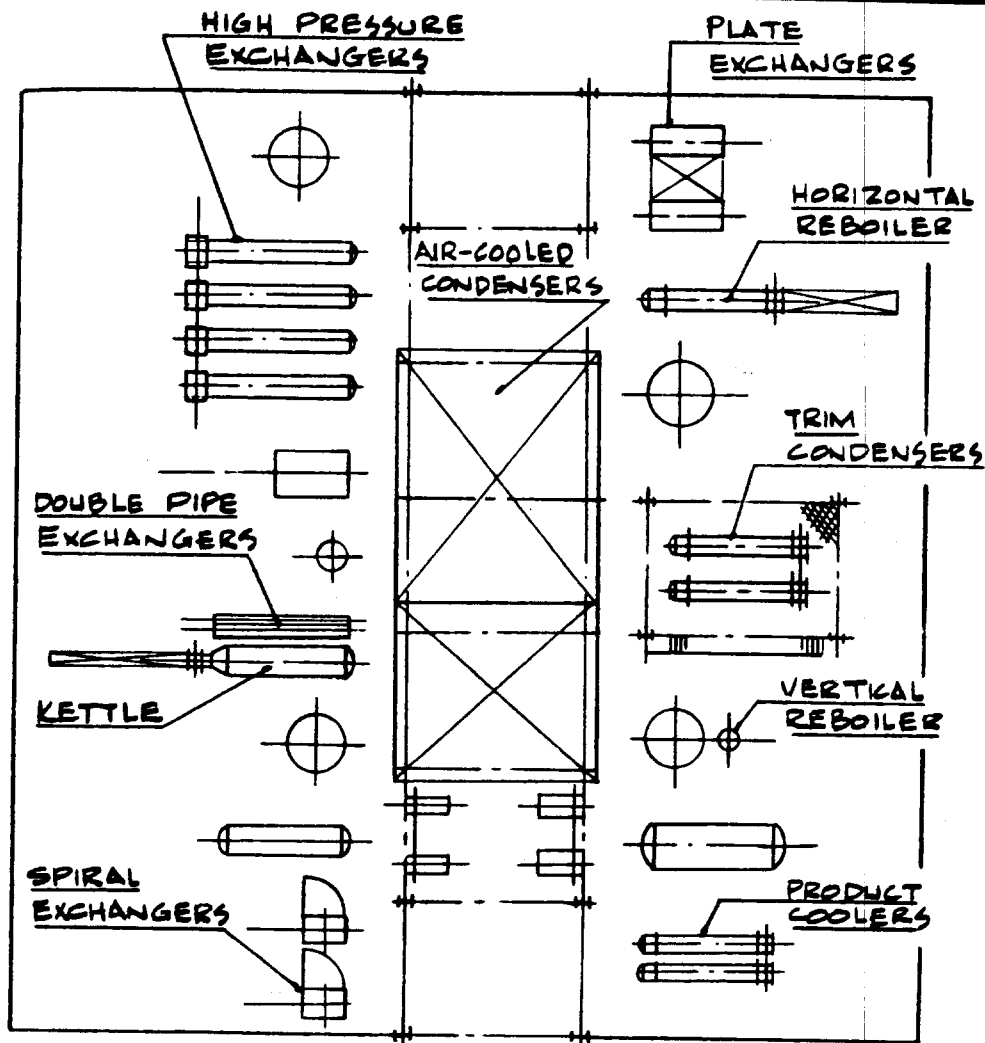


EXHIBIT 6-10
Typical Plot Plan of
Several Exchanger
Applications

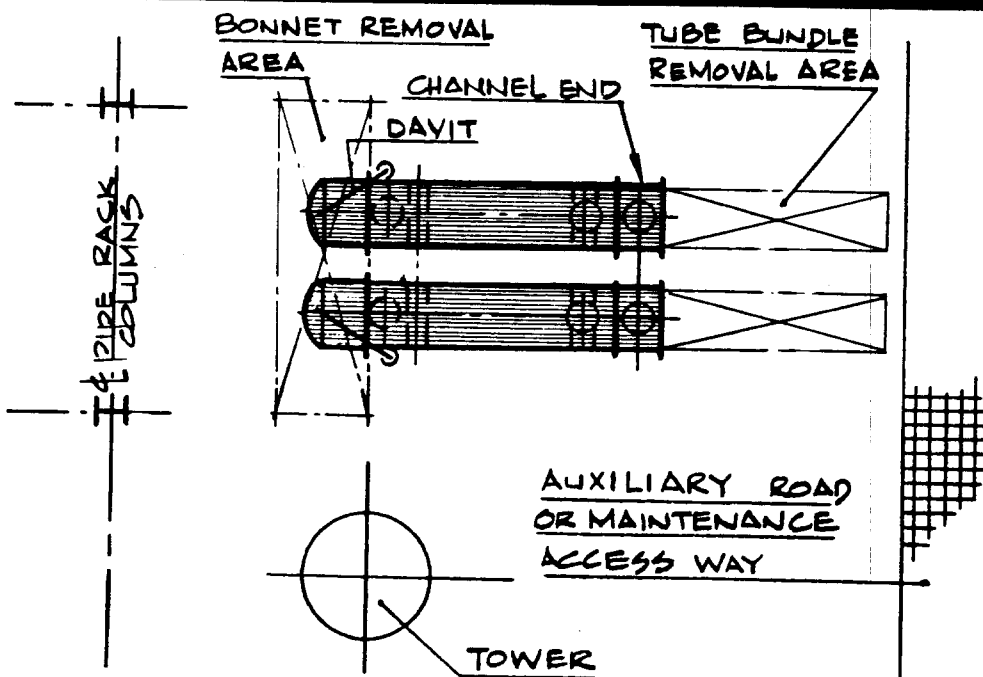
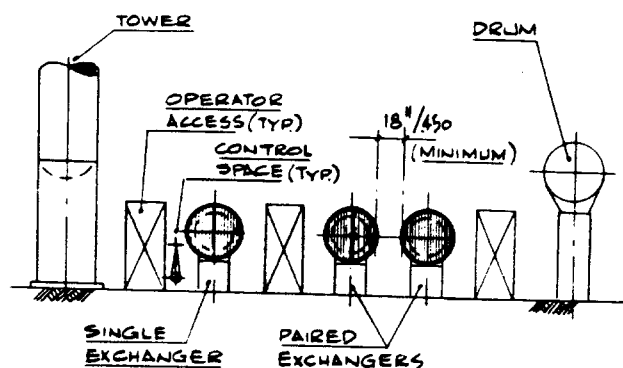
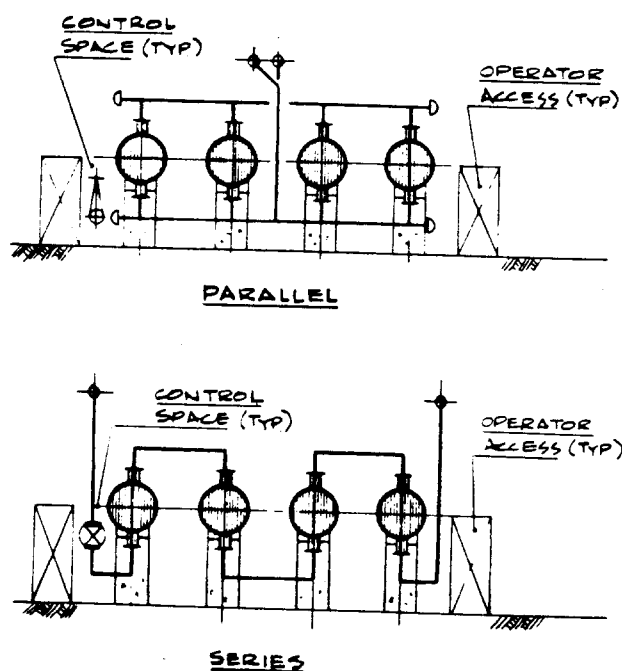
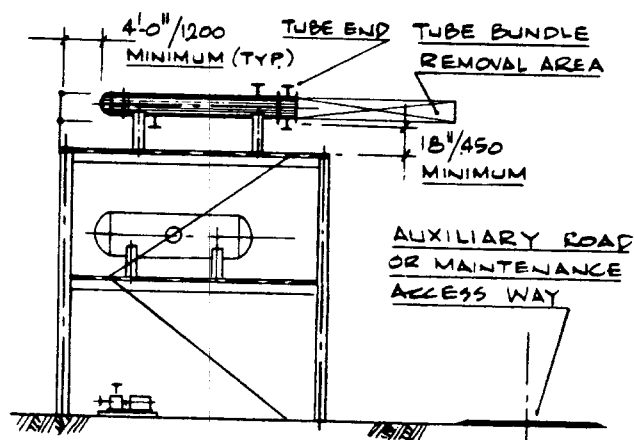


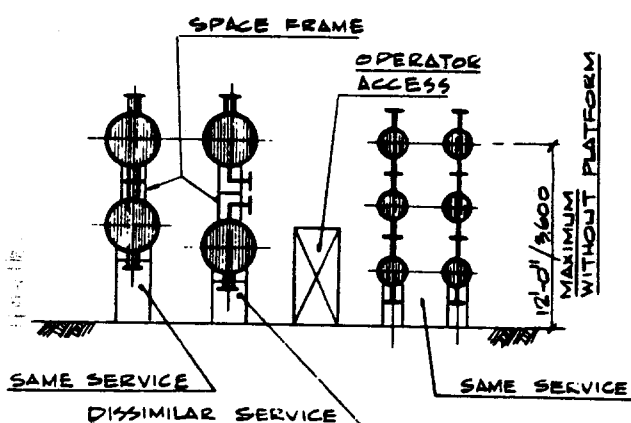
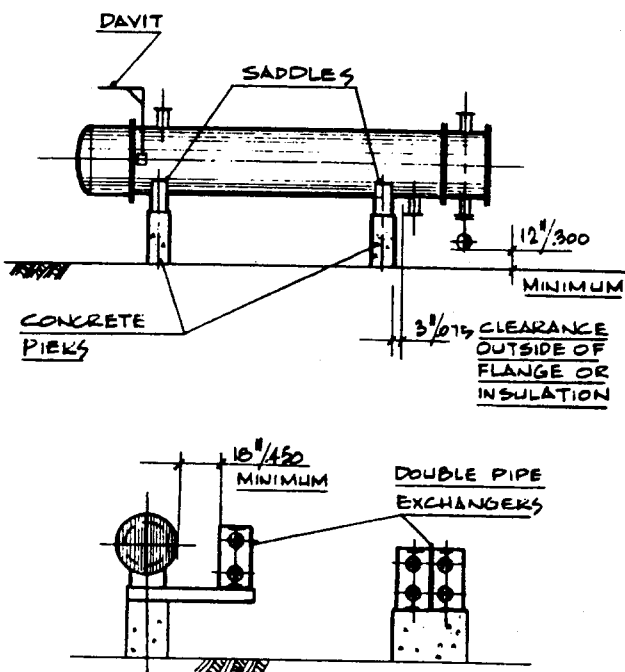
EXHIBIT 6-11
Sample Exchanger
Orientation

EXHIBIT 6-12 Sample Single and Paired Exchanger Installation**EXHIBIT 6-13** Parallel and Series Exchanger Installations**EXHIBIT 6-14** Sample Structure-Mounted Exchanger Installation

support economic pipe runs, flexibility, process requirements, and operator and maintenance access. Support of the equipment (e.g., for air coolers or vertical reboilers) can also influence heat exchanger location. Exhibit 6-10 depicts a typical plot plan with several heat exchanger applications. Horizontal shell and tube exchangers should be positioned so that the channel end faces the auxiliary road or maintenance access way for tube bundle removal with adequate space provided at the front end of the exchanger for bonnet removal. This exchanger orientation is shown in Exhibit 6-11.

Exchangers can be located as single items, in pairs (this is the most common installation), or in larger groups when no intermediate control is required between the shell and tube streams. The single and paired installation is shown in Exhibit 6-12. Paired exchangers may operate in series, parallel, or dissimilar services; grouped exchangers operate only in series or parallel. Exhibit 6-13 shows samples of parallel and series exchanger installations.

Paired or grouped exchangers should be spaced to

EXHIBIT 6-15 Stacked Exchanger Installations**EXHIBIT 6-16 Typical Horizontal Exchanger Supports**

allow a minimum of 18 in (450 mm) between the outside of adjacent channel or bonnet flanges to facilitate access to flange bolts for maintenance. Space should be provided on either side of paired exchangers and at both ends of grouped exchangers for control and operator access. Exhibit 6-14 illustrates a structure-mounted installation and its required access areas.

Horizontal exchangers may be stacked to a preferred maximum top shell centerline elevation of 12 ft (3,600 mm) from grade or platform, as depicted in Exhibit 6-15. Stacking of exchangers above this height may require platforming for access to channel and bonnet flanges and fixed handling devices.

Horizontal shell and tube exchangers may be located at grade or elevated in steel or concrete structures when process requirements or space availability dictate. Support of horizontal exchangers, as shown in Exhibit 6-16, is by saddles attached to concrete piers for grade-mounted installations and by saddles attached to steel frames in elevated installations. When possible, supports should be inline for common foundation design.

If process requirements permit, shell and tube exchangers can also be mounted in a vertical position, supported by lugs and tower nozzles in a tower-supported installation (as shown in Exhibit 6-17), within concrete or steel structures (as shown in Exhibit 6-18), and by concrete piers (as shown in Exhibit 6-19). The same considerations for maintenance, control, and operator access should be given for vertical installations as are for horizontal installations.

An important feature to remember when working with tower-supported vertical reboilers, not requiring springs, is highlighted in Exhibit 6-17A.

1. The layout designer must set the reboiler support lug elevation 1 in/.025 above the platform steel, and not at the steel elevation.
2. Before maintenance, the 1-in/.025 gap will be shimmed, thereby enabling the reboiler load to

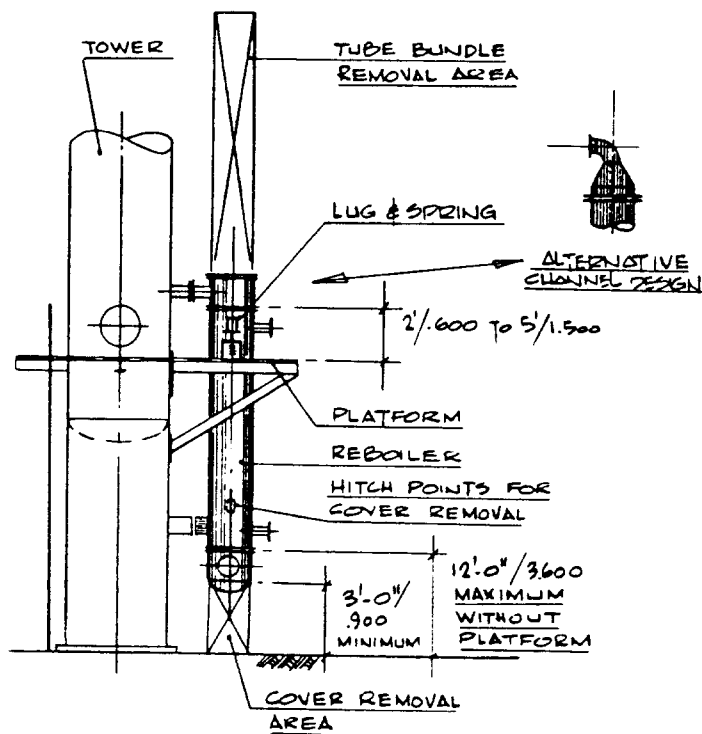


EXHIBIT 6-17
Tower-Supported Vertical
Installation

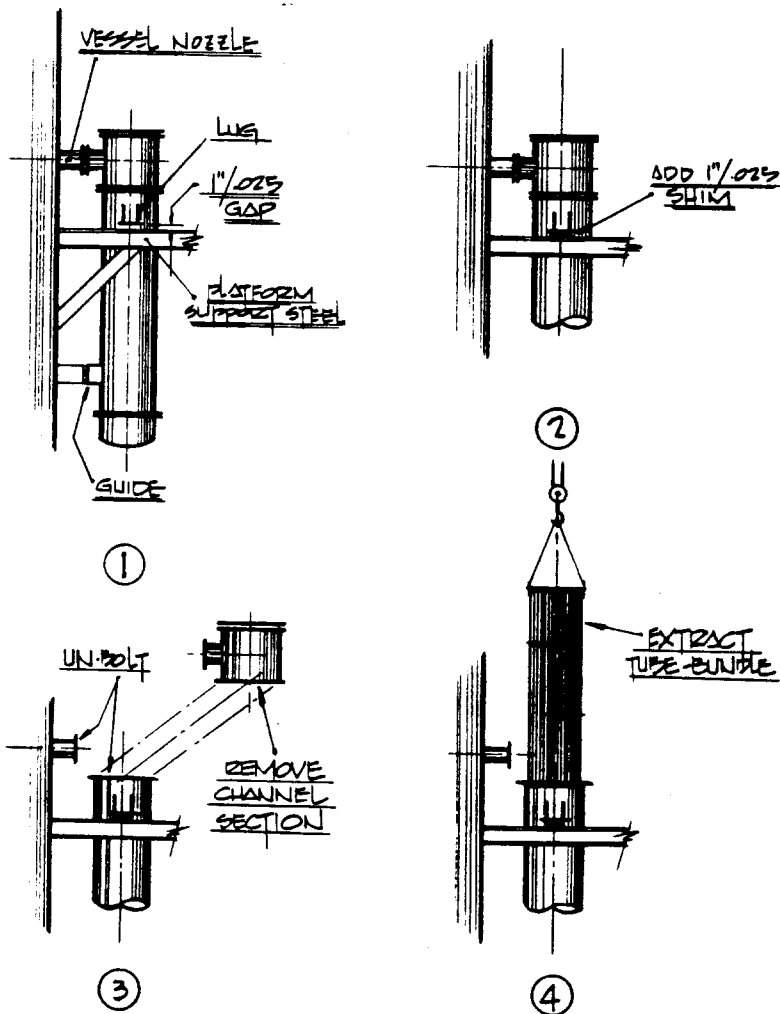


EXHIBIT 6-17A
Tube Bundle
Maintenance

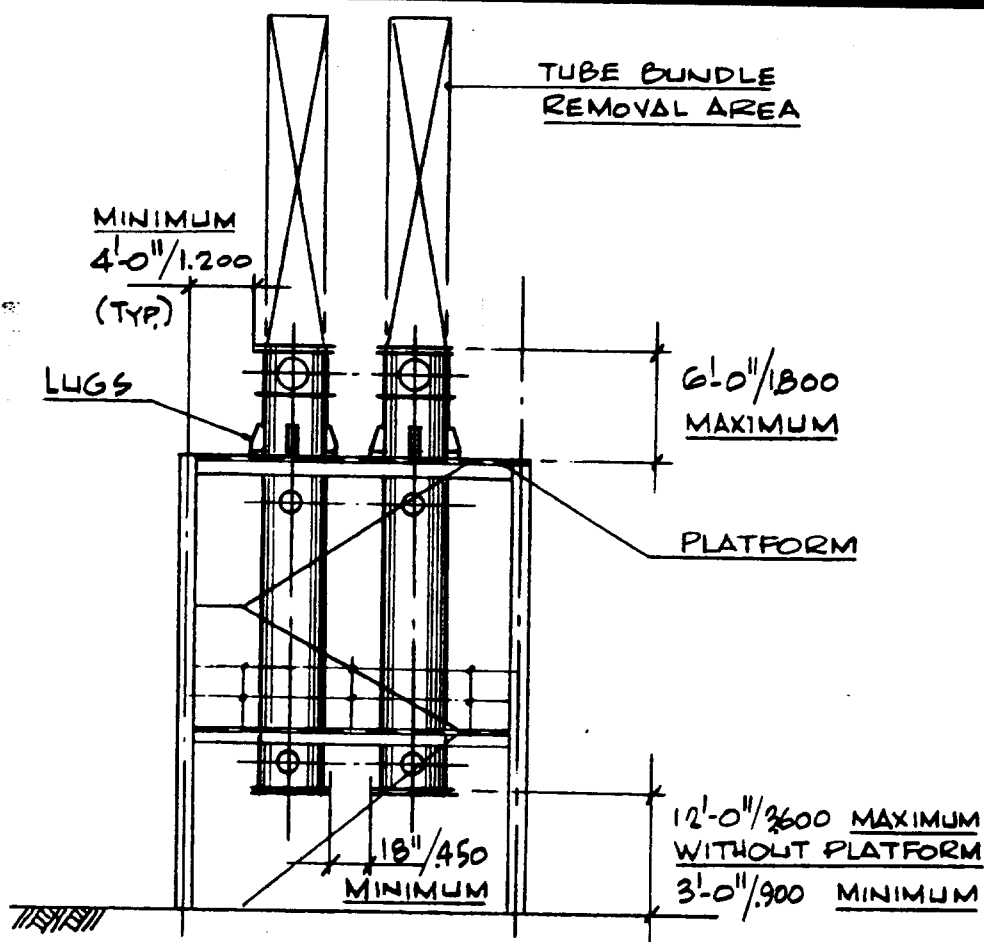


EXHIBIT 6-18
Structure-Supported
Vertical Installation

be carried by the platform steel during maintenance turnaround.

3. The nozzle and channel flange will be unbolted and the channel section removed.
4. The tube bundle is then ready to be removed.

Spiral and plate exchangers can operate in series or parallel, but, because of their configuration and maintenance requirements, it is preferable to position them as single items. Space is provided at both ar-

rangements for control and operator access, with enough room allowed at the spiral exchanger to swing the cover plates open, as shown in Exhibit 6-20, and at the plate exchanger to remove the individual plates, as shown in Exhibit 6-21.

Air coolers are located adjacent to the equipment that they serve for piping flexibility and maintenance. They can be supported from grade, at the top level of structures, or above pipe racks, which is the most common installation. The tube bundle bank can be

EXHIBIT 6-19
Pier-Mounted Vertical
Installation

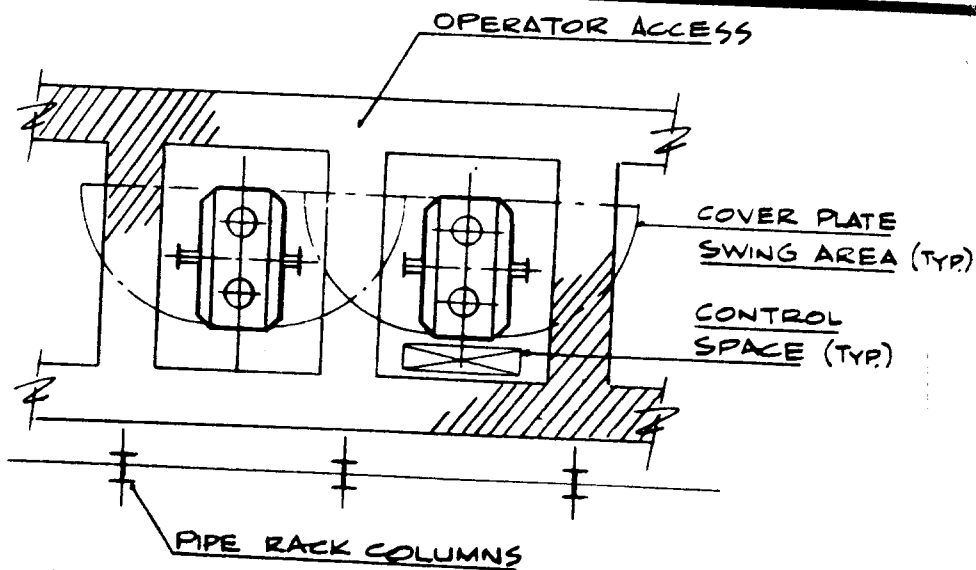
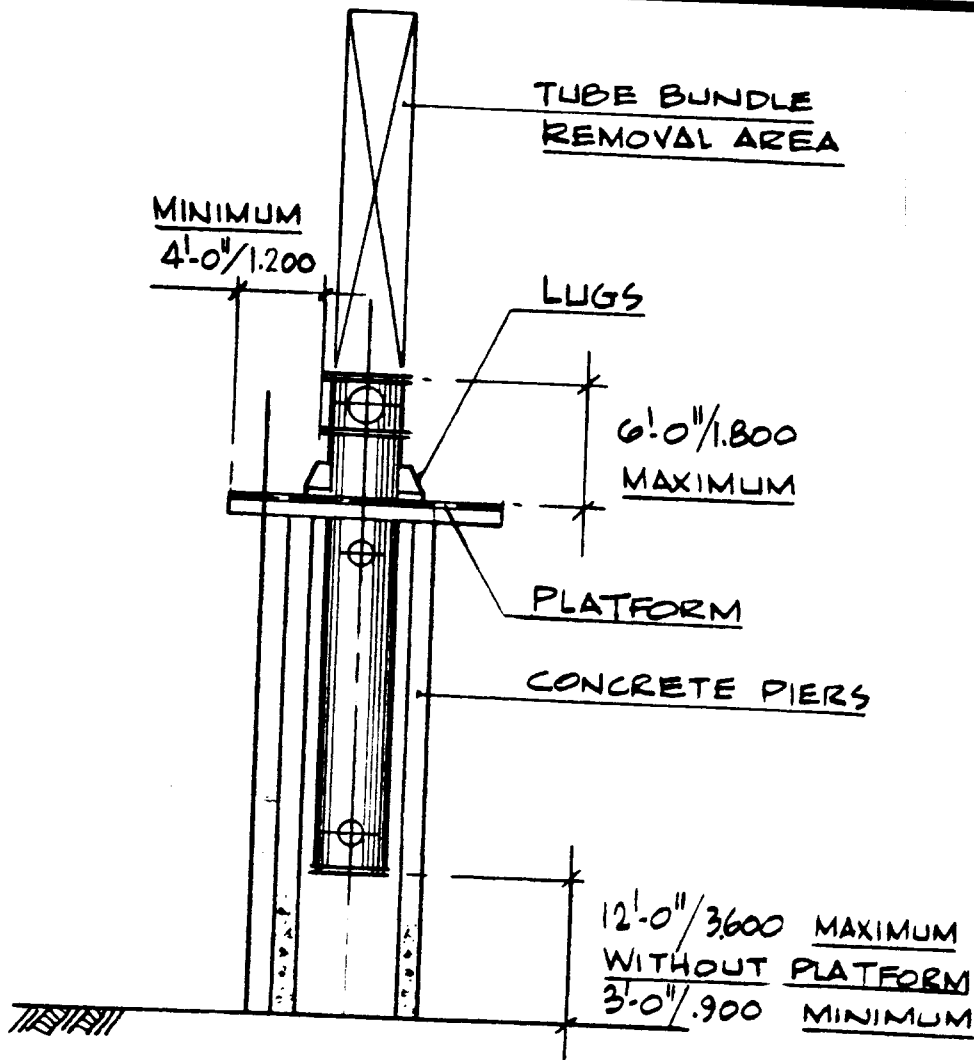


EXHIBIT 6-20
Control and Operator
Access in a Spiral
Arrangement

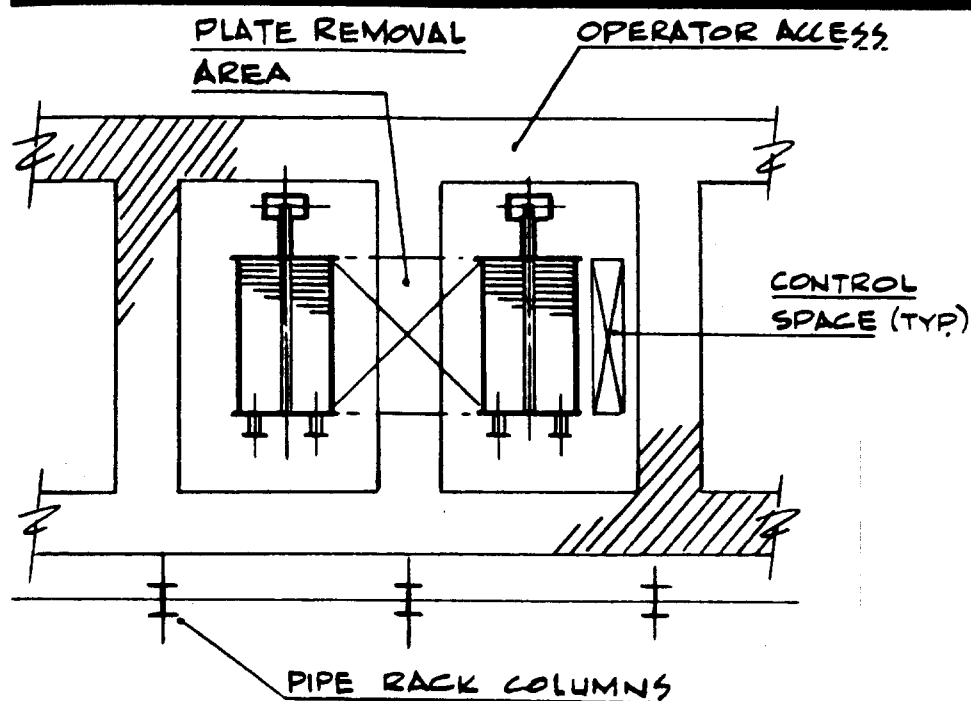


EXHIBIT 6-21
Control and Operator
Access in a Plate
Arrangement

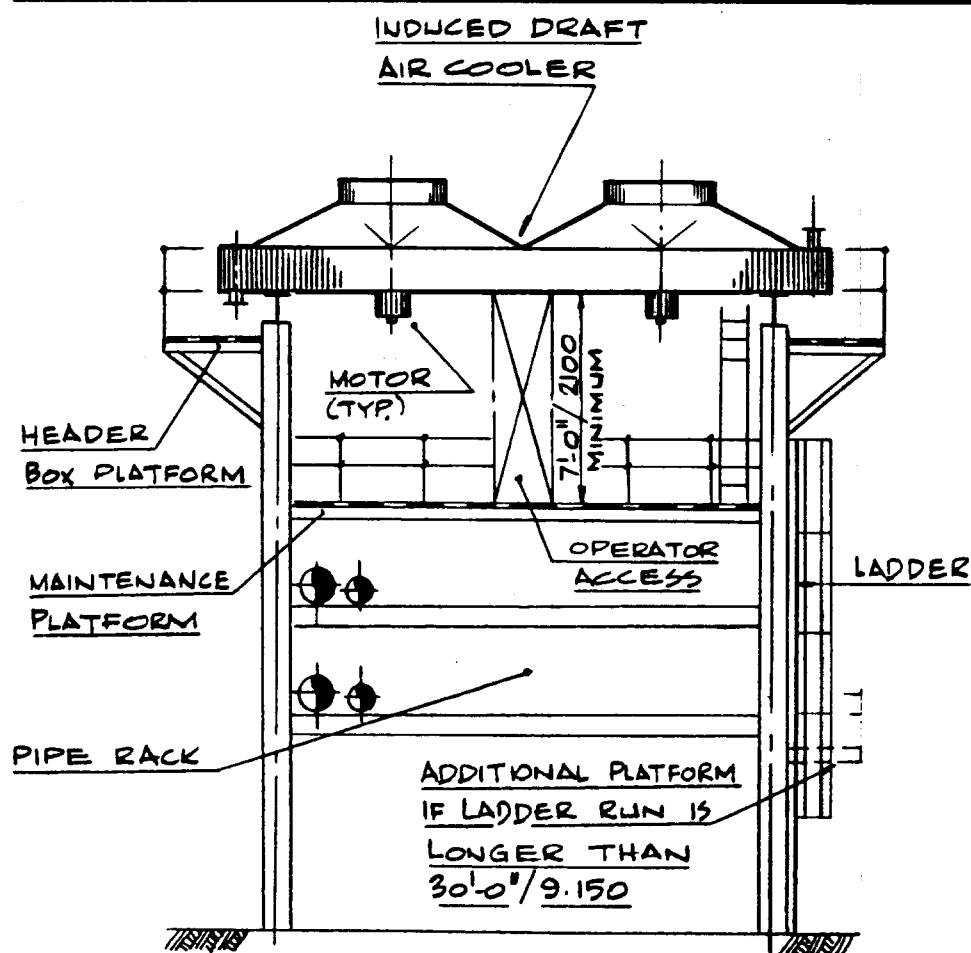


EXHIBIT 6-22
Typical
Column-Supported Air
Cooler Arrangement

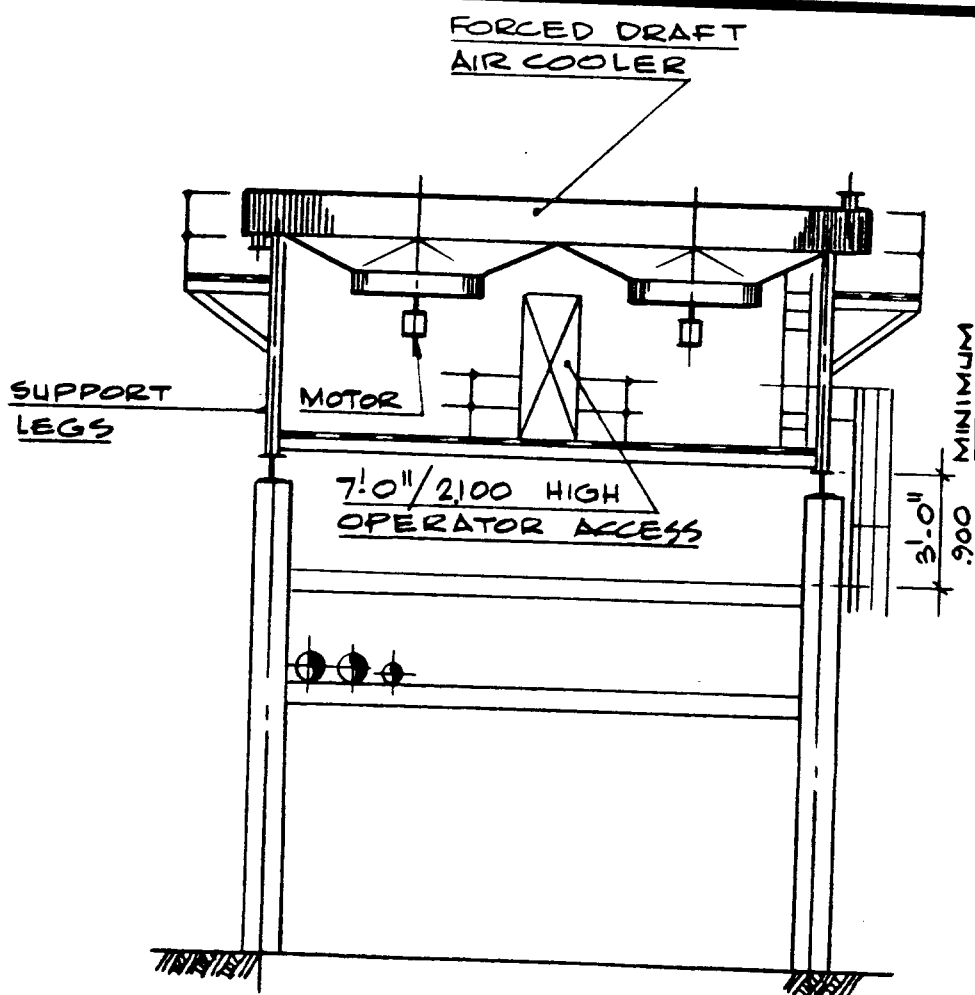


EXHIBIT 6-23
Typical Leg-Supported
Air Cooler Arrangement

supported by steel legs from the air cooler vendor or by extending the pipe rack or structure columns to the underside of the bank. Generally, the air cooler vendor furnishes header box and motor access platforms. Ladders are provided for exit to grade to suit maximum ladder runs and safety requirements. Exhibits 6-22 through 6-25 show various air cooler support and platform configurations, which include column-supported, leg-supported, fixed-platform, and traveling-

platform arrangements.

When designing the air cooler configuration, the plant layout designer must consider the source of the supporting column. As seen in Exhibit 6-26, arrangement A, developed by the contractor, allows changes to platforming and pipe support loading late in a project without affecting the air cooler vendor's scheduled delivery dates to the job site. In arrangement B, any such late changes would cause the air cooler vendor

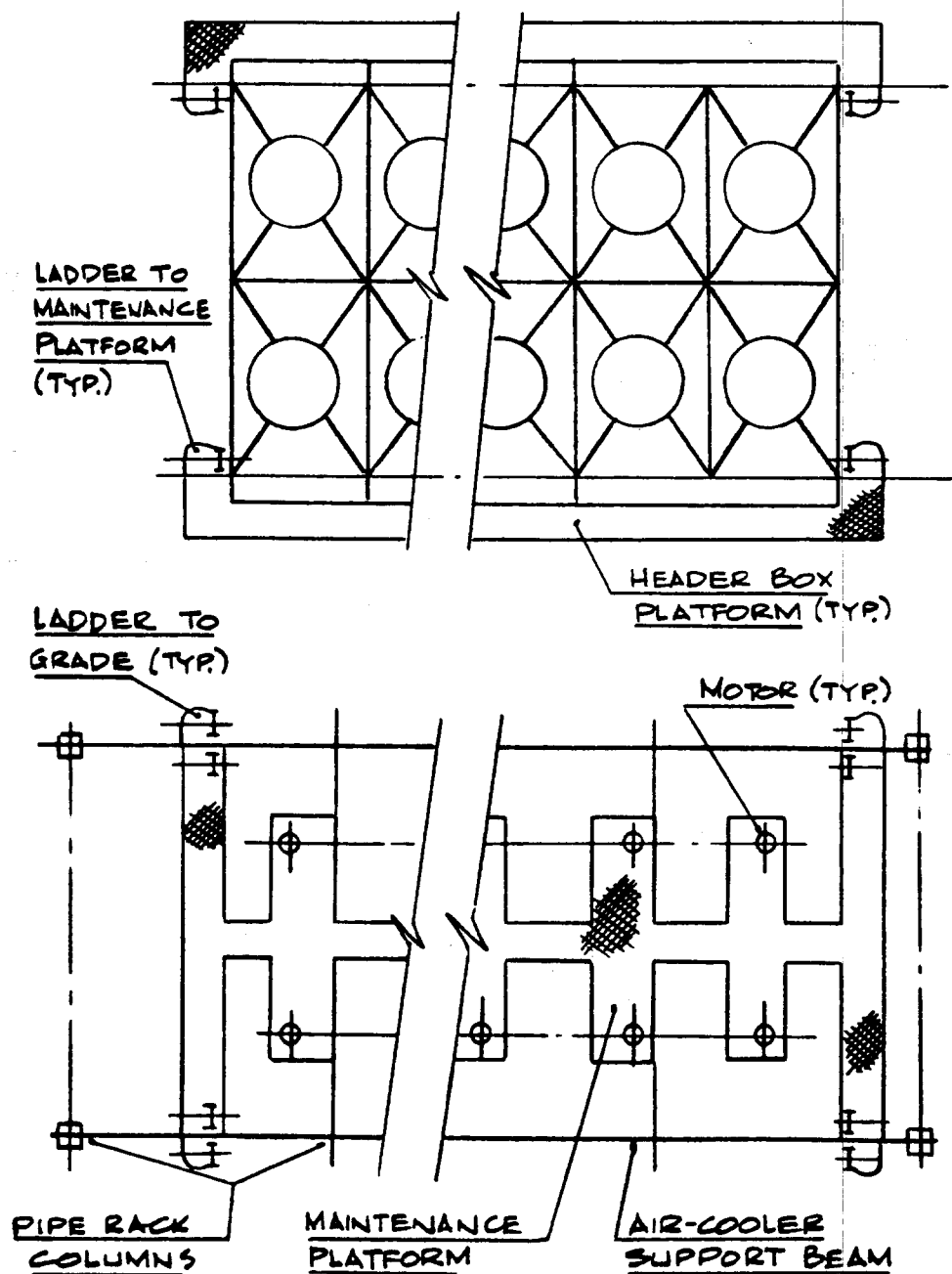


EXHIBIT 6-24
Typical Fixed-Platform
Air Cooler Arrangement

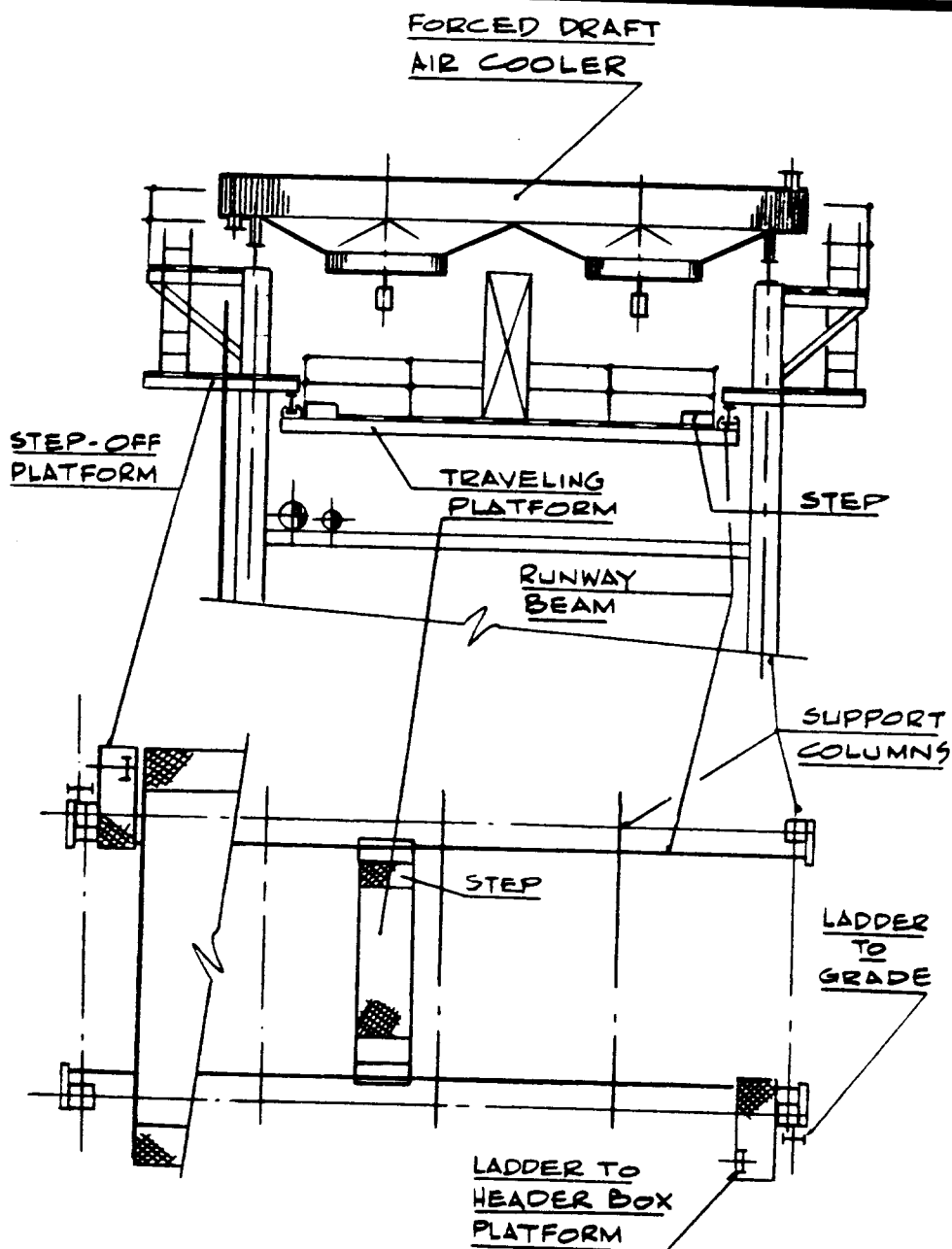


EXHIBIT 6-25
Typical
Traveling-Platform Air
Cooler Arrangement

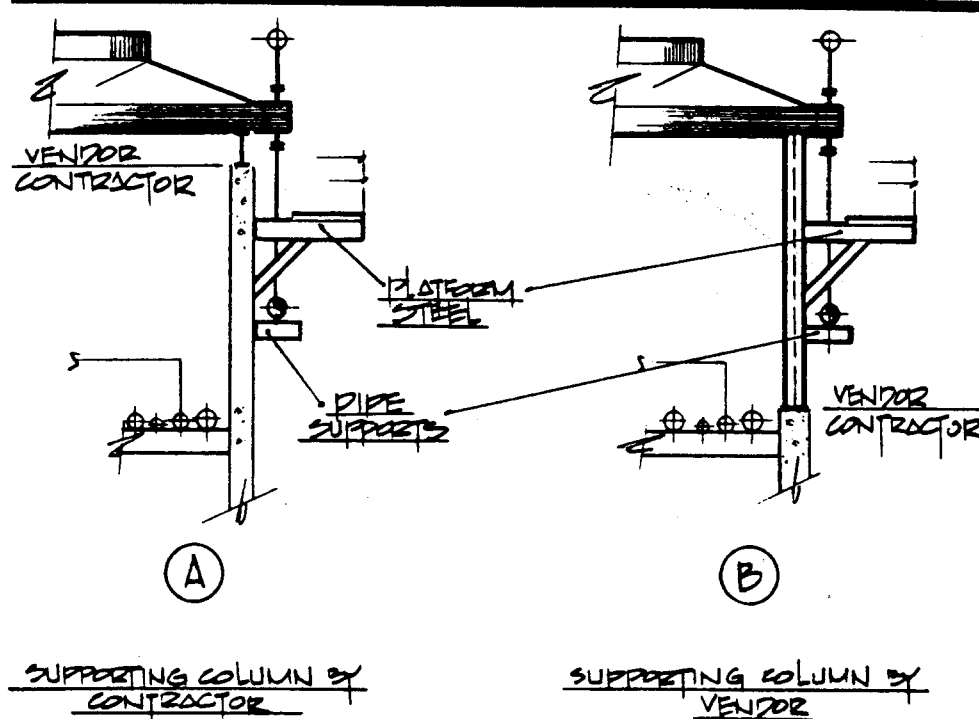


EXHIBIT 6-26
Considerations for
Vendor- or
Contractor-Supplied
Supporting Columns

to redesign the support legs or platforming, causing delays in delivery and extra costs.

NOZZLE ORIENTATION

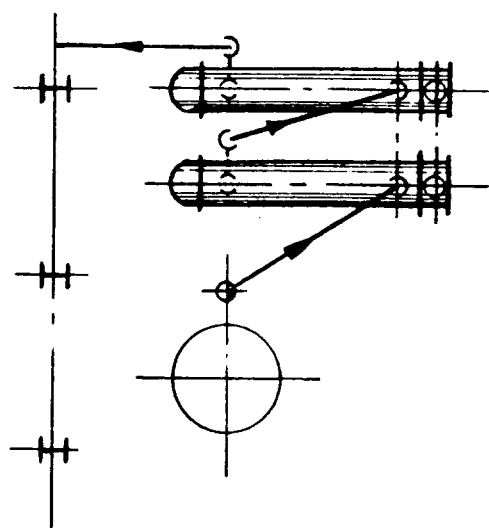
Nozzle orientation and location can affect the piping configurations at most exchanger arrangements. A decision by the piping designer to relocate the exchanger nozzles can often produce a neat and cost-effective arrangement. Although the piping designer does not have the freedom to independently relocate exchanger nozzles, suggested alternate nozzle locations can be made to the exchanger engineer in the interest of improving external piping arrangements—for example, alternative B in Exhibit 6-27 highlights an

improved arrangement by relocating exchanger nozzles. Exhibit 6-28 shows allowable nozzle configurations.

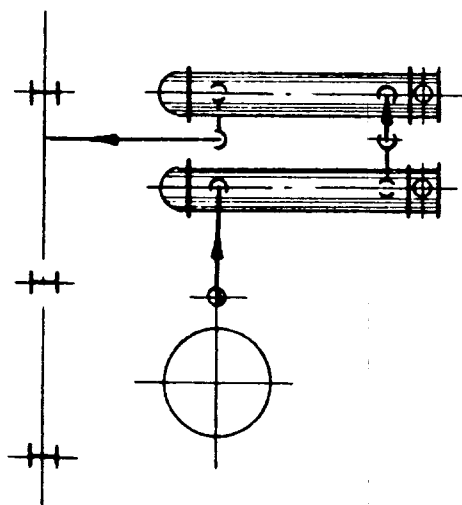
Elbow or gooseneck nozzles are especially useful in reducing the height of large stacked exchangers. Exhibit 6-29 highlights the effects of using elbow nozzles on stacked exchangers.

Air cooler nozzle locations can also affect piping configurations. A single-pass arrangement can make the return piping on an overhead condenser very long and can also increase the height of the air cooler. Reorienting the air cooler or making the unit a double-pass arrangement can improve the piping configurations. Exhibit 6-30 shows alternative nozzle configurations for air cooler piping.

EXHIBIT 6-27
Alternative Arrangements
for Locating Exchanger
Nozzles



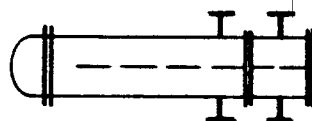
ALTERNATIVE "A"



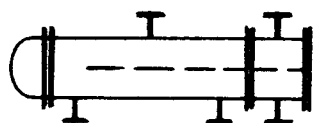
ALTERNATIVE "B"



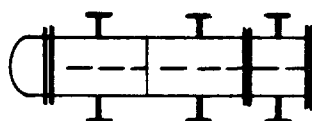
SINGLE-PASS SHELL



DOUBLE-PASS SHELL



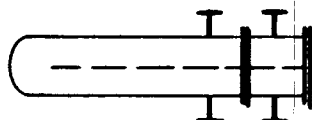
SINGLE SPLIT-FLOW SHELL



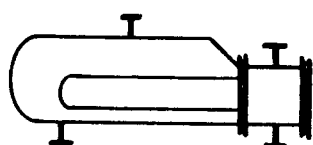
DOUBLE SPLIT-FLOW SHELL



SINGLE-PASS SHELL



DOUBLE-PASS SHELL



KETTLE-TYPE REBOILER



SINGLE-PASS SHELL

EXHIBIT 6-29
Effect of Elbow Nozzles
on Stacked Exchangers

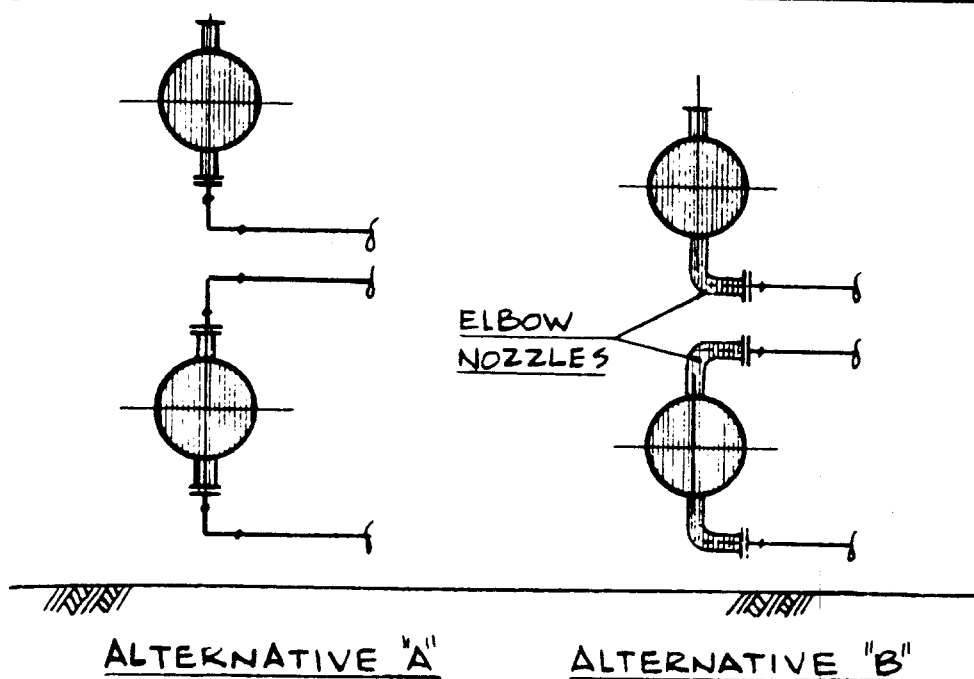
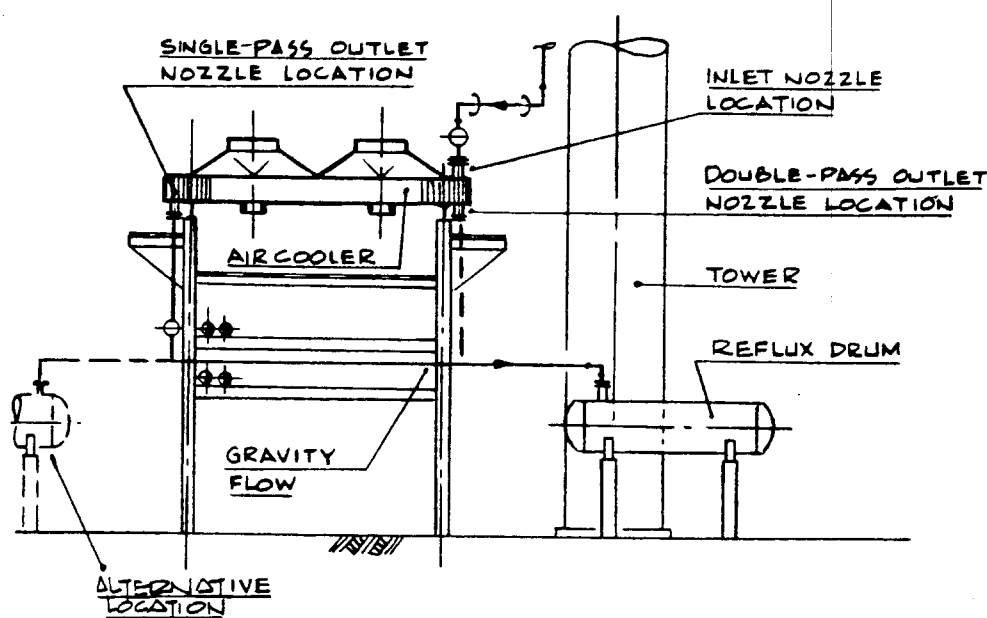


EXHIBIT 6-30
Alternative Air Cooler
Nozzle Configurations



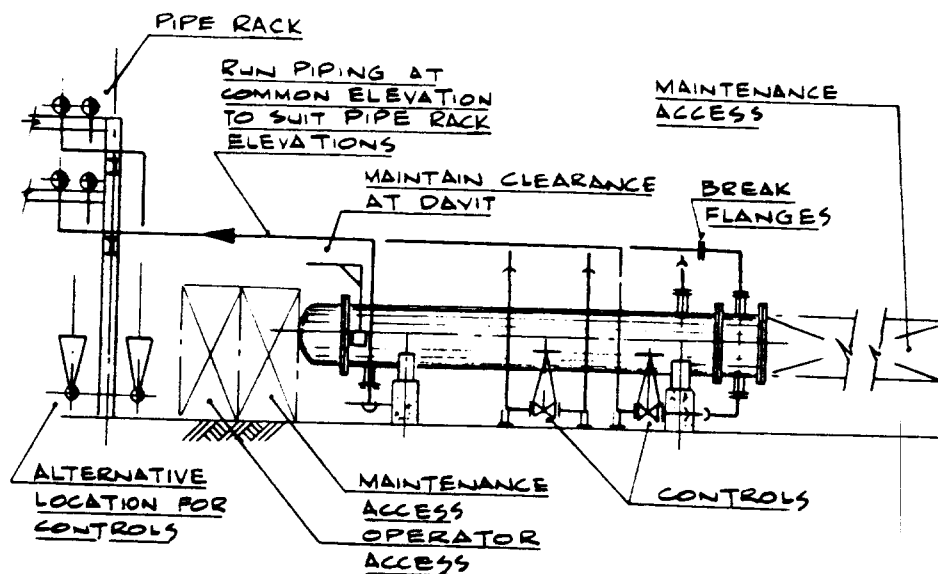
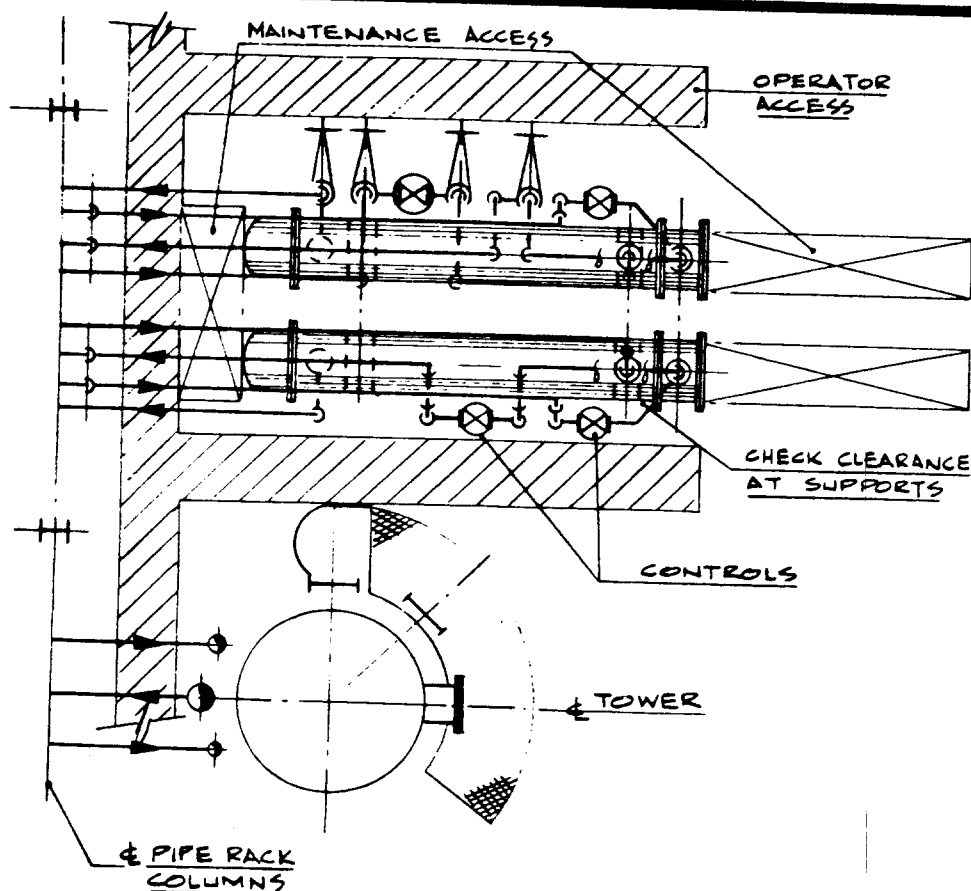
EXCHANGER PIPING

Exchanger piping must be routed in such a manner that it meets economy, flexibility, support, and operation and maintenance access requirements. Piping at shell and tube exchangers is positioned to allow adequate space for removal of channel heads and shell covers. The free space at the side of horizontal shells can be used for placement of controls. Piping is elevated a minimum distance from grade or platform to provide operator headroom clearances, to offer ease of support, and to meet designated pipe rack eleva-

tions. Large-diameter or more expensive piping cannot be set to accommodate smaller or less expensive piping. Piping connected to channel head nozzles should be furnished with break flanges to facilitate the removal of the channel head.

Piping at spiral and plate exchangers is also positioned to allow the opening of covers and the removal of plates. Controls at the spiral exchanger are located on the ends of the unit, clear of the cover plate swing area, and at the front and on one side for the plate

EXHIBIT 6-31
Piping Arrangement for
Horizontal Shell and
Tube Exchangers



exchanger. Piping is elevated in a fashion similar to the shell and tube arrangements. Piping attached to the cover plate nozzles of the spiral units is furnished with break flanges. Piping at air coolers is not routed

over tube banks or fans and should be kept clear of the designated space for motor maintenance. Exhibits 6-31 through 6-44 show various piping configurations for heat exchangers.

EXHIBIT 6-32
Piping Arrangement for
Underground Cooling
Water System

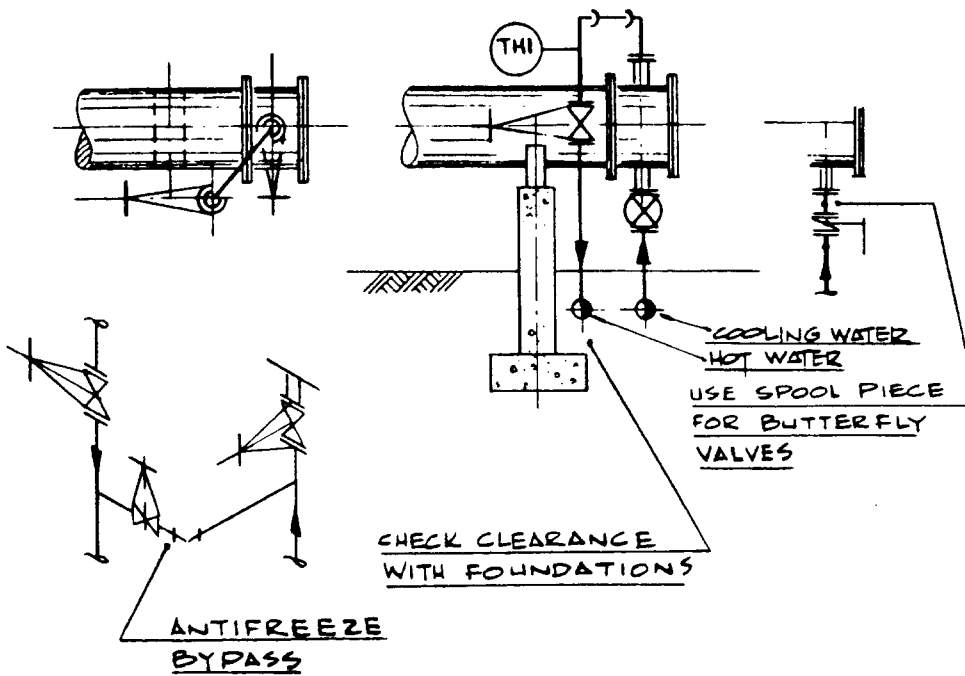
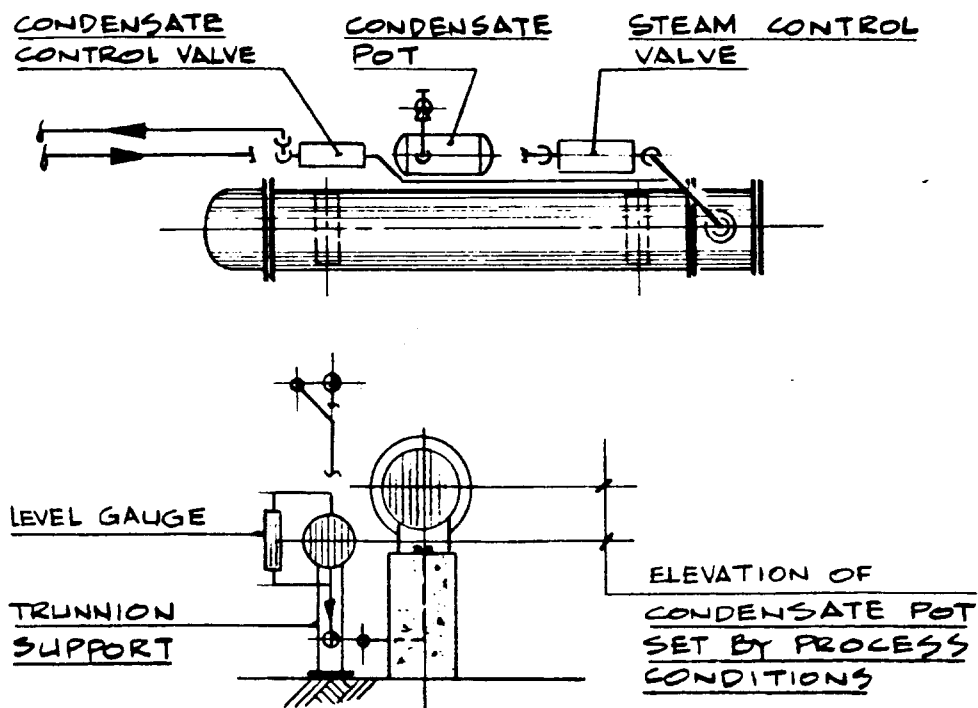


EXHIBIT 6-33
Piping Arrangement for
Steam and Condensate
System



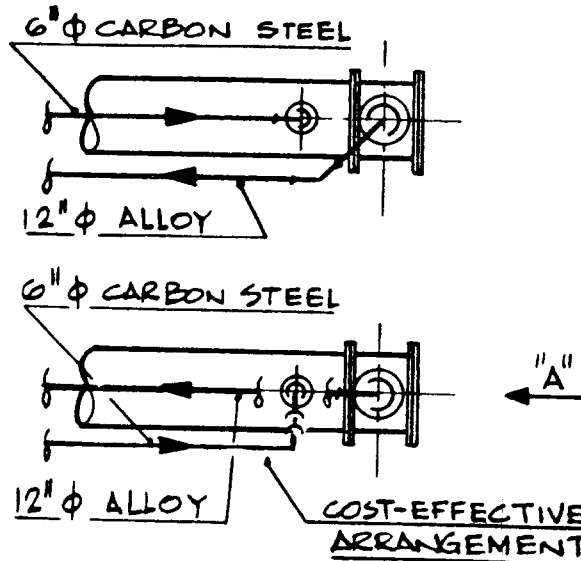
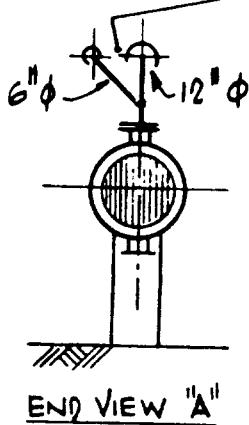
CHECK CLEARANCE

EXHIBIT 6-34
Sample of Piping
Economy Arrangement

EXHIBIT 6-35 Supports for a Piping Arrangement

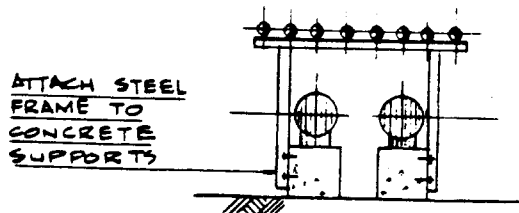
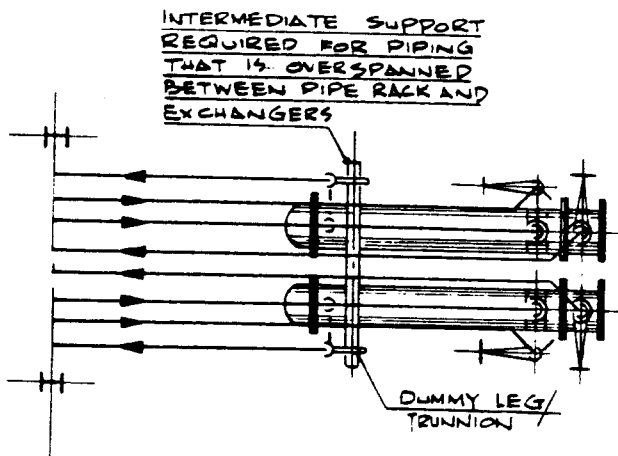


EXHIBIT 6-36 Piping Arrangement for Horizontal Reboiler

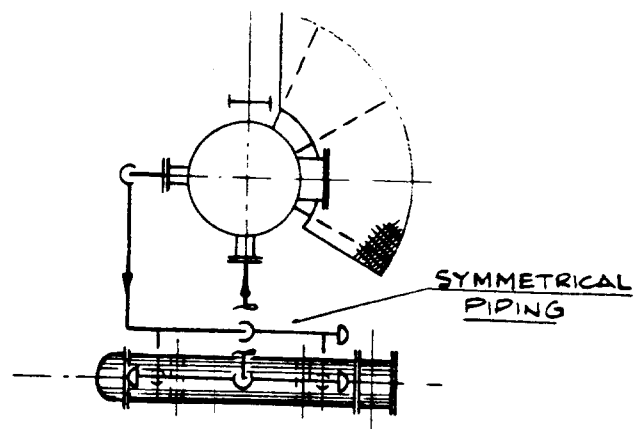
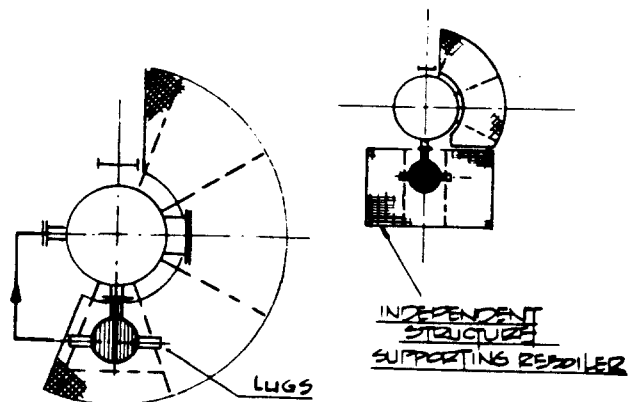
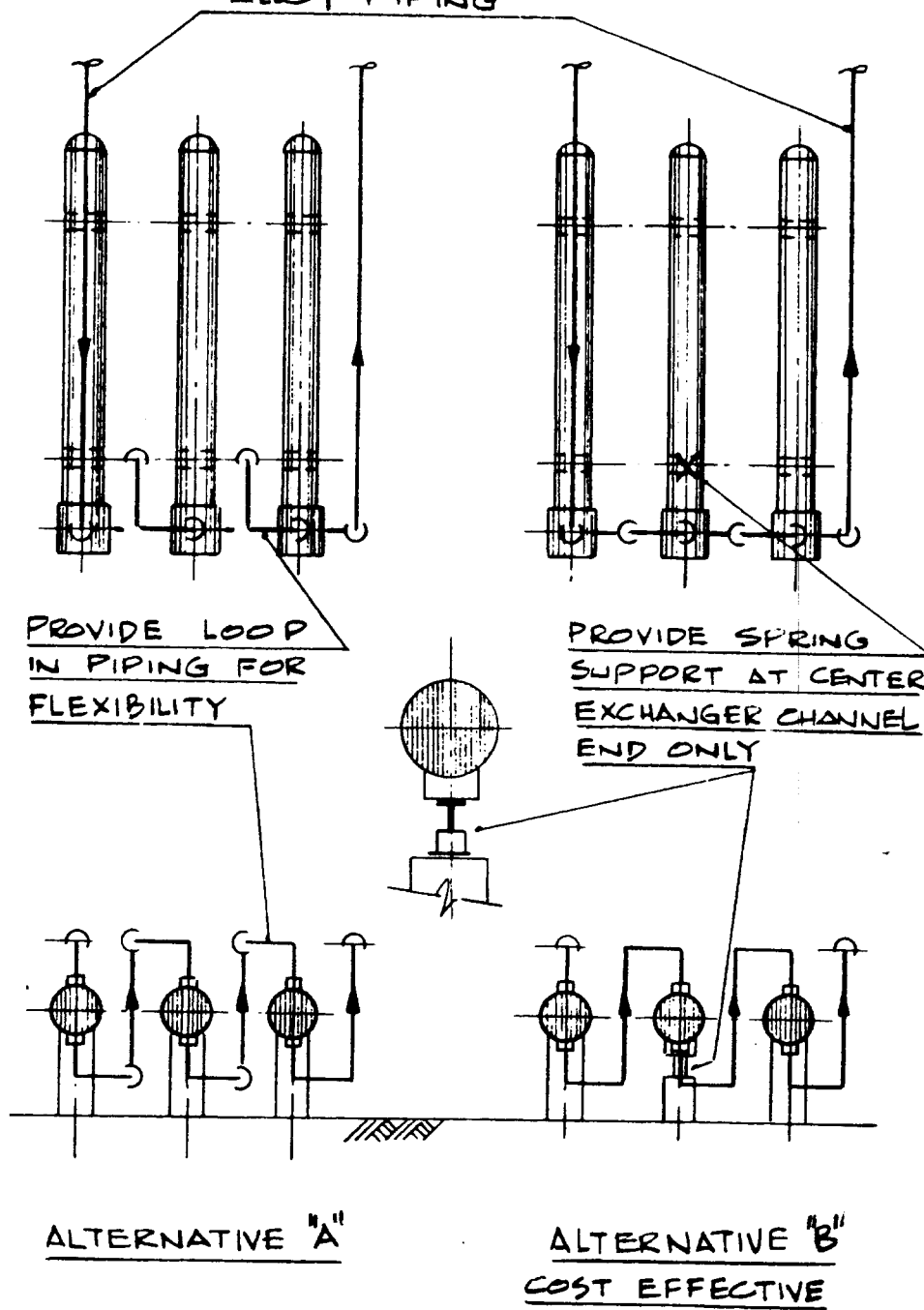


EXHIBIT 6-37 Piping Arrangement for Vertical Reboiler



HIGH-TEMPERATURE, HIGH-PRESSURE
ALLOY PIPING

EXHIBIT 6-38
Piping Arrangement for
High-Temperature,
High-Pressure Feed
Exchangers



LOCATE PIPING BENEATH
PLATFORM FOR EASE
OF SUPPORT

EXHIBIT 6-39
Piping Arrangement for
Feed Exchangers

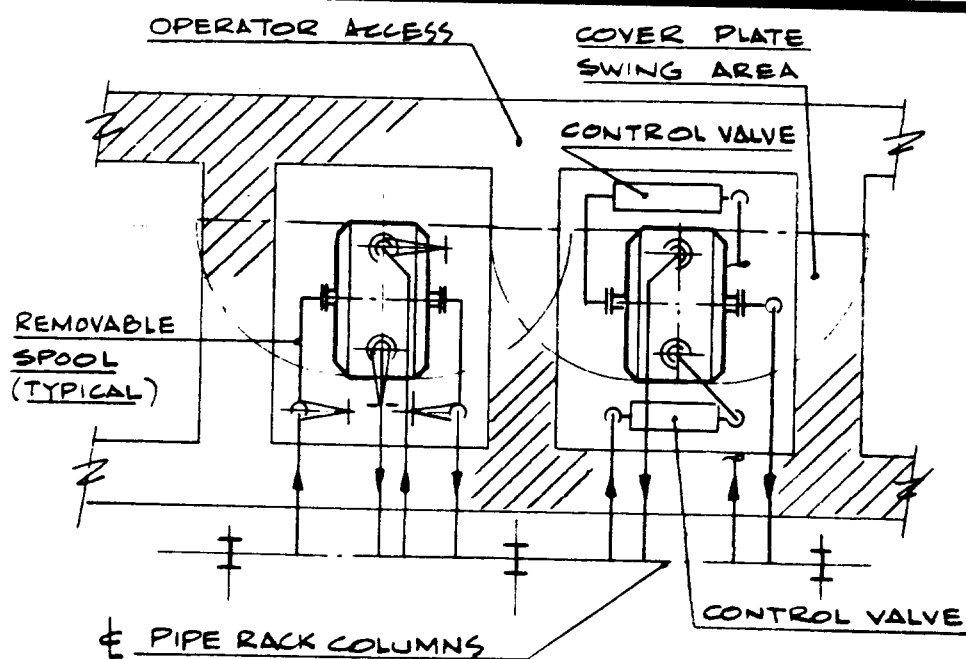
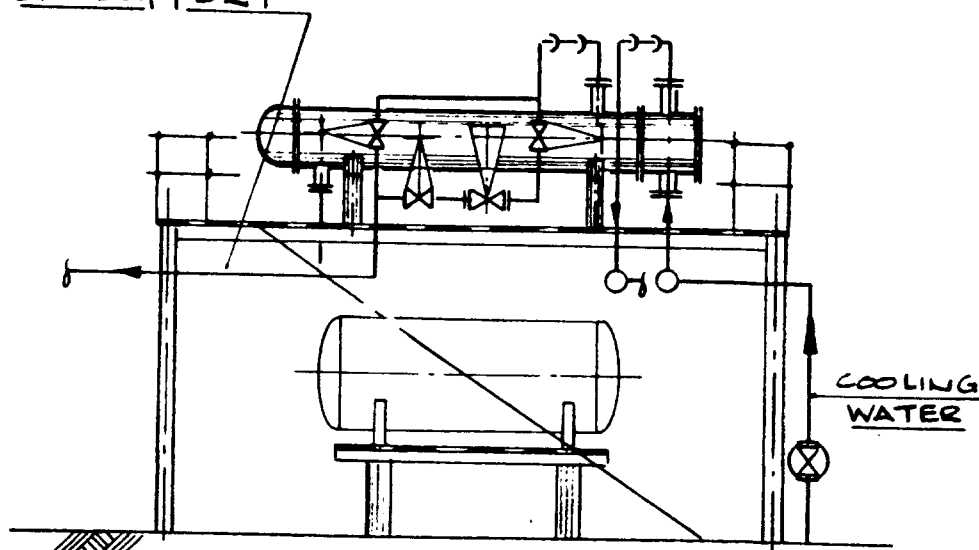


EXHIBIT 6-40
Piping Arrangement for
Spiral Exchangers

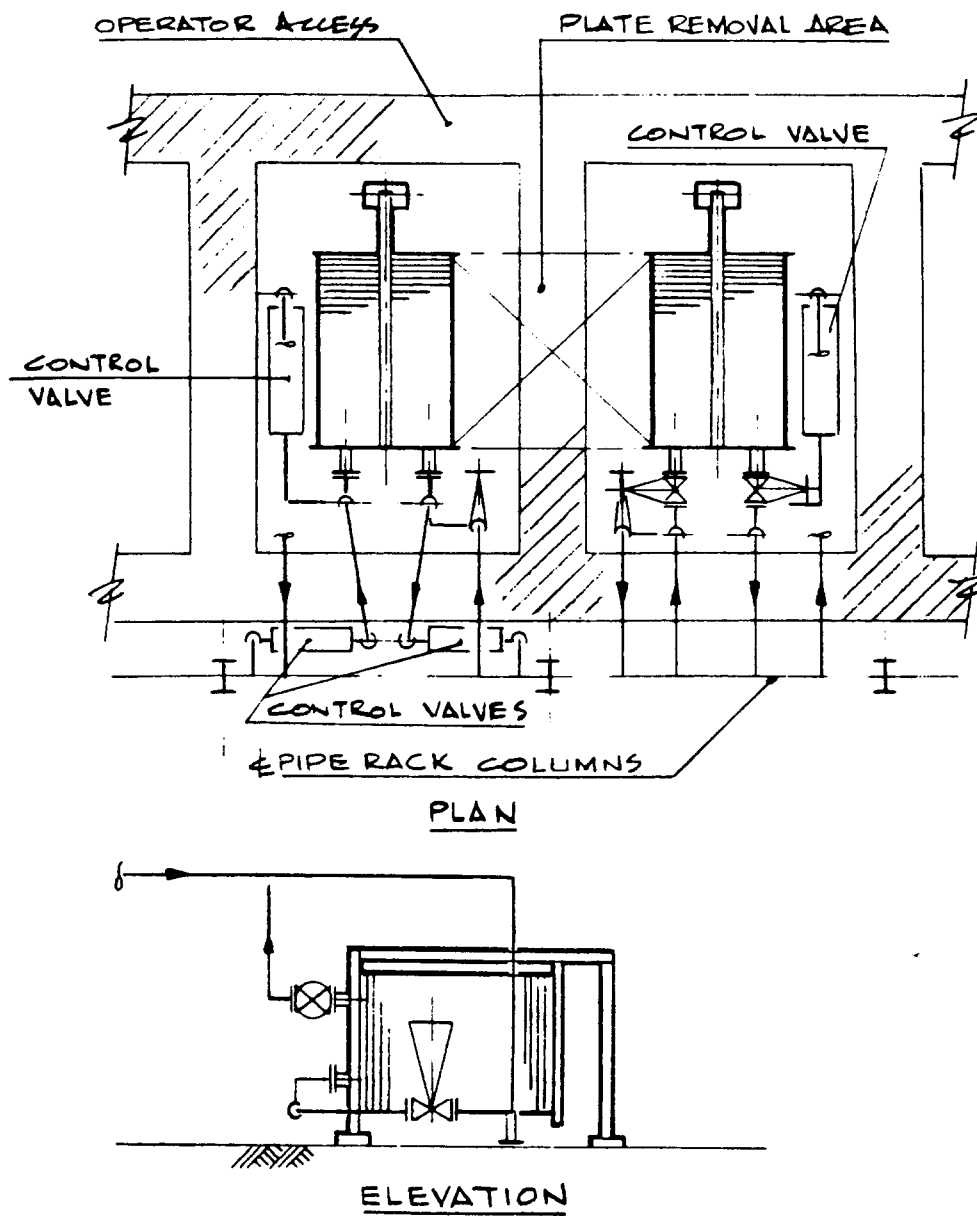


EXHIBIT 6-41
Piping Arrangement for
Plate Exchangers

EXHIBIT 6-42 Air Cooler Piping Configurations

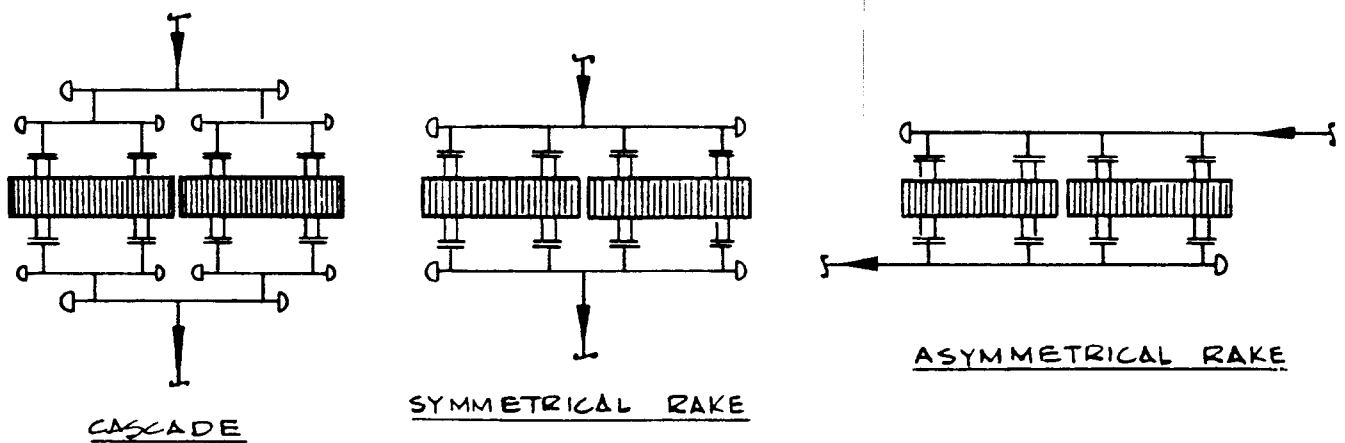
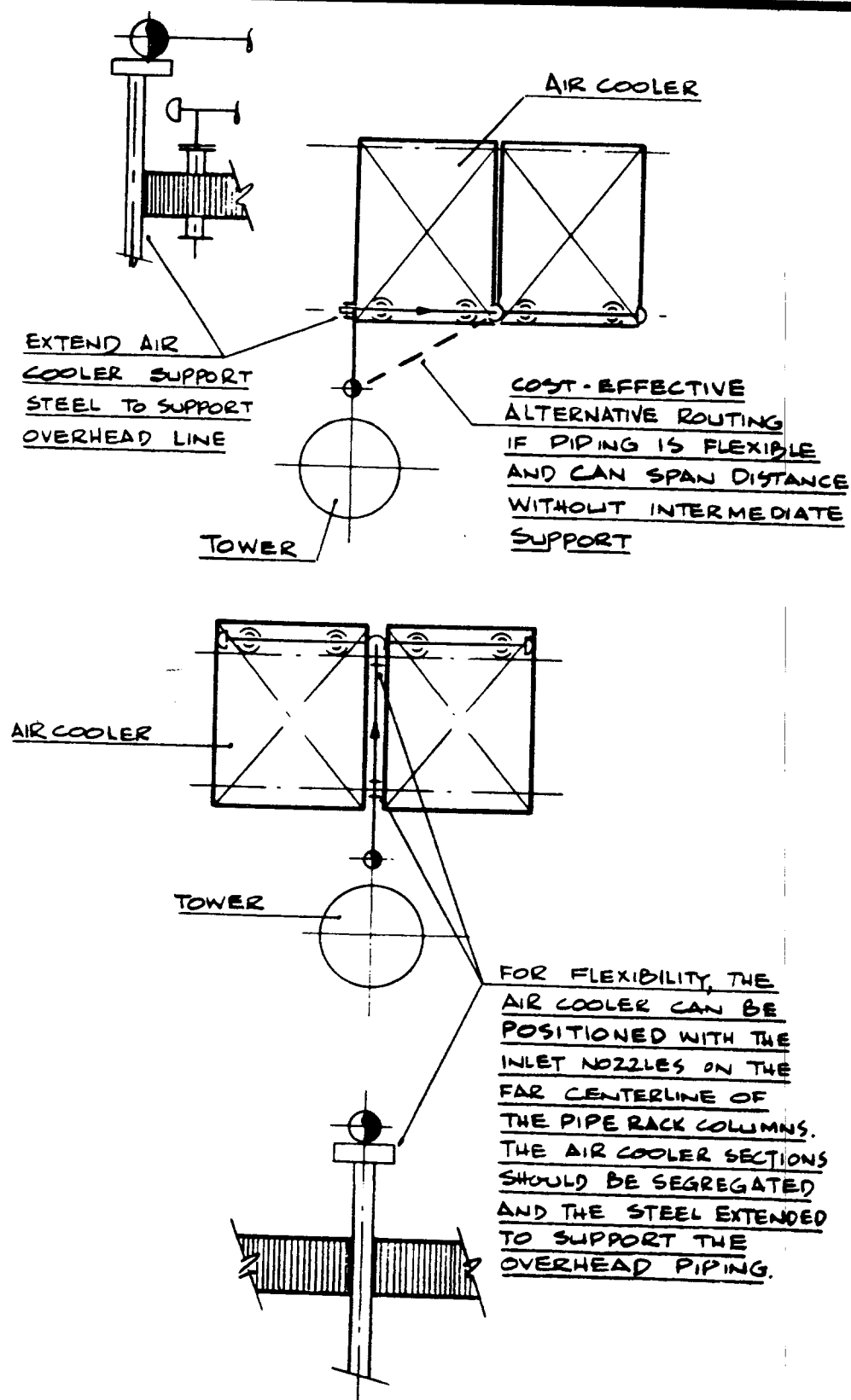


EXHIBIT 6-43
Overhead Piping
Arrangements for a
Condensing Air Cooler



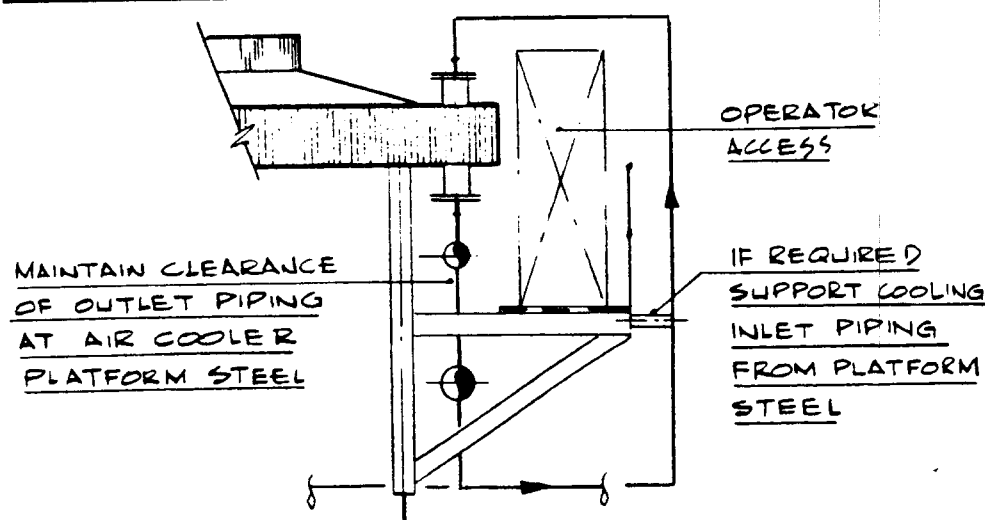


EXHIBIT 6-44
Inlet and Outlet Piping
Arrangement for a
Product Air Cooler

EXCHANGER MAINTENANCE

Like an automobile radiator, the internals of heat exchangers require periodic cleaning and repair. It is important for exchangers and related components to be positioned to facilitate access to their internal parts.

For the shell and tube heat exchangers, the tubes and the interior of the shell can be cleaned in place with high-pressure steam or water and rodding devices. If the design of the exchanger permits, the tube bundle can also be removed for repair or cleaning. Tube bundles and head and shell covers can be removed by built-in fixed handling devices (e.g., davits, hitch points, pulling posts), fixed structures with trolley beams and traveling gantry cranes, or by mobile equipment (e.g., cranes and hydraulic bundle extractors). Exhibits 6-45 through 6-48 provide examples of tube bundle removal equipment. Considerable saving can be achieved if the plant is serviced by mobile equipment.

Air cooler units are not furnished with fixed han-

dling devices for removal of tube bundles. Minor repairs (e.g., tube plugging) are usually accomplished with the air cooler in place; for major repairs, air cooler sections are removed by mobile cranes, as shown in Exhibit 6-49. Internal servicing at plate exchangers can be done manually. In the event of a tube failure, individual tubes are closed by inserting a plug through the end of the header box and hammering it into place, as shown in Exhibit 6-50.

The use of tube bundle extractors eliminates the need for permanent tube bundle removal structures, with considerable saving to the plant. These mechanisms weigh seven tons and are capable of pull forces greater than 500,000 lbs. The extractor is lifted into position by crane and clamped to the shell flange of the exchanger, which is stripped for bundle removal. Held in position by the crane and balanced by the extractor's leveling cradle, the bundle is pulled out of its shell with pull rod attachments that use hydraulic force. The whole unit is then lowered to grade and can be relifted onto a truck for off-site repair or cleaning.

EXHIBIT 6-45
Bundle Pulling Post

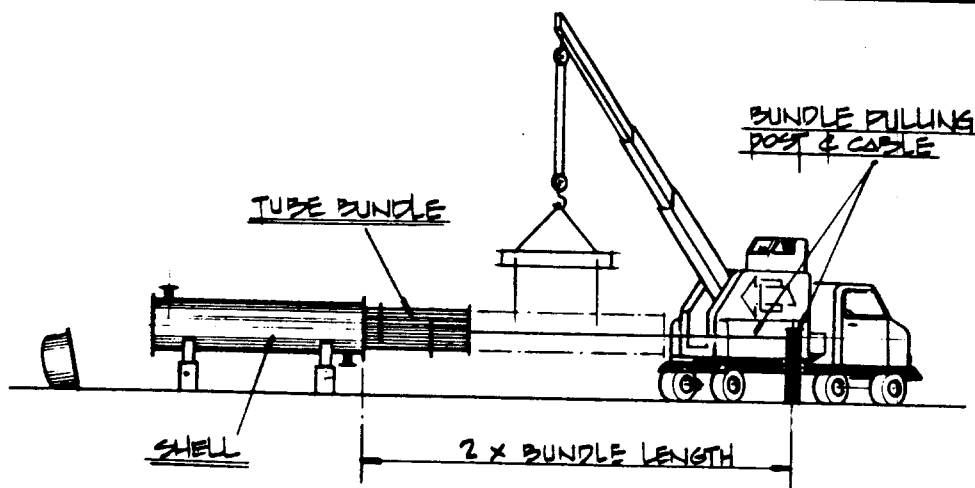
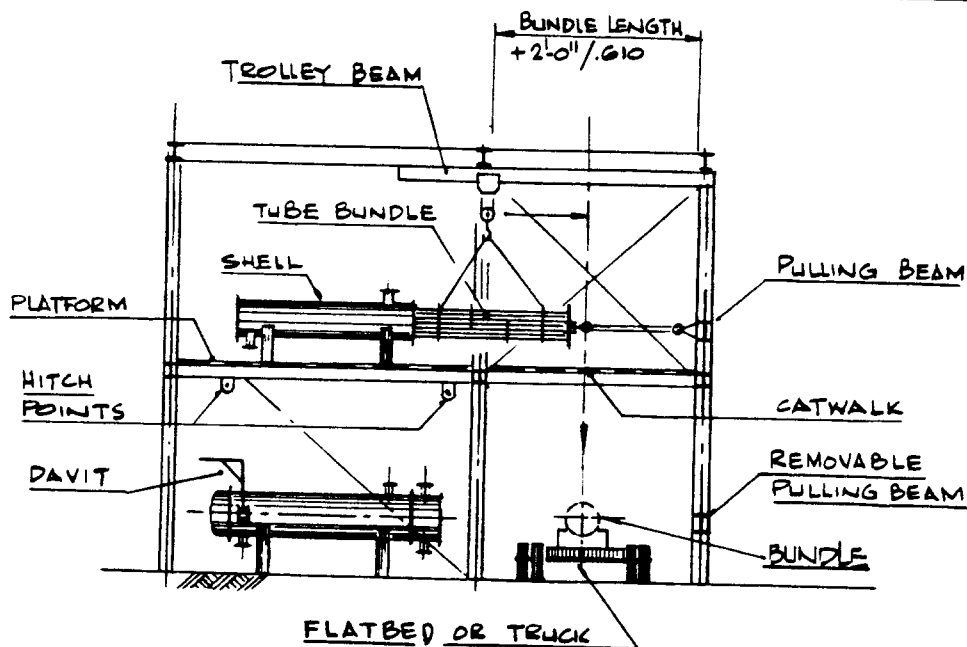


EXHIBIT 6-46
Fixed Structure with a
Trolley Beam



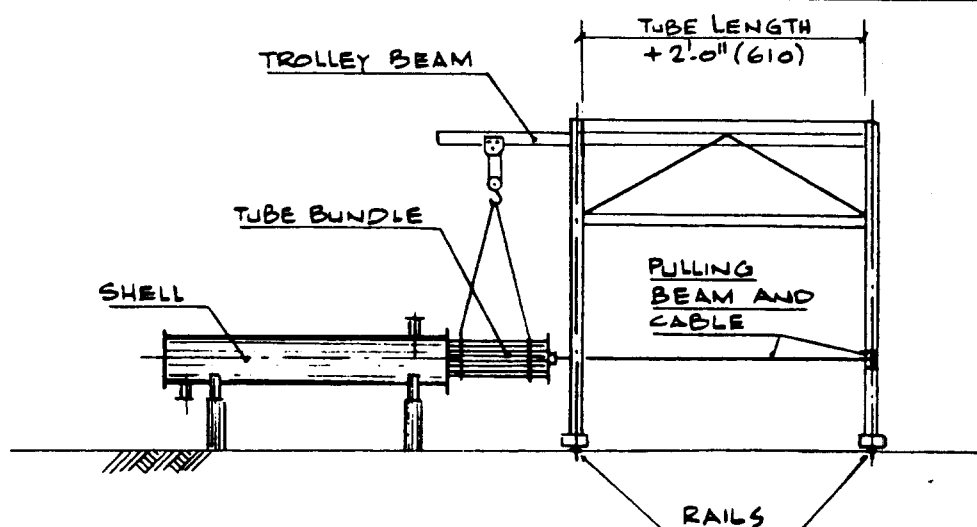


EXHIBIT 6-47
Fixed Structure with a
Traveling Gantry

EXHIBIT 6-48 Removal of a Tube Bundle by Crane

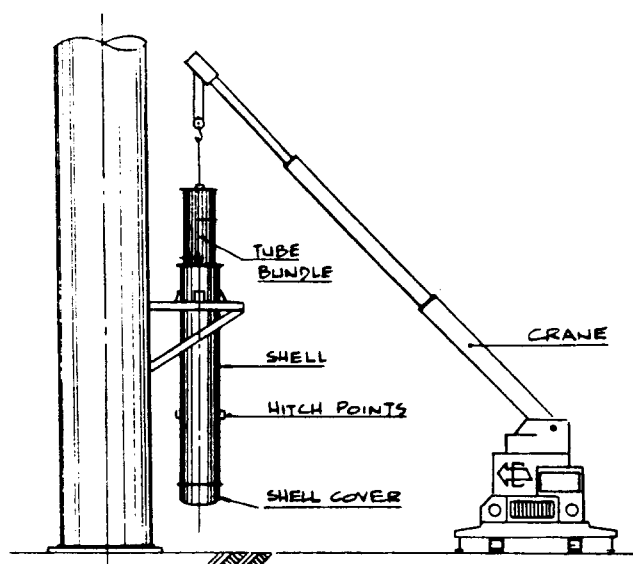
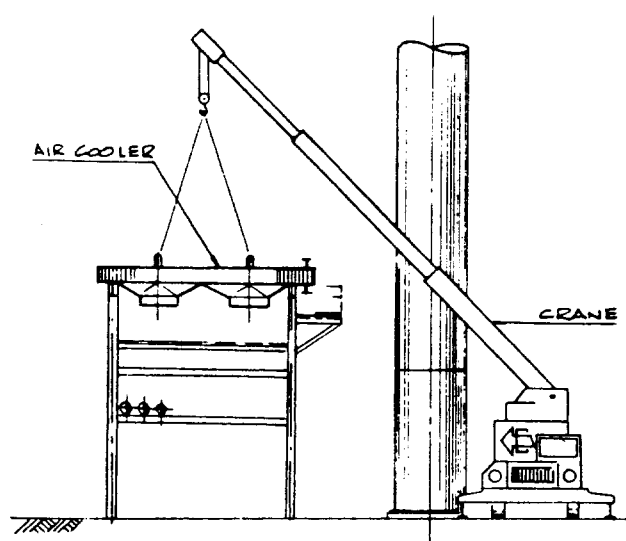


EXHIBIT 6-49 Removal of Air Cooler Sections with a
Mobile Crane



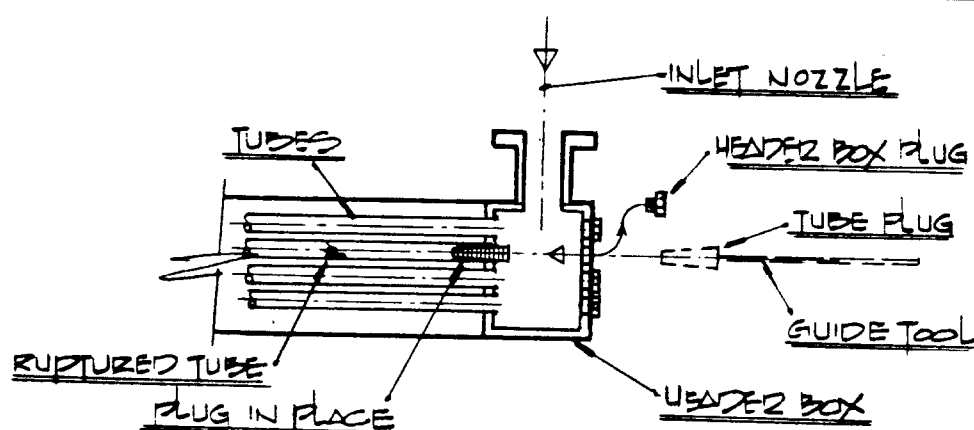


EXHIBIT 6-50
Air Cooler Tube Plugging

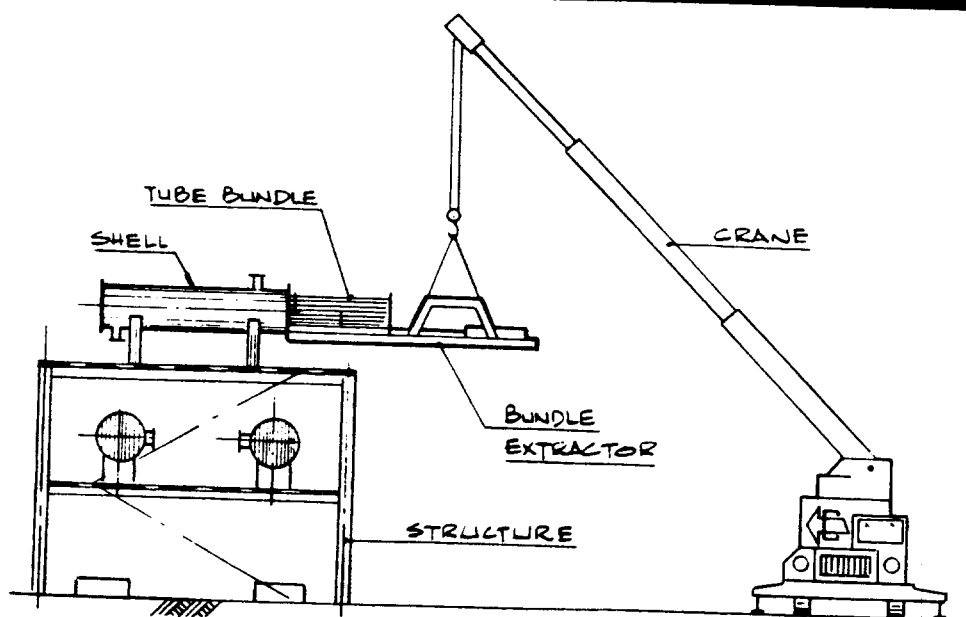
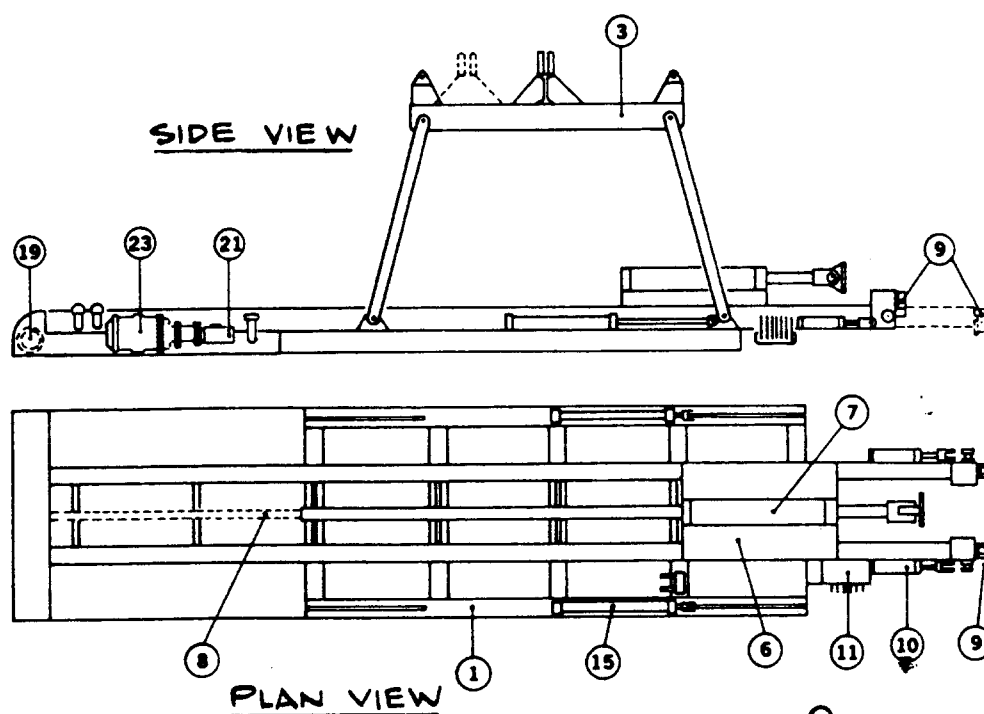


EXHIBIT 6-51
Bundle Removal Using an
Extractor and a Mobile
Crane

HYDRAULIC TUBE BUNDLE EXTRACTOR

EXHIBIT 6-52
Tube Bundle Extractor
Details



Item No.		Legend	
3	Main superstructure	8	Drive chain
9	Flange clamp	9	Flange clamp
19	Hydraulic motors	10	Sling cylinders
21	Tandem pumps	11	Hydraulic control valves
23	Air motor	15	Balance cylinders
1	Main frame	18	Reaction lugs
6	Cylinder main car	26	Air cylinder for reaction lugs
7	Main cylinder		

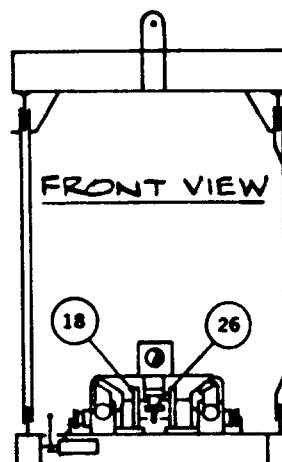


EXHIBIT 6-53 Tower-Mounted Air Cooler

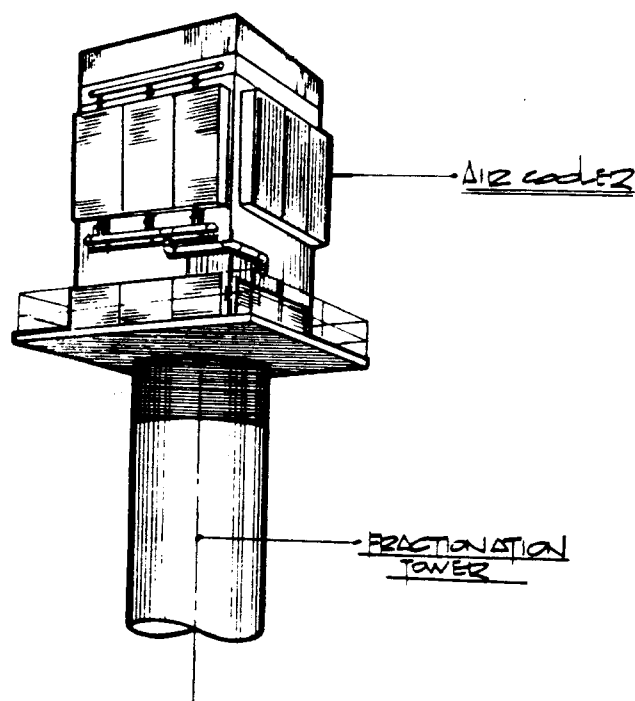
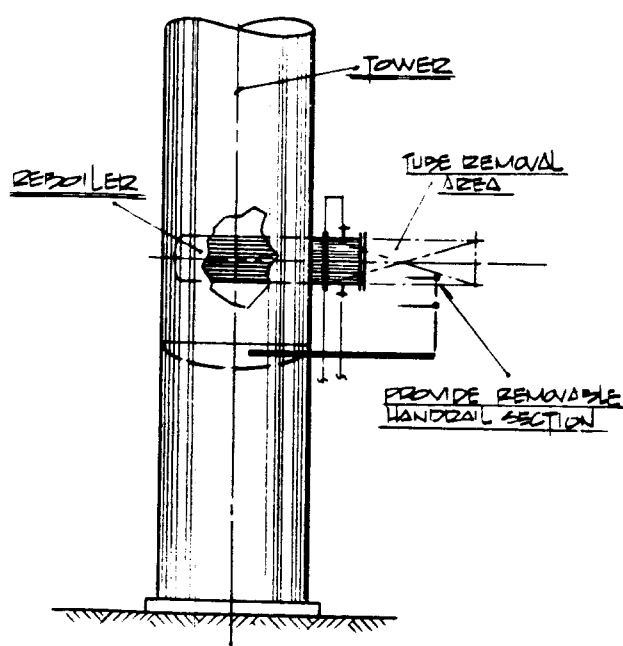


Exhibit 6-51 illustrates an elevated exchanger with the extractor and crane in position for bundle removal. Exhibit 6-52 provides details of a hydraulic tube bundle extractor.

This chapter has highlighted the principal layout requirements for the heat exchanger configurations

EXHIBIT 6-54 Stab-In Reboiler



most commonly used in process plants. A wide range of items, however, can be identified as heat exchange equipment for specific situations. Generally, these items have design features similar to those for common applications. Care should be taken to arrange the equipment so that the basic rules for exchanger layout are followed. Exhibits 6-53 and 6-54 show examples of more unusual heat exchanger equipment.

Furnaces

Furnaces, also referred to as heaters, are one of the main pieces of equipment in a process complex. A furnace may raise the temperature of a gas or hydrocarbon liquid to meet specific processing needs or, in the case of pyrolysis and reformer furnaces, cause a chemical or physical change to the medium. A circular or box-type configuration is primarily used; variations to each design are covered throughout this chapter. In addition, because of the various types of furnaces, this chapter covers some basics of furnace design and discusses how to approach a piping layout as it relates to maintenance, operation, and safety.

BASIC OPERATION AND PRIMARY PARTS OF A FURNACE

Exhibit 7-1 illustrates the basic makeup of a furnace. As shown in this exhibit, the basic parts of a furnace include:

- The radiant section—Houses rows of horizontal or vertical tubes that carry the product to be heated.
- Burners—These are primarily fired by oil or gas and are located in the radiant section.
- The convection section—Located above or downstream from the radiant section. It houses rows of horizontal tubes that are heated by the hot flue gases.
- The stack—This is usually located above the convection section and carries the flue gases to the atmosphere.
- Insulation—Lines the walled surfaces of the radiant and convection sections.

The furnace operates in the following manner. Fuel is fed to the burners located along the furnace floor. It is then ignited by a pilot gas line located in the burner. The combustion air flow is regulated by adjustment of the air registers. For proper operation within a furnace, a natural draft must be maintained. As the tem-

perature increases, the hot flue gas rises out of the stack and begins to exert a negative pressure within the radiant and convection sections. For optimum operation, there should be a pressure of approximately -0.35 in of water columns just inside the air register of the burner. There should be a pressure of -0.2 in of water columns at the furnace floor, with a further drop to -0.5 in at the top of the radiant section, and -0.7 in at the base of the stack. Maintaining these levels ensures adequate air flow to the burner. Peep doors are provided along the radiant walls to allow plant operations personnel to view the burners while making fuel flow adjustments.

A product is introduced into the radiant tubes and is heated to the maximum operating temperatures. It then exits the furnace. Steam enters the convection section tubes and is raised to a superheated temperature by the hot flue gases.

The damper, which is used to control the draft in the furnace, is located in the stack. Adjusting the damper controls the pressure balance within the furnace. The stack height is determined by the draft requirements of the furnace but may be adjusted. Draft gauges are used to check pressure levels.

It should be understood that there are many variables to this description. Burners may be located in the side walls or roof of the radiant section. Insulation may be refractory brick, ceramic fibers, or a mineral wool blanket. The product may flow into the convection section tubes, exit that section through crossover piping, and flow through the radiant section. Multiple furnaces may be tied to one common stack by breeching.

TYPES OF FURNACES

The principal types of furnaces are box, circular, pyrolysis, and reformer.

Box-type Exhibit 7-2 shows a box-type furnace that houses rows of horizontal or vertical tubes in the radi-

EXHIBIT 7-1
Basic Furnace Operation

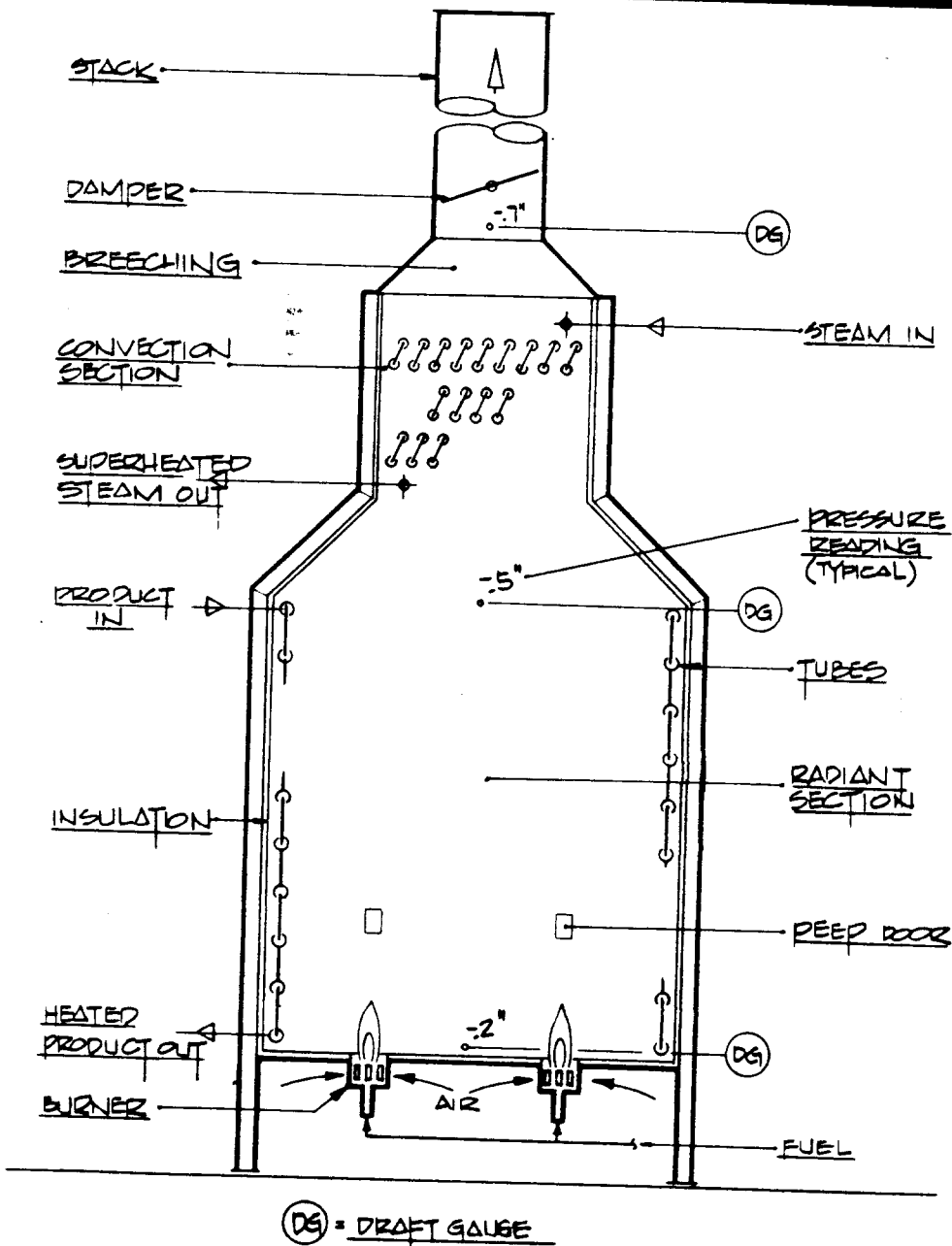
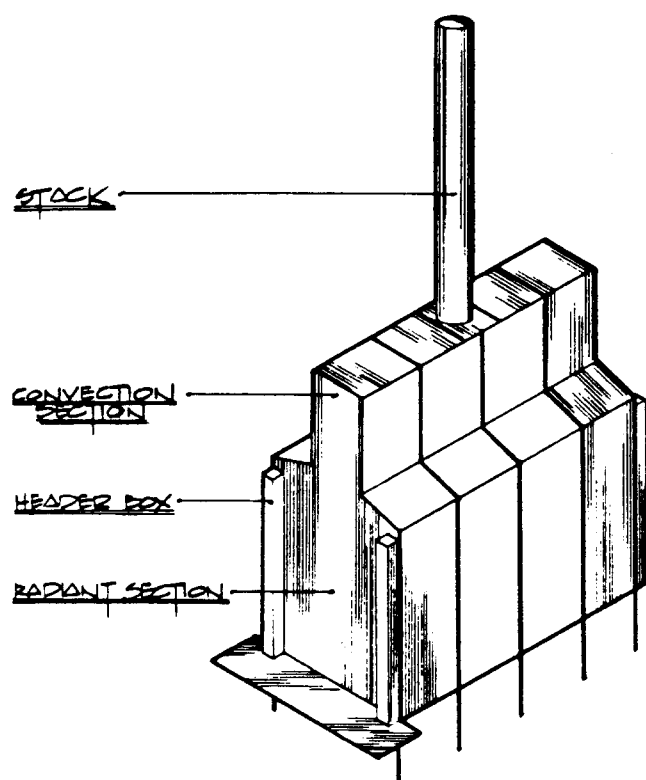


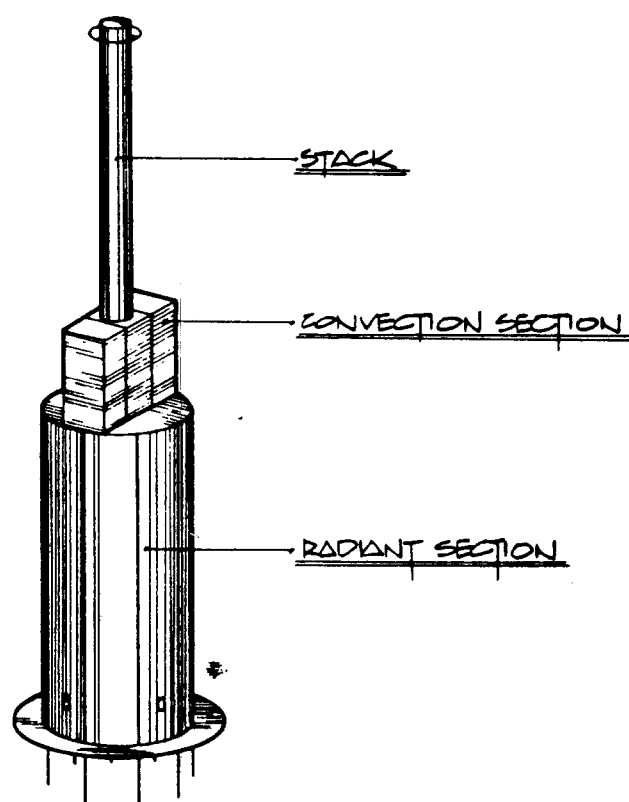
EXHIBIT 7-2 Typical Box-Type Furnace



ant section. The convection section is located downstream from the radiant section, where flue gas may pass in an upward or downward flow. Rows of burners are located in the radiant section; this is the primary source of product heating.

Circular Exhibit 7-3 illustrates a circular furnace that houses tubes mounted vertically or helically in the radiant section. These furnaces are generally used for such smaller duties as start-up heaters or reboilers. Inlet and outlet connections are usually located at the top or the bottom of the radiant section, depending on

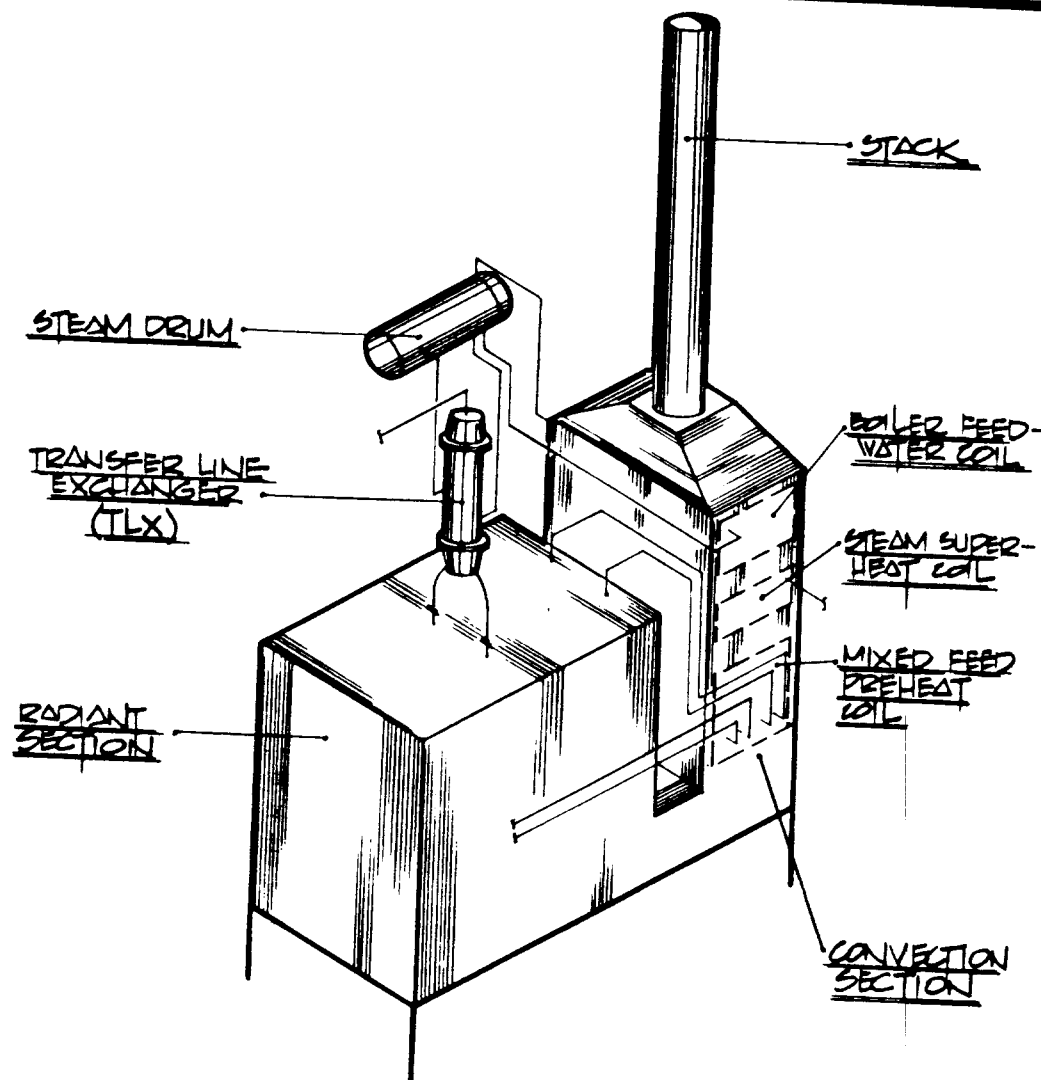
EXHIBIT 7-3 Typical Circular Furnace



the product being heated, and are located at one end of the convection section.

Pyrolysis Exhibit 7-4 illustrates a pyrolysis furnace whose product tubes are placed in the center of the radiant section because of a relatively short residence time, high heat transfer rate, and need for even temperature distribution in the tubes. An integral waste heat recovery system that employs the use of a steam drum and a transfer line exchanger (TLX) is also shown. Steam decoking is required to clean the internal walls of the process tubes.

EXHIBIT 7-4
Typical Pyrolysis Furnace



Reformer In a reformer furnace, shown in Exhibit 7-5, preheated process fluid flows through catalyst-filled tubes, which are usually located in the center of the radiant section. This type of furnace may have single or multiple compartments; burners may be mounted in the roof, wall, or floor. Heat recovery systems may also be employed through the use of waste heat boilers or the convection section's steam generation coils.

TERMINOLOGY

The following sections list common furnace terms.

Blowdown steam Blowdown steam is used for tube cleaning or removal of products from the inlet piping in the event of fire.

Blowdown system A blowdown system is the piping

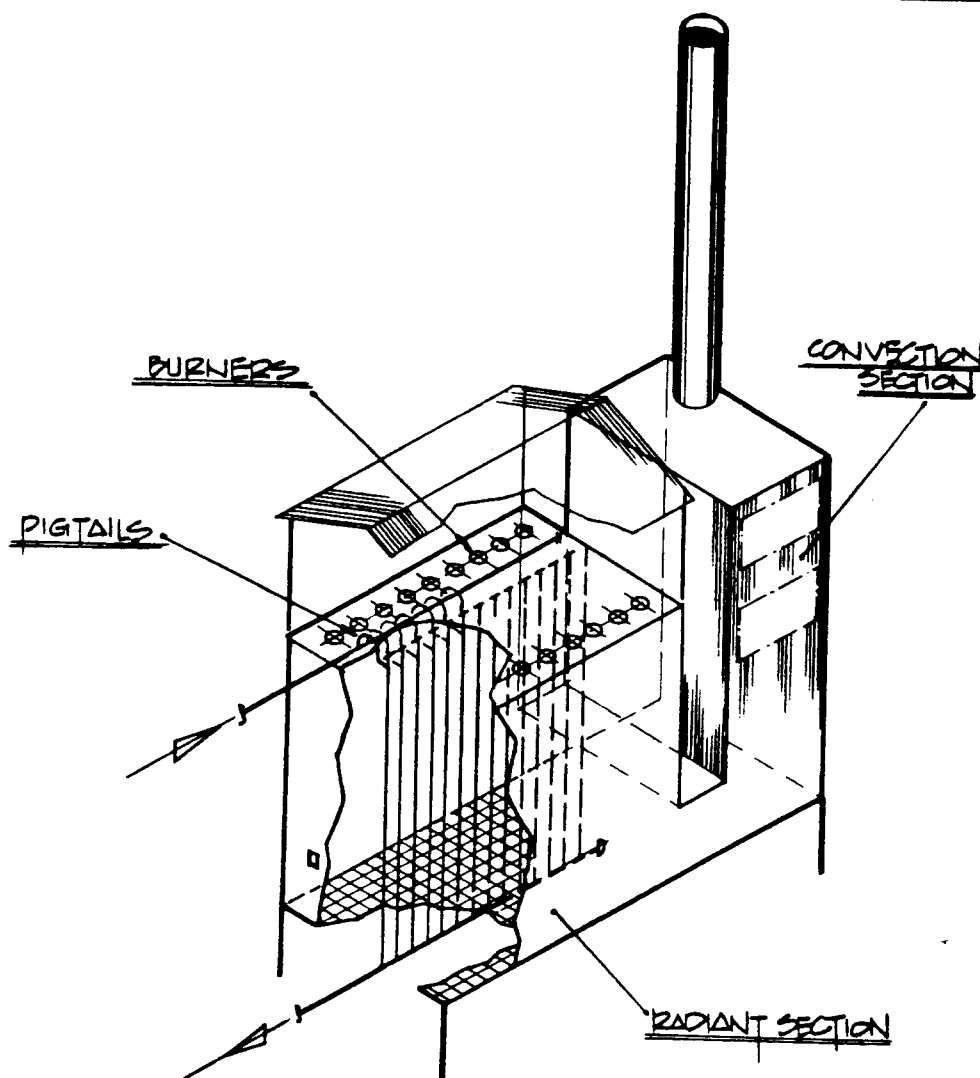
system used to carry waste away from piping or tubes for disposal.

Breeching Breeching refers to the duct work that collects flue gases along the furnace box outlet for transmission to the stack.

Burners Supplied with air and fuel necessary for combustion, burners heat the product in the tubes in the radiant section of the furnace. The most common types of burners are gas; air and gas; air and oil or gas; and oil, which requires air, oil, and atomizing steam.

Burner management package This device is designed to control such burner operations as monitoring purge sequence, igniter and main fuel start-up, pilot flame, main flame, and heater conditions. Limiting devices are built into the package that shut down the furnace if unsafe operating conditions arise.

EXHIBIT 7-5
Steam Reformer Furnace



Clean-out access doors Access is provided to the interior of the furnace for maintenance personnel.

Convection section This compartment houses rows of primarily horizontal tubes located downstream from the radiant section that are used for additional heating in a process unit. Passing the hot flue gases over these tubes can provide additional duty. Examples include preheating process streams, steam superheating, and additional steam generation. Provisions must be made to remove these tubes for inspection, repair, or replacement.

Crossover piping This piping interconnects the radiant and convection sections and is usually furnished by the furnace vendor.

Damper Located in the stack or duct, this device is used to control drafts in the furnace. Dampers are

usually flat plates that rotate on a shaft resting on pillow blocks set in the steel shell, similar to a butterfly valve.

Decoking The coke built up in many hydrocarbon furnace tubes during operation is removed by injecting steam and air into the tubes.

Draft gauge This instrument is used to check pressure in a furnace.

Explosion doors In the event of an explosion in a furnace, doors specifically designed to blow out and protect against a major structural failure are provided; they act like safety valves in a piping system.

Header A header is the fitting that connects two tubes in a flow pattern.

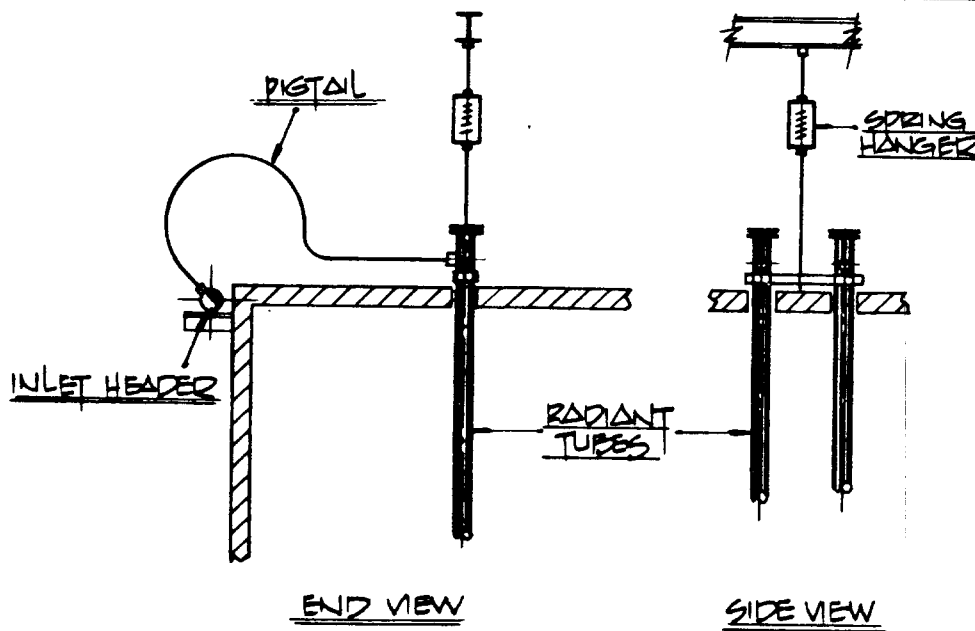


EXHIBIT 7-6
Pigtail Detail

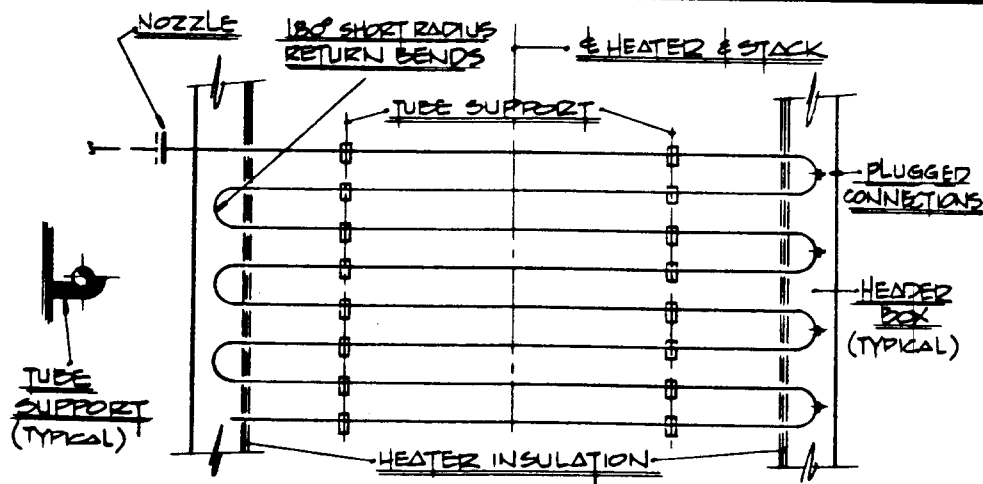
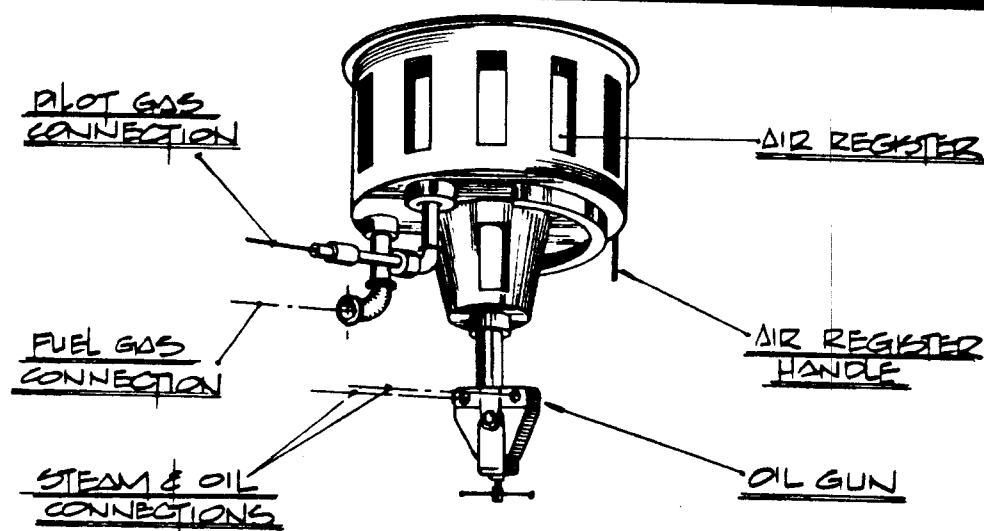


EXHIBIT 7-7
Typical Radiant Coil

EXHIBIT 7-8
Combination Oil and Gas
Burner



Header boxes Most ends of tubes are connected by U-bends that make inspection difficult. Therefore, special return fittings with plugged connections are provided that permit inspection and cleaning. Because the removable plugs are subject to leaking, all headers must be completely enclosed in header boxes. Snuffing steam is used to suppress fire in this area.

Peep doors Small doors are provided in the wall or floor of the radiant section to permit visual inspection of burners during start-up or operation.

Pigtails Small-bore flexible piping configurations connect the radiant tubes to the inlet and outlet headers, as illustrated in Exhibit 7-6.

Radiant section The main compartment of a furnace is the radiant section, in which process streams are heated, usually in vertical tubes, by heat from burners mounted in the walls, roof, or floor.

Refractory The refractory is made up of insulating bricks capable of withstanding high temperatures in furnaces.

Soot blowers Soot blowers are mechanical devices that clean residue build-up on the exterior of the convection tubes. They are usually furnished when oil-fired burners are used.

Stack Located downstream from the convection section, the stack is designed to carry flue gases directly to the atmosphere or to divert them through secondary ducts to an air preheating system. Stack elevations are usually established by a furnace designer to operate

on natural drafts. If the height of the stack is increased to suit safety conditions, a fan must be added. If emission probes are needed in a stack, ladders and platforms are added as required.

Snuffing steam This is steam that is injected into the combustion chambers or header box of a furnace to suppress a fire.

Transfer line The outlet of the process tubes are tied into a piping header called a transfer line, which feeds the main process tower.

Tubes Piping within the furnace carries the medium to be heated. A typical radiant coil is shown in Exhibit 7-7.

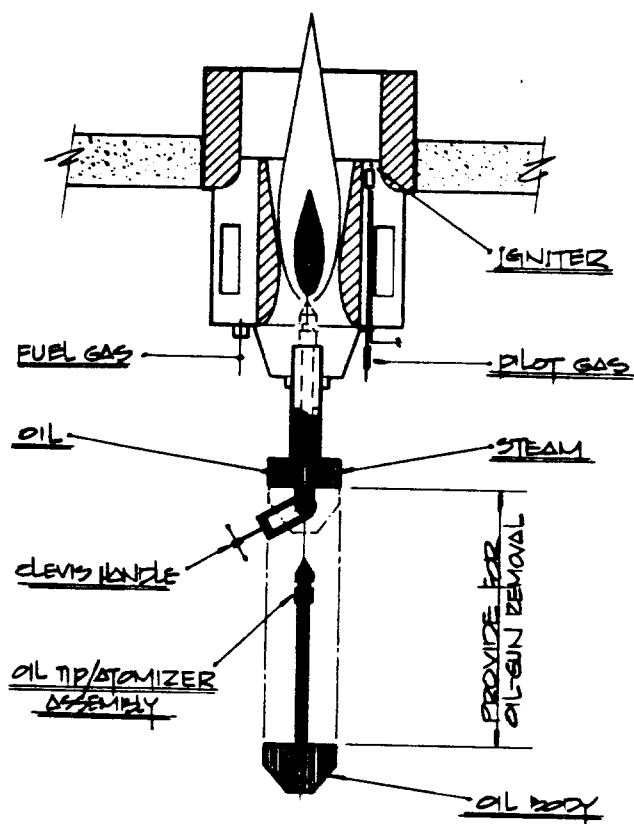
BURNERS

Furnace structure and heat-release requirements are the determining factors in the selection of the correct burner design. Burners are fired by a wide range of gaseous and liquid fuels, and a variety of configurations are used throughout the industry. It is recommended that the designer take full advantage of all burner data available from vendors to gain a greater understanding of the operation and maintenance requirements of each design.

The combination oil and gas burner is shown in Exhibit 7-8. Some of the features of this burner include:

- It is designed to fire horizontally or vertically.
- Oil spillage in the radiant section cannot cause burner plugging.

EXHIBIT 7-9 Maintenance Area for a Combination Oil and Gas Burner

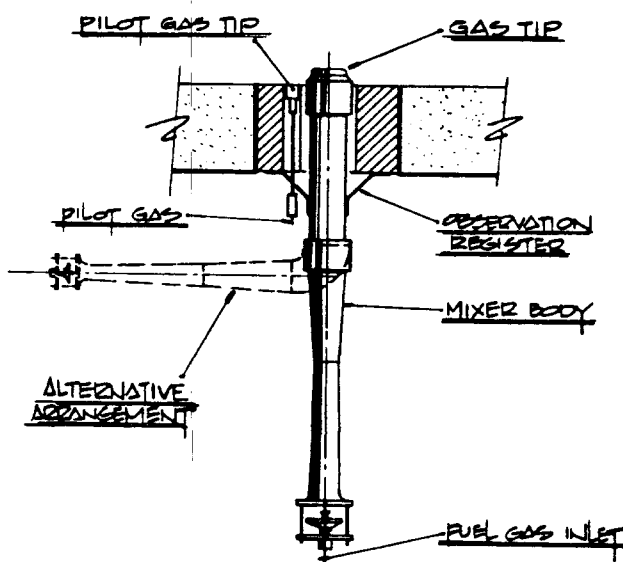


- It burns any oil that can be pumped.
- It burns any fuel gas safely and quietly.
- All parts of the burner can be inspected closely while the burner is in operation.

Exhibit 7-9 shows the maintenance area that must be provided when developing a layout for a combination oil and gas burner. By shutting off the oil and steam to the oil gun, the oil tip/atomizer assembly can be changed while the heater is in operation.

The windproof gas burner, shown in Exhibit 7-10,

EXHIBIT 7-10 Windproof Gas Burner



is easy to light and fires in any position. It requires no combustion controls to maintain maximum efficiency. The burner may be straight or L-shaped, according to layout requirements.

Burners may be arranged in single or multiple rows and located in the roof, wall, or floor, as shown in Exhibit 7-11. Many burners are operated and controlled through the use of burner management systems.

COMBUSTION AIR PREHEATING SYSTEMS

The overall thermal efficiency of a furnace is improved if the air that enters the radiant section around the burners is preheated. Economic studies are performed early in a project to determine the feasibility of such a system. The two most common preheating sys-

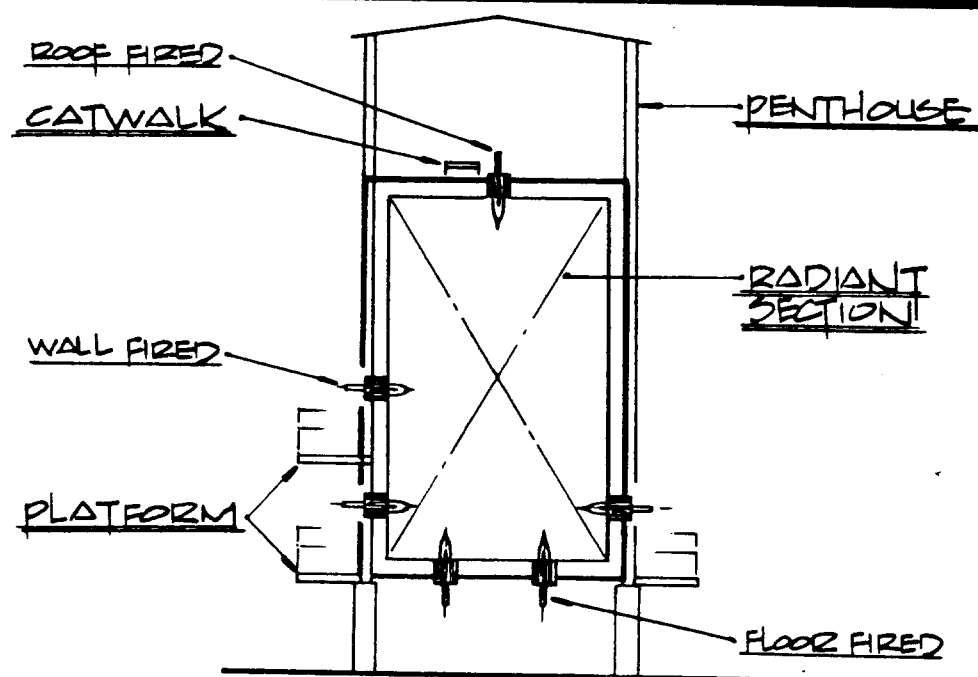


EXHIBIT 7-11
Sample Burner Locations

tems are regenerative systems and recuperative systems.

A typical regenerative system is shown in Exhibit 7-12. Hot flue gas exiting the convection section is diverted through a duct to a heat exchanger called an air preheater. Incoming fresh air is heated and sent by a forced draft fan to the burner plenum, where it enters the burner through the air register for combustion. An induced draft fan draws the flue gas through the preheater and sends the cooled gas back into the atmosphere through the stack.

A conventional recuperative (closed-loop) system is illustrated in Exhibit 7-13. Oil is circulated through the convection section tubes, heated, and sent through the inlet air duct, where it releases its heat. The hot air then enters the burner for combustion, and the hot oil is recirculated to a storage tank for recycling. From a layout standpoint, the hot oil system with a storage

tank and pump is far less complex than the regenerative system.

GENERAL ARRANGEMENT OF FURNACES

This section describes the general arrangement of various types of furnaces and discusses how operation and maintenance affect furnace elevation, how to plan all necessary access, and platform requirements, associated equipment, and stack design. Exhibit 7-14 shows a typical arrangement of a circular furnace.

Setting Furnace Elevation

The location of burners and the possible need for air preheating ducts are two primary factors to be consid-

EXHIBIT 7-12
Typical Regenerative
System

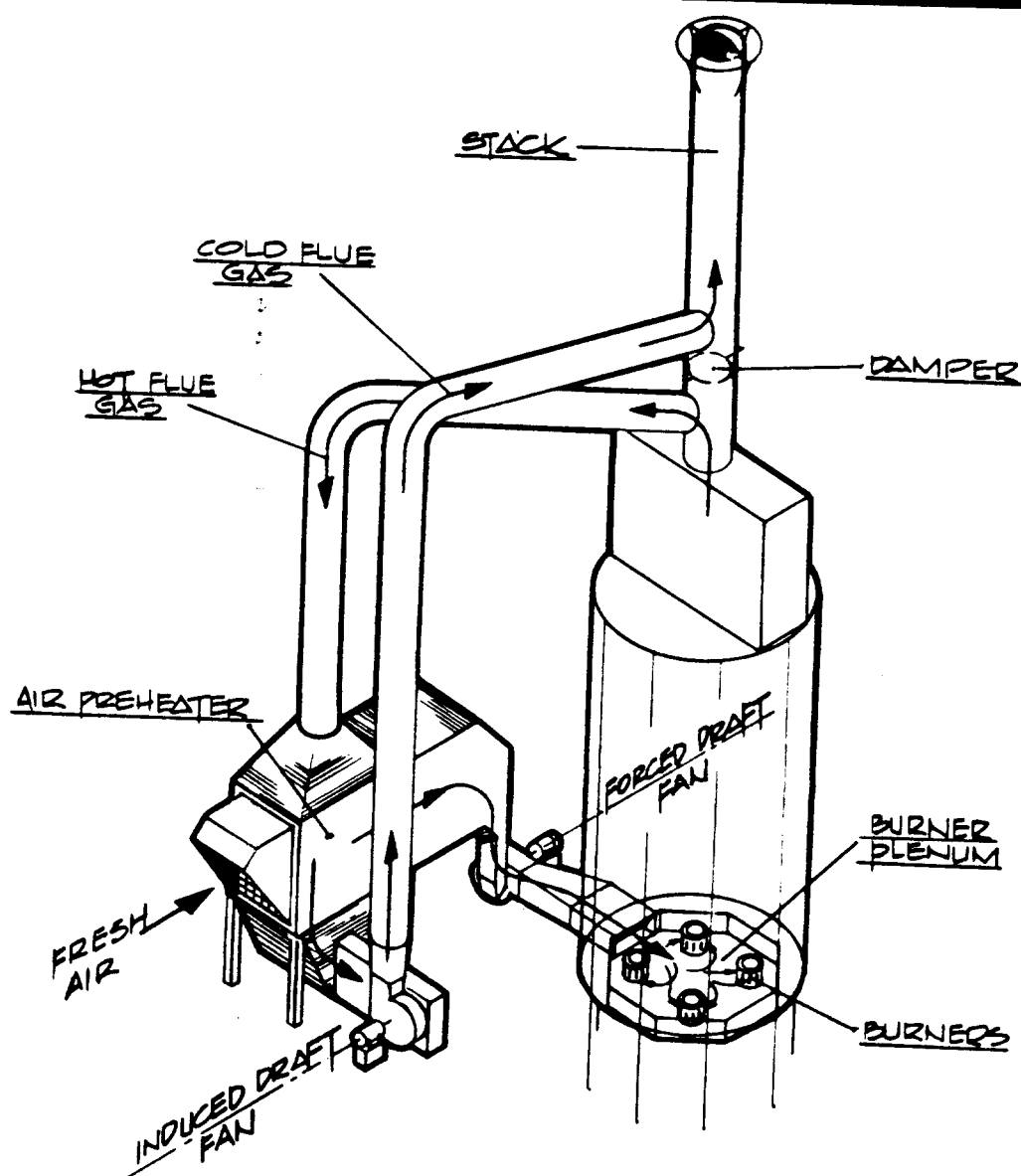
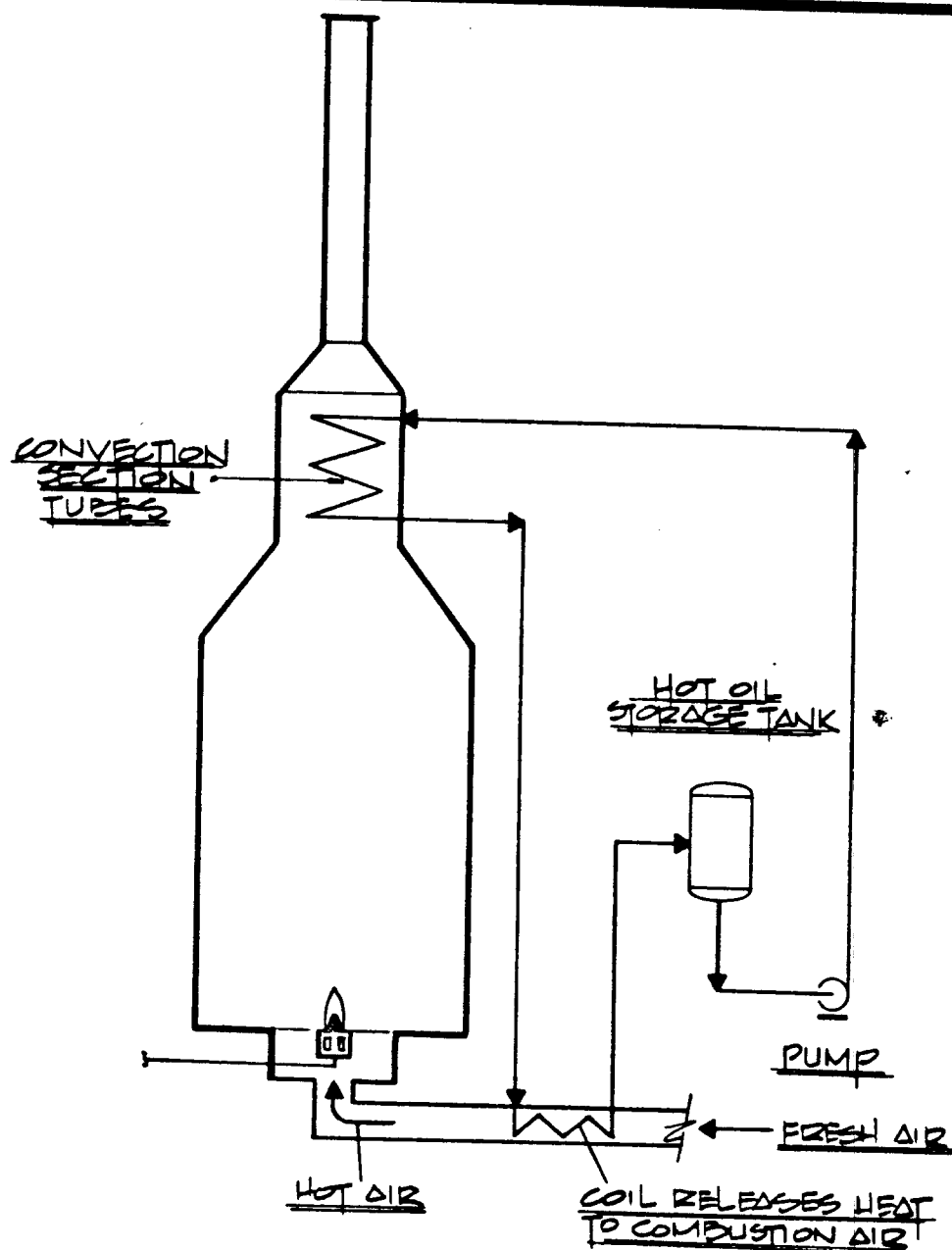


EXHIBIT 7-13
Conventional
Recuperative System



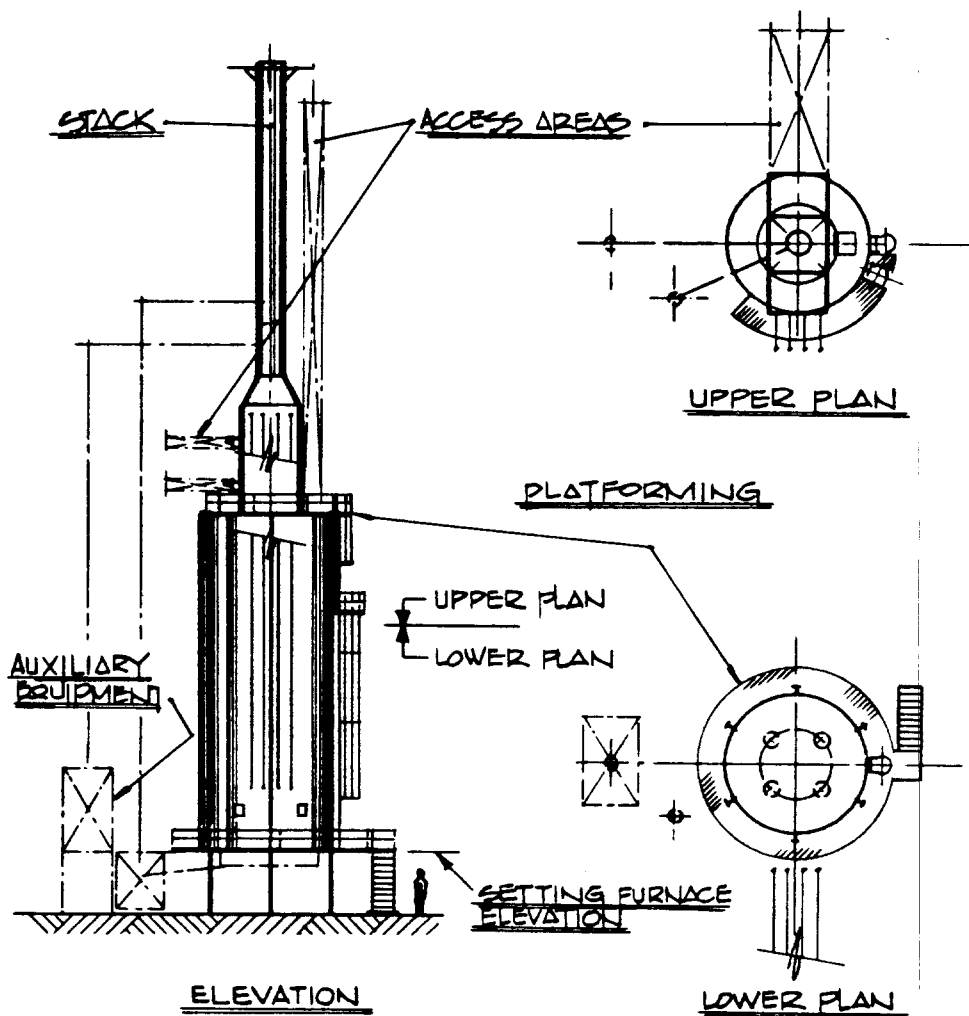


EXHIBIT 7-14
Typical Arrangement of a
Circular Furnace

ered when the elevation of a furnace is established. If, as shown in Exhibit 7-15, the burners are floor mounted, the elevation should be set high enough to allow an operator to walk freely under the furnace or ducting but not necessarily under all the burner piping.

The preferred location of the burner operating

valves is on the firing platform at the peep doors, not beneath the furnace. When wall-mounted burners are used, the elevation of the furnace can be lower because there are no major maintenance or operational requirements beneath the furnace to be addressed.

Access for operation and maintenance is a major consideration in the development of a furnace layout.

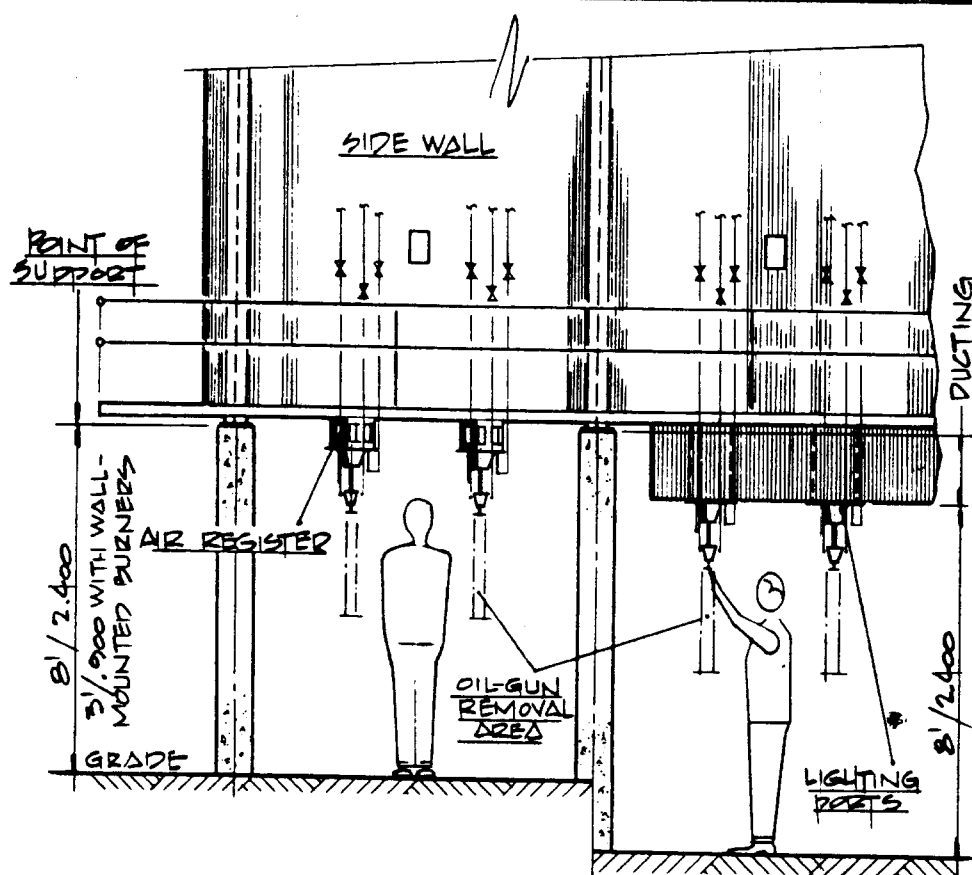


EXHIBIT 7-15
Setting a Furnace
Elevation

Access requirements are reviewed for tube removal, soot blowers, damper control, header boxes, burners, and burner management skids and control panels.

Because furnace tubes must be periodically replaced, clear areas are provided directly in line with the tubes. The removal mechanism may be a trolley beam located on the stack of a circular furnace, a crane, or a cherry picker. If only one or two tubes require removal, a tube extractor, similar to the type used for extracting shell and tube exchanger bundles, may be used. As can be seen in Exhibit 7-16, radiant

tube removal in a circular furnace is accomplished by pulling the tubes through an access door located in the top of the radiant section. This is performed by using a hoist attached to the circular trolley beam on top of the stack. Once the tubes are lifted out of the radiant compartment, they are pulled away from the furnace and lowered to grade. The convection section tubes are removed in a manner similar to the one shown for the box-type furnace in Exhibit 7-17. Here again, the access area must allow the tubes to be pulled clear of the furnace, permitting the crane to

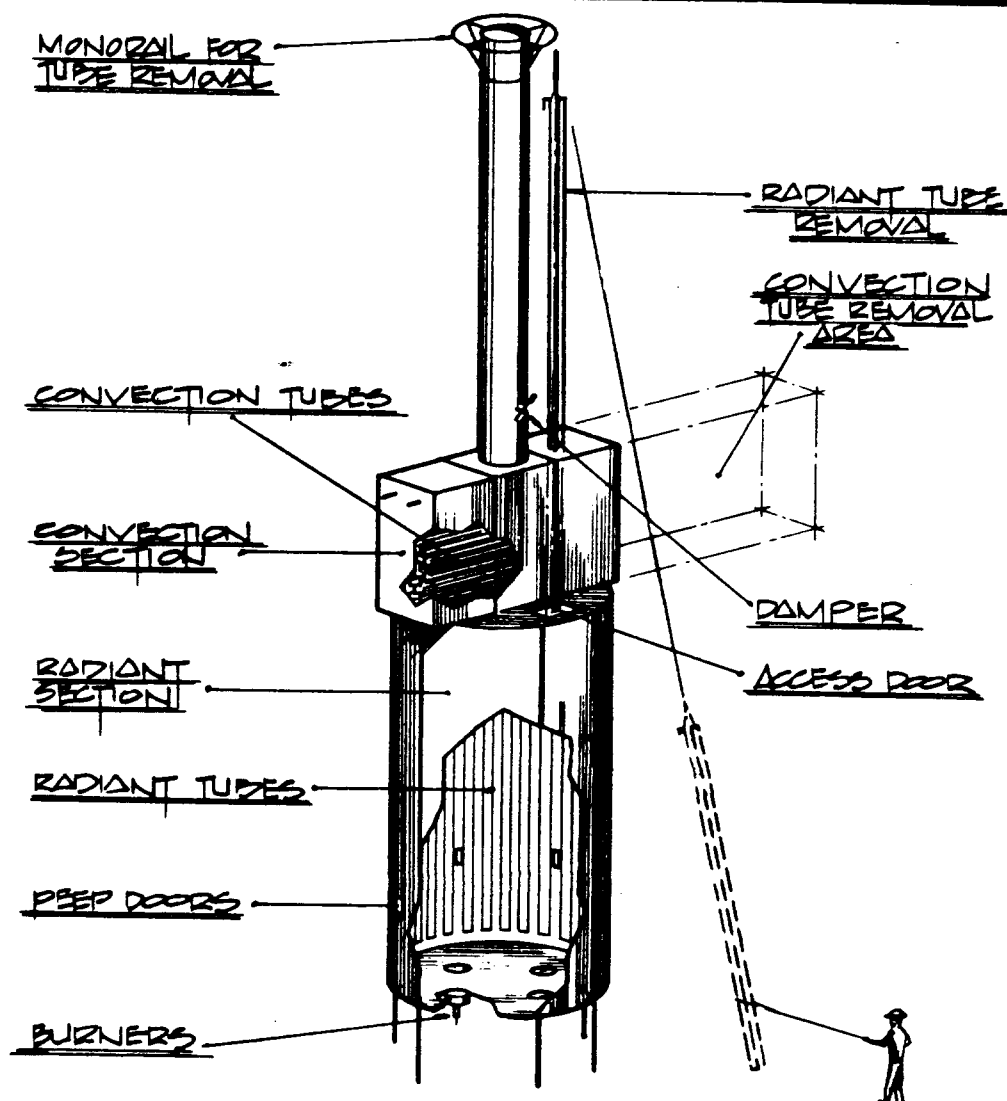


EXHIBIT 7-16
Radiant Tube Removal in
a Circular Furnace

EXHIBIT 7-17
Convection Section Tube
Removal in a Box-Type
Furnace

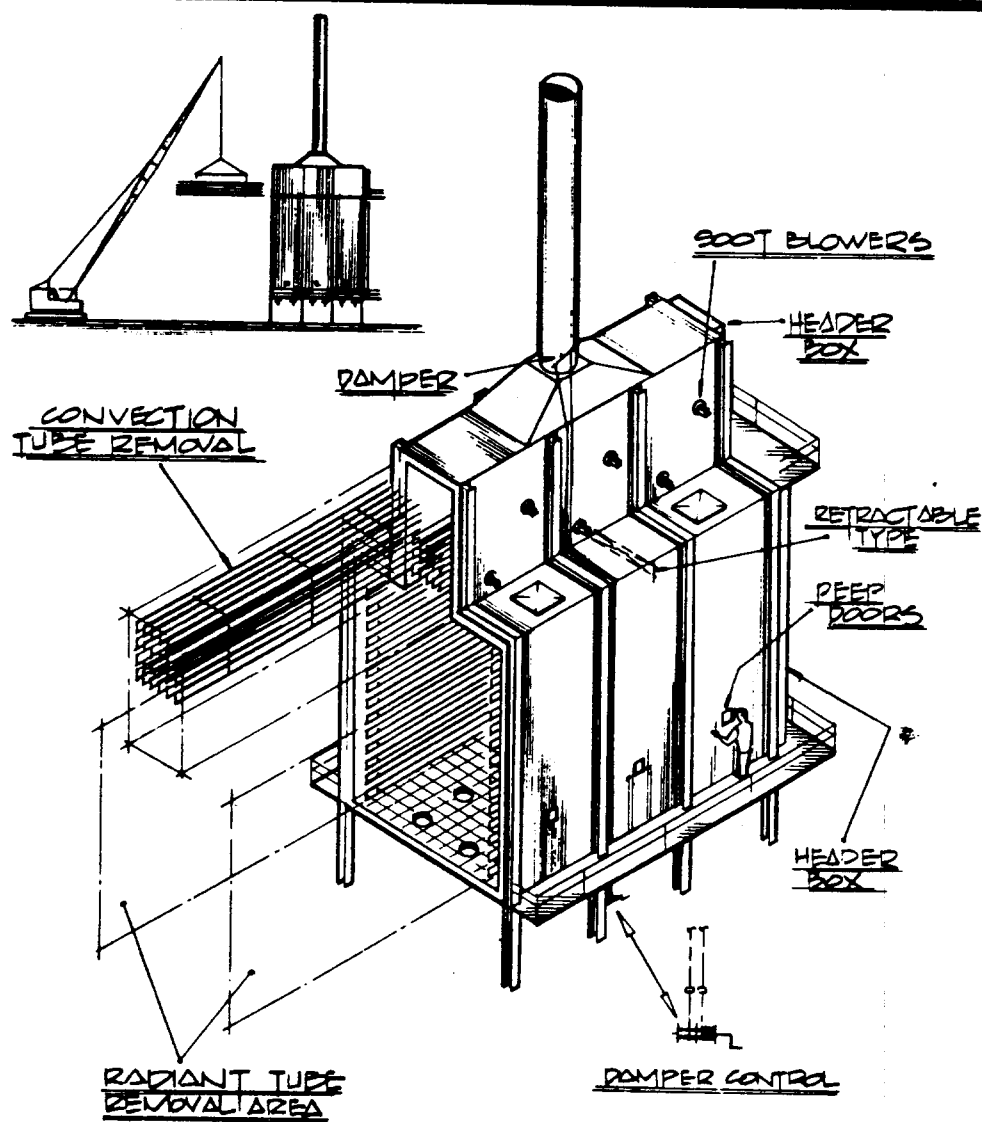


EXHIBIT 7-18
Damper Mechanism

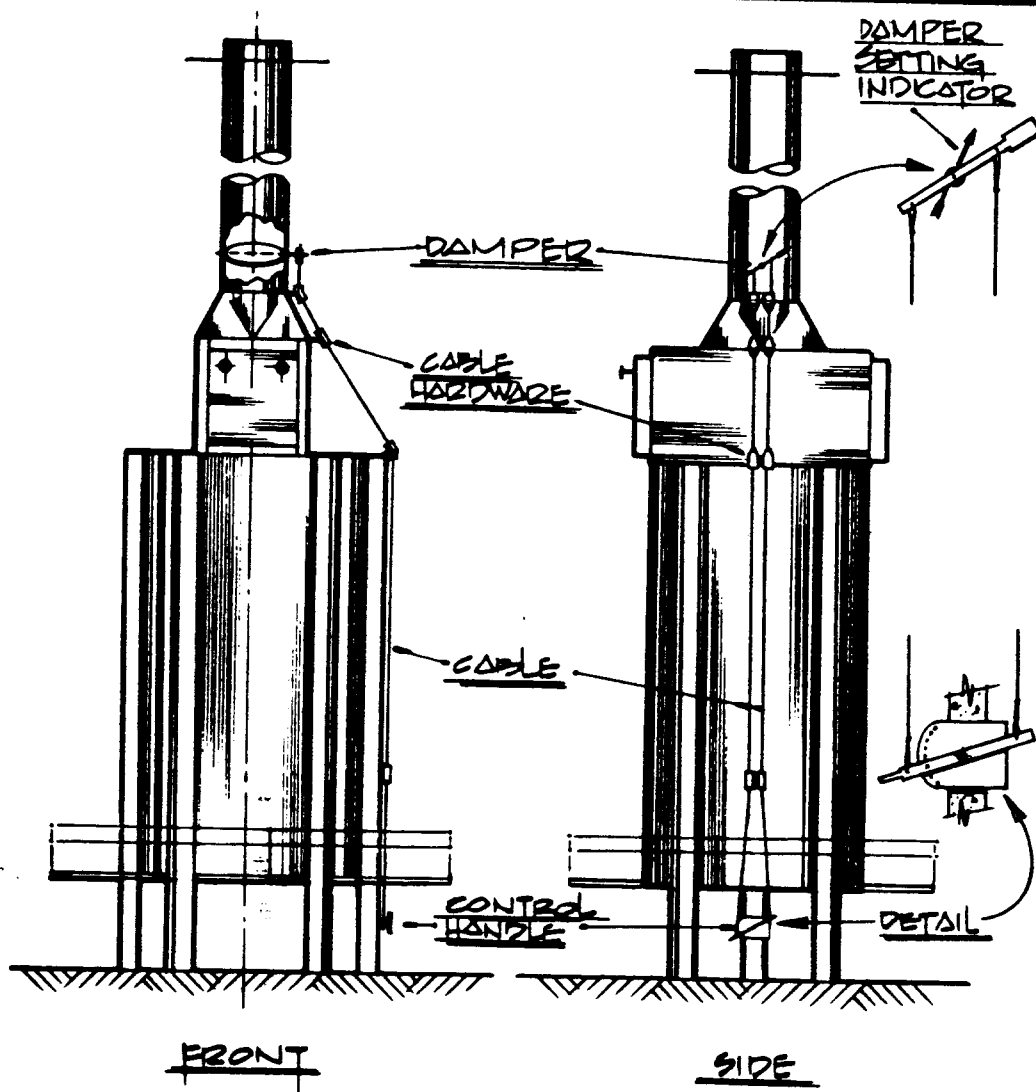


EXHIBIT 7-19
Header Box Detail

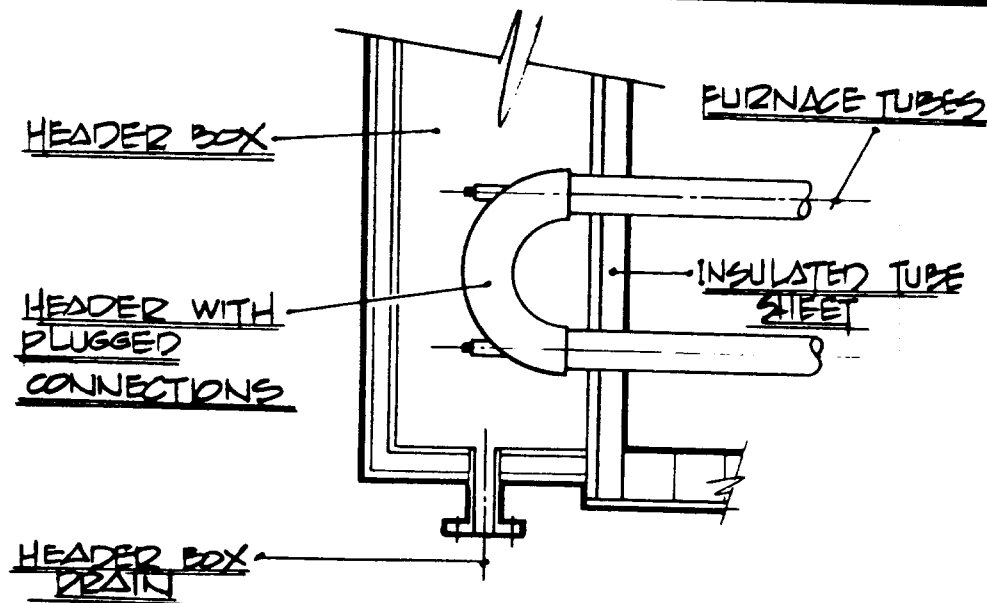


EXHIBIT 7-20
Burner Management Skid

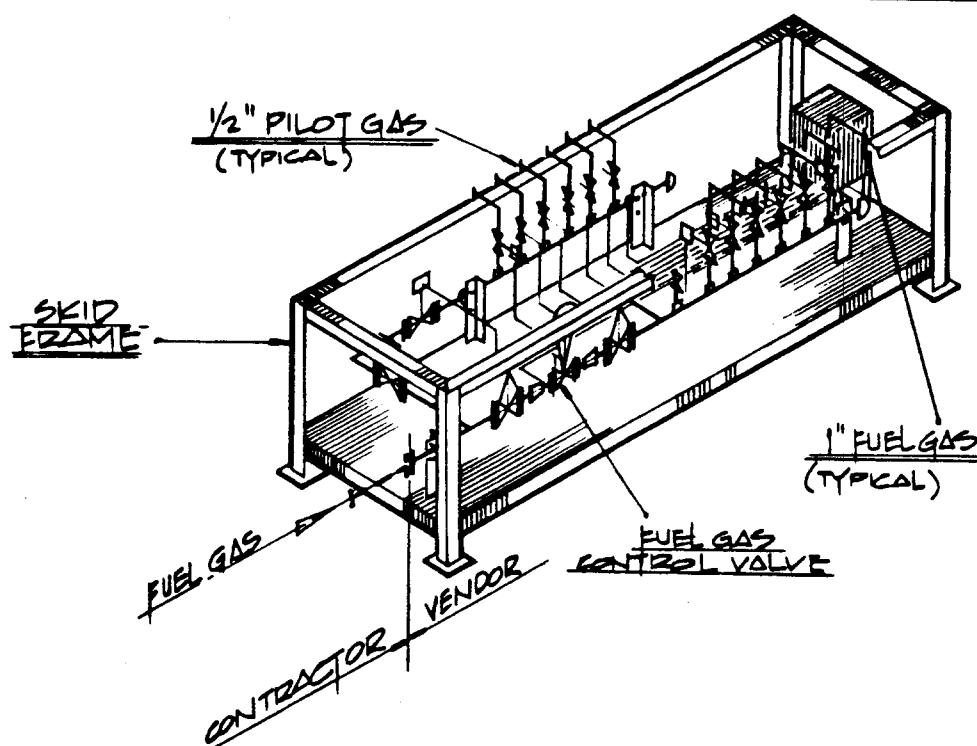
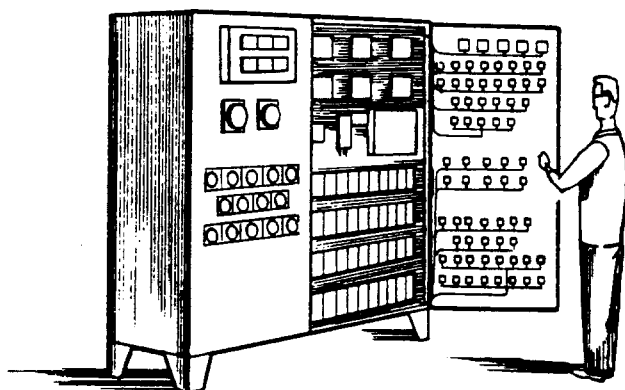


EXHIBIT 7-21 Burner Management Control Panel



swing away and lower the tubes to grade.

Soot blowers have different access requirements, depending on the type used. One type is fixed to the convection section wall and occupies a relatively small area, unlike the retractable type, which is furnished with a horizontal support beam that enables the mechanism to insert the lance during operation.

Dampers, located in the stack, are usually regulated by a device located at grade, as depicted in Exhibit 7-18. Cables strung through guides fixed to the damper and adjustment lever, or control handle, may be locked into various positions as desired. Air-actu-

ated operators are less commonly used for damper adjustments, which are routinely made during start-up when the proper pressure balance within the furnace must be obtained.

Header boxes, as shown in Exhibit 7-19, are enclosures around the fittings that connect two tubes. The fittings, called headers, are furnished with plugged connections for cleaning. The header boxes are sealed from the inside of the furnace by an insulated tube sheet, and, because this area is a possible source of fire, a snuffing steam connection is provided for fire suppression. A drain connection is also provided for leak detection. Clear access must be provided around the header box to permit inspection and tube cleaning or replacement.

Burner access is required for ignition on start-up, air flow control through register adjustment or control handles, and oil-gun maintenance. Access is also required to allow routine operator inspection for any sign of leaks, particularly when flexible hoses are used.

Burner management systems are vendor-supplied packages consisting of all primary valving and instrumentation necessary to start up, operate, and shut down all burners of a furnace under regular or emergency conditions. A typical burner management skid is shown in Exhibit 7-20, and a burner management control panel is shown in Exhibit 7-21.

Platform requirements for furnaces are no different

EXHIBIT 7-22
Circular Furnace Platform
Requirements

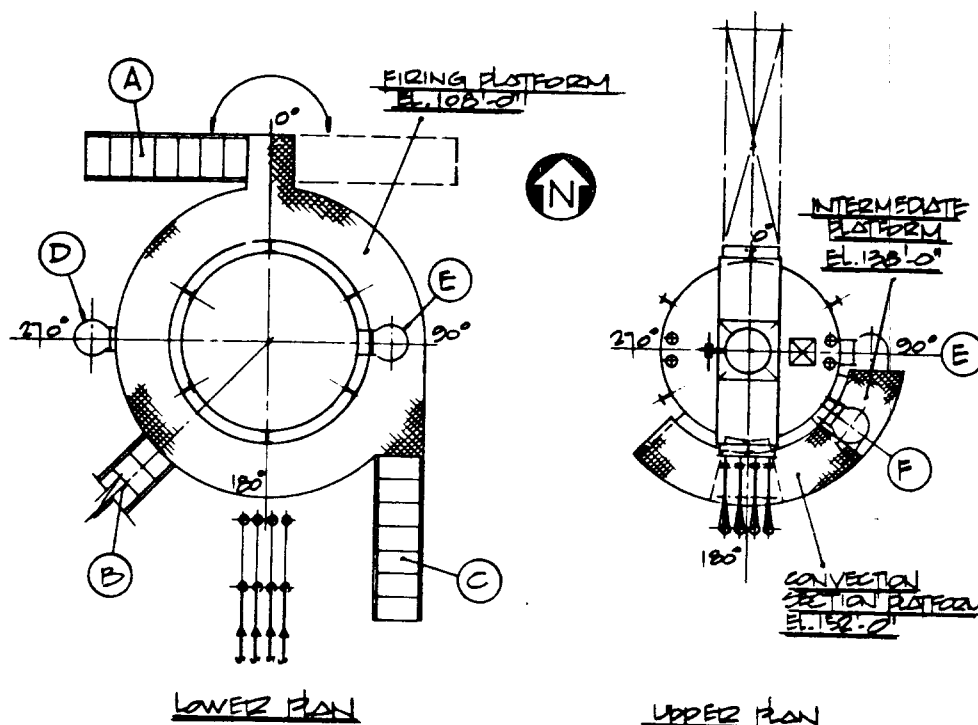
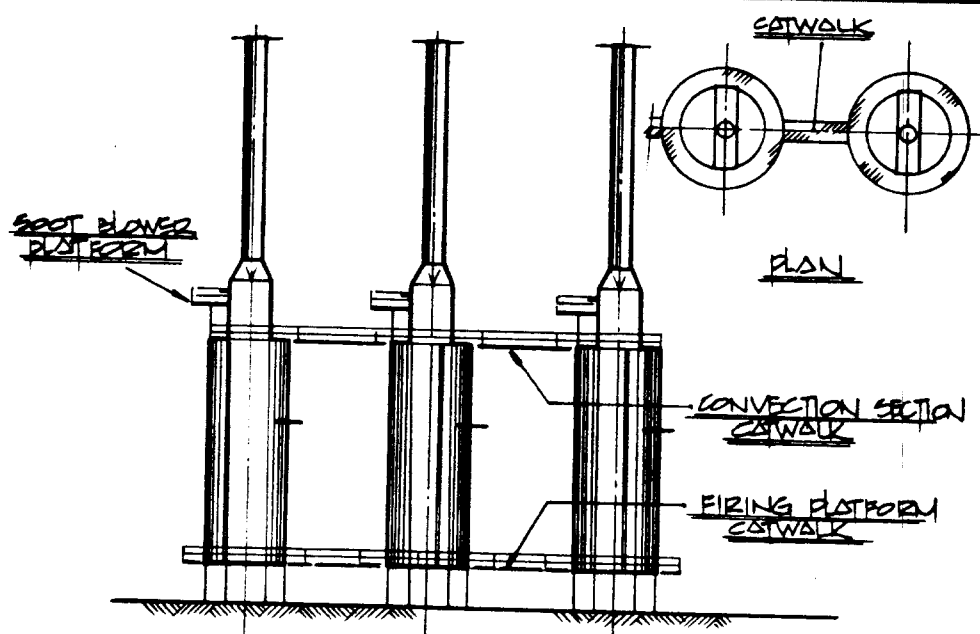


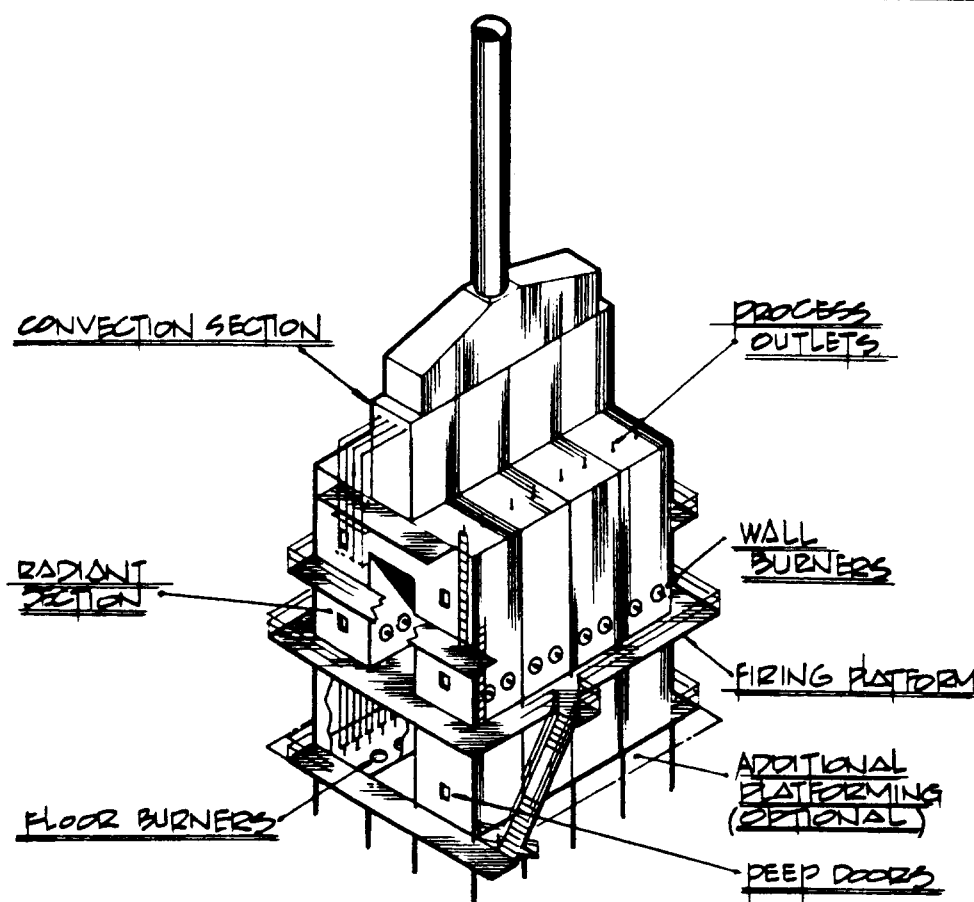
EXHIBIT 7-23
Miscellaneous Platform
Requirements for a
Circular Furnace



from any other large piece of equipment that needs operator and maintenance attention. Because each heater is designed to meet specific process needs, may fire with different fuels and require air preheating or soot blowers, and is subject to client needs, each design should be approached as a unique layout, following basic guidelines.

A circular furnace platform layout is shown in Exhibit 7-22. The firing platform, which is usually a full 360° circle, can be reached by a variety of stairway configurations and ladders, as illustrated on the lower plan in this exhibit. Each scheme shown may be set to accommodate the layout as required. Stairway variations shown here are:

EXHIBIT 7-24
Pyrolysis Furnace Ladder
and Platform
Requirements



- Stairway A—Perpendicular, which can be set to either side of the landing.
- Stairway B—Radial.
- Stairway C—Tangential.

Access to all other platforms on this type of furnace is by ladder, indicated on the exhibit as follows:

- Ladders D and E—Limited to a 30-ft (9150-mm) maximum ladder run per Occupational Safety and Health Administration (OSHA). An intermediate platform is required.
- Ladder F—Enables plant personnel to gain access to both sides of the upper furnace by the convection section platform.

Additional platform requirements—for example, for access to soot blowers or interconnecting platforms between groups of similar heaters—are shown in Exhibit 7-23. Catwalks are planned for the firing platform and top of the radiant section for operator convenience.

A pyrolysis furnace, shown in Exhibit 7-24, has both wall- and floor-mounted burners. The wall-mounted burner piping can be operated from the firing plat-

form and viewed from the peep door on the end wall. The floor-mounted burners can be operated from grade at the edge of the furnace or from an optional lower firing platform. Additional platforming is required for access to draft gauges, peep doors, and the convection section. Because the primary operator level is at the burners, stairways are used for access and ladders are provided for all other levels.

A reformer furnace, shown in Exhibit 7-25, has a penthouse and roof-mounted burners. In addition to platforms and a stairway for regular maintenance and operation, ladders are provided in case of an emergency. Other platforms are for access to peep doors, draft gauges, and piping, as required.

Auxiliary Equipment

A soot blower mechanically cleans soot build-up on convection section tubes in fuel-oil-fired heaters. A soot blower essentially consists of a lance (i.e., pipe) with nozzles specifically located for the tube section to be cleaned and a connection for the blowing medium, which is steam or air. There are two types of blowers: fixed and retractable.

EXHIBIT 7-25
Reformer Furnace
Platforms

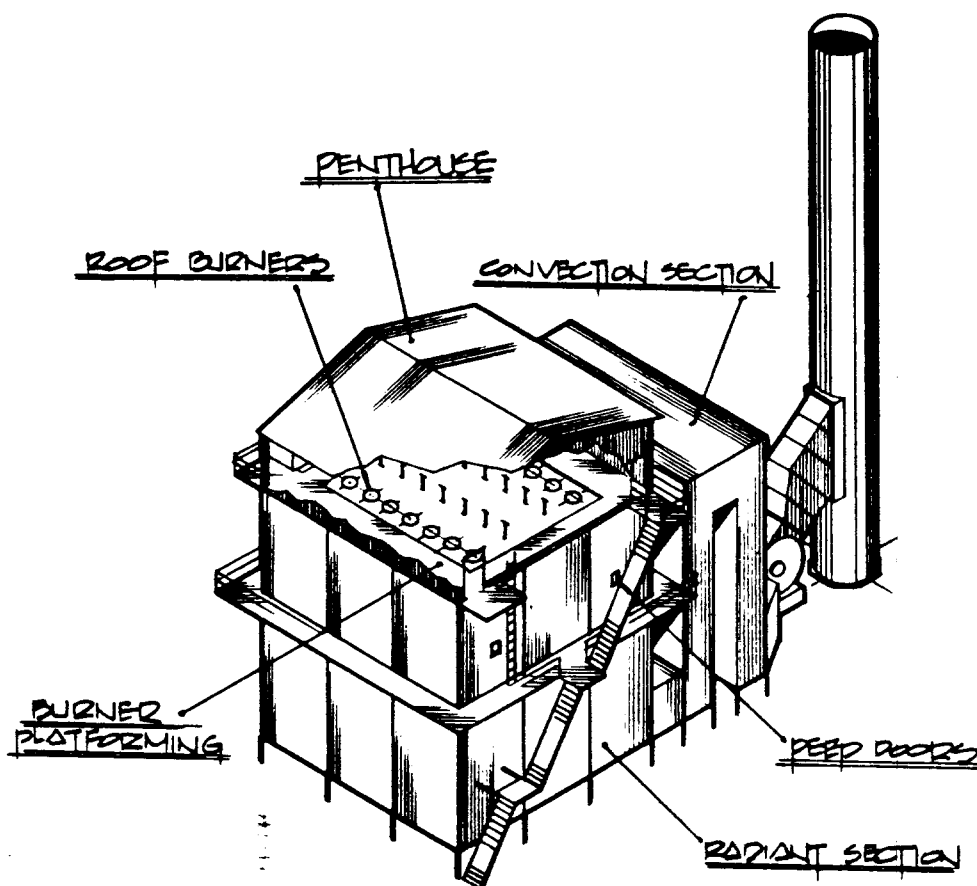
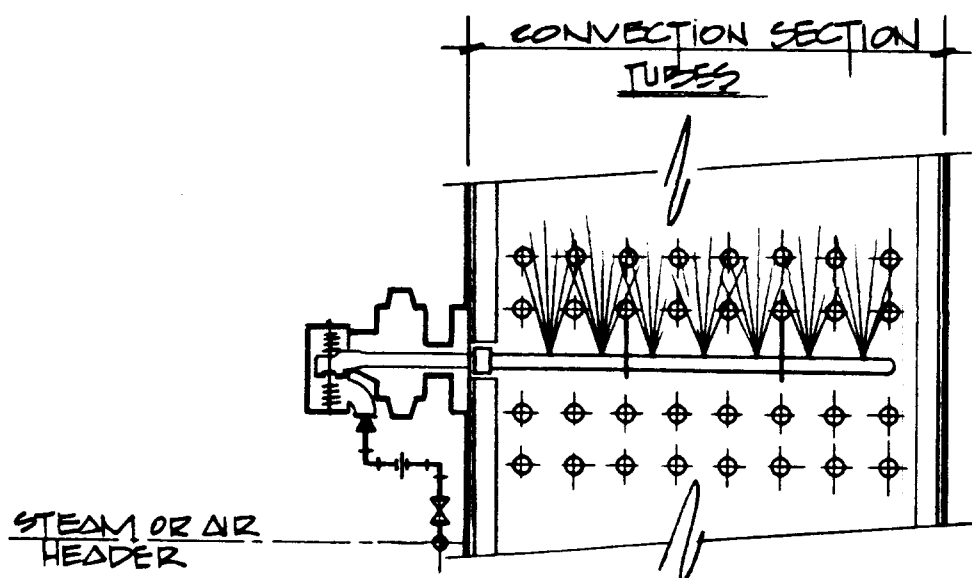


EXHIBIT 7-26
Fixed Soot Blower



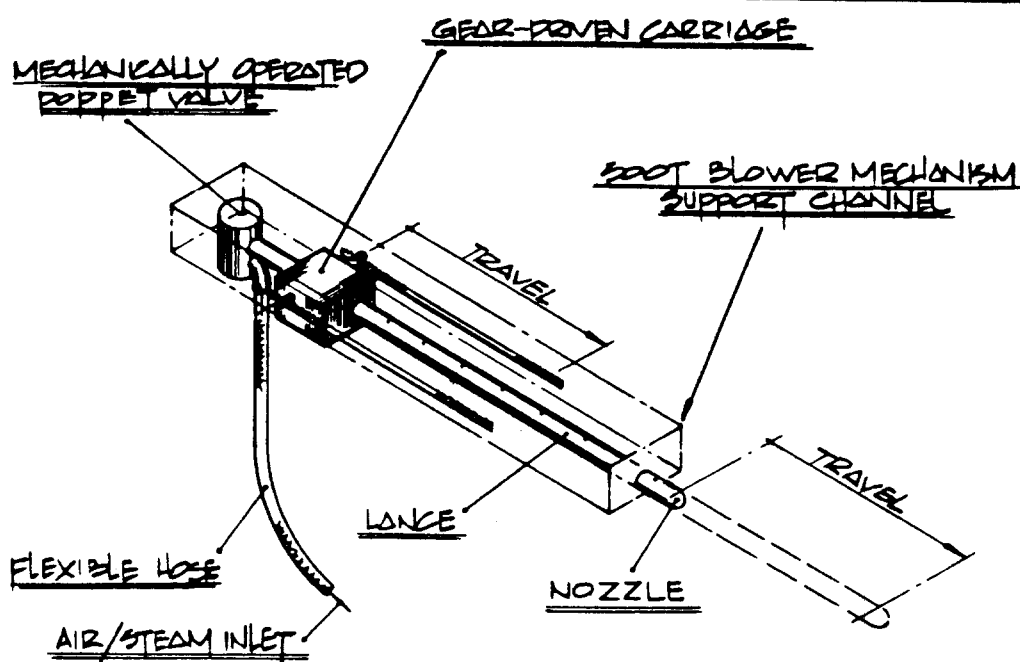


EXHIBIT 7-27
Retractable Soot Blower

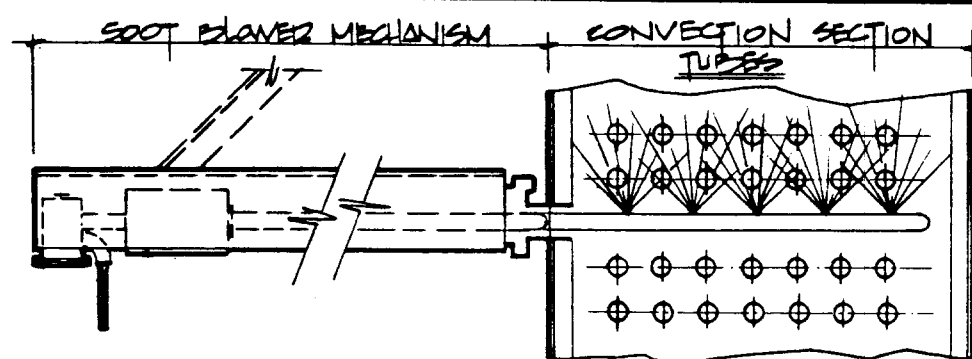


EXHIBIT 7-28
Soot Blower in Operation

A fixed soot blower, shown in Exhibit 7-26, is mounted directly on the convection section wall and is hard-piped as shown. A retractable soot blower, illustrated in Exhibit 7-27, allows the lance to be removed from the convection section during operation. Some of the principal components are the support channel, the gear-driven carriage, the poppet valve (used to control the flow of the cleaning medium), and the lance with nozzles. Exhibit 7-28 depicts a soot blower in operation. As the lance enters the heater, the blowing medium cuts a path through the deposits until the lance reaches its apex. The lance then reverses rotation and is indexed so that on the retraction path it cleans surfaces not covered on insertion. The reversed rotation and indexing allow the soot blower to peel and strip all deposits efficiently and with less chance of heater tube erosion.

An induced draft fan may be required for furnace operation, as shown on top of the convection section

in Exhibit 7-29. Platforms designed specifically for each fan configuration should be adequate for maintenance and operation of the drive and fan mechanism.

Exhibit 7-30 shows a typical arrangement of a single-zone pyrolysis furnace with an integral waste heat system, which requires a steam drum and a heat exchanger (often called a transfer line exchanger). Because the preheater and ducting on an average-sized combustion air preheating system are somewhat large, the plant layout designer should pay extra attention to the amount of space that is finally used for this equipment. After enough room is allotted for maintenance and operation of the forced and induced draft fans and blowers, the distance from the outer edge of the preheater to the centerline of the furnace should be kept to a minimum, as shown in Exhibit 7-31.

Whenever furnaces are arranged in groups on a plot plan, the plant layout designer should consider using a common stack, as depicted in Exhibit 7-32.

EXHIBIT 7-29
Induced Draft Fan

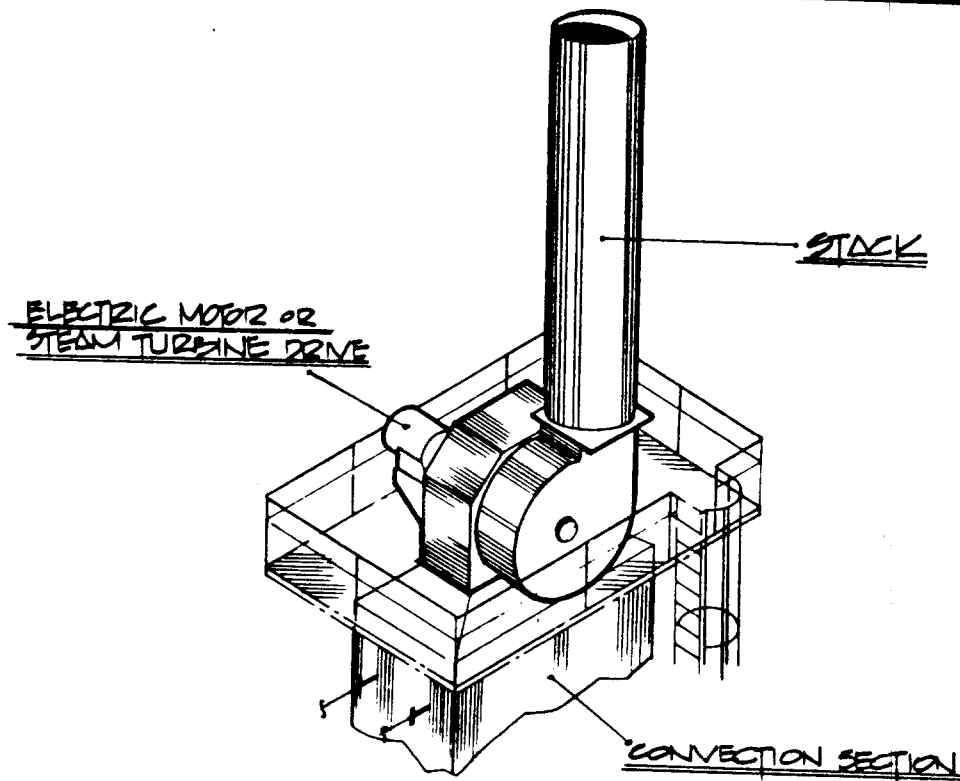
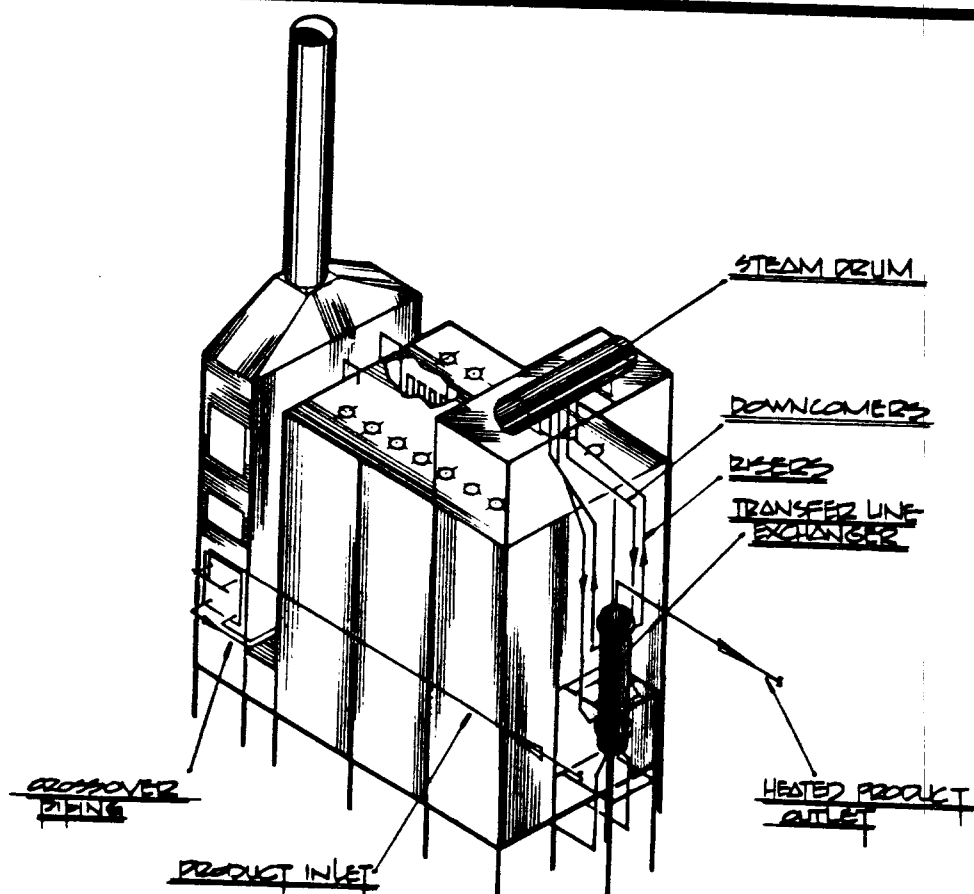


EXHIBIT 7-30
Steam Drum and Transfer
Line Exchanger



HEATED AIR TO FLENUM

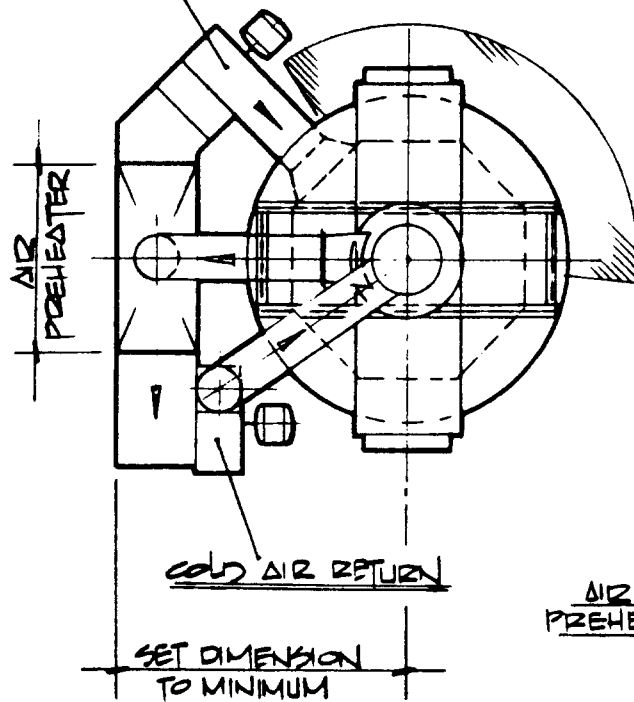


EXHIBIT 7-31
Combustion Air
Preheating System

AIR PREHEATER

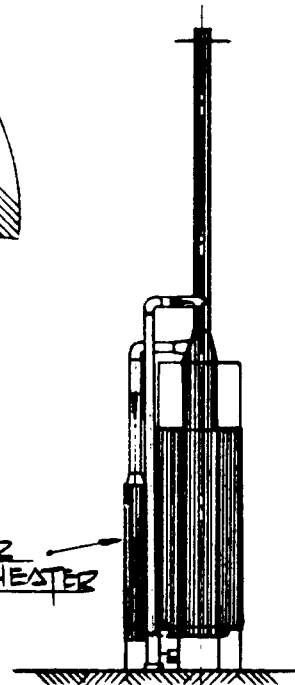
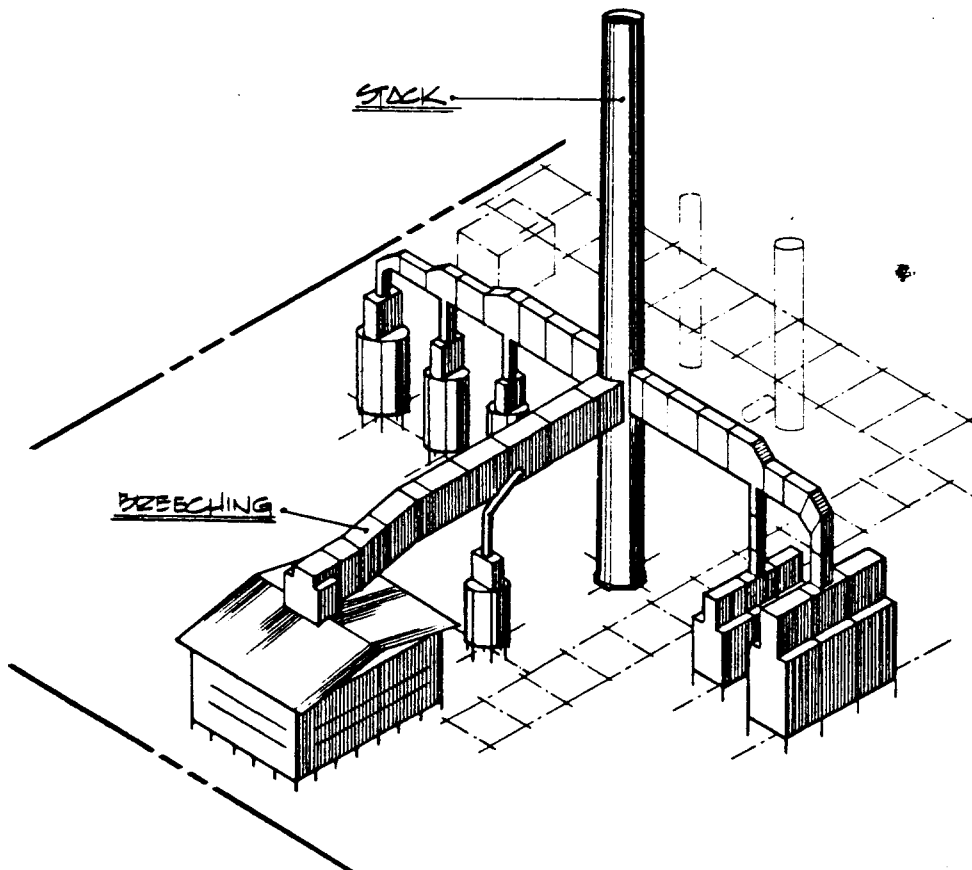


EXHIBIT 7-32
Common Stack for
Multiple Furnaces



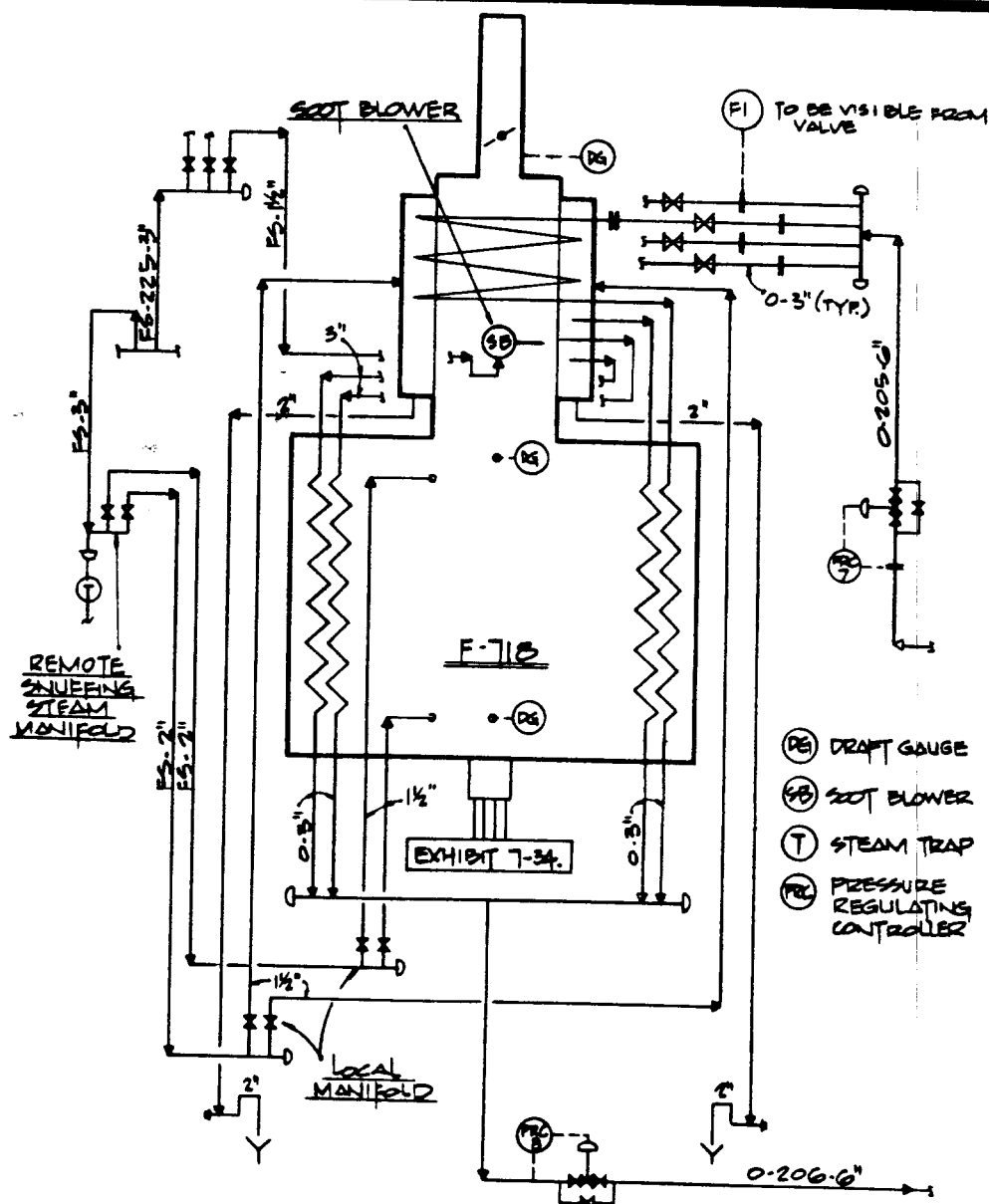
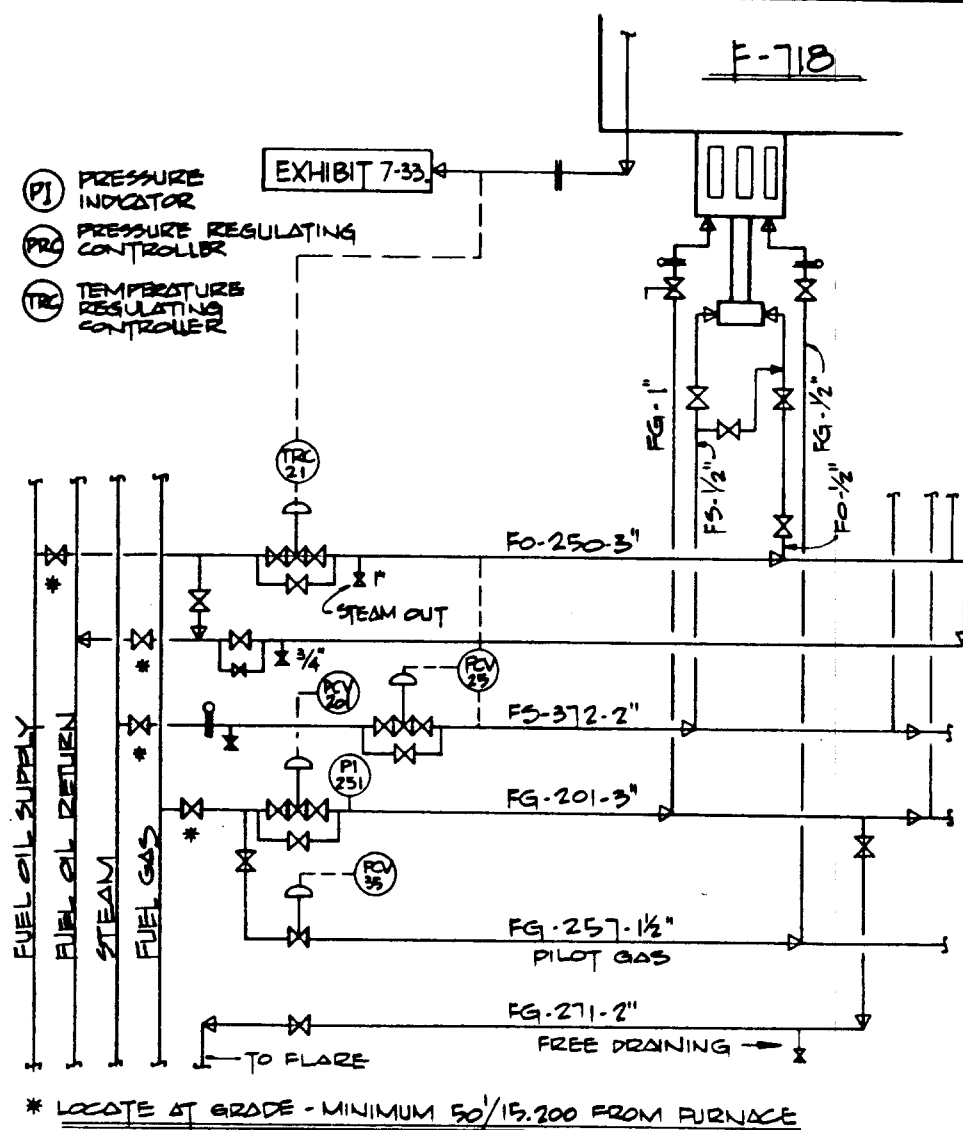


EXHIBIT 7-34
Piping and
Instrumentation Diagram
for a Combination Burner



Economic constraints usually determine the feasibility of this design feature; all furnace configurations can use this breeching concept.

PIPING LAYOUT FOR A FURNACE

This section details the piping layout of circular and box-type furnaces. Although such special features as snuffing steam are actually required for both heaters, they are explained for one application only.

Circular Furnace Piping

Exhibits 7-33 and 7-34 present simplified piping and instrumentation diagrams for a circular furnace. The furnace has 6-in inlet and outlet lines, with control valves, combination burners, and soot blowers in the

convection section. The furnace plan and elevation for the upper level of this furnace are shown in Exhibits 7-35 and 7-36, respectively. The stack shown in Exhibit 7-36 is equipped with a trolley beam (an optional feature) that pulls the radiant tube bundles during maintenance. The need for platforms depends on the instrument requirements. The damper setting is regulated from grade by a cable-operated mechanism supplied by the furnace vendor.

In the convection section, three stationary soot blowers are fed by 1.5-in leads from the fire steam header located below them. This piping is kept close to the convection section wall to maximize the available work area for plant personnel. The four 3-in product inlet lines have manual control valves and local flow indicators that must be visible when personnel are operating the valves. They are located at the

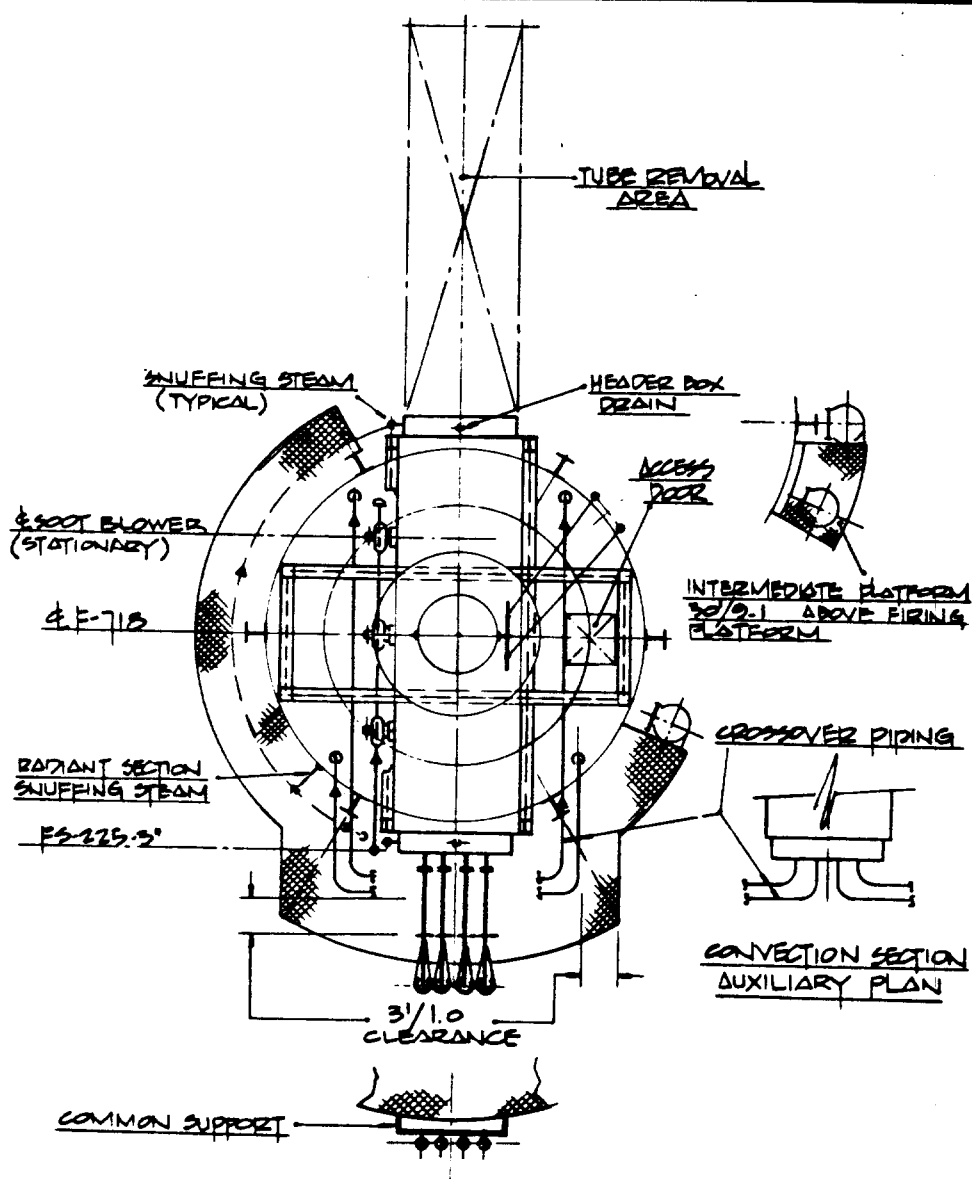


EXHIBIT 7-35
Plan for the Upper Level
of a Circular Furnace

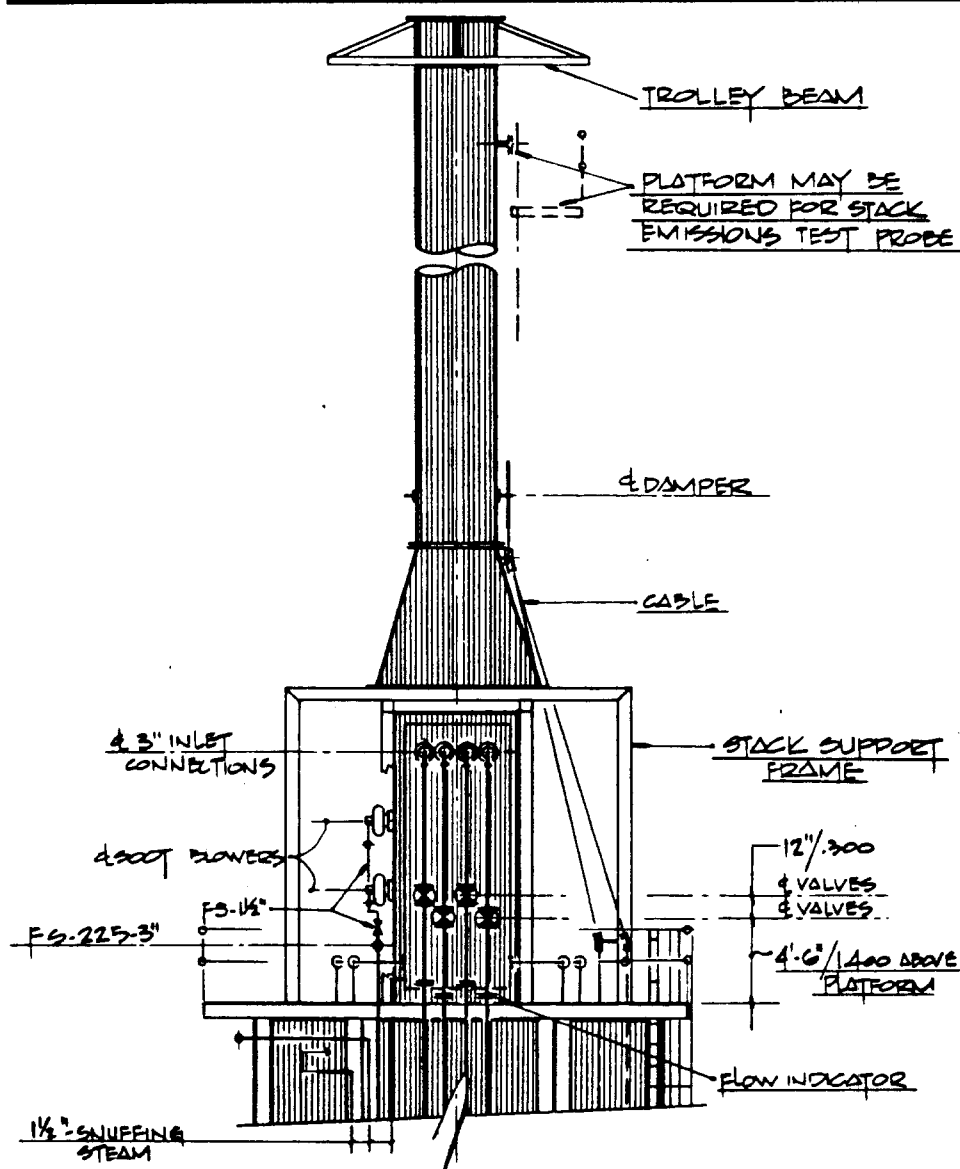
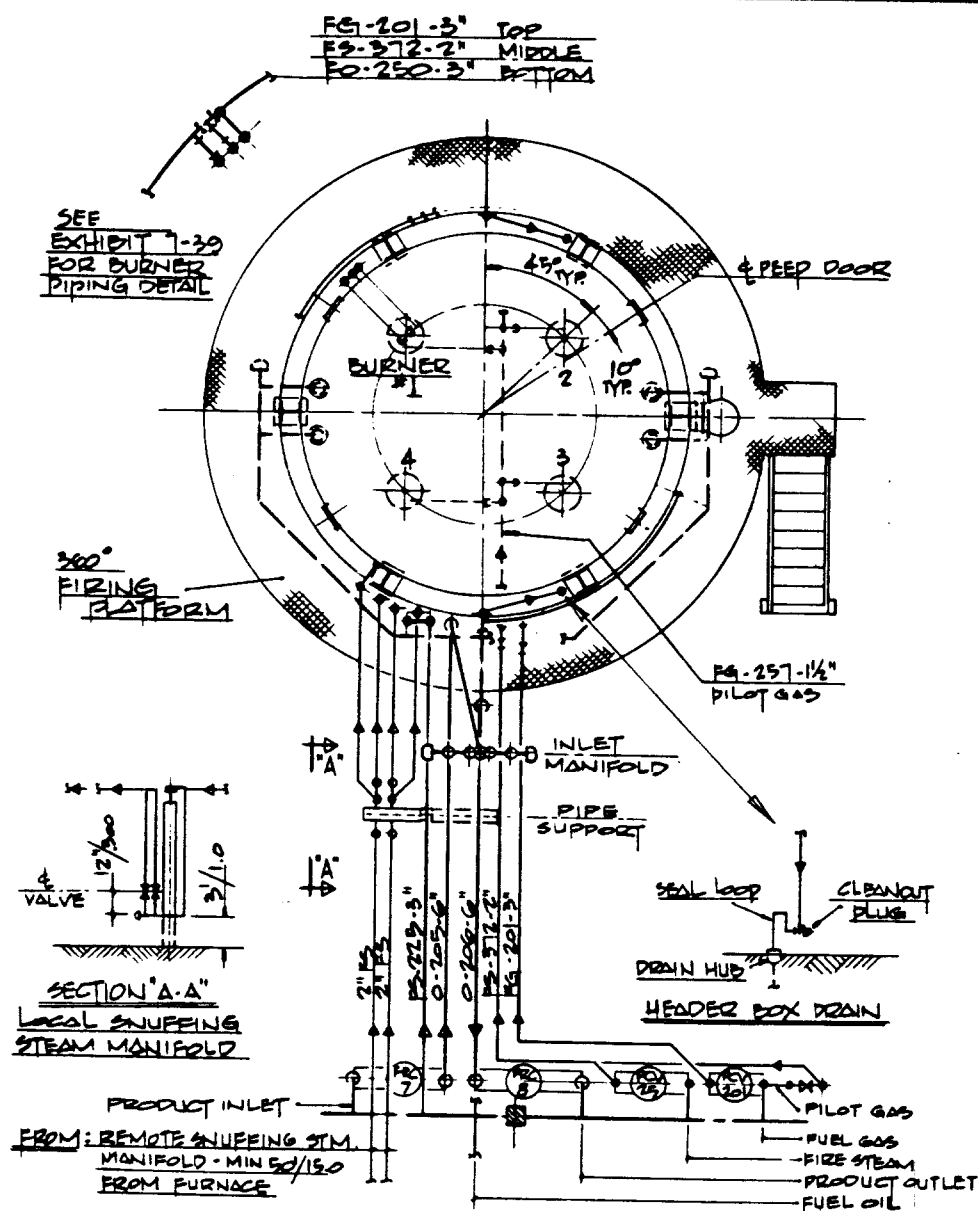


EXHIBIT 7-36
Furnace Elevation for the
Upper Level of a Circular
Furnace

EXHIBIT 7-37
Lower Plan for a Circular
Furnace



upper platform for economic reasons—placing them at grade would require running four individual lines up the entire furnace. The snuffing steam lines are grouped together for common support until they reach the top of the radiant section. The line to the header box on the opposite side is run radially around the heater. Bending small lines is generally not a problem and saves fittings and welds. Platforms are designed to permit plant operations and maintenance personnel clear access to all valves, instruments, and soot blowers.

The lower level of the circular furnace is shown in Exhibits 7-37 through 7-39. In the radiant section, all piping should be grouped together for common sup-

port when practical, as shown in Exhibit 7-38.

Snuffing steam, which is used to suppress a fire in the header box in the convection or radiant sections, is supplied through local and remote manifolds. The remote manifold should be no closer than 50 ft (15,000 mm) from the furnace. In Exhibit 7-37, the local manifold is located at grade, next to the intermediate pipe support column. If the local area is unreachable in an emergency, steam would be supplied from the remote manifold. The inlet and outlet control stations are located along the pipe rack adjacent to the furnace. This particular furnace uses manually controlled valves for each burner. The burner supply headers—fuel gas, fire steam, and fuel oil—are run

EXHIBIT 7-38
Furnace Elevation for the
Lower Level of a Circular
Furnace

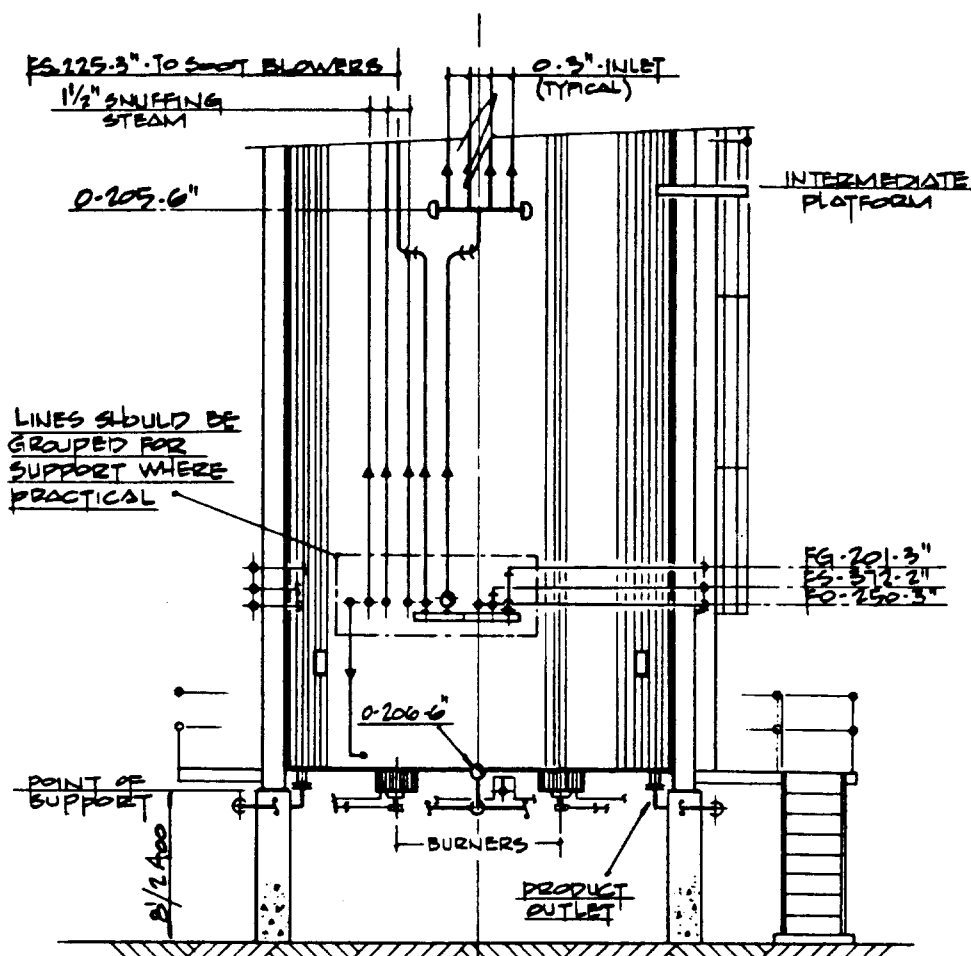


EXHIBIT 7-39
Burner Piping Detail

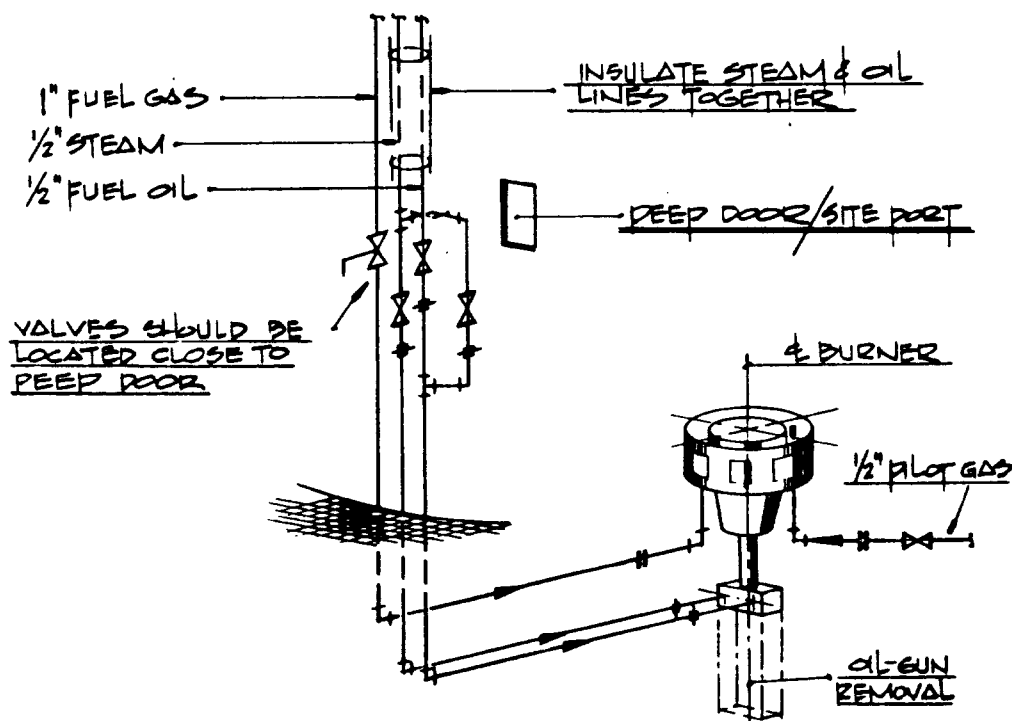
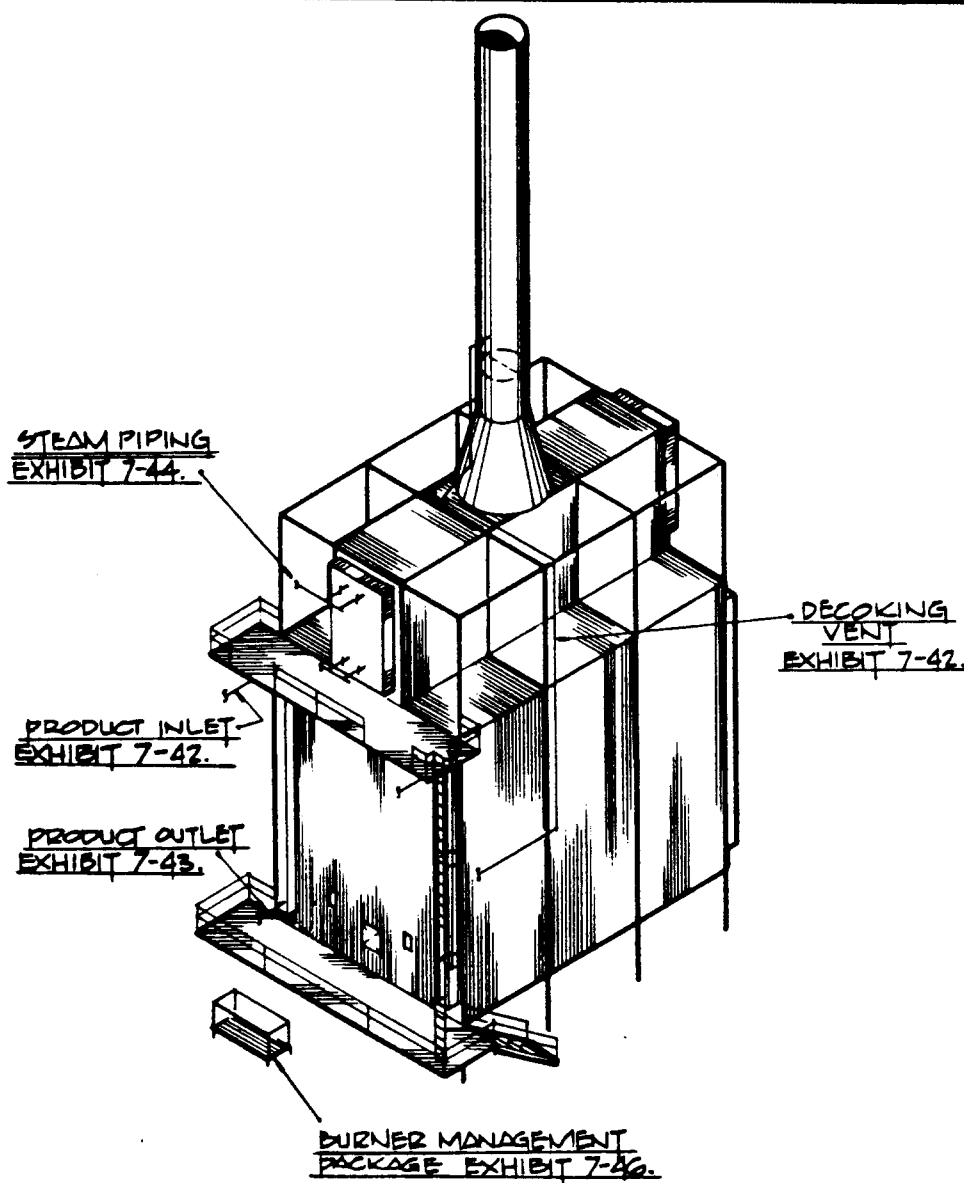


EXHIBIT 7-41
Box-Type Furnace



that any single ladder run must not exceed 30 ft (9,150 mm). The plant layout designer must ensure that tube removal areas remain clear of any obstruction.

Box-Type Furnace Piping

Exhibit 7-40 is a sample piping and instrumentation diagram for a box-type furnace. This heater has 6-in product inlet and outlet leads, a swing ell used for decoking, a convection steam coil, and a burner management system. Exhibit 7-41 provides an overall view of the furnace in this example and indicates the major parts of the furnace.

Exhibit 7-42 shows the decoking operation. Product inlet line A is shown in the decoking mode, and inlet B

is set for regular operation. With the swing ell bolted to the steam and air line, the tube cleaning process may begin. Each coil is drained and blown out with steam. Header plugs are removed—the removable header-box panels are illustrated in Exhibit 7-43. A cleaning tool is used to remove coke deposits from the inner wall of each tube. Once this is completed, the plugs are replaced and the burners are fired. Steam is introduced to remove any remaining coke deposits. The steam flow rate must be sufficient to prevent overheating of the tube walls; air is then added to burn off any remaining coke deposits. Steam and air discharge to the stack above the damper through the vent line. Steam is introduced one final time to flush the tubes clean. All decoking flows are

EXHIBIT 7-42 Decoking Operation for a Box-Type Furnace

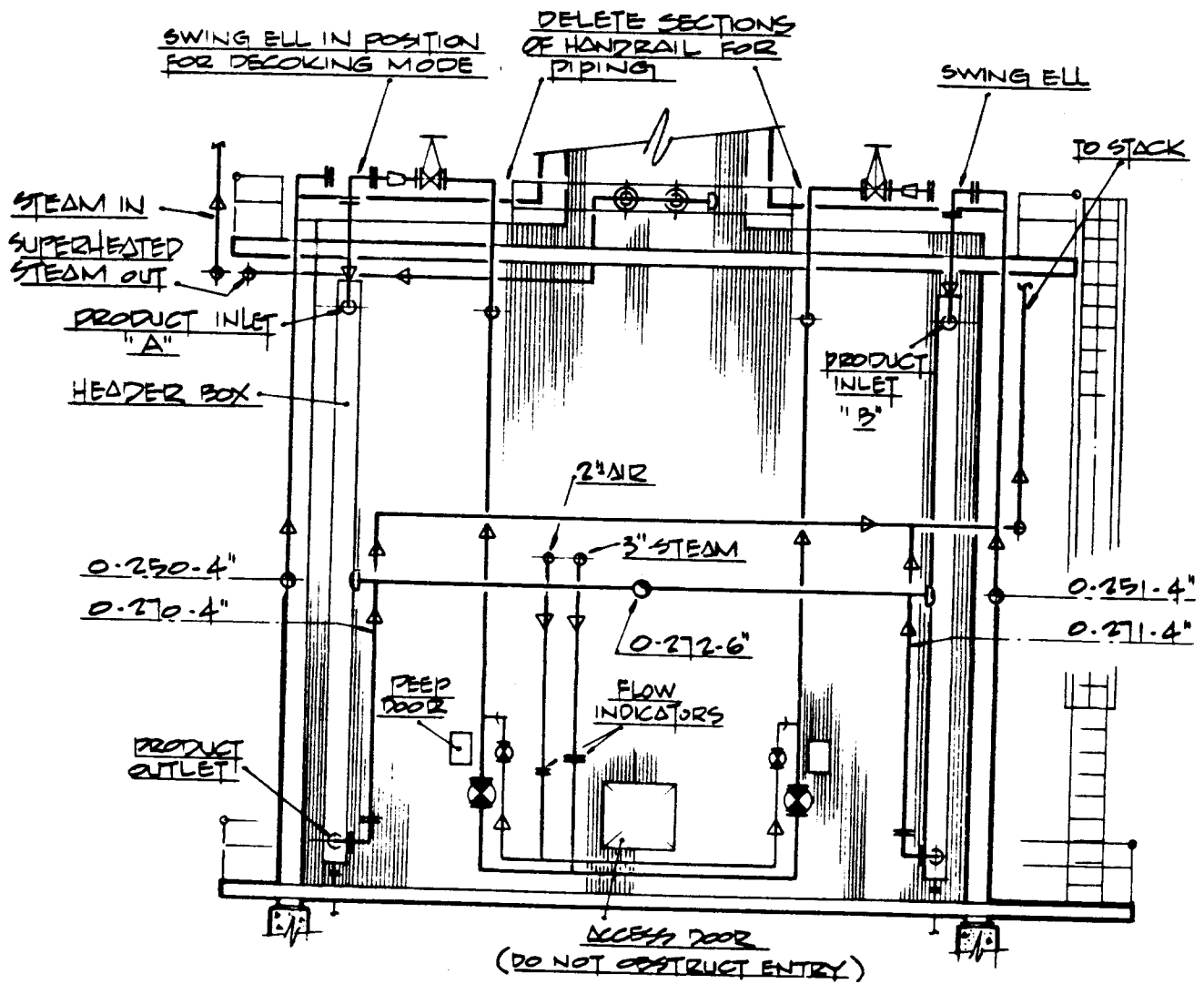
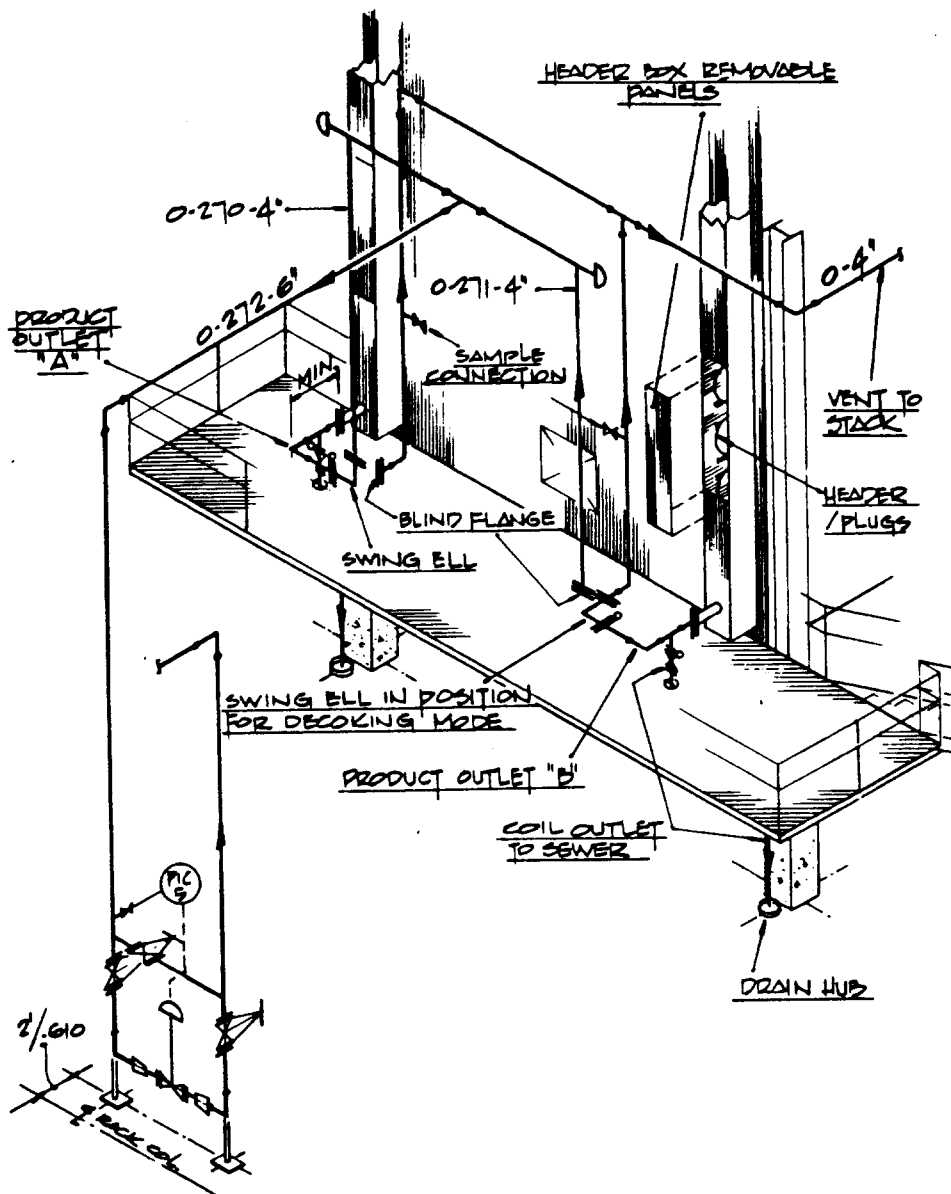


EXHIBIT 7-43
Product Outlet and
Decoking Piping



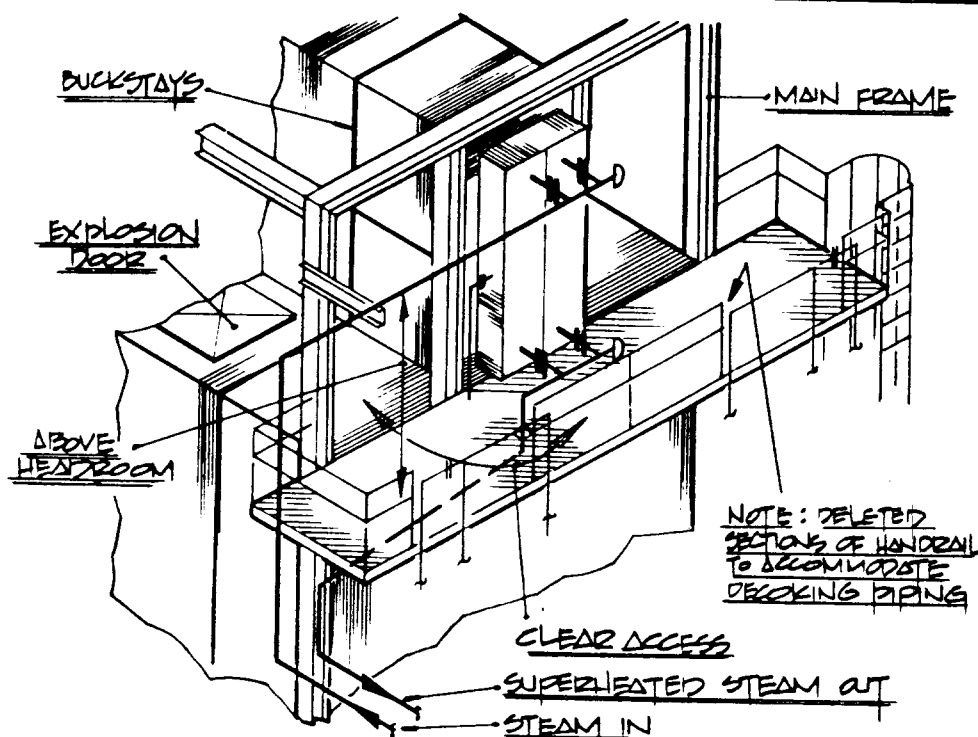


EXHIBIT 7-44
Convection Section
Steam Piping with
Miscellaneous Structural
Details

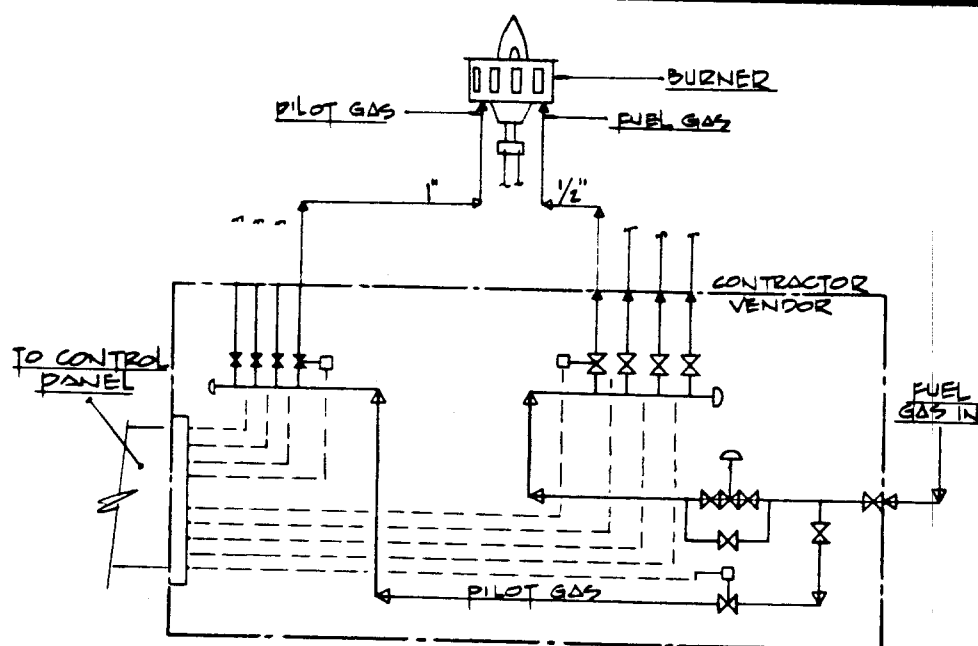
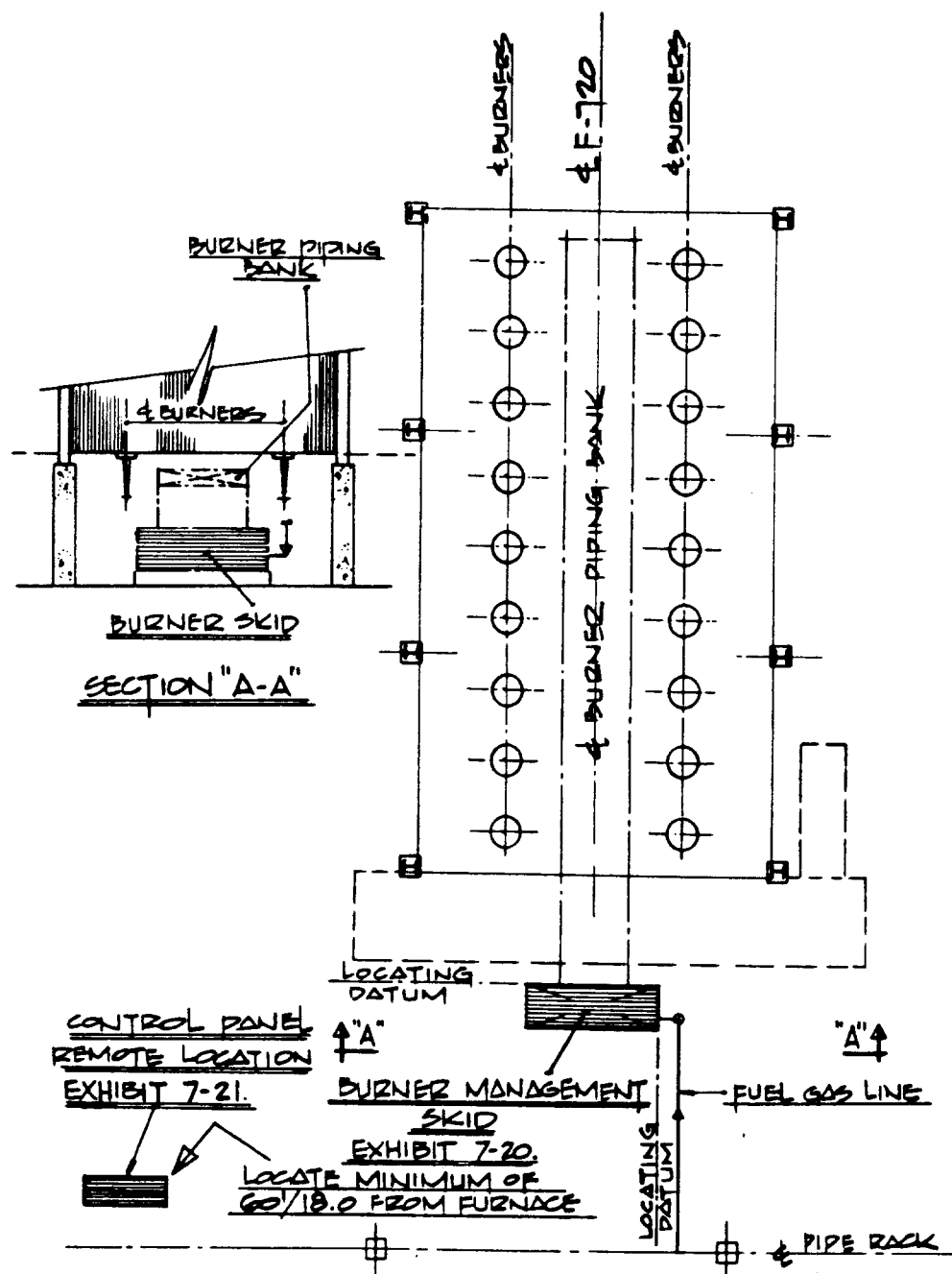


EXHIBIT 7-45
Piping and
Instrumentation Diagram
for a Burner Management
Skid

downflow operations, except the vent line to the stack. The swing ell is positioned to be accessible to maintenance personnel. The steam and air manual control valves and their local flow indicators must be located at the peep doors to allow the tubes to be viewed during this operation because overheating can cause damage to furnace tubes.

Exhibit 7-43 also shows the product outlet line and its decoking hook-up. Line A is set up in its usual operation configuration; line B is set in the decoking mode. As the steam and air are blown through the radiant tubes, any waste is carried to the sewer or, if preferred, to a drum for removal. The vent line is run to the stack. Once again, the plant layout designer

EXHIBIT 7-46
Burner Piping



must avoid blocking access to the header boxes when developing the piping layout in this area of the furnace.

Convection Section Piping

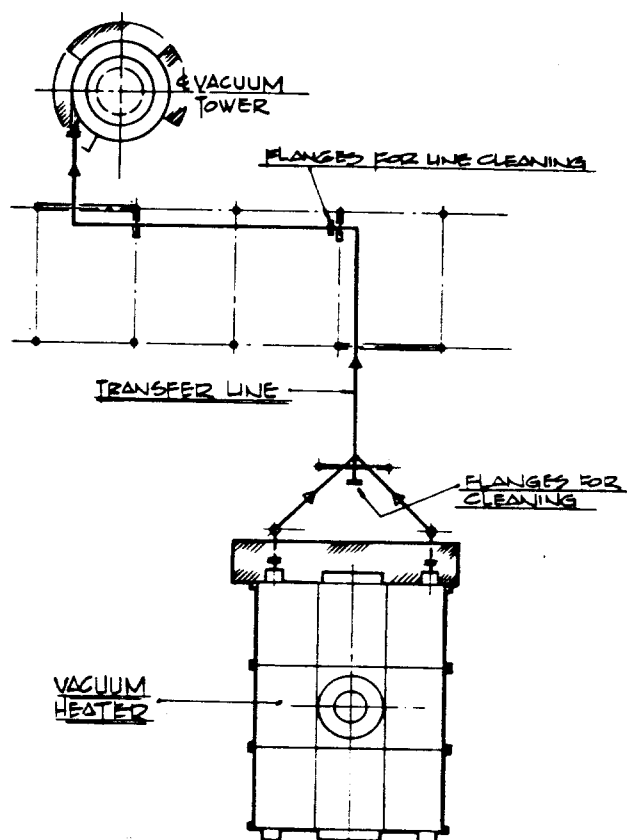
Exhibit 7-44 illustrates the convection section steam coil piping along with some miscellaneous structural details. The steam inlet line can be run horizontally to the inlet nozzles because the elevation is above headroom. The superheated steam outlet piping can be routed below the platform so that it will not pose a

hazard to plant operations and maintenance personnel. The structural feature highlighted here is the absence of handrails to permit access to the decoking piping. The plant layout designer must notify the furnace vendor of this requirement on a mark-up of the platform arrangement drawing.

Burner Management System Piping

Exhibit 7-45 is a sample piping and instrumentation diagram of a burner management system supplied by the burner vendor. The engineering contractor sup-

EXHIBIT 7-47 Transfer Line Layout



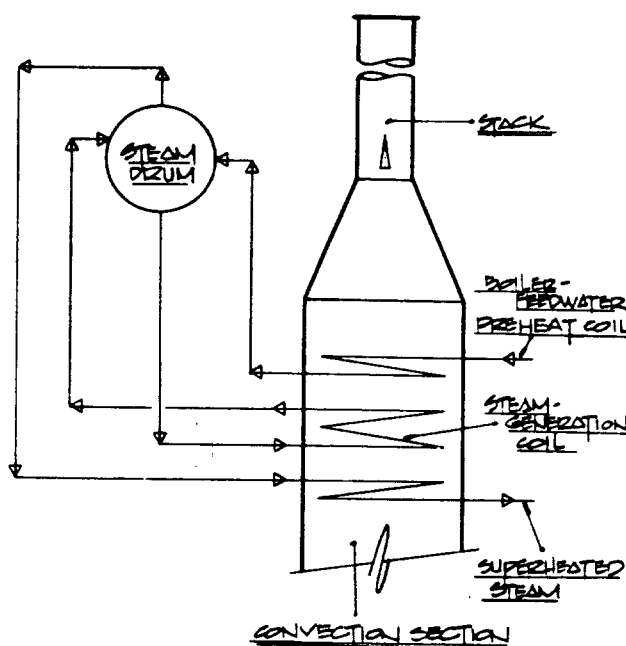
plies the fuel gas to the burner skid and may be required to run the fuel gas and pilot gas to the individual burners.

Exhibit 7-46 is a plan at grade of the burner management skid and control panel in relation to the furnace and burners. The skid is located directly in line with the furnace centerline to provide the most direct piping to the individual burners. The burner management control panel is remotely located at a minimum of 60 ft (18,000 mm) from the furnace. Plant operations personnel may ignite the burners from this panel by sending a spark to the igniter located at the pilot gas tip within the burner and activating the solenoid valves on the skid.

Transfer Line Piping

A furnace transfer line is the primary product outlet header from a heater or furnace to a process tower. A typical vacuum tower transfer line layout is shown in Exhibit 7-47. Because many transfer lines tend to coke, the length of the line should be kept to a minimum. Quench oil injection near the furnace outlet is another means of reducing line coking. As shown in the ex-

EXHIBIT 7-48 Steam-Generation Thermosiphon Circuit

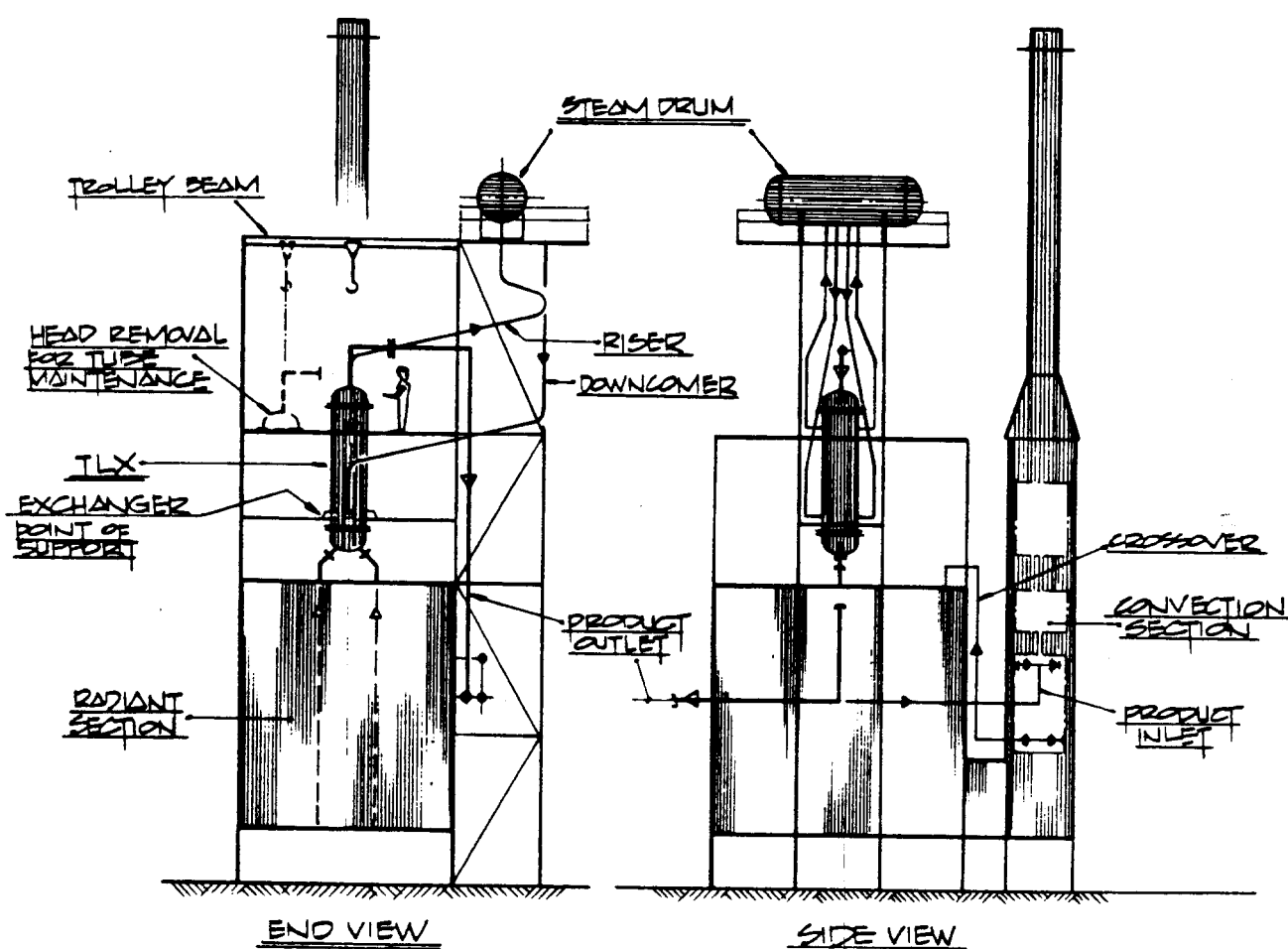


hibit, the transfer line should run horizontally and in the most direct route possible to satisfy all stress and flexibility requirements. The addition of line flanges should be planned to facilitate cleaning if coking becomes severe.

A typical steam-generation thermosiphon circuit is shown in Exhibit 7-48. Briefly, this circuit is the difference of the water-steam mixture and the static head in the downcomer that maintains fluid circulation. Locating the steam drum at the top of the furnace provides the static head and collects the steam being generated. Steam returns to the top portion of the drum, while the water lines come off the bottom. Loops and pockets must be avoided when laying out the downcomer, and riser piping and any horizontal lines must slope toward the waste heat boiler or convection coil. When pumps are used in this circuit, it is called forced circulation.

Transfer line exchanger piping is shown in Exhibit 7-49. This example shows how the heated product outlet of a pyrolysis furnace is used to generate steam. The main consideration is the downcomer and riser piping between the steam drum and transfer line exchangers. Lines should be run with a pronounced slope to avoid undesirable slug flow, which tends to occur in horizontal piping runs. Vertical expansion loops can be easily spring-supported from the structure. The transfer line exchanger is supported by two lugs just above the bottom channel flange, and a trolley beam is provided to remove the top head for maintenance. In this system, the product line enters the

EXHIBIT 7-49 Transfer Line Exchanger Piping

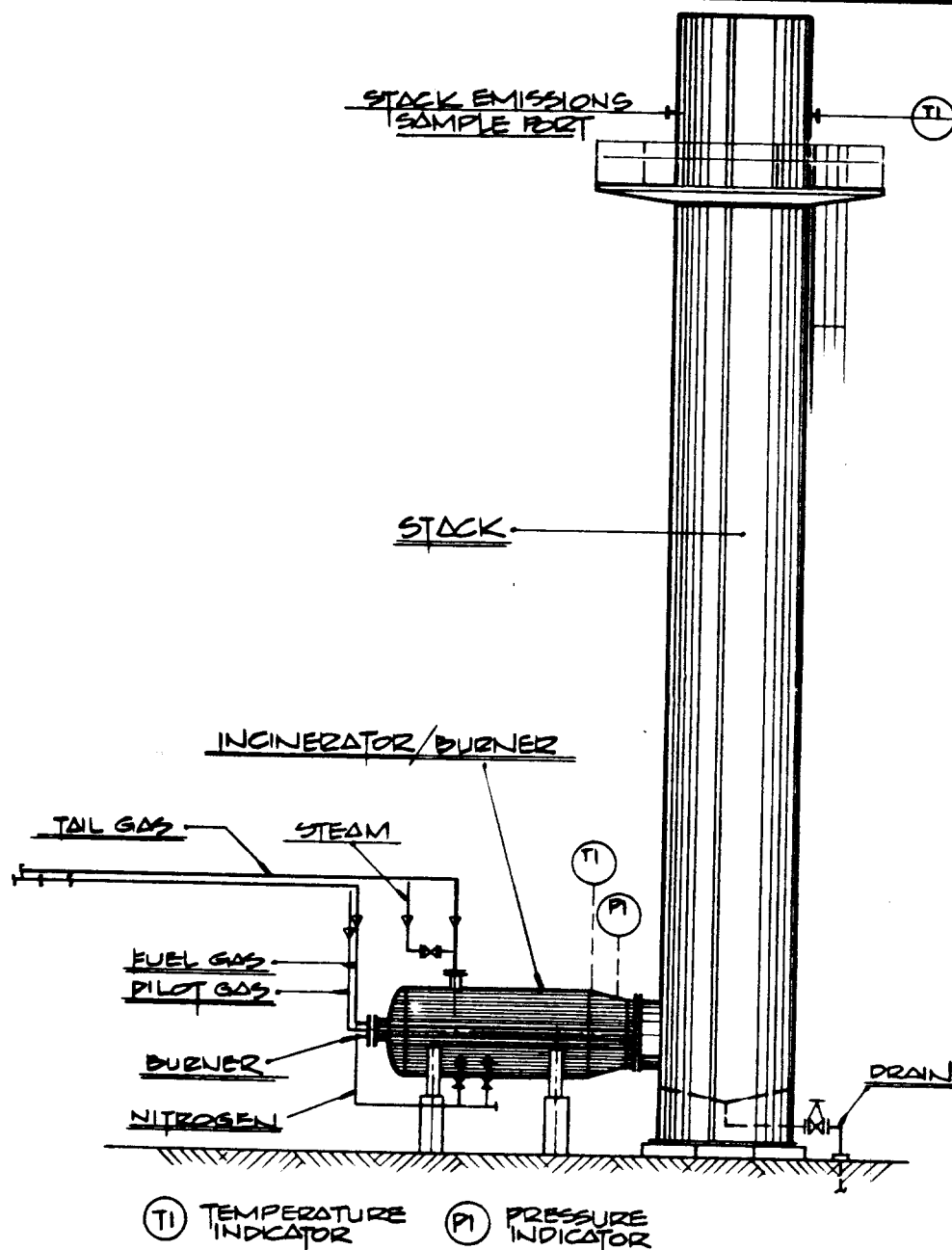


convection section, exits the coil into the crossover piping, and then enters the radiant tubes through the top of the heater. The heated product outlet from the two rows of radiant tubes enters the transfer line exchanger from the bottom, transferring its excess heat energy to the steam piping, and exits at the top of the exchanger.

TAIL GAS INCINERATOR AND WASTE HEAT UNIT

Waste gases containing liquids that must be disposed of and that for environmental or safety reasons cannot be directed to the flare system are burned in a tail gas incinerator, shown in Exhibit 7-50. The horizontal in-

EXHIBIT 7-50
Tail Gas Incinerator



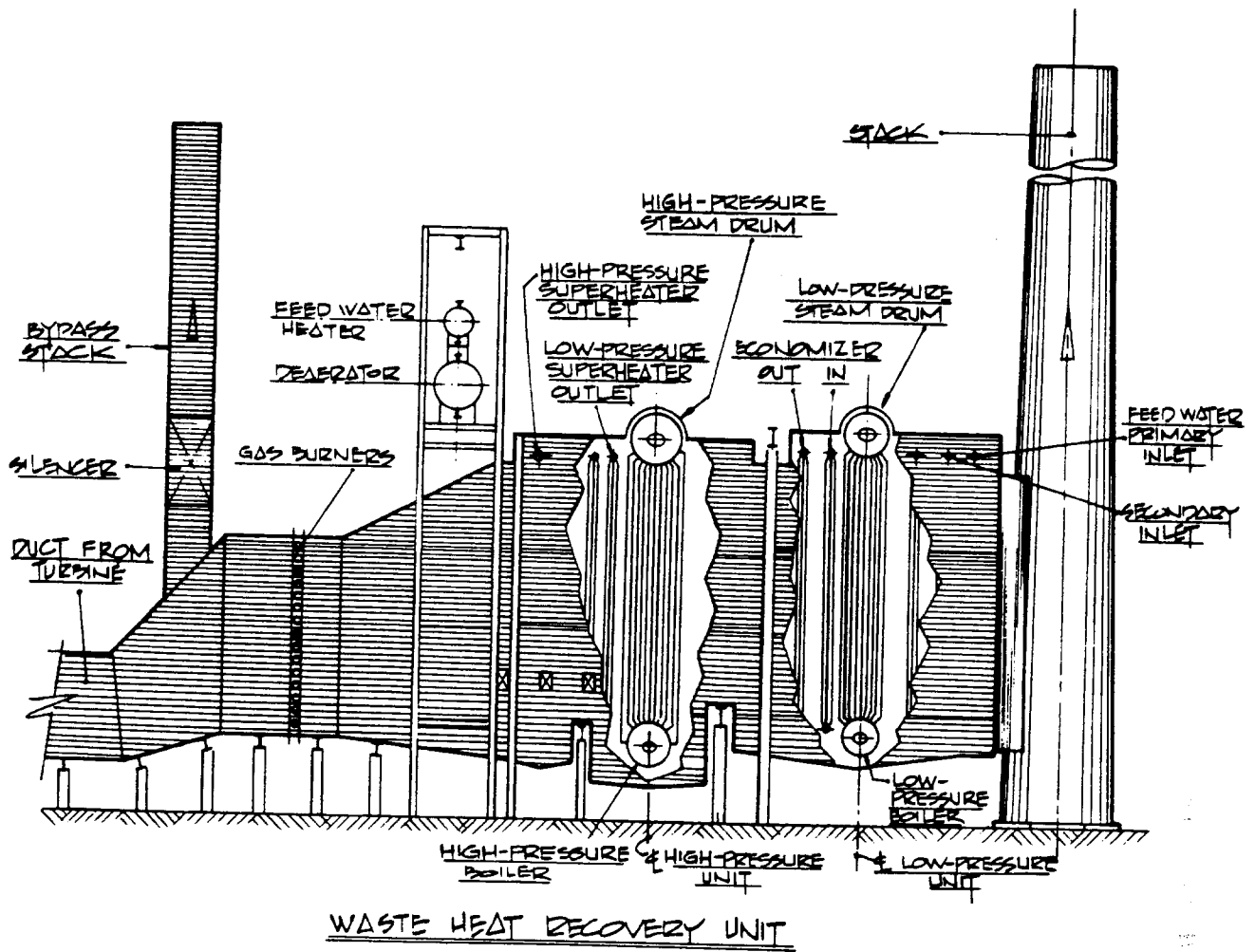
incinerator is bolted directly to the stack. The waste product enters the top inlet and is disposed of by a burner firing directly into the chamber. Piping usually associated with this equipment includes fuel gas, pilot gas, steam, nitrogen, and a liquid drain outlet located in the stack.

The waste heat recovery unit, illustrated in Exhibit 7-51, uses the waste gases of 800° to 1,200° F (425° to 650° C) from a gas turbine to generate high- and low-pressure steam for plant use. As can be seen in this exhibit, duct burners located in the inlet of this unit can be used if the turbine is shut down, providing a

continued heat source for steam generation. Because the physical makeup of these waste heat units varies in size and overall configuration, a detailed piping layout is not shown.

Because the configuration of equipment and associated items covered in this chapter may vary significantly among vendors, the plant layout designer should study the principles outlined and adjust each layout accordingly. Consideration for maintenance, operation, safety, and economics, as well as the use of common sense, results in an effective overall furnace design.

EXHIBIT 7-51 Waste Heat Recovery Unit



CHAPTER 8

Pumps

This chapter highlights the types of pumps commonly found in industrial plants, along with maintenance and operation considerations for a centrifugal pump piping layout.

Exhibit 8-1 shows an electric motor-driven horizontal pump that is familiar to plant layout designers. The two primary piping connections are the suction and discharge nozzles (i.e., liquid inlet and outlet). The impeller within the pump case draws the liquid into the pump and sends it out at a high velocity. The impeller shaft is sealed with a stuffing box where the shaft exits the case to prevent the pump fluid from leaking. Drips from wearing seals are picked up in the stuffing box drain. The pump shaft is connected to the drive shaft by a coupling, which is enclosed within protective housing. Both pump and driver are mounted on a common baseplate. Miscellaneous pump leaks that collect within the baseplate during operation are drained through a connection at the front of the pump.

Pump size and configuration vary for the following reasons:

- The commodity being pumped.
- The viscosity of the liquid.
- Capacity.
- Pressure.
- Temperature.
- Available head requirements.
- Physical limitations.

Initial pump piping layouts are done with preliminary information. The equipment engineer supplies the plant layout designer with a catalog cut of the pump that most closely represents the one to be purchased. In many cases, this data does not change significantly if the engineer has made the correct selection. Piping layouts are started early in the study phase; when the certified vendor drawings become available later in the project, minor adjustments are made as

required. Dimensions of nozzle locations or baseplate sizes may change slightly, but revisions to physical nozzle locations (i.e., from top to side or side to front) do not usually occur when the data is finalized. Working closely with the equipment and system engineers acquaints the principal parties with the exact design conditions and minimizes rework.

PUMP TERMINOLOGY

This section highlights some of the most common terms that the plant layout designer encounters when creating a pump layout.

Allowable nozzle loading The allowable nozzle loading is the maximum amount of stress that the piping configuration may impose on the pump suction and discharge nozzles, as set by the vendor, client, or code. The pipe stress engineer is responsible for working within this tolerance by coordinating the piping design early in a project and rechecking all calculations before formal fabrication issues of piping drawings are made.

Net positive suction head NPSH is one of the most important terms a plant layout designer needs to understand when developing an equipment layout that includes pumps and vessels. The required net positive suction head is a measure of the pressure drop of the liquid as it moves from the inlet of the pump to the eye of the impeller. It is a characteristic of the pump that is generally determined by testing and is expressed in "feet of water" by the pump manufacturer.

Vapor pressure When the pressure in the pump suction line falls below the vapor pressure of a liquid, the liquid flashes, or changes to vapor. Because no ordinary liquid pump can pump only vapor, liquid flow to the pump falls off and the unit is said to be vapor bound.

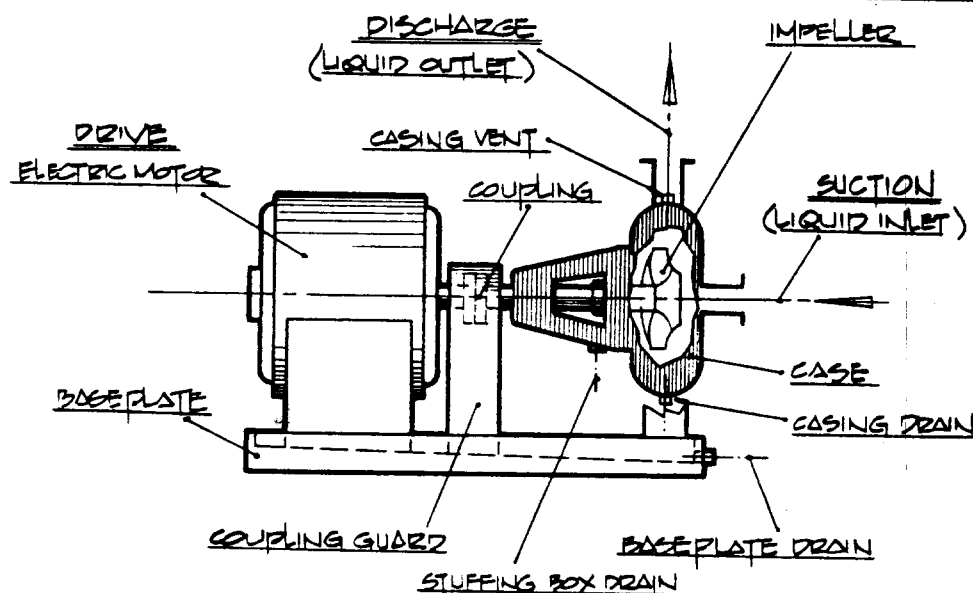


EXHIBIT 8-1
Centrifugal Pump

Available net positive suction head The available NPSH is the net pressure available in a given system, based on vessel pressure and static head, minus the liquid vapor pressure and functional losses in the system. The goal is to maintain equipment heights and minimize pump suction piping to ensure that the available NPSH is greater than the required NPSH. Insufficient NPSH can reduce pump capacity and efficiency and lead to cavitation damage.

Cavitation The rapid collapse of vapor bubbles that can produce noise, result in a loss of head and capacity, and create a severe erosion of the impeller and casing surfaces in the adjacent inlet areas.

API (American Petroleum Institute) pumps This term refers to the horizontal, single-stage pumps found in the petroleum industry. The standard developed by vendors, contractors, and users entitled "API 610—Centrifugal Pumps for General Refinery Ser-

vice" is used to specify pumps for purchase. To a plant layout designer, an API pump is a large, refinery-type pump.

AVS (American Voluntary Standard) pumps This standard, issued by the Hydraulic Institute, outlines several pumps with standard dimensions. They are interchangeable for a given size, regardless of who builds the pump, with no effect on foundation, piping design, or type of electric motor used.

NPSH REQUIREMENTS

An example of how to deal with a typical NPSH problem is shown in Exhibit 8-2. The required NPSH in this example is 22 ft (6,700 mm). If a horizontal pump is used, the bottom tangent line of vessel A must be a minimum of 22 ft (6,700 mm) above the centerline elevation of the shaft. If a vertical pump is used, the

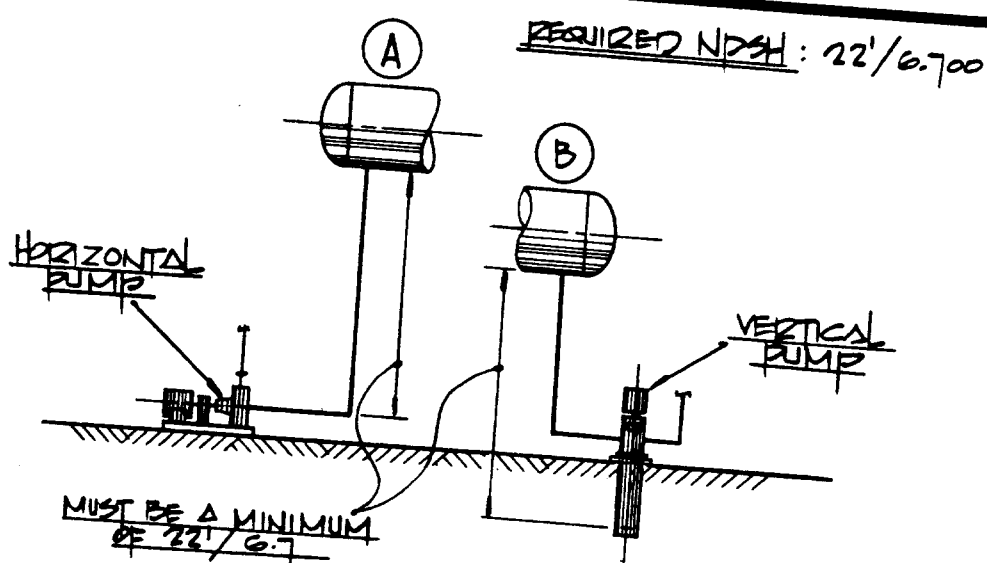


EXHIBIT 8-2
NPSH Example

vessel B tangent line is located closer to grade because NPSH is calculated from the bottom impeller of the pump located below grade. Although vertical pumps require less of a vessel support structure and possibly less piping, they are more expensive to buy and maintain. Therefore, a horizontal pump application is a more desirable solution in this instance. Vertical pumps are better used to draw suction from large surface condensers that service large compressors.

TYPES OF PUMPS

Pumps are classified as centrifugal, positive displacement (reciprocating), or rotary.

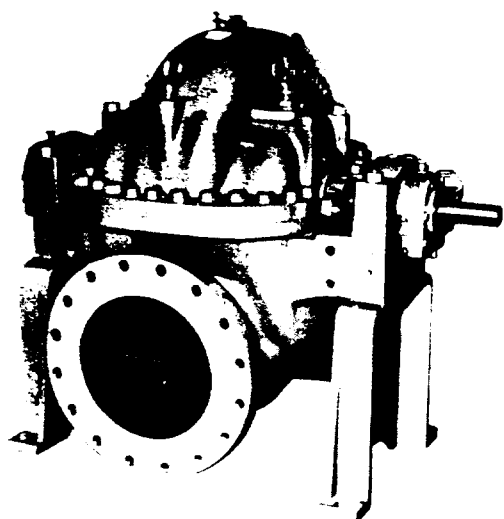
Centrifugal Pumps

The majority of pumps used in industry are centrifugal because of their flexibility in flow rates, pressure, and

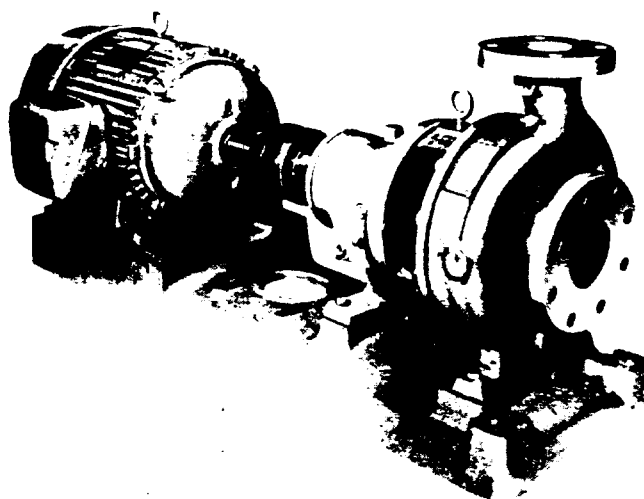
temperature. They are usually driven by electric motors or steam turbines. They may be single stage or multistage, depending on pressure requirements in the system, and can be horizontal or vertical. Centrifugal pumps, unlike reciprocating and rotary pumps, operate at constant speed and can deliver any capacity from zero to maximum, depending on the head design and suction conditions. Exhibit 8-3 depicts some of the more common variations of centrifugal pumps.

Positive Displacement (Reciprocating) Pumps

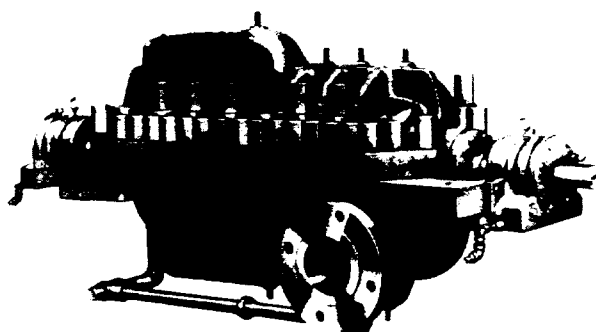
These pumps are commonly used to move viscous liquids, inject chemicals or additives into a system, or pump quantities too small for centrifugal pumps. These pumps discharge a definite quantity of liquid during piston or plunger movement through the stroke distance. Exhibit 8-4 shows two typical reciprocating pumps.



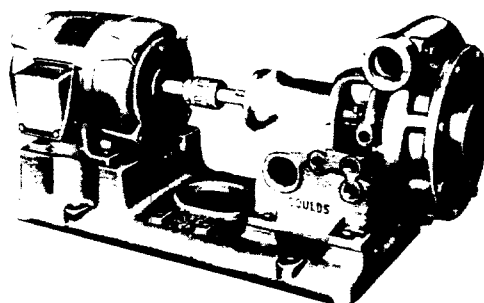
a. Horizontal Split-Case, Double Suction Pump



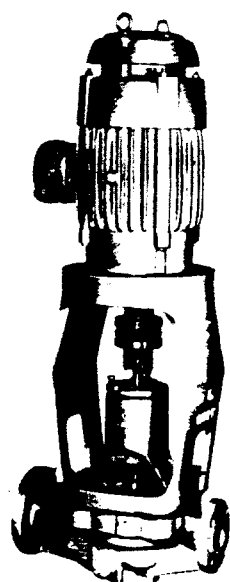
**b. Chemical Process Pump (ANSI)
(for chemical and corrosive liquids)**



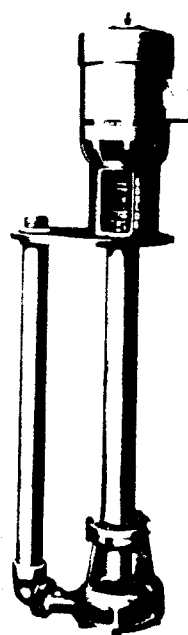
c. Multistage, High-Pressure Pump



d. Horizontal Frame-Mounted Pump



e. Inline Process Pump



f. Vertical Sump Pump

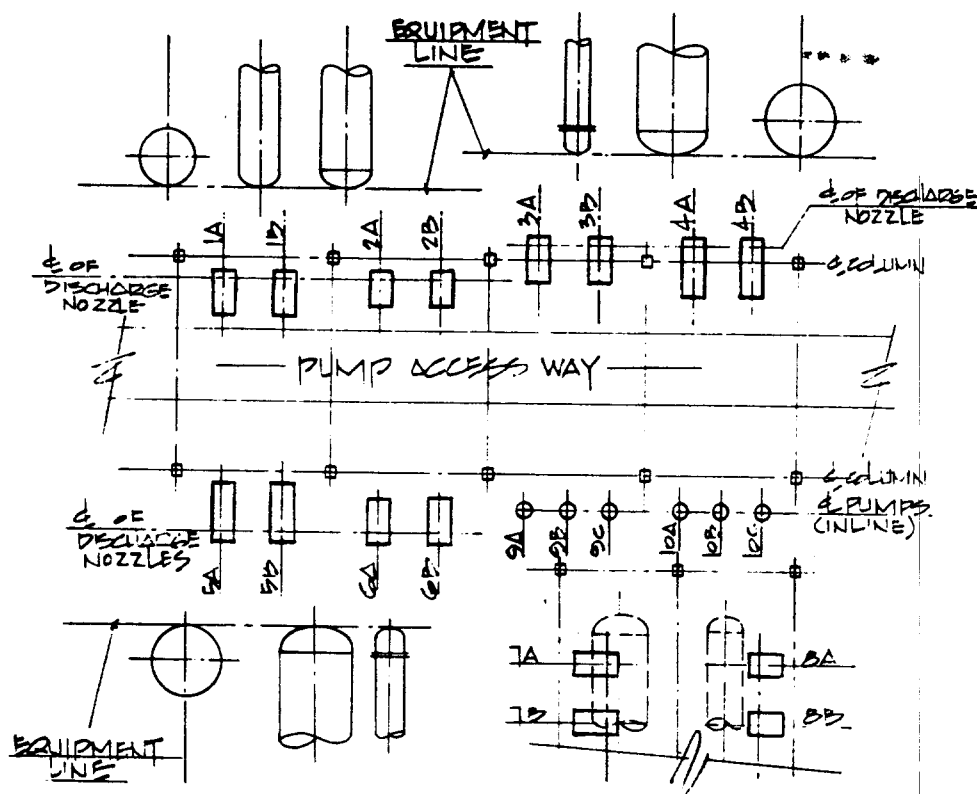


EXHIBIT 8-6
Typical Pump Locations:
Plan

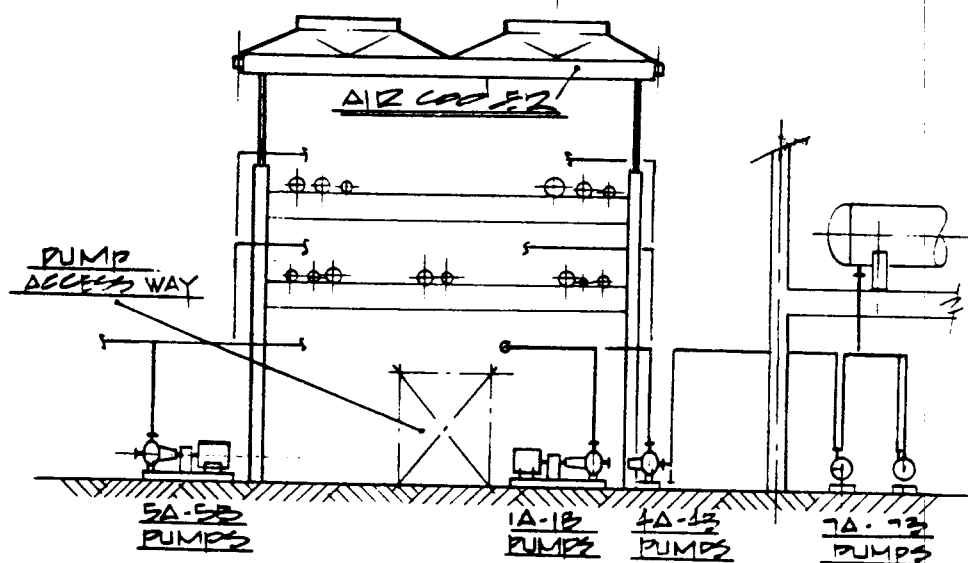


EXHIBIT 8-7
Typical Pump Locations:
Elevation

for lines entering or leaving the pipe rack, as shown in Exhibit 8-8.

Pumps 5A, 5B, 6A, and 6B in Exhibit 8-6 are located outside the confines of the pipe rack. This is the usual arrangement when hydrocarbon spills are more likely. Pumps 7A, 7B, 8A, and 8B are located directly under the process equipment that they serve, which is sup-

ported in the structure above. Drums and shell and tube exchangers are less associated with dangerous spills and therefore may have pumps located directly beneath them. Supporting pump piping is also facilitated by the proximity of the steel.

Pumps 9A, B, and C and 10A, B, and C are inline and are treated basically as a piping item (e.g., a control

EXHIBIT 8-8 Pump Discharge Location

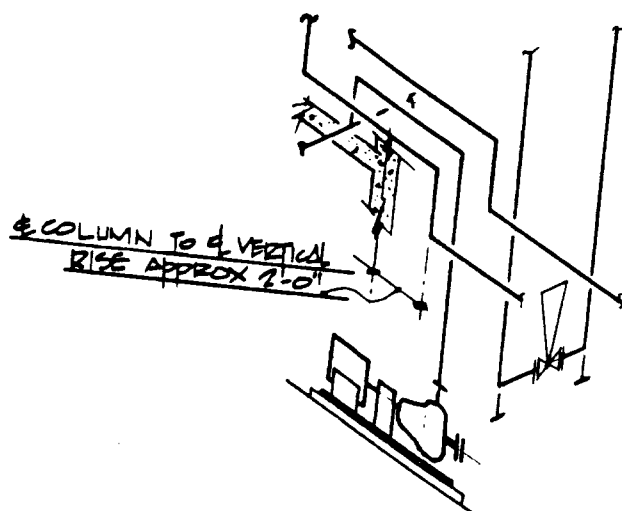


EXHIBIT 8-9 Vertical Condensate Pump

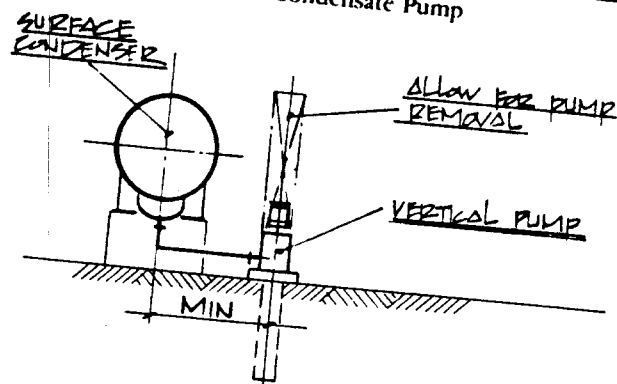
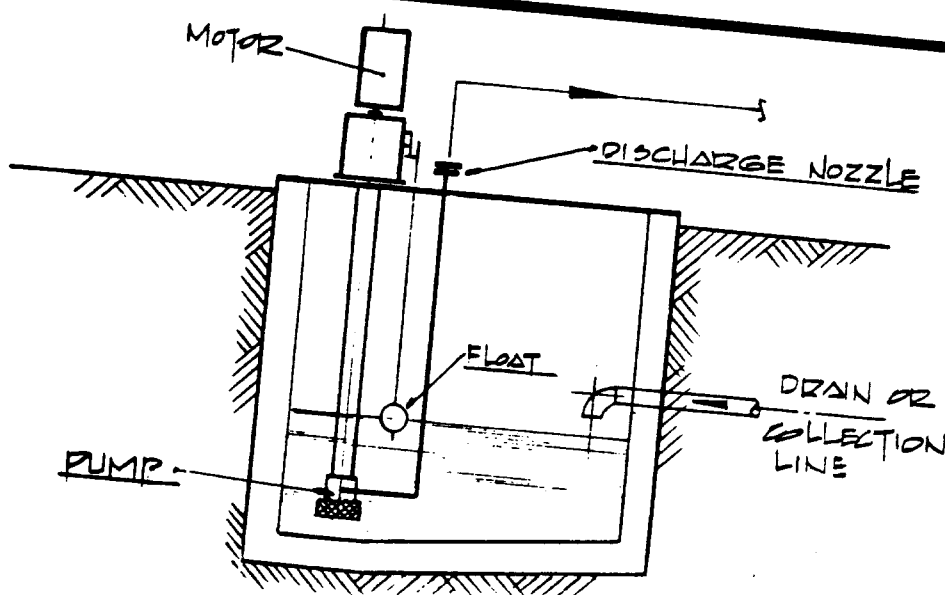


EXHIBIT 8-10 Sump Pump



valve). Adequate access must be planned to the pump and drive, which may be removed for maintenance.

Locating Boiler Feed Pumps

Because boiler feed pumps take water from a deaerator and generally operate close to the vapor pressure of the liquid, they must be located as close to the deaerator as possible.

Locating Vertical Pumps

Vertical pumps are used when NPSH requirements make using horizontal pumps impractical. Exhibit 8-9

shows a typical condensate pump that is located adjacent to the surface condenser it serves.

Exhibit 8-10 depicts a sump pump that is generally used to remove waste material collected in a concrete or steel pit. A screen at the bottom of the pump suction connection reduces the possibility that the pump will foul during operation. The discharge connection may be piped to another holding vessel, a pond, or a waste-removal vehicle.

Centrifugal pumps in vacuum service are shown in Exhibit 8-11. Because the system operates at a negative pressure and extremely high temperatures, the location of these pumps must be either directly under the tower or just outside the support columns. When the

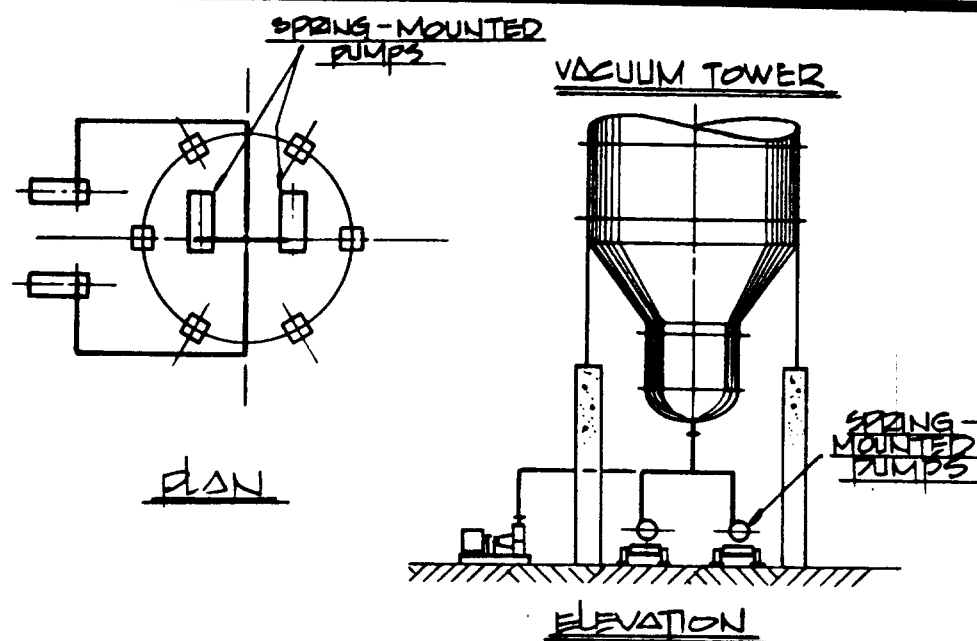


EXHIBIT 8-11
Centrifugal Pumps in
Vacuum Service

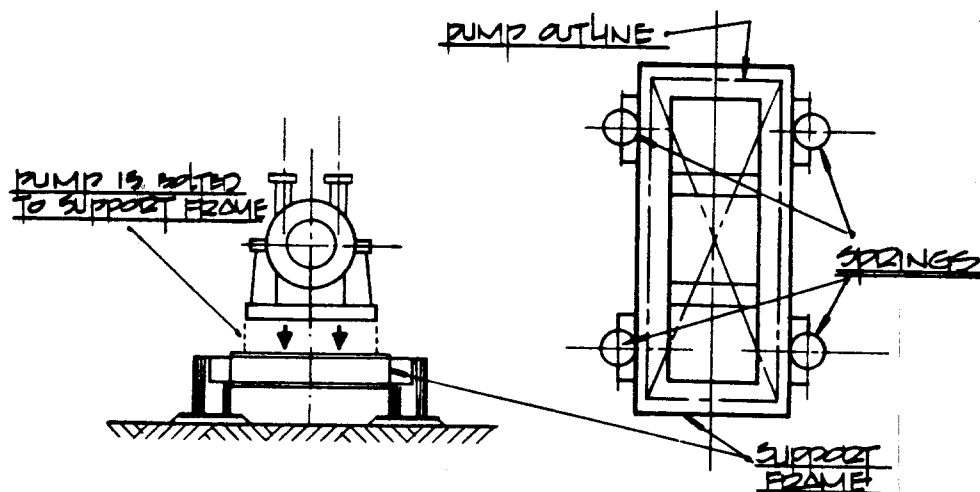


EXHIBIT 8-12
Spring-Mounted Pump

pumps are located directly under the tower, it may be necessary to support the pumps with springs, as shown in Exhibit 8-12. This essentially consists of a steel frame with four spring supports attached to the sides. The pump is then set into the steel frame and secured. During operation, the pump is free to move within the design limits of the four springs, reducing the stress imposed on the nozzles by high temperatures.

PUMP PIPING

This section highlights some common pump piping configurations. Although horizontal pumps are shown

in most of the exhibits, the arrangements are typical for all types of pump applications. Exhibit 8-13 illustrates the components that are usually found in pump suction and discharge piping.

The suction line has a positive shut-off valve; in this example, it is a gate valve. The temporary tee-type strainer (shown in Exhibit 8-14) catches any foreign matter that may have collected in the piping during construction. After the suction and discharge valves have been shut off, the blind flange is unbolted and put aside and the strainer is pulled out. This strainer is generally used only for start-up. Exhibit 8-15 shows a basket strainer that may also be used in a pump suction line.

Although this particular strainer does not need ad-

EXHIBIT 8-13
Components of a Typical
Pump Suction and
Discharge Piping System

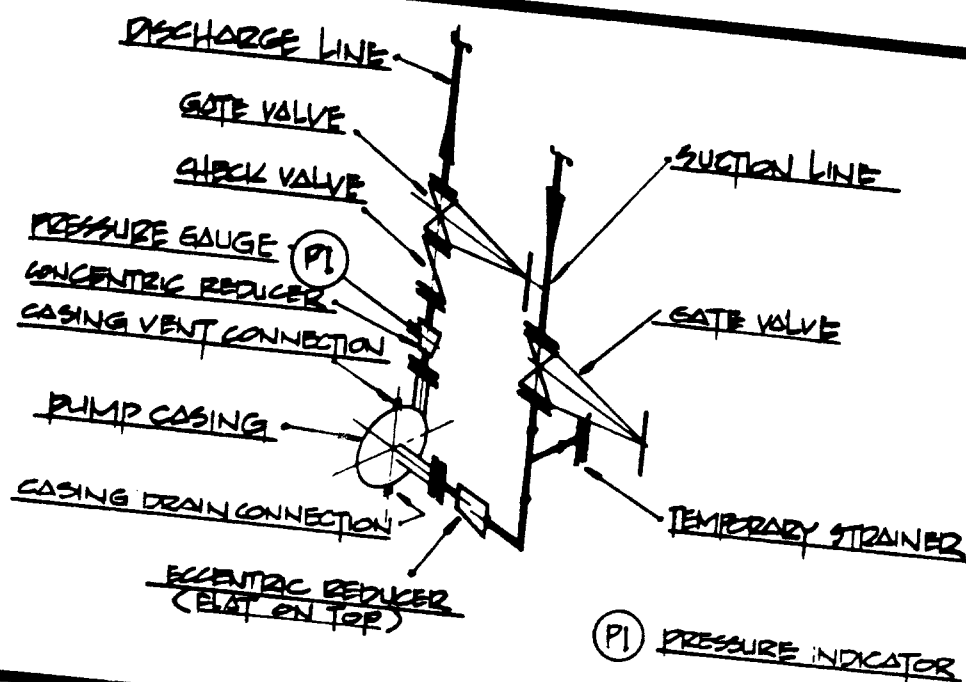


EXHIBIT 8-14
Typical Temporary
Tee-Type Strainer

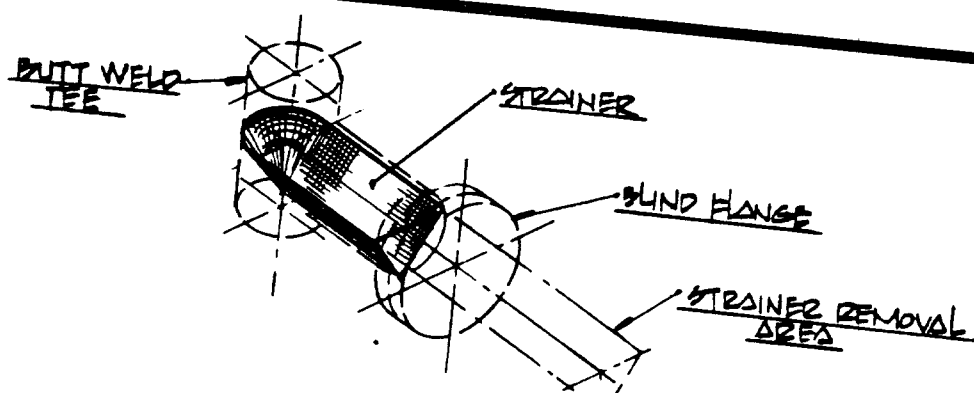


EXHIBIT 8-15
Typical Basket Strainer

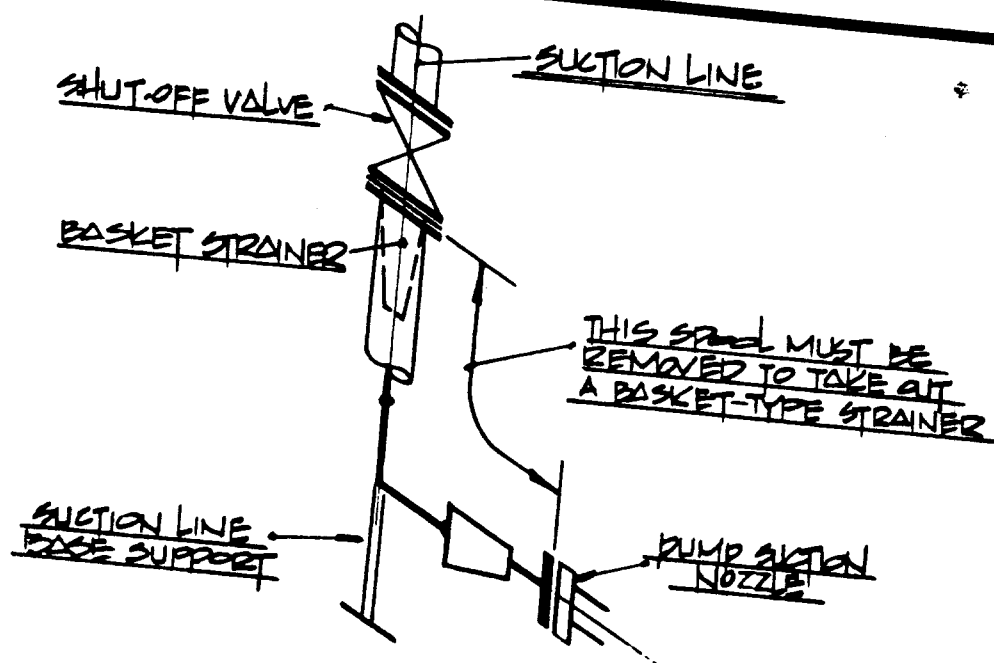
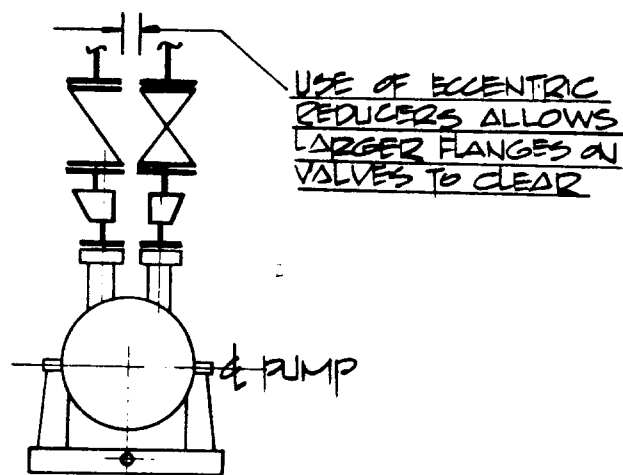
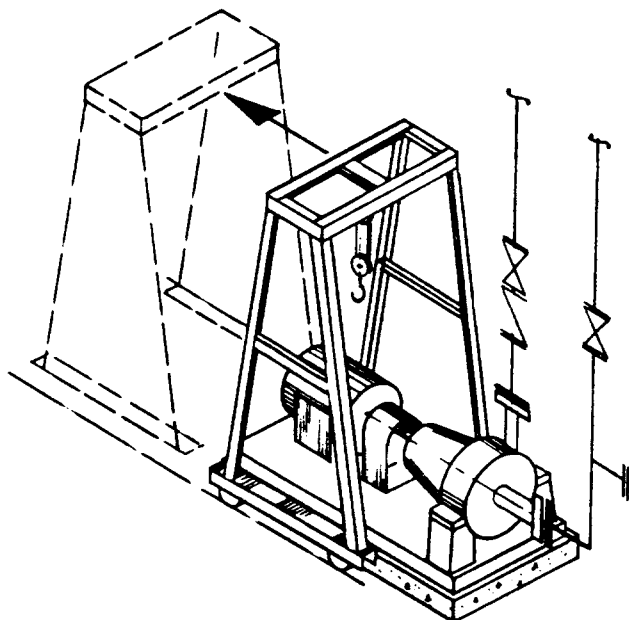


EXHIBIT 8-16 Eccentric Reducers**EXHIBIT 8-17** A-Frame for Pump Maintenance

ditional fittings for its removal and cleaning if reused, it does require additional maintenance because of the downstream flanges of the valve. The pump nozzle and possibly the base support under the elbow must be unbolted to pull the spool piece and remove the strainer. The next common fitting is a reducer; this should be an eccentric type as shown in Exhibit 8-16, with the flat side on top to reduce the possibility of cavitation in the pump.

Piping Layout Considerations

Before initiating a piping layout in a pump area, the plant layout designer must consider several factors that are critical to optimum design. The first factor concerns the support of the pump piping, which often includes large expansion loops for flexibility. If the pumps are located under a pipe rack or structure, support is relatively easy. If not, the plant layout designer must consult with the stress engineer for the best location for equipment such as stops and hangers. Pumps in an open area often require a much larger structure for pipe supports. Allowable loading on a pump nozzle is very low, and the piping must be properly supported to avoid overstressing the nozzles. Vendors may void pump warranties if the allowable loads are exceeded.

Client pump and driver maintenance procedures must also be known at this stage, especially those regarding how each item is to be physically removed. Very small pumps may be removed by hand; larger pumps require the use of an A-frame, as depicted in Exhibit 8-17. Very large pumps may be removed by a cherry picker.

The next factor to consider is duplicate piping configurations at groups of pumps of similar size. For example, a new chemical plant had 203 pumps, of which almost 75% required piping ranging from 1½ in to 3 in in diameter and had a maximum operating temperature of 230° F. A layout designer, working with a stress/support engineer, designed the piping with a

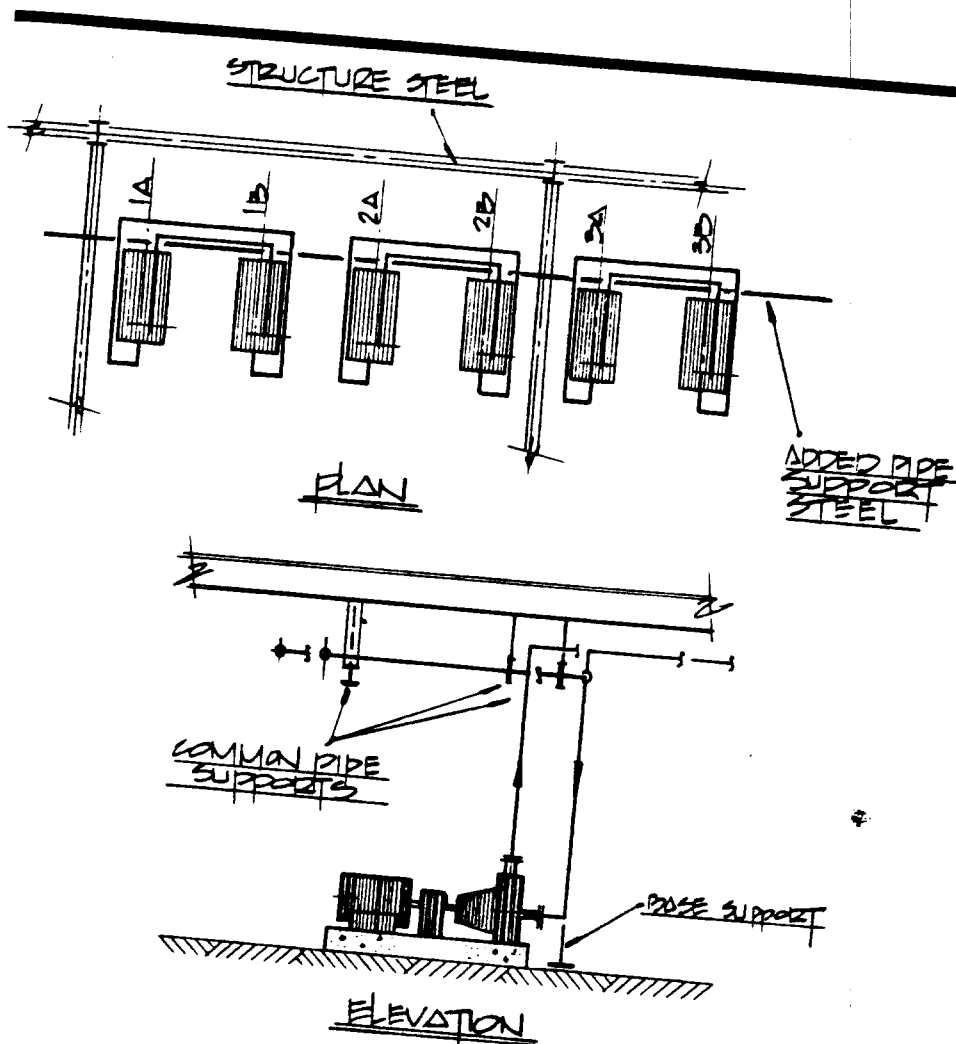
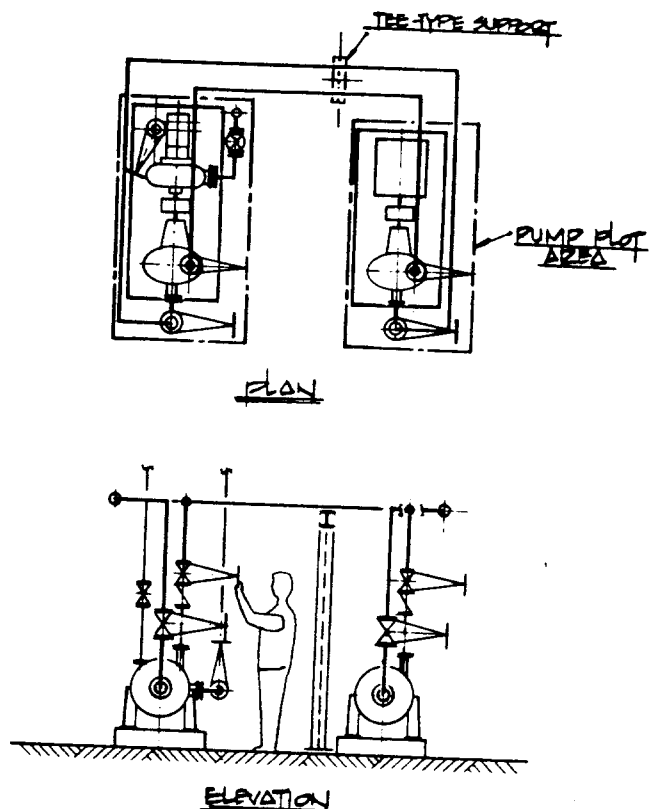
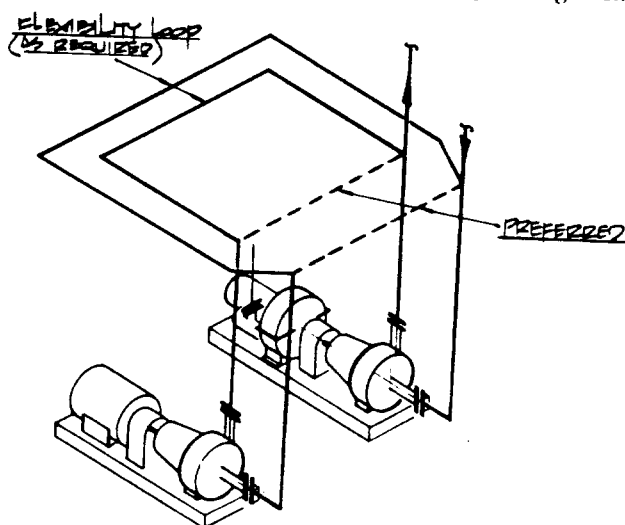
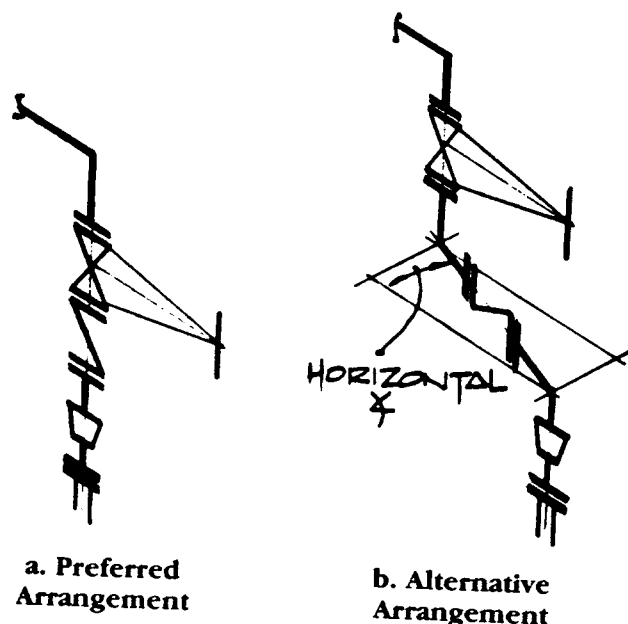


EXHIBIT 8-18
Standardized Pump
Layout

flexibility loop that was based on a 3-in line operating at 230° F. This layout was duplicated for 76 pairs of pumps, or 152 total. Although the piping as designed was conservative and slightly more costly for the 1½-in and 2-in pumps, engineering, fabrication, and construction time could be reduced through standardization. A fully dimensioned sketch of this particular standard design was given to each designer on the

project. If the pumps in the designer's area fell into the 3-in, 230° F operating temperature category, the design was copied exactly. The 152 pumps were designed and supported once and in an identical manner.

Uniformity of design in piping, supports, and steel were the results of thinking ahead. This is what a client pays for when hiring an engineering contractor. Spending more on engineering may reduce construc-

EXHIBIT 8-19 Maintenance and Operational Access Requirements**EXHIBIT 8-20** Primary and Standby Pump Arrangement**EXHIBIT 8-21** Block Valve Handwheel Elevations

tion costs, or spending more on materials may save both engineering and construction costs. A pump layout should be viewed not on an item-by-item basis but as a whole area. Exhibit 8-18 shows an example of a standardized pump layout. The designer must also be aware of all operation and maintenance concerns with all pump layouts. Maintenance and operational access needs are illustrated in Exhibit 8-19.

When developing an equipment arrangement in pump areas, the layout designer must envision potential obstructions around the pumps (e.g., large block valves, steam turbine piping, and tee-type pipe supports from grade). Four feet (1,200 mm) is a generally accepted distance between pumps or associated piping.

When expansion loops are required between pumps, it is necessary to partially run the lines over the pump and driver. Every effort must be made to minimize maintenance obstructions by running the piping either outside the area directly over the pumps, or at a high enough elevation to permit the removal of the pump or driver.

Orientation of block valves must minimize the plot area required. Elevation of the valves should generally be as low as possible and common in both lines when practical.

Multiple-Pump Piping Arrangements

There are many ways to design multiple-pump hook-ups. This section discusses several configurations that satisfy various conditions. The primary and standby

EXHIBIT 8-22
Two Primary Pumps and
One Common Standby
Pump

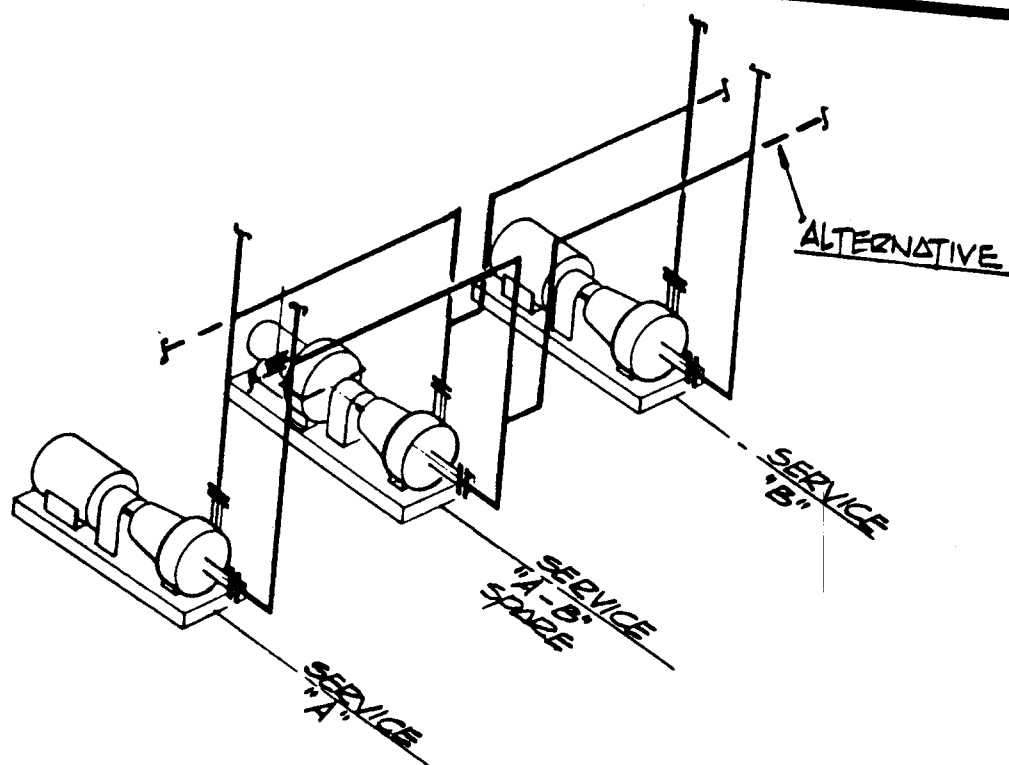
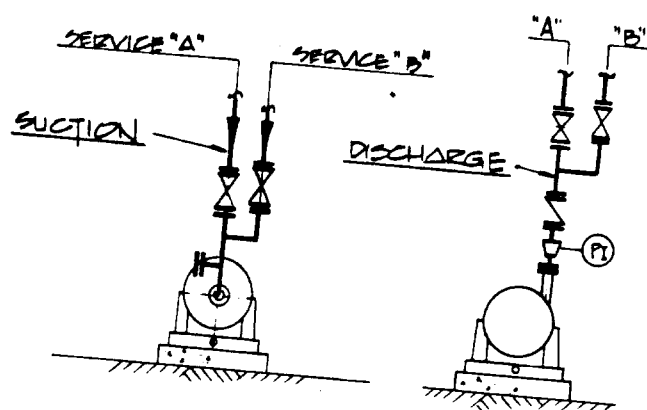


EXHIBIT 8-23 Common Standby Pump



pump arrangement illustrated in Exhibit 8-20 indicates two ways in which the pumps may be tied together. Although the preferred hookup is directly across and over headroom, the operating temperature of many pumps requires the addition of a flexibility loop to reduce stresses on the pump nozzles. The loop need not take the routing as shown, but it should be configured so that the piping receives optimum support. Another concern is the elevation of the block valve handwheel in the discharge line, which must be within the reach of plant operations personnel—the preferred arrangement and an alternative layout are

shown in Exhibit 8-21. In larger line sizes with higher pressure ratings, the valves place the horizontal piping too high, especially if they are beneath the pipe rack. Therefore, the alternative arrangement shown in the exhibit solves the layout problem.

Exhibit 8-22 illustrates how a common standby pump is used for two primary pumps; this is the ideal layout, with flexibility loops added as required. Exhibit 8-23 shows how the suction line for service B is tied into the suction line for service A below or downstream from the block valve and upstream from the strainer. The discharge line for service B is tied in downstream from the check valve.

Pumps for hot slurry service may be configured in another manner, as shown in Exhibit 8-24. Because the line requires a large flexible loop, the amount of dead leg in the line for the nonoperating pump must be minimized. The plant layout designer should discuss this particular arrangement with the vessel engineer. When the vessel data sheets are sent out for quotation, the split bottoms outlet connection is included in the basic design. Making this type of decision too late can be very costly and may delay delivery of the vessel. The designer should not just take information as is but should look for ways to improve the overall design or lower the cost of the plant in all disciplines.

Pumps whose suction lines come from below grade are shown in Exhibit 8-25. This is the one time that the reducer absolutely must have the flat side on top to

EXHIBIT 8-24
Primary and Standby
Pump for Hot Slurry
Service

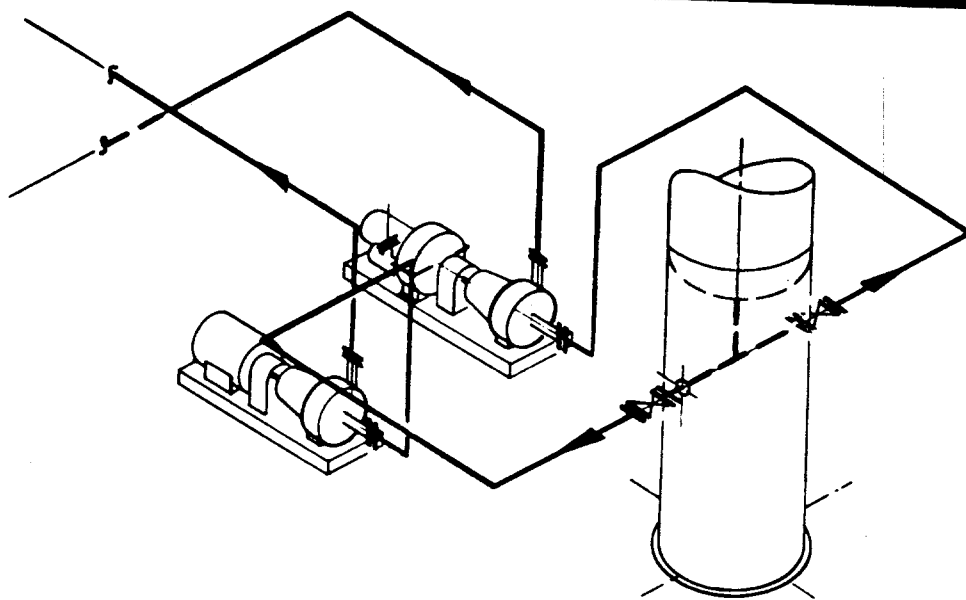
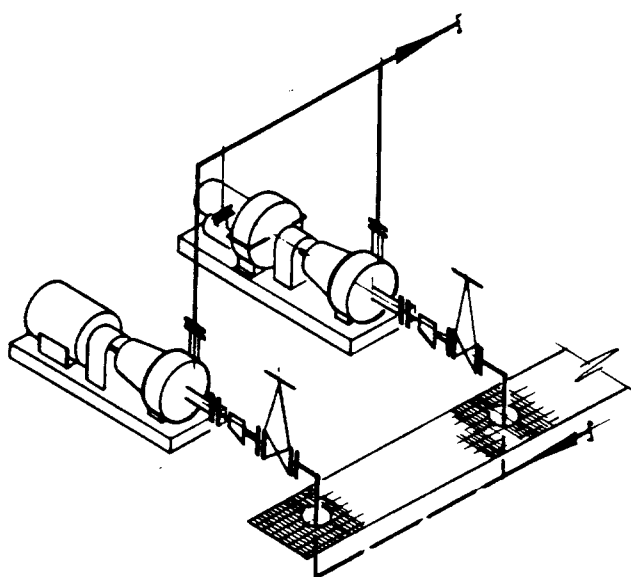


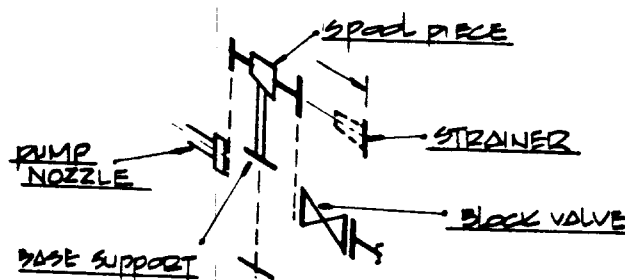
EXHIBIT 8-25 Primary and Standby Pump with
Below-Grade Suction



avoid cavitation. Use of a basket strainer is more practical in this case because the spool piece containing the strainer could be lifted out, as illustrated in Exhibit 8-26.

Avoiding cavitation in a pump is a concern in all services but particularly when the liquid operates close to the vapor pressure. Boiler feed pumps, shown in Exhibit 8-27, generally operate close to the vapor pressure of the feed water. As a result, it is imperative that changes in direction be minimized. Designers may add flexibility to the suction line when it is convenient to support it, but this may disrupt the flow and increase the possibility of cavitation. The preferred

EXHIBIT 8-26 Spool Piece Removal

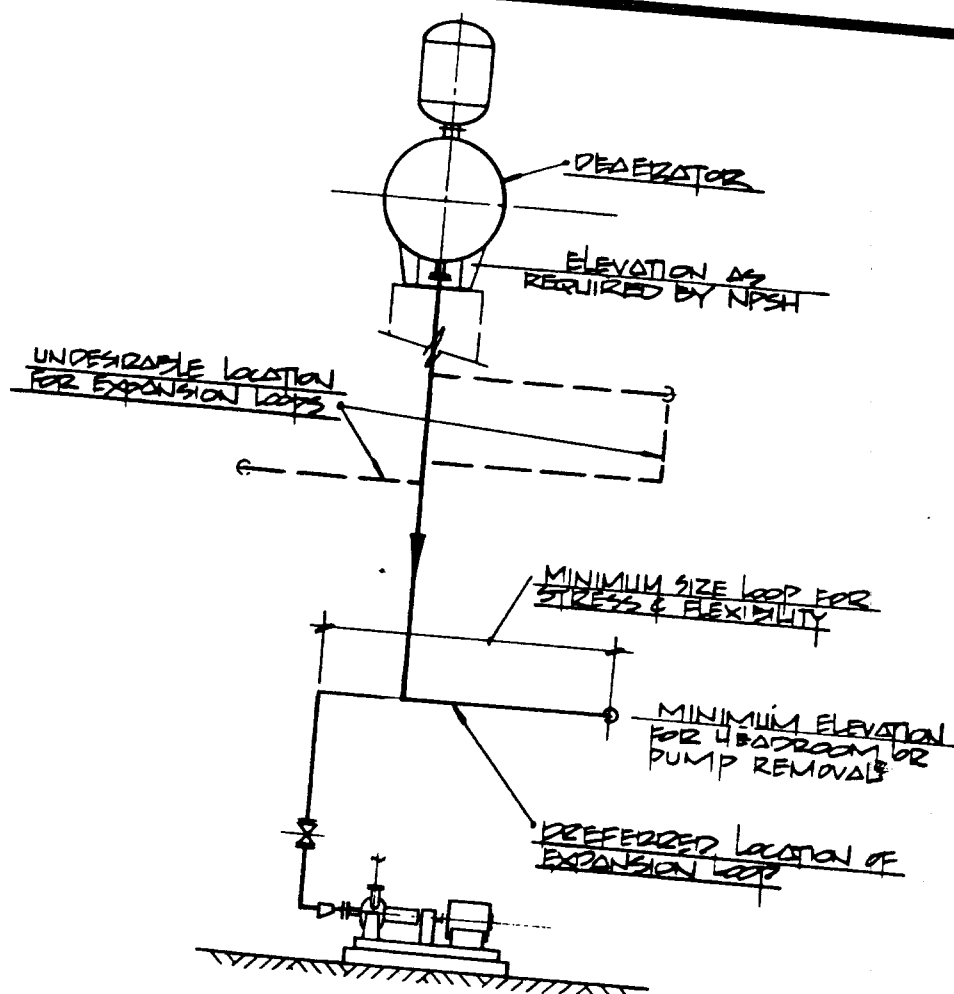


arrangement has a maximum straight drop out of the deaerator down to where the flexibility loop is required. Although support may be more difficult, optimizing the operation of the pump is of primary concern and should take precedence.

There are many solutions that can remove CO_2 from process gas, some of which operate close to the vapor pressure of the liquid. Exhibit 8-28 shows one way to solve this problem. The use of multiple nozzles reduces the changes in direction in the suction line. Extending the nozzles to a maximum distance before exiting the skirt above headroom and adding a slight slope to the horizontal run also helps streamline the piping. The suction strainer must be located away from the pump, as shown in the vertical portion of the line, and placed low enough to maintain. Once again, early planning by the plant layout designer allows this additional nozzle feature to be added to the quote documents.

When sidesuction nozzles are used on centrifugal pumps, a minimum of five diameters of straight run is added to the line before it enters the nozzle. This

EXHIBIT 8-27
Boiler Feed Pumps



distributes the liquid evenly because the flow is coming in perpendicular to the impeller. Exhibit 8-29 displays this configuration for a centrifugal pump.

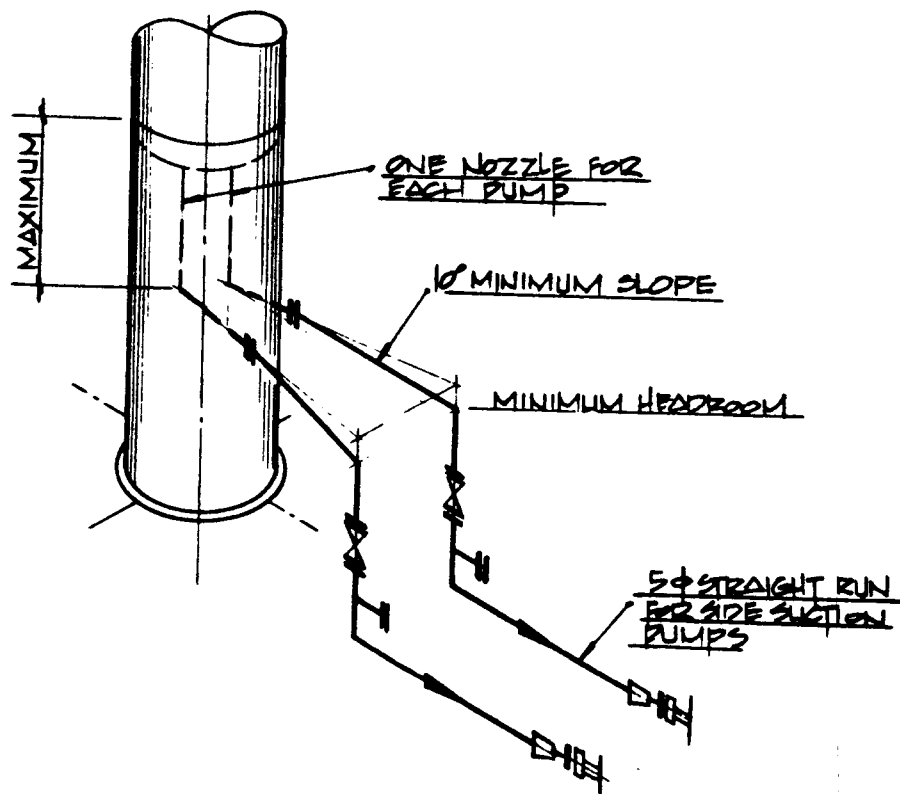
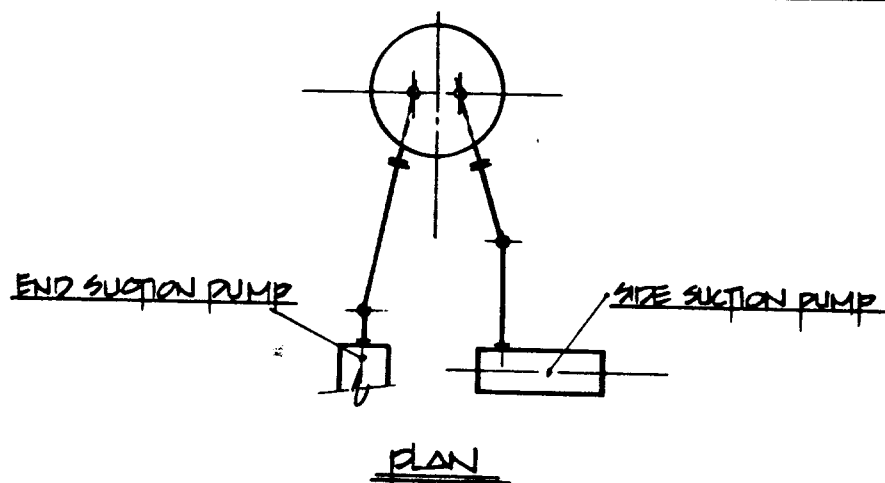
Steam Turbine Piping Arrangements

When a steam turbine piping arrangement is being developed, it is important to avoid the introduction of

steam condensate into the turbine case, which could damage the blades. A typical turbine arrangement is shown in Exhibit 8-30.

The steam supply comes off the top of the supply header and reduces condensate carry-over into the turbine. The block valve isolates the turbine when it is not in use. A drip leg is provided at the low point of the system to remove any condensate. A control valve is placed adjacent to the turbine. The steam exhaust

EXHIBIT 8-28
CO₂ Medium Pumps



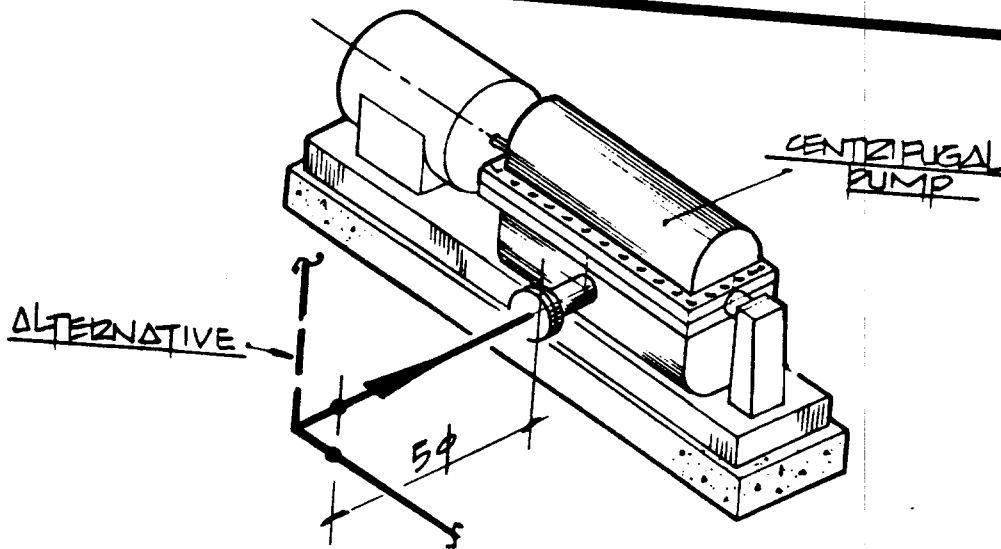
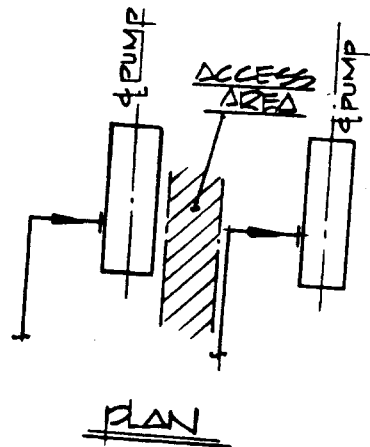


EXHIBIT 8-29
Side-Suction Nozzles on a
Centrifugal Pump



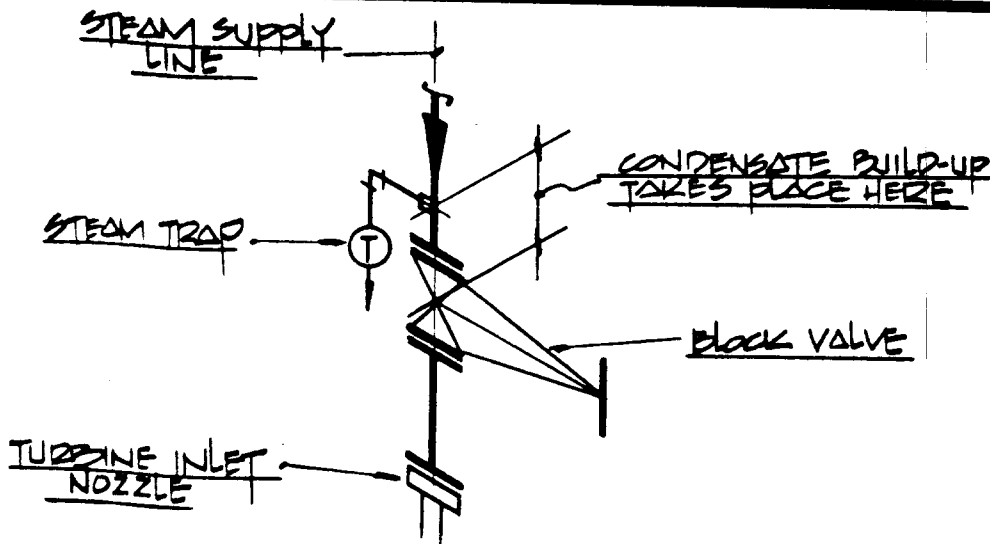
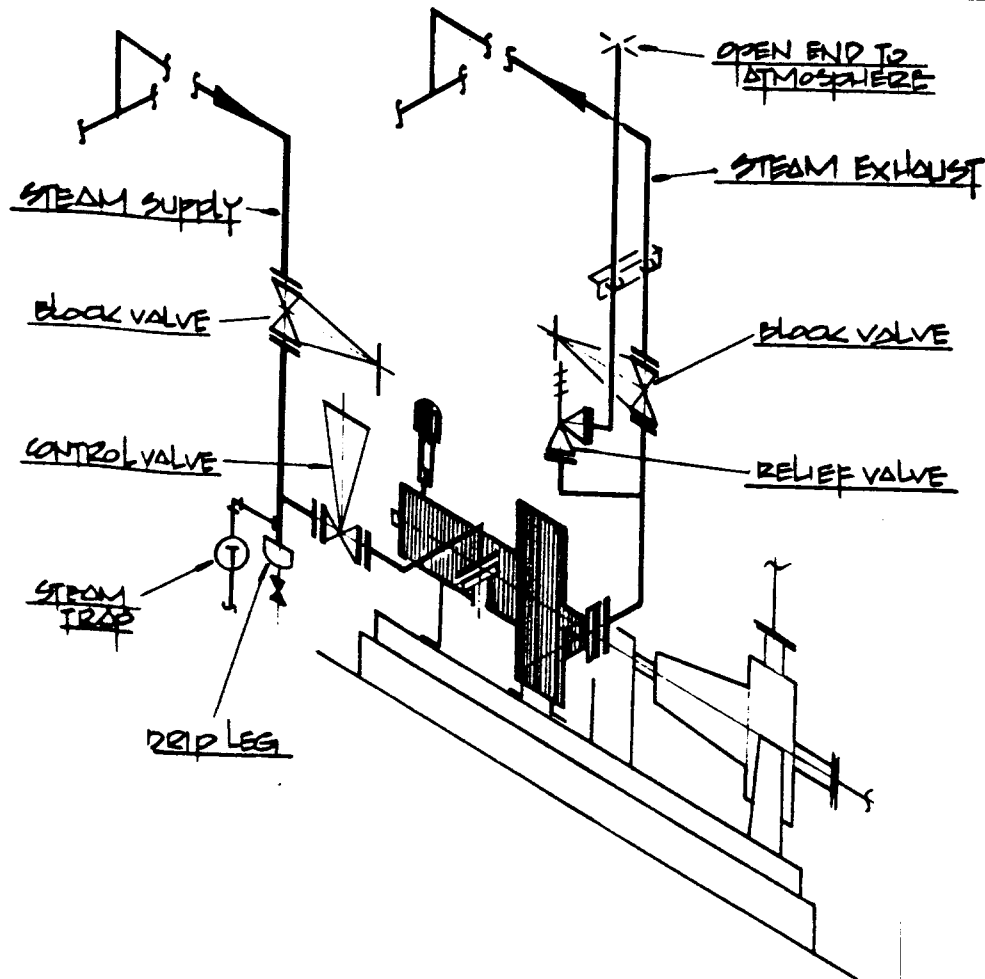
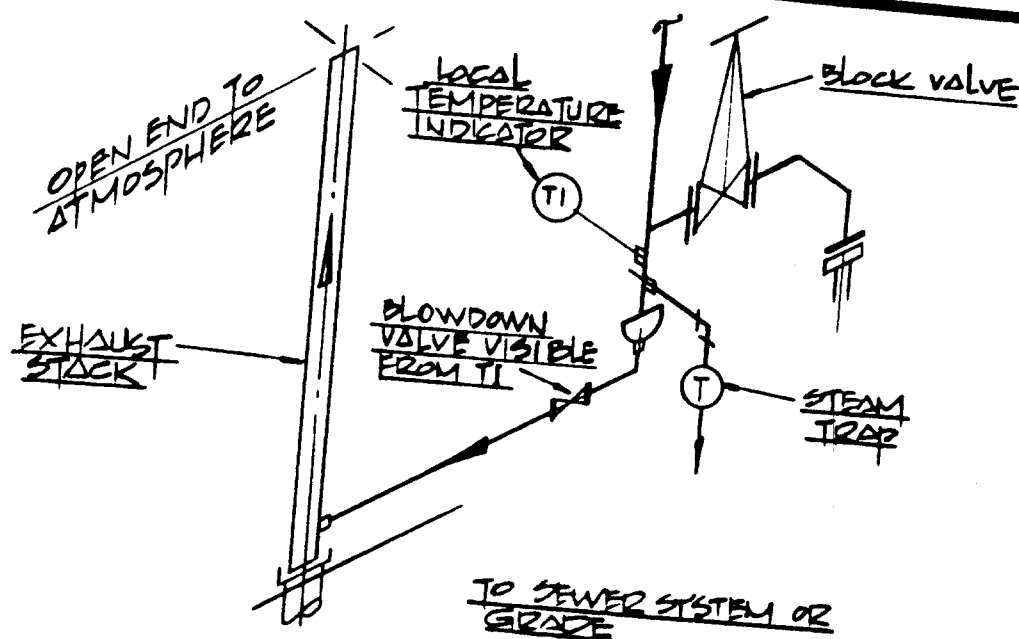


EXHIBIT 8-32
Condensate Blowdown
Line



line block valve is provided for isolation. A relief valve is also provided as a protection device should the exhaust valve be closed before cutting off the steam supply. This line must vent to a safe location away from plant personnel. Additional consideration must be given to access to the turbine for maintenance or inspection of lube oil connections, packing glands, and the governor.

Exhibit 8-31 shows an improper steam supply line arrangement; the steam trap does not come off the low point in the system. The condensate that builds up above the block valve enters the turbine when the valve is opened, damaging the blades. This configuration must be avoided.

Removal of condensate at multistage turbines is another serious concern because if the water slugs, the thrust bearings can fail. A typical method of safely removing excess condensate without endangering the operator who drains the line is shown in Exhibit 8-32. A temperature indicator, which is visible from the blowdown valve, indicates the presence of water in the system. Opening the valve releases the hot condensate into the exhaust stack. The hot steam can then vent safely overhead, and the condensate is dumped to grade or directly to a drain system.

Auxiliary Pump Piping Arrangements

Many pumps have auxiliary piping that is supplied by the vendor or the engineering contractor. This piping delivers cooling water to mechanical seals, bearings, stuffing boxes, gland quench, and lantern ring flush

and may be run to the pump support pedestal for high-temperature services.

Pump vendors usually supply the auxiliary piping to the mechanical seals through a harness. When pump fluid is used, a line is attached to the vent connection on the pump case. The circulated seal fluid must be sent back to the pump stream or returned through the seal to pump internal clearances. In viscous or high-temperature hydrocarbon liquids, the seal fluid medium circulates from an external source through connections on the pump seal. This medium may be a clean gas oil. In all cases of auxiliary pump piping, the plant layout designer must carefully review the vendor drawing and piping and instrumentation diagrams to ensure that all requirements for cooling or seals have been covered by one of these documents. Exhibit 8-33 shows a typical auxiliary pump piping arrangement. The cooling water in and out of this particular pump is from above grade; however, many cooling water systems are below grade, and the plant layout designer must find a suitable location for this connection.

PUMP PIPING SUPPORTS

A plant layout designer must have some basic knowledge of stress and pipe supports to generate a sound pump piping arrangement that will not be radically redesigned by a stress/support engineer. Some simple rules, if followed, enable the designer to satisfy two of the most important considerations illustrated in Ex-

EXHIBIT 8-33
Auxiliary Pump Piping

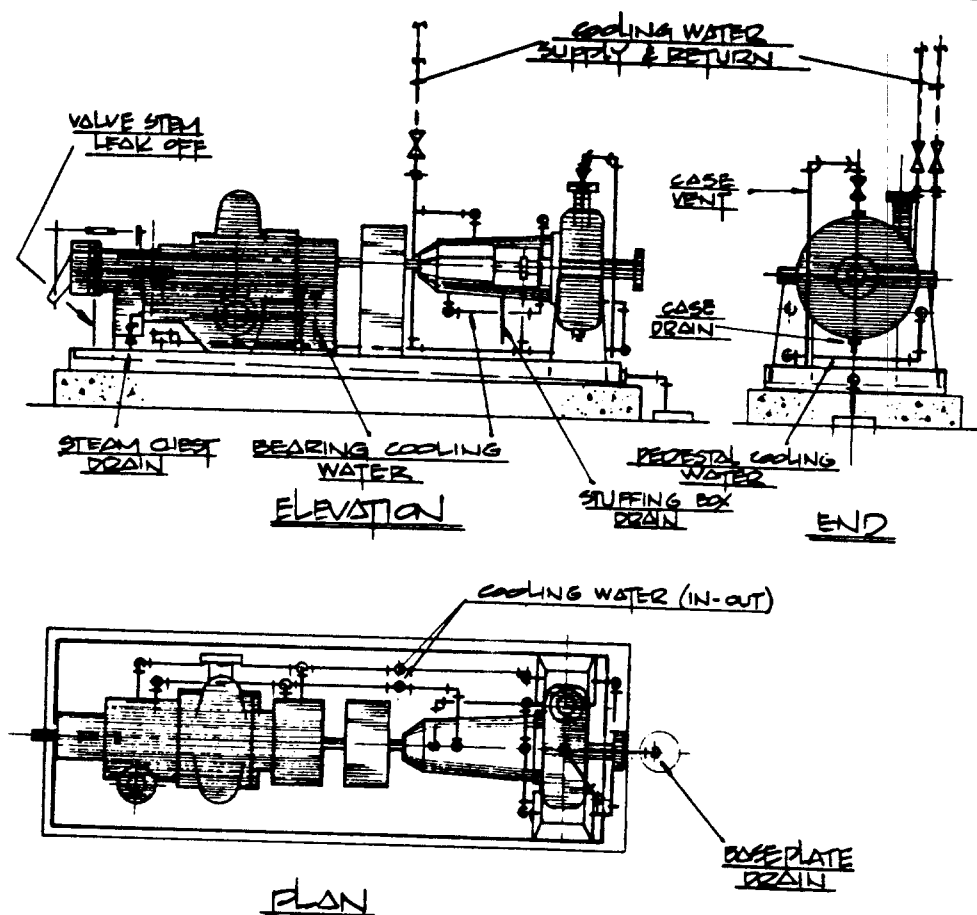


Exhibit 8-34: supporting the suction line under the elbow and supporting the discharge line within five diameters of the top elbow.

The suction line is commonly supported under the elbow adjacent to the pump nozzle. This may be a hard support (i.e., pipe or a structural steel member), adjustable type, or spring support for high-temperature pumps. If pumps are located in poor soil areas or where differential settlement may occur, extending the pump block foundation may be necessary to pick up the base support. The stress/support engineer and civil engineer need to be part of this decision.

The discharge line should be supported as close to the top elbow as possible and should be within five

diameters of that elbow. Pump nozzle loading falls under the API-610 code. There are two ways of supporting the discharge line. One is to sit the spring support on the steel with a rod hanger and clamp; the other version is to place a base spring on the steel with the discharge line resting directly on the load flange of the spring. Because the hanger rod could pose a danger during a fire, each project should be reviewed for such concerns. Loading on steam turbine nozzles falls under the NEMA-SM-21 code, which is different from the allowable nozzle loads on pumps.

Inline pumps do not require a direct support but are held in place by the suction and discharge line supports, as shown in Exhibit 8-35.

EXHIBIT 8-34
Typical Pump and
Turbine Support
Considerations

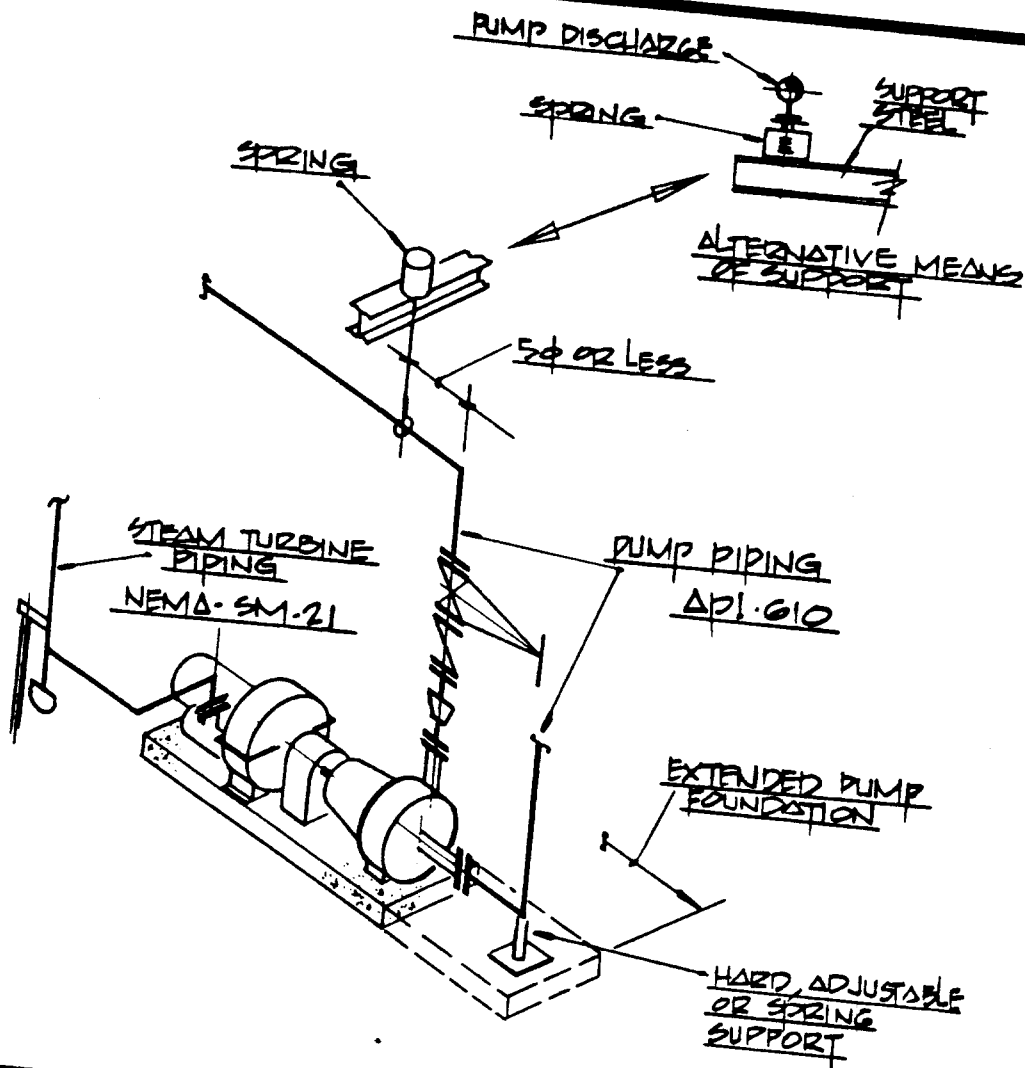
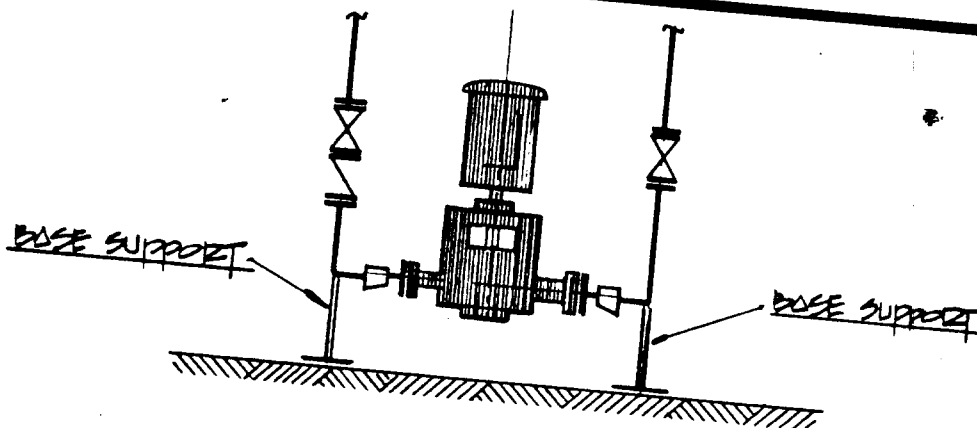


EXHIBIT 8-35
Typical Inline Pump
Support



Reactors

Reactors are used in processing facilities to contain catalysts that promote chemical transformation of feeds or as agents to remove unrequired materials from feeds. Reactors are generally vertical steel hollow vessels and often operate under very high temperatures and pressures. One of the principal layout features of the reactor is the requirement for catalyst loading and unloading. The use of catalyst-charged vessels are essential to modern processes and have found widespread application in the production of chemical and refinery products.

This chapter highlights the general requirements for reactor plant layout design. It provides instructions on how to locate nozzles, instruments, piping, and controls to provide convenient and safe platforms for operator and maintenance access.

PROCESS OPERATION

There are many catalyst-charged vessels within the category of reactors, mainly because their characteristics and layout requirements are similar. Examples of these are desulfurizers, methanators, and guard chambers. The desulfurizer, which usually operates with a twin vessel, is responsible for the removal of sulfur from feedstock by absorbing the sulfur on the internally loaded catalyst. When the catalyst becomes saturated with sulfur, regeneration takes place and the spent catalyst becomes refurbished. Exhibit 9-1 shows a typical desulfurizer process arrangement.

The reactor used in a typical hydrotreater unit is more versatile. In the hydrotreating process, the treated stream is mixed with hydrogen and heated to between 500° and 800° F (260° to 427° C). The hydrogen-oil mixture is then charged to a reactor filled with a pelleted catalyst, and the following reactions take place:

- The hydrogen combines with sulfur to form hydrogen sulfide.

- Some of the nitrogen is converted to ammonia.
- Any metals entrained in the oil are deposited on the catalyst.
- Some of the olefins, aromatics, and naphthenes become hydrogen saturated and some cracking takes place, causing the formation of butanes, propane, and lighter gases. Exhibit 9-2 shows a typical hydrotreater process arrangement.

Catalysts promote a reaction but do not react in any way themselves. The catalyst used inside reactors is generally ball or pellet shaped and, depending on the type of service, can be made from a variety of materials, including alumina, zinc oxide, or even such an expensive metal as platinum.

DESIGN CONSIDERATIONS FOR REACTORS

Although some reactors (e.g., those used in methanol and catalytic reforming units) are spherical, most are vertically mounted vessels with elliptical heads. There are fewer connections for the plant layout designer to be concerned with than there are with the distillation tower. Generally, connections are limited to inlet and outlet, maintenance access, unloading, sample, and temperature. Internally, reactors are furnished with bed supports, screens, inlet baffles, outlet collectors, catalysts, and inert materials. Exhibit 9-3 depicts a typical reactor and its principal components.

Nozzle requirements and overall dimensions of the reactor are highlighted on the process vessel sketch furnished by process engineering and are included in the process release package. If the reactor operates in a high-pressure service, it is recommended, for clearance purposes, that the plant layout designer obtain the shell thickness of the vessel before proceeding with layout arrangements. Exhibit 9-4 shows a typical reactor process vessel sketch, and Exhibit 9-5 shows a high-pressure reactor.

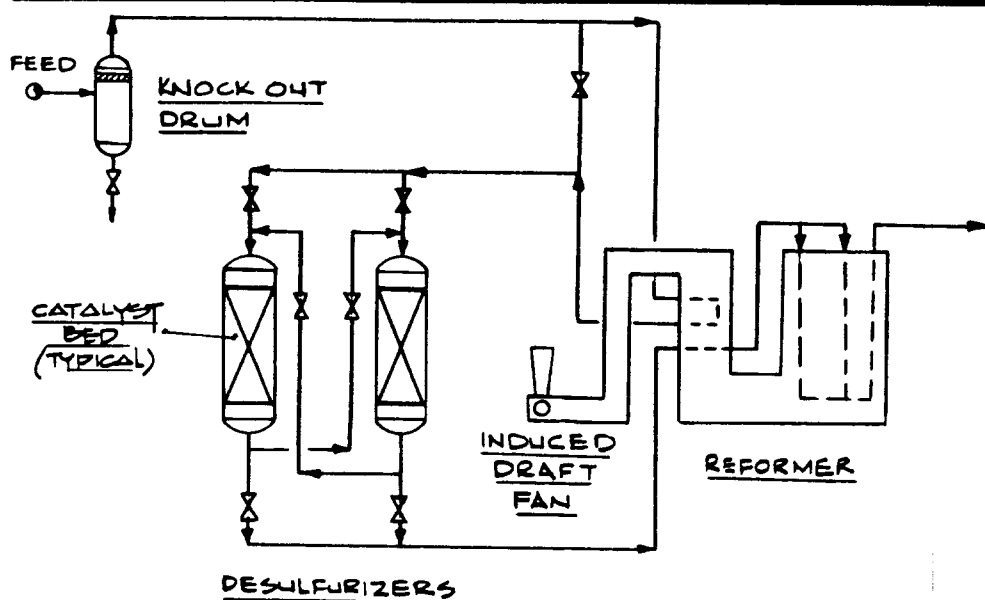


EXHIBIT 9-2 Hydrotreater Process

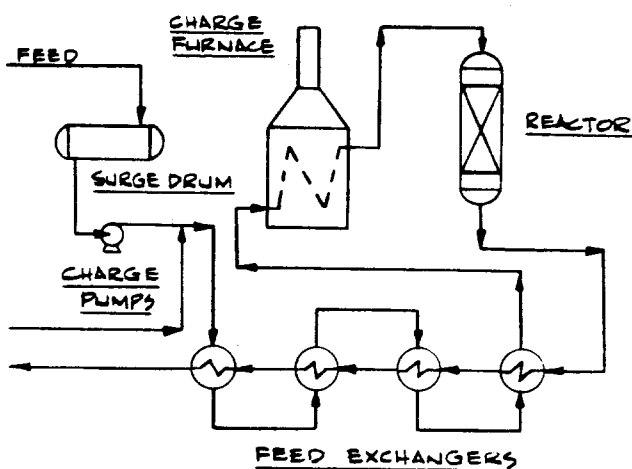
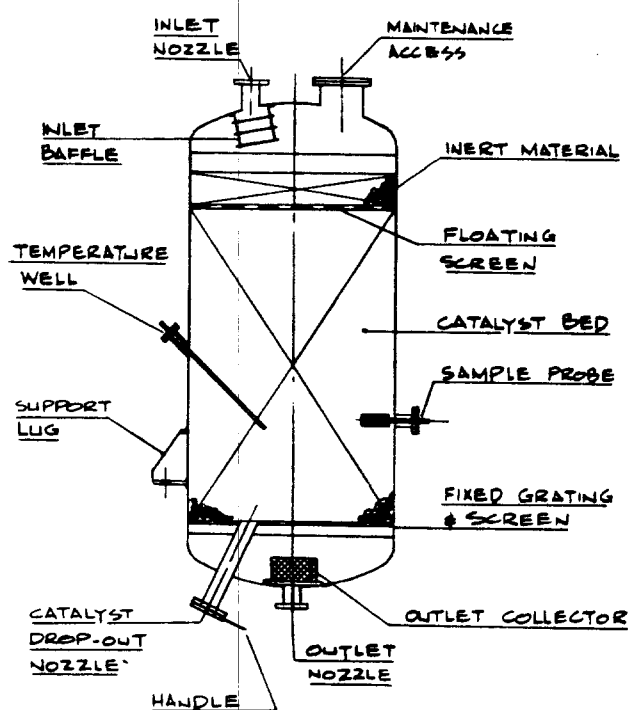


EXHIBIT 9-3 Typical Reactor



LOCATION OF REACTORS

Reactors are located within a process unit adjacent to related equipment and in a suitable position for operation and catalyst loading and unloading. A reactor operates in sequence and close to a furnace because expensive high-temperature piping runs must be minimized. Exhibit 9-6 illustrates a partial plot plan of a hydrotreater unit.

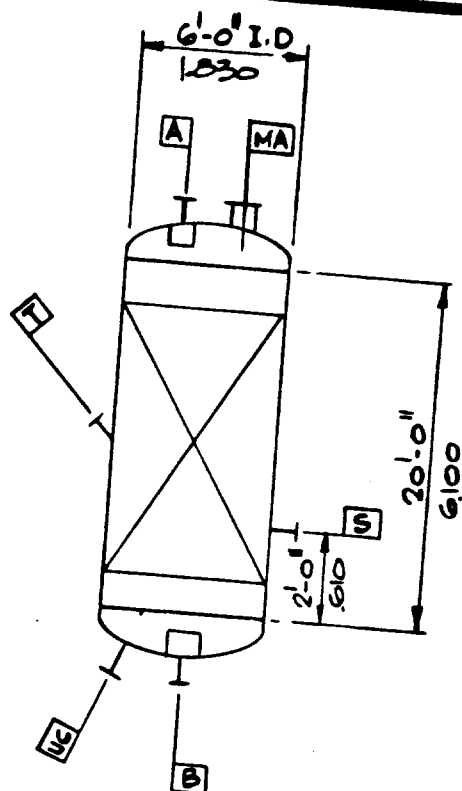
SUPPORT AND ELEVATION

There are four principal methods of support for reactors: a skirt from a concrete foundation, lugs from

concrete piers, a ring girder from a concrete table top, and a skirt from a concrete table top. Exhibit 9-7 depicts these four arrangements.

Reactor elevation is dictated by the catalyst's unloading nozzle or clearance for the outlet piping, whichever results in the lower tangent line elevation. The tangent line elevation, however, could be much higher to suit specific client unloading requirements

EXHIBIT 9-4
Process Vessel Sketch



NOZZLE SUMMARY		
SYMBOL	SIZE	SERVICE
A	8" 600* RF	INLET
B	8" 600* RF	OUTLET
S	3" 600* RF	SAMPLE
T	1" 600* BJ	TEMPERATURE
UC	12" 600* RF	CATALYST DROP OUT
MA	24" 600* RF	MAINTENANCE ACCESS

EXHIBIT 9-5 High-Pressure Reactor

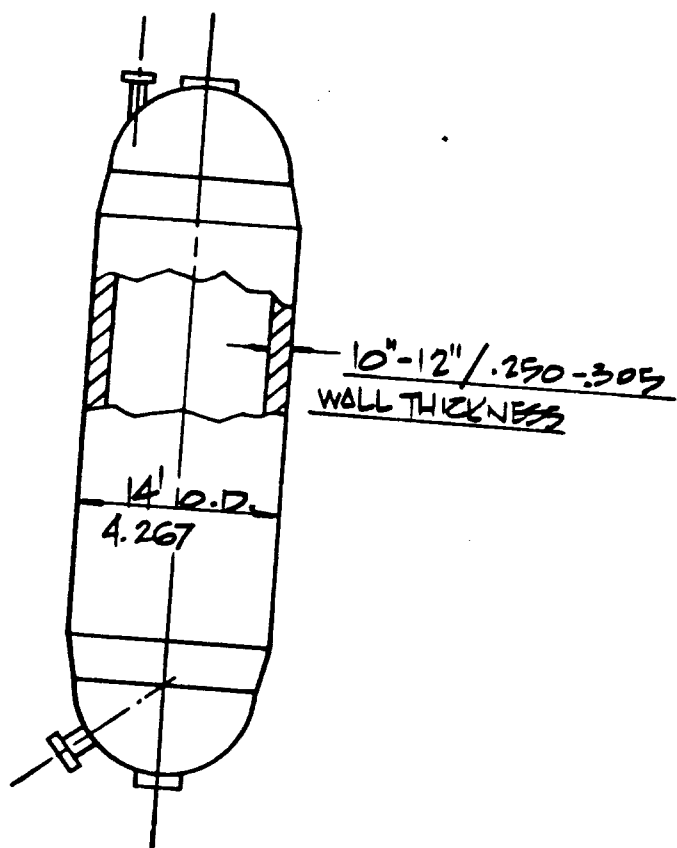


EXHIBIT 9-6 Partial Plot Plan for a Hydrotreater Unit

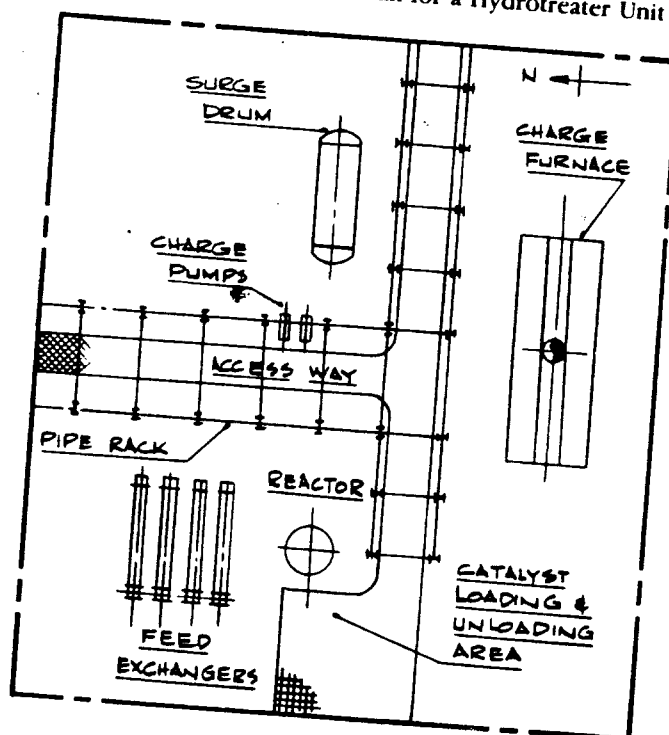
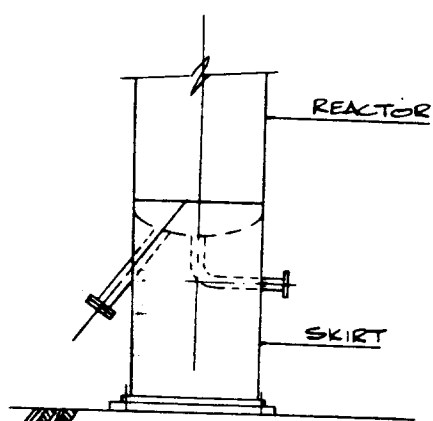
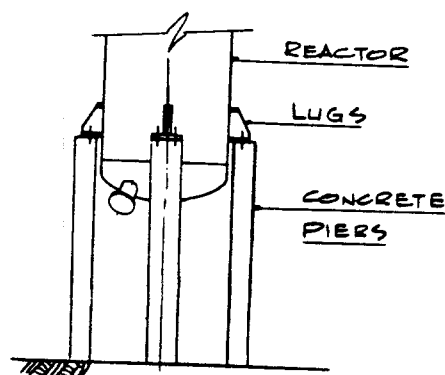
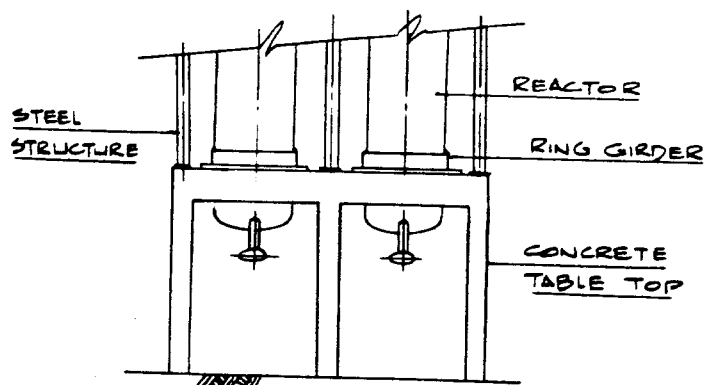
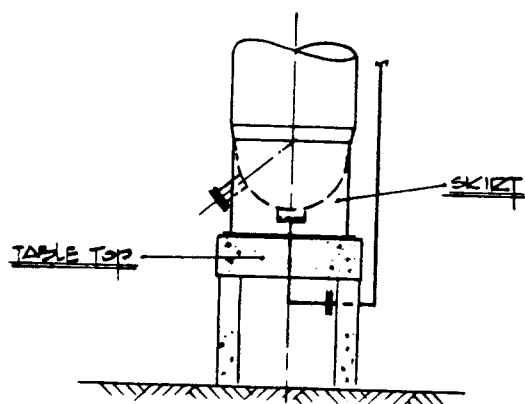


EXHIBIT 9-7 Methods for Reactor Support**a. Skirt Supported (Foundation)****b. Lug Supported****c. Ring Girder Supported****d. Skirt Supported (Table Top)**

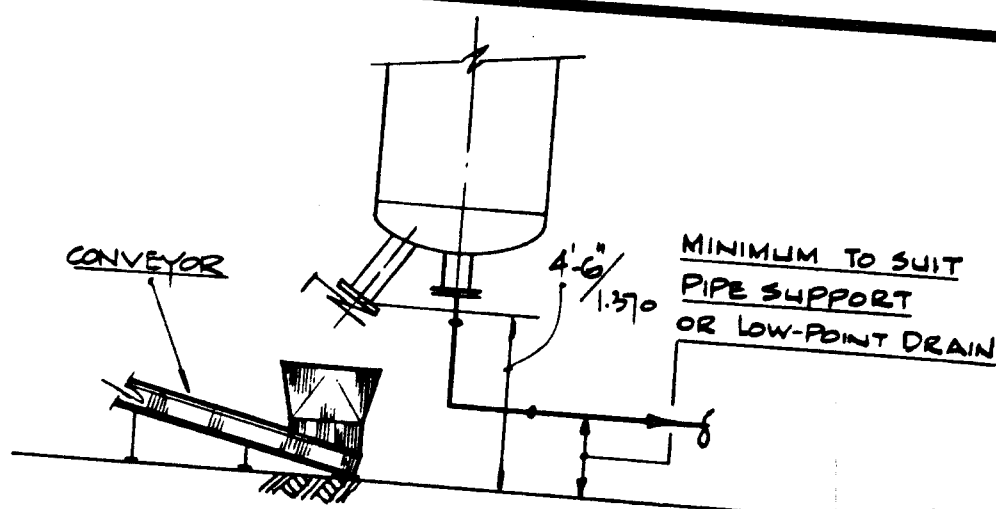


EXHIBIT 9-8
Minimum Reactor
Elevation Requirements

(e.g., truck unloading). Exhibit 9-8 depicts minimum elevation requirements, and Exhibit 9-9 shows direct unloading into a truck. To set the elevation of reactors, the plant layout designer requires the following information:

- Reactor dimensions.
- Type of heads.
- Support details.
- Bottom outlet size.
- Unloading nozzle size.
- Client preference for catalyst handling.

NOZZLE LOCATIONS AND ELEVATIONS

Nozzles are located to suit process operation and maintenance requirements and to facilitate an eco-

EXHIBIT 9-9 Direct Unloading from a Reactor to a Truck

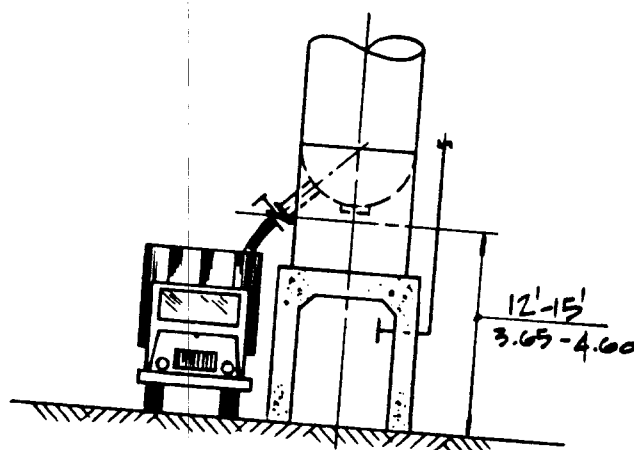
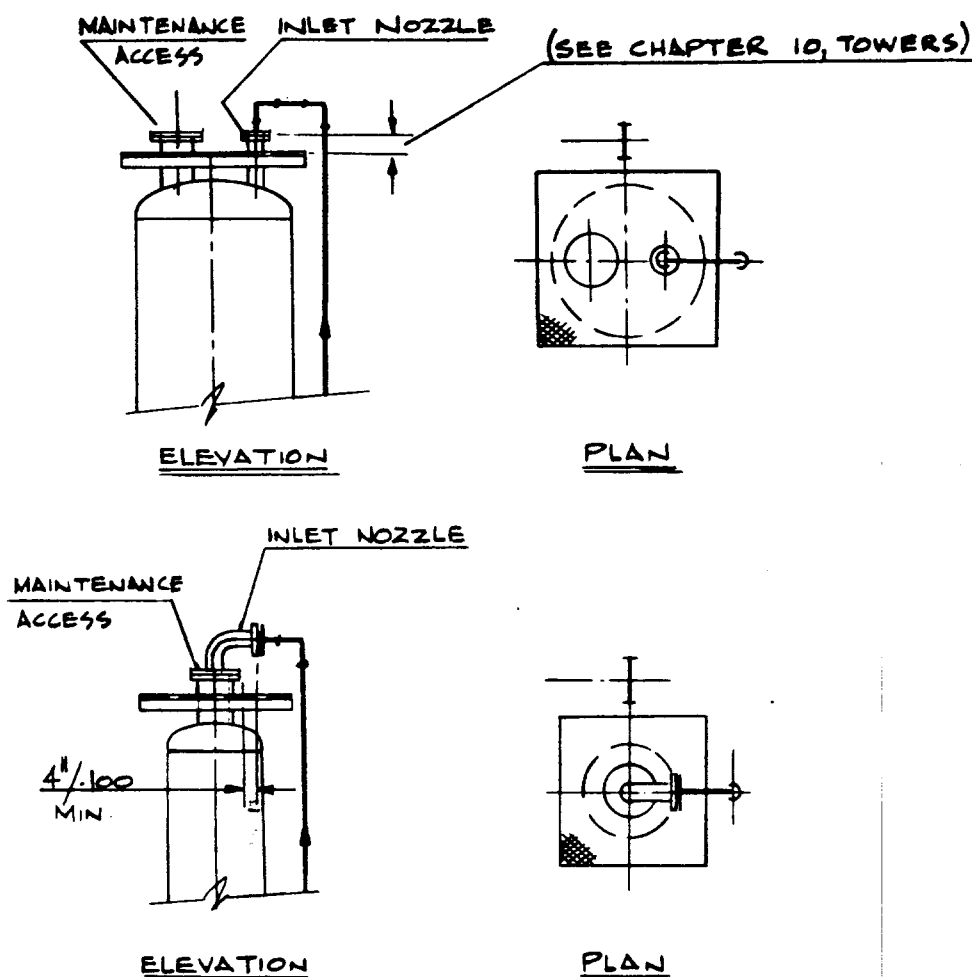


EXHIBIT 9-10
Top-Head Nozzle
Arrangements



nomic and orderly interconnection of piping between the reactor and related equipment. The following information is required to locate and elevate reactor nozzles:

- Process vessel sketch.
- Instrument vessel sketch.
- Piping and instrumentation diagram.
- Piping line list.
- Nozzle summary.
- Plant layout specification.
- Insulation requirements.

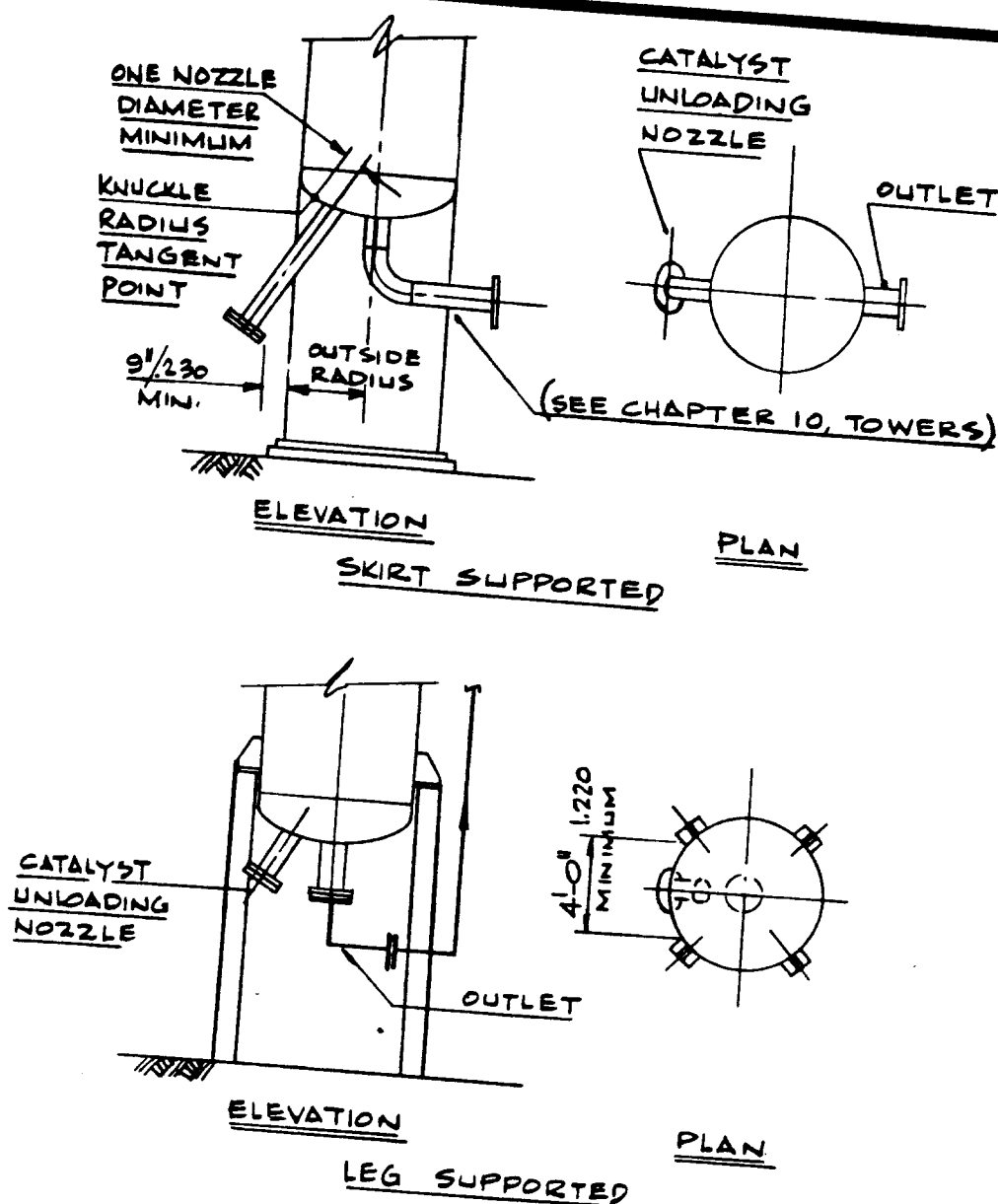
The process inlet is located at the top head of the reactor along with maintenance access, which is used for catalyst loading. On small-diameter reactors whose space is limited, the inlet nozzle can be integral with maintenance access. Exhibit 9-10 shows typical top-head arrangements.

The process outlet and the catalyst unloading noz-

zle are located on the bottom head of the reactor. If the reactor is skirt supported, the outlet is arranged like a tower bottoms outlet. If supported by lugs or by a ring girder, the nozzle is vertical on the centerline of the vessel that terminates at the nozzle flange. The catalyst unloading nozzle is angled from the bottom head to clear the skirt and is positioned between the piers on lug-supported reactors and below the table top on ring girder-supported reactors. Exhibit 9-11 depicts typical bottom-head arrangements. In certain cases, especially with stacked reactors, catalyst unloading nozzles are located in the side shell of the reactor, as shown in Exhibit 9-12.

Temperature instruments are usually required at reactors; they are used to measure the temperature at different levels of the catalyst bed. These instruments can be individual nozzles located at various levels on the shell of the reactor or, to minimize multiple connections, immersed in a well from the top of the reactor, either on an individual nozzle or through the maintenance access. Instrument requirements for re-

EXHIBIT 9-11
Bottom-Head Nozzle
Arrangements



actors are usually highlighted on a vessel instrument sketch that is furnished by the instrument engineer. Exhibit 9-13 illustrates side shell-mounted temperature instruments, and Exhibit 9-14 shows the top-head vertical arrangement.

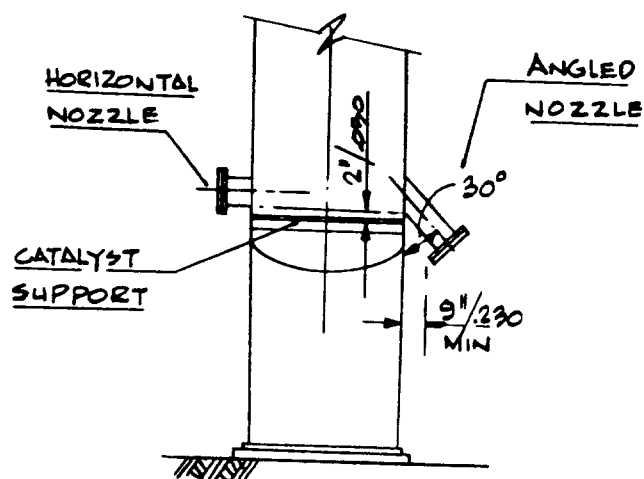
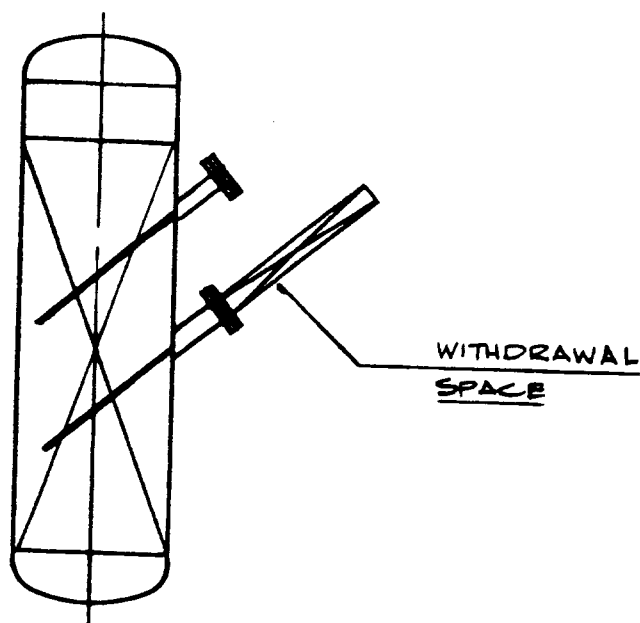
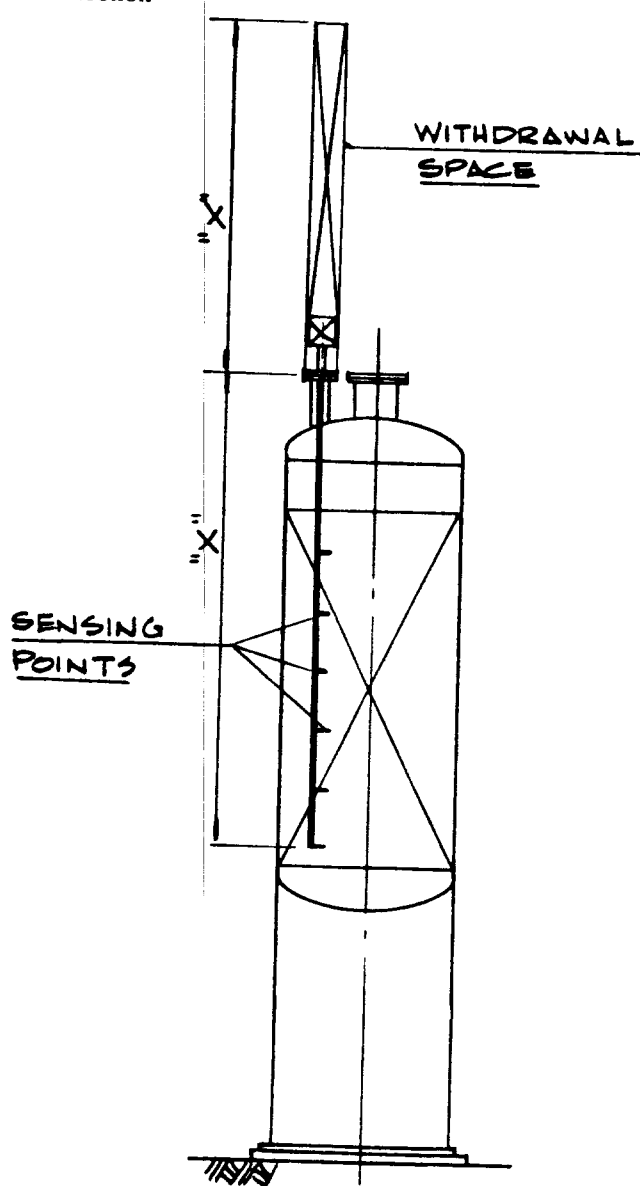
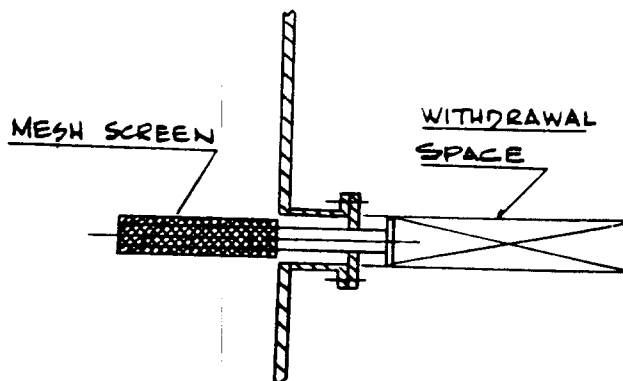
Sample probe connections, which are sometimes specified, are usually located on the side shell of the vessel as shown in Exhibit 9-15.

PLATFORM ARRANGEMENTS

Platforms are required at reactors for access to valves, instruments, blinds, maintenance accesses, and catalyst loading as well as at stacked reactors for catalyst

unloading. Platform elevations are determined by the items that require operation and maintenance; on tall reactors, platform elevations are set to accommodate a maximum ladder run length of 30 ft (9,150 mm). Exhibit 9-16 shows platform and ladder elevation requirements.

Reactors taller than 30 ft (9,150 mm) should be treated much like towers (see Chapter 10) for platform requirements except that, for reactors, intermediate platforms and ladders are required only for access to temperature instruments, sample probes, catalyst unloading nozzles at stacked vessels, and maximum ladder runs. Because of the economics of platform bracket welding or client preference, however, reactors must sometimes be surrounded by steel

EXHIBIT 9-12 Side Shell-Mounted Catalyst Unloading Nozzles**EXHIBIT 9-13** Side Shell-Mounted Temperature Connections**EXHIBIT 9-14** Vertically Mounted Temperature Connection**EXHIBIT 9-15** Sample Probe Connection

structures with stairs for operator and maintenance access. On reactors shorter than 30 ft (9,150 mm), only a top-head platform is needed. Exhibits 9-17 through 9-21 show typical reactor platform arrangements.

PIPING ARRANGEMENTS

Reactor piping must be arranged for ease of support and positioned to suit interconnection with related

EXHIBIT 9-16
Reactor Platform and
Ladder Elevation
Requirements

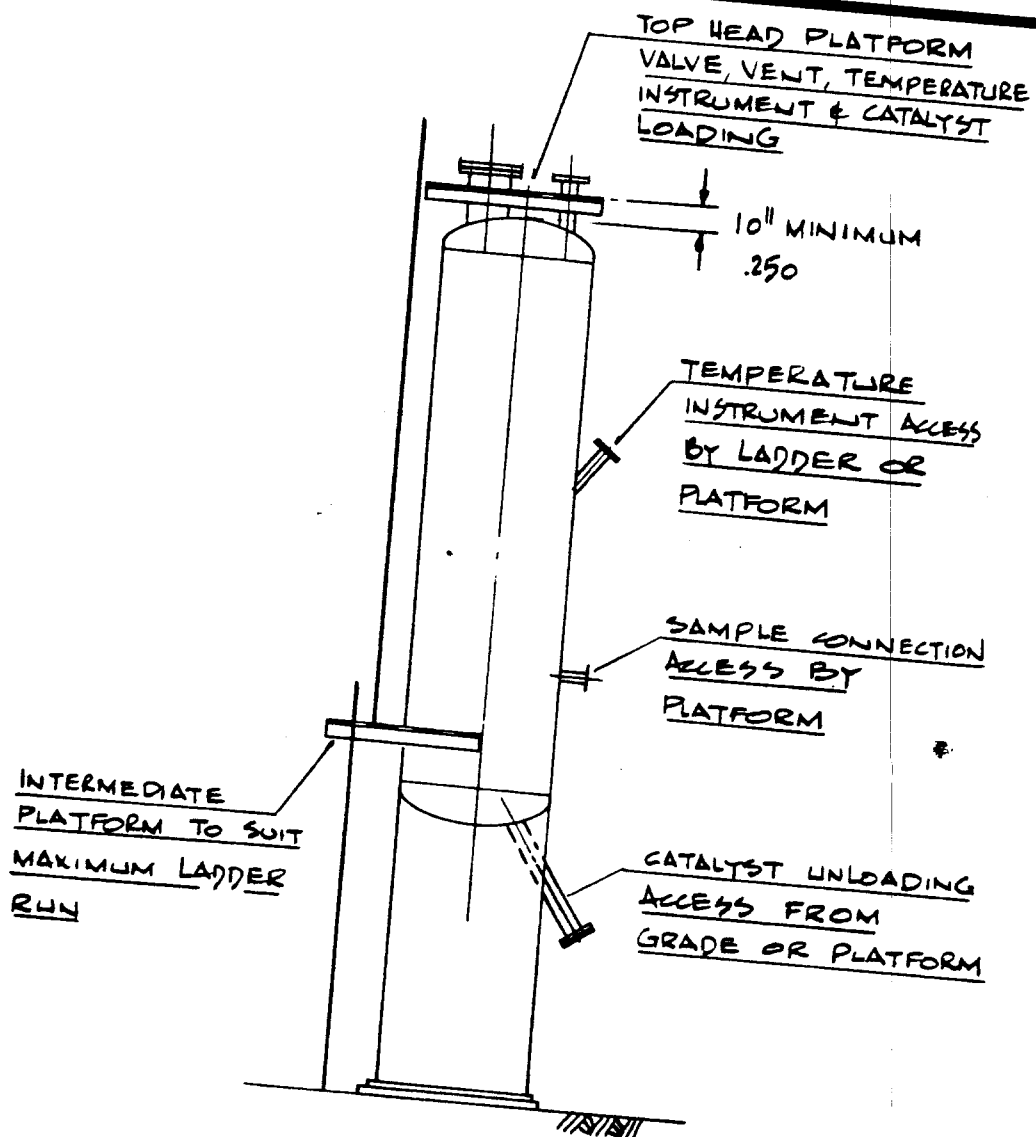


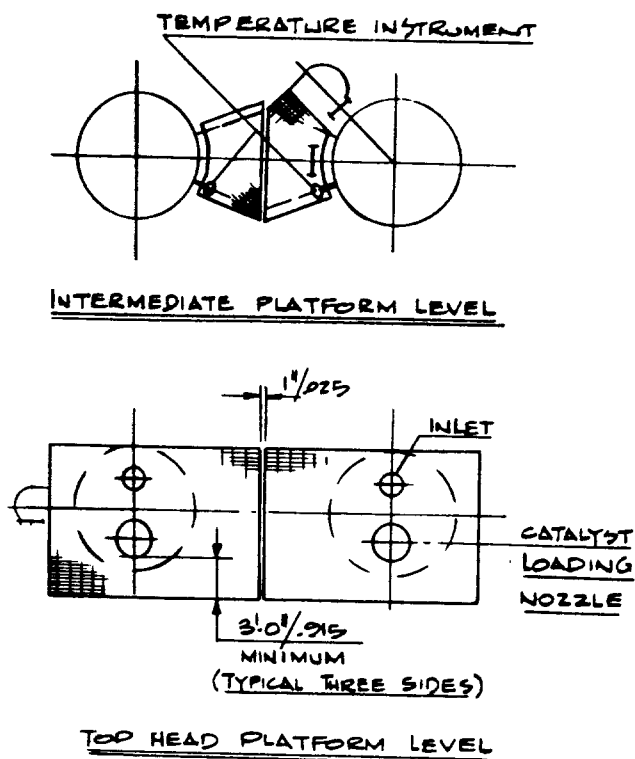
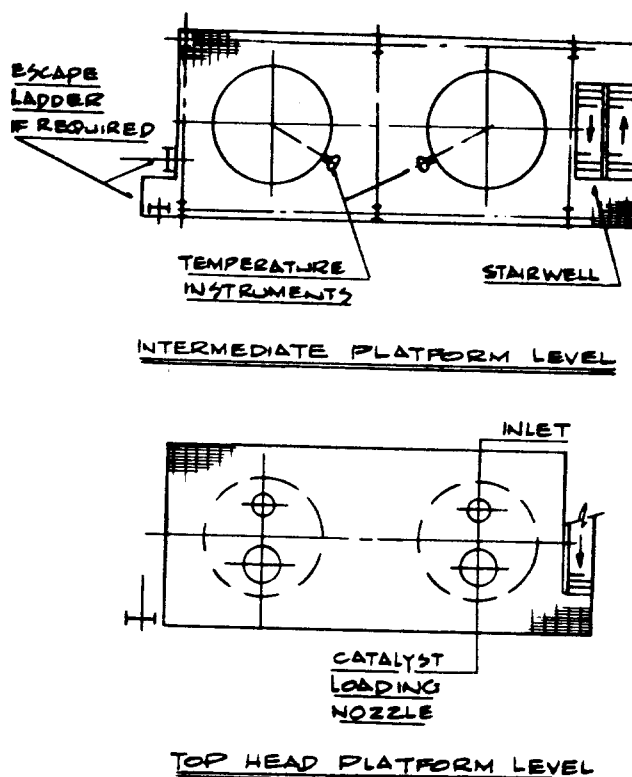
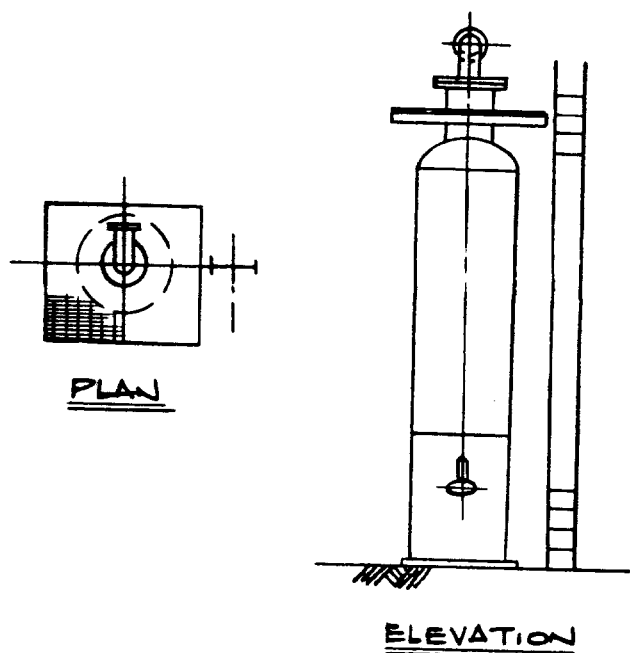
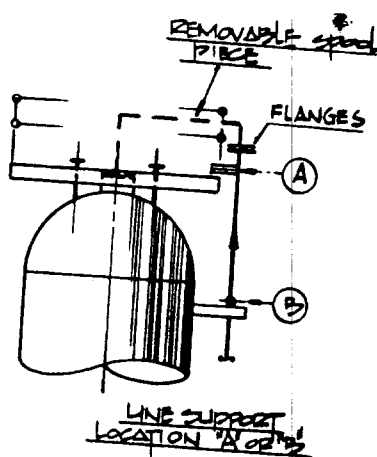
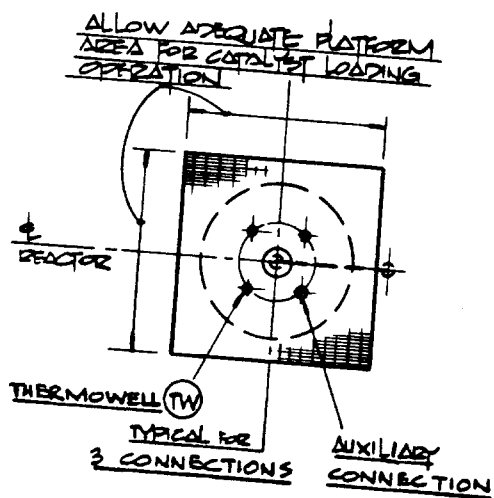
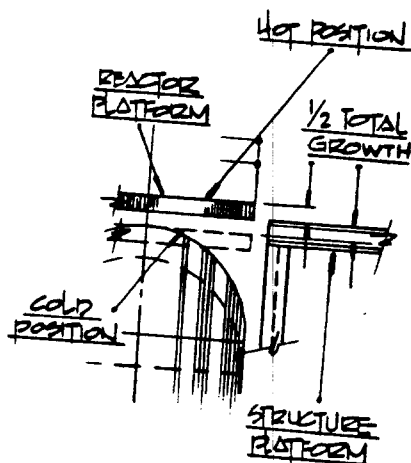
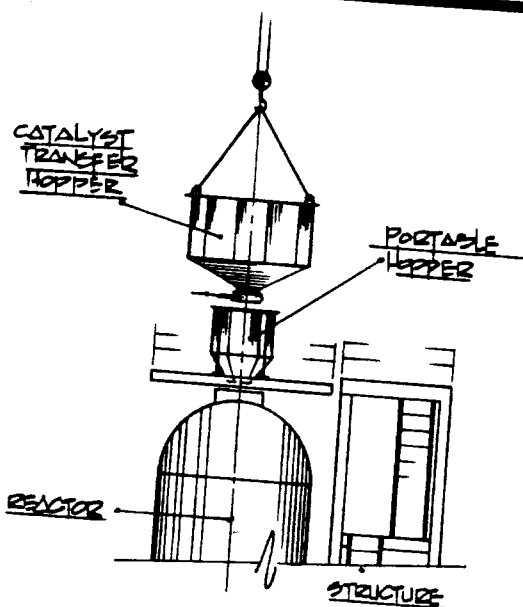
EXHIBIT 9-17 Vessel-Supported Platform Arrangement**EXHIBIT 9-19 Structure-Supported Platform Arrangement****EXHIBIT 9-18 Single Platform Arrangement**

EXHIBIT 9-20
Top Platform
Arrangements



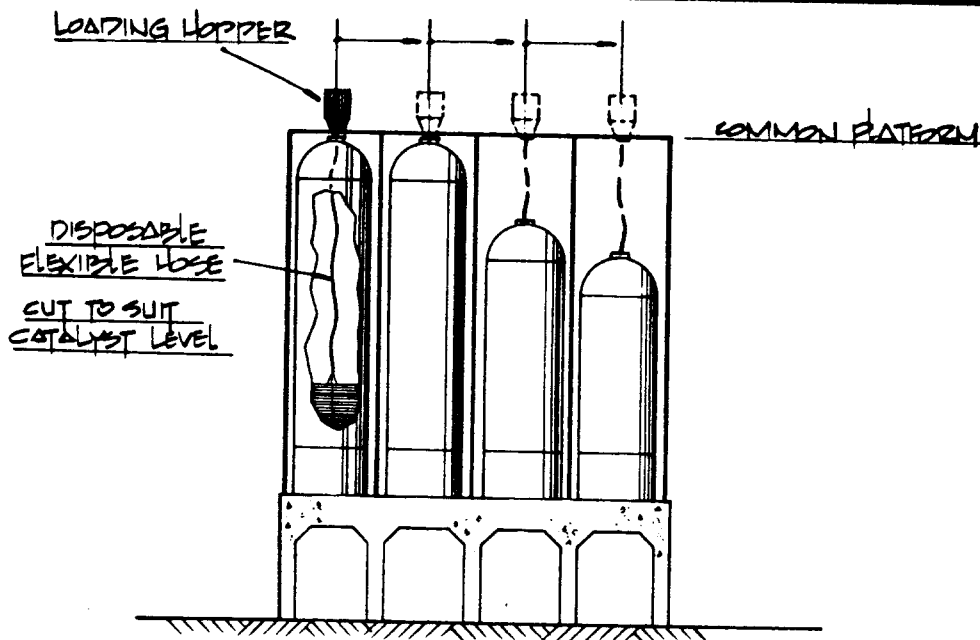


EXHIBIT 9-21
Multiple-Reactor
Arrangement

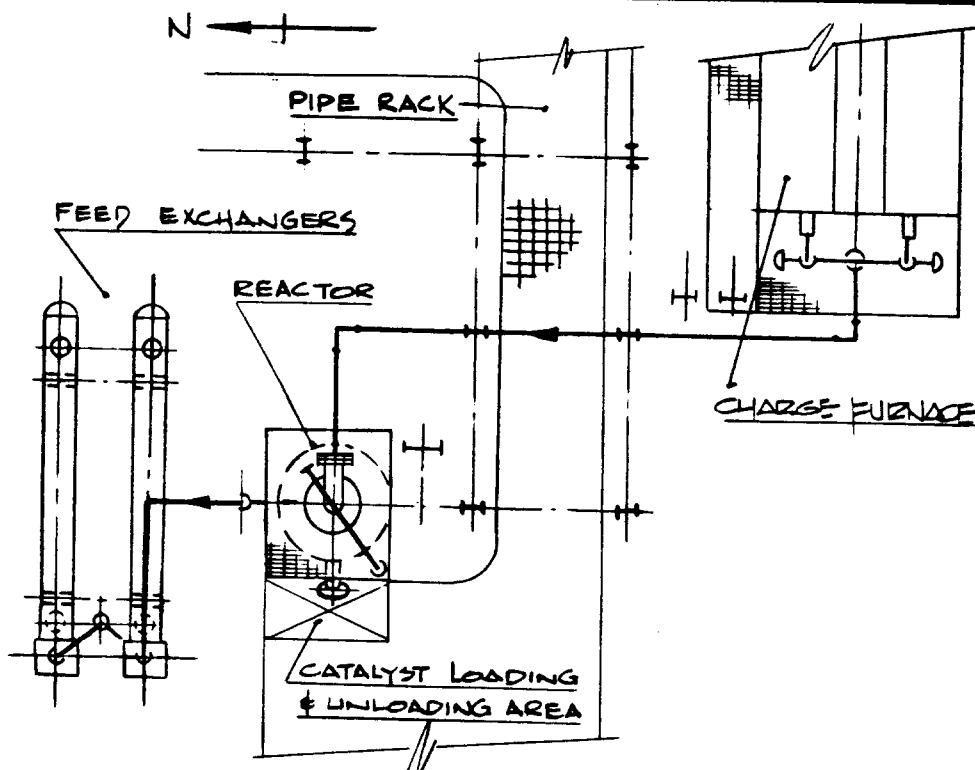


EXHIBIT 9-22
Single-Reactor Piping
Arrangement

EXHIBIT 9-23
Reactors in Series:
Manually Operated Valve
Manifold

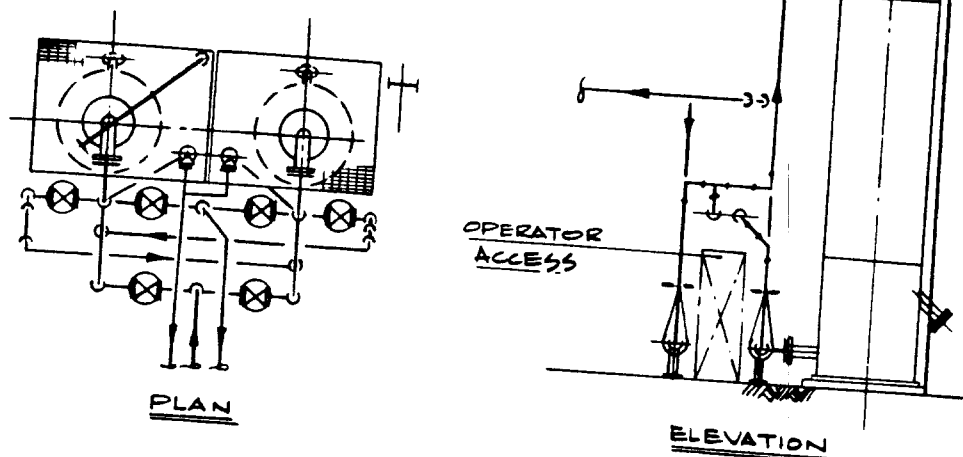
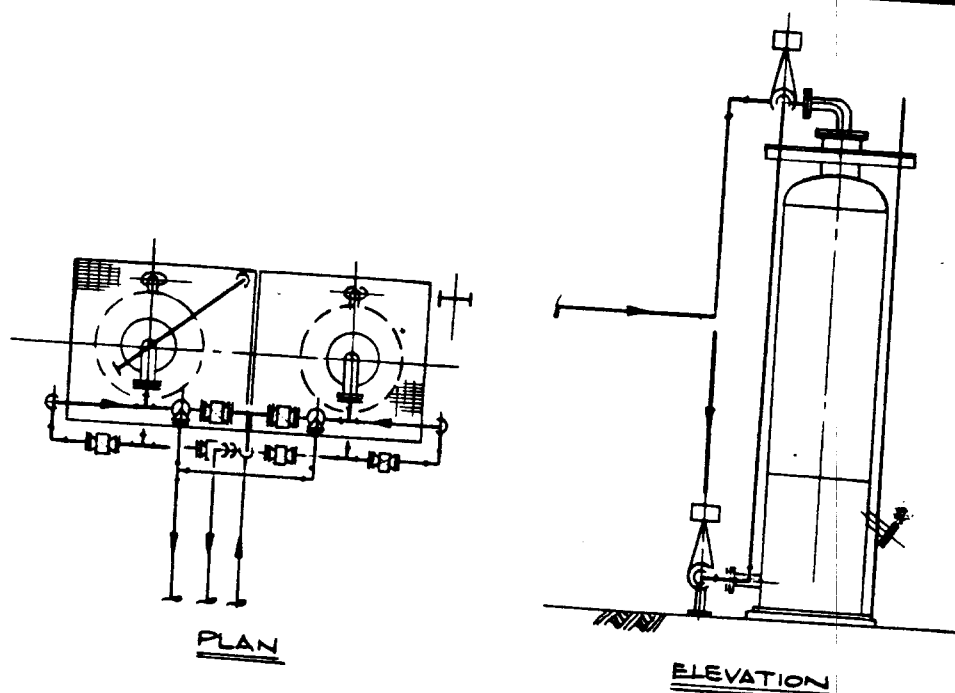


EXHIBIT 9-24
Reactors in Series:
Remotely Operated Valve
Manifold

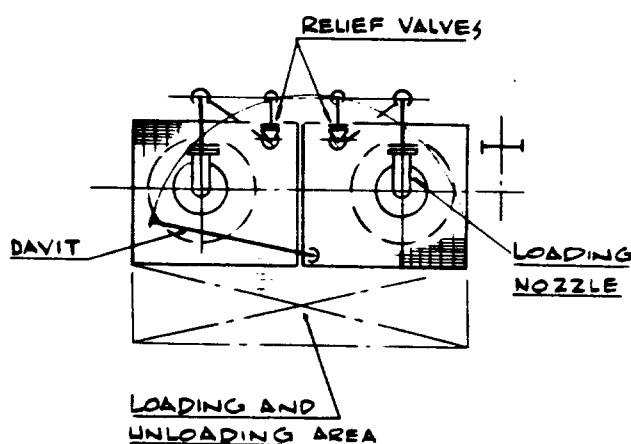


equipment. Because reactors often operate at very high temperatures, piping must be arranged with sufficient flexibility to absorb excessive stress under usual operating conditions.

Piping at reactors or other similar catalyst operating equipment can be relatively simple in configuration, as shown in the process flow diagram in Exhibit 9-2, or more sophisticated, as shown in the flow diagram in Exhibit 9-1. In the single-reactor arrangement, which has no controls to influence the design, the piping can

be routed directly between related equipment to suit economics, flexibility, and supports, as shown in Exhibit 9-22. If the facility operates in a series, the piping system is designed to accommodate regeneration of a catalyst in one reactor while the other is still on stream, as shown in Exhibit 9-23. To do this, the system is furnished with controls and crossover bypasses. For ease of operation, the valve manifolds for regeneration should be located at grade. If these valves are controlled remotely, however, the overhead manifold

EXHIBIT 9-25 Davit Arrangement



can be located at the top-head platform, as shown in Exhibit 9-24.

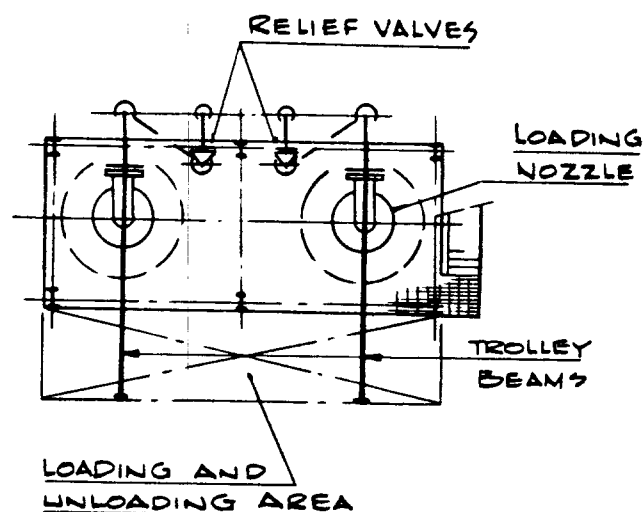
Relief valves are usually furnished as part of the reactor piping system and should be located in accordance with the arrangements shown in Chapters 5 (Drums) and 10 (Towers).

MAINTENANCE

Handling such removable items as relief valves and valve drives for off-site repair and catalyst loading can be achieved by fixed handling devices or by mobile equipment. Fixed handling devices can be davits or, for structure-mounted reactors, trolley beams. Exhibit 9-25 depicts a typical davit arrangement, and Exhibit 9-26 shows a trolley beam arrangement.

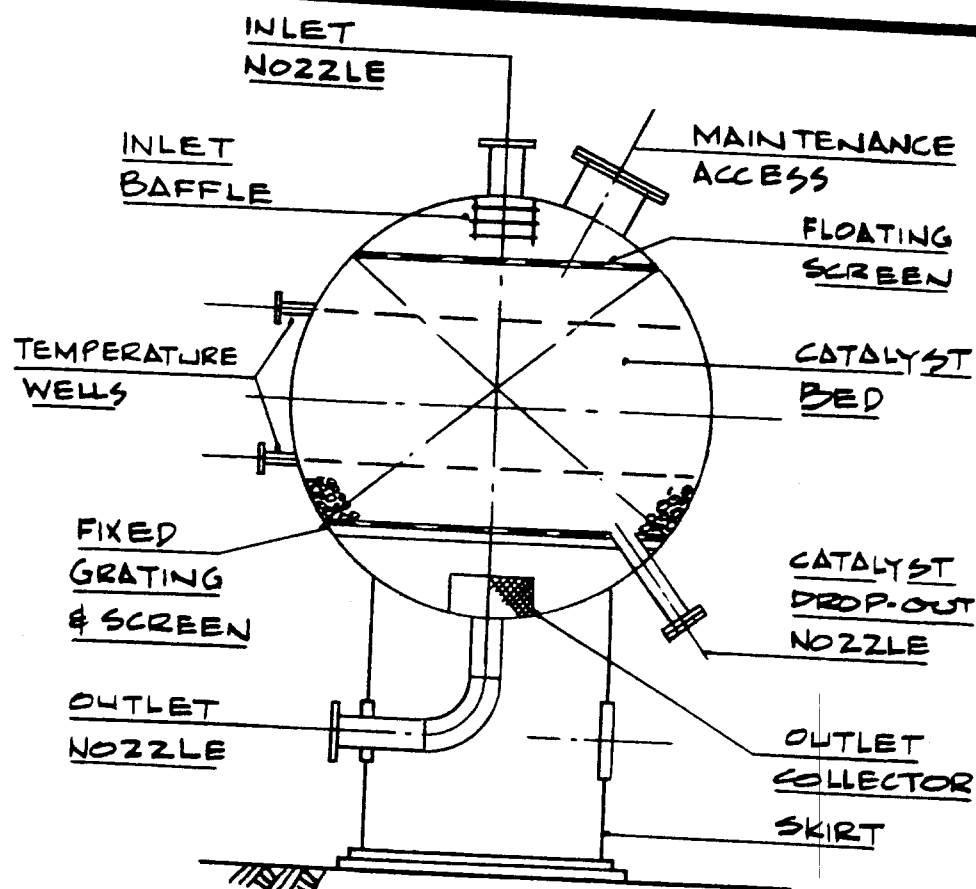
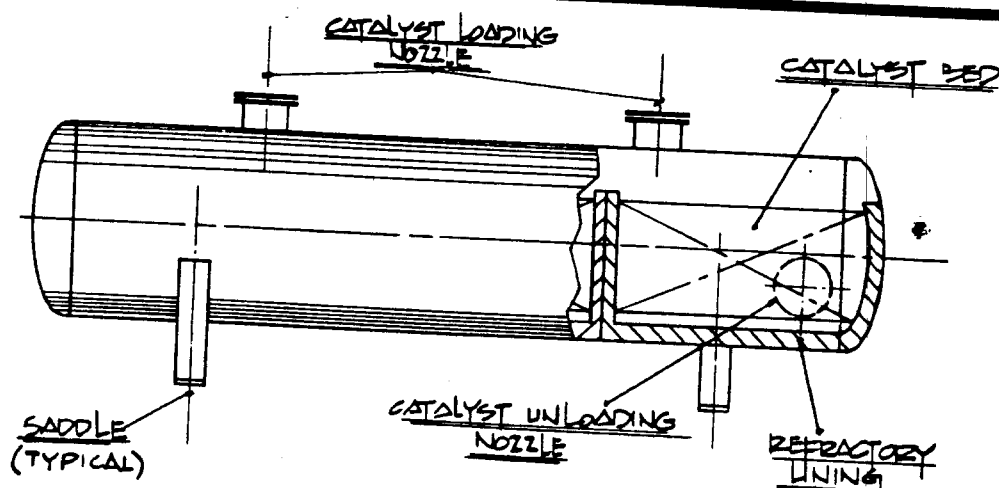
Catalysts are loaded through the top-head maintenance access of the reactor after removal of the inlet nozzle if integral to the maintenance access cover flange. If the catalyst is not supported on a fixed grating and screen assembly, which would be fabricated

EXHIBIT 9-26 Trolley Beam Arrangement



with the vessel, the first step is to load the bottom head and unload the nozzle with inert material. The inert material could be silica pellets or alumina balls, which are usually larger than the catalyst and support the catalyst bed. The inert material is then covered with the bottom floating screen. The catalyst is first sieved through a mesh screen to remove the finer particles. It is then loaded into a bucket or sock and lowered through the maintenance access, where it is manually distributed in layers until the reactor is filled to the required capacity. The top and bottom layers of catalyst are usually a larger mesh than the main bed. The top floating screen is then installed and covered with an additional layer of inert material that is used to hold down the screen assembly during regeneration and eliminates inlet gas turbulence during operation.

The catalyst is removed infrequently. Removal is accomplished during shutdowns after cool-down by allowing the catalyst to exit through the bottom unloading nozzle. After removal of the flange cover on

EXHIBIT 9-27
Spherical ReactorEXHIBIT 9-28
Horizontal Reactor

the unloading nozzle, the catalyst can be allowed to free fall to a temporary containment area or be removed using an industrial vacuum, or a temporary valve may be used to control the unloading rates. Exhibits 9-27 through 9-30 are examples of less common reactor arrangements.

The dimensions, clearances, and guidelines high-

lighted in this chapter are examples of reactor arrangements. The plant layout designer, however, should be familiar with company and client standards before proceeding with reactor layout and should coordinate this effort with such supporting groups as vessel, systems, process, civil, and instrument engineering.

EXHIBIT 9-29 Jacketed Reactors

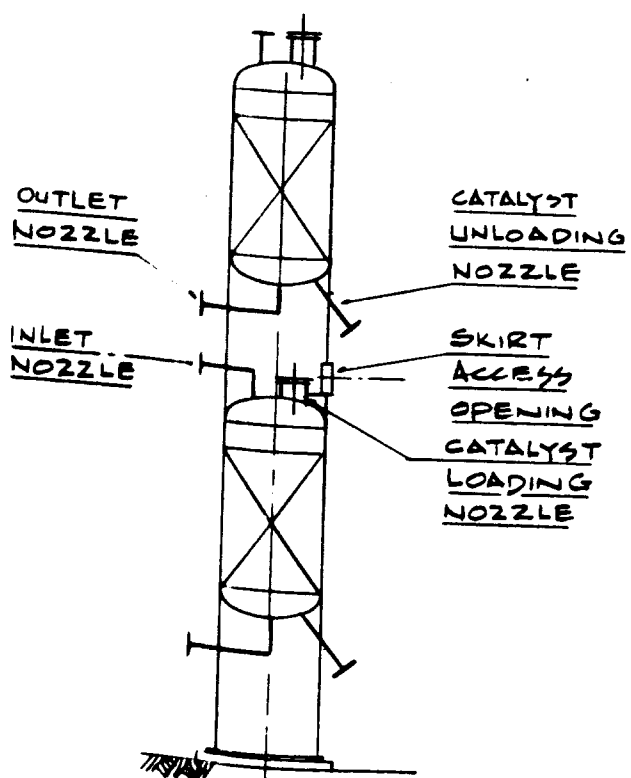
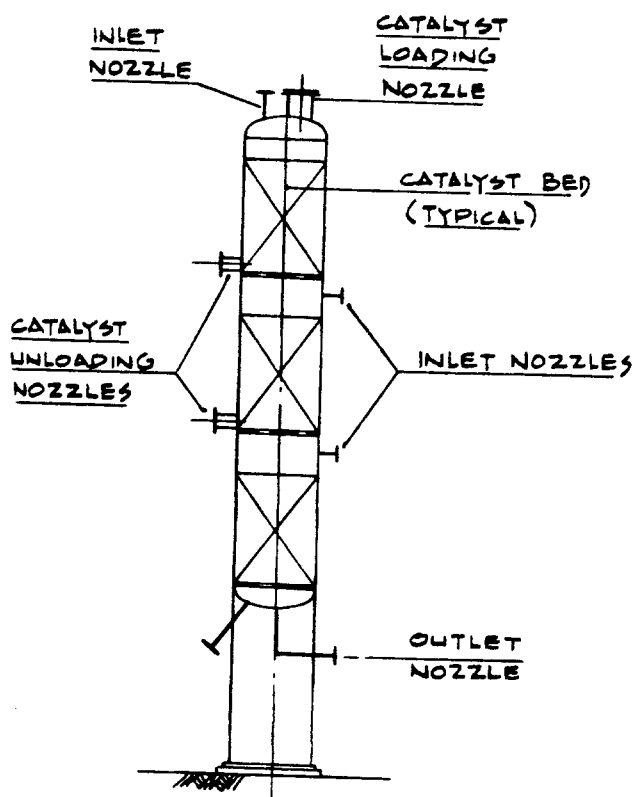


EXHIBIT 9-30 Multibed Reactor



Towers

Towers, also referred to as columns, are one of the principal pieces of equipment of any processing facility. Towers are cylindrical steel vessels that are used for distilling raw materials in the production of such products as gasoline, diesel, and heating oil. The plant layout designer must understand the internal structure of a tower and how it operates to produce a satisfactory design.

This chapter highlights the general requirements for tower plant layout design. It describes the internal workings of towers and provides the information required to orient nozzles; locate instruments, piping, and controls; and provide platforms and ladders for operator and maintenance access.

THE DISTILLATION PROCESS

Crude oil is of little commercial use; when separated, or broken down, however, oil becomes one of the most valuable commodities in the world. Crude oil is a mixture of hydrocarbon compounds with a wide range of boiling points from 100° F (38° C) to 1,400° F (760° C).

Separation, or distillation, is a process by which a liquid mixture is partially vaporized. The vapors are then condensed, separating the individual components of the mixture. As the temperature of crude oil is raised, the initial boiling point (IBP) is reached. As boiling continues, the temperature rises. The lightest material, butane, is produced first, at IBP, just below 100° F (38° C); the heavier materials are produced below 800° F (427° C). The residue includes everything above 800° F (427° C). Exhibit 10-1 shows the distribution of the different products at the various temperature ranges.

The evolution of distillation towers is best explained in three basic steps:

- The batch shell still process.
- The continuous shell still process.

- The fractional distillation process.

Batch Shell

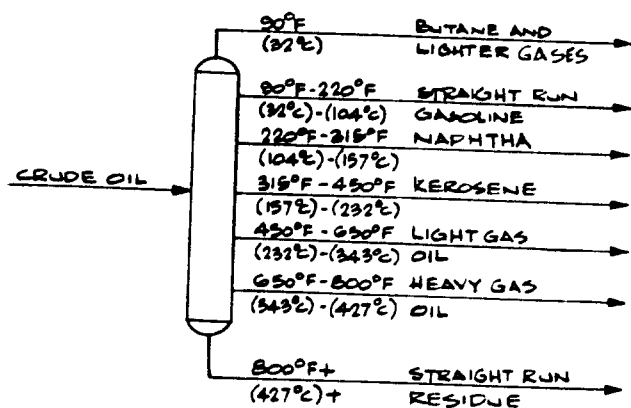
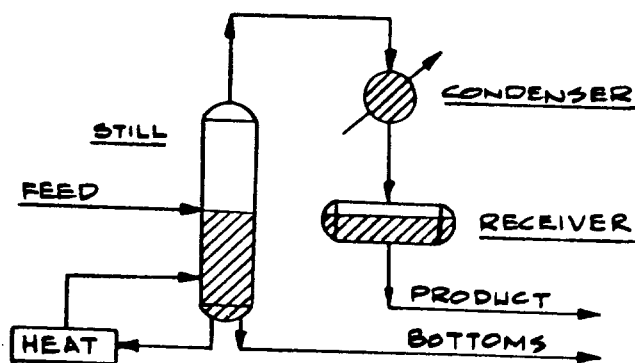
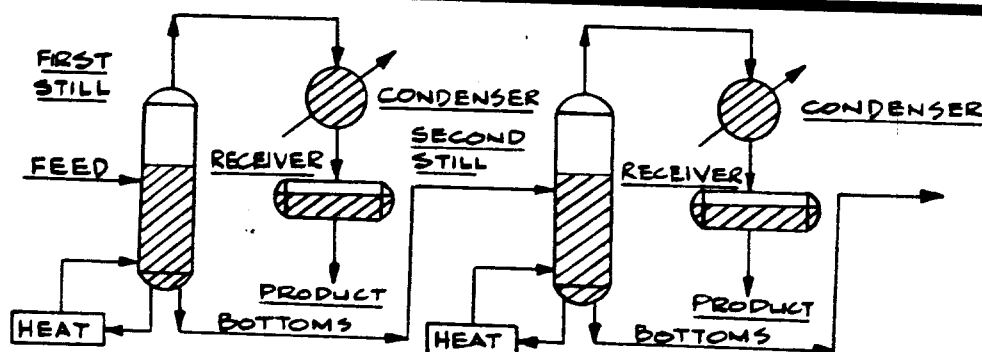
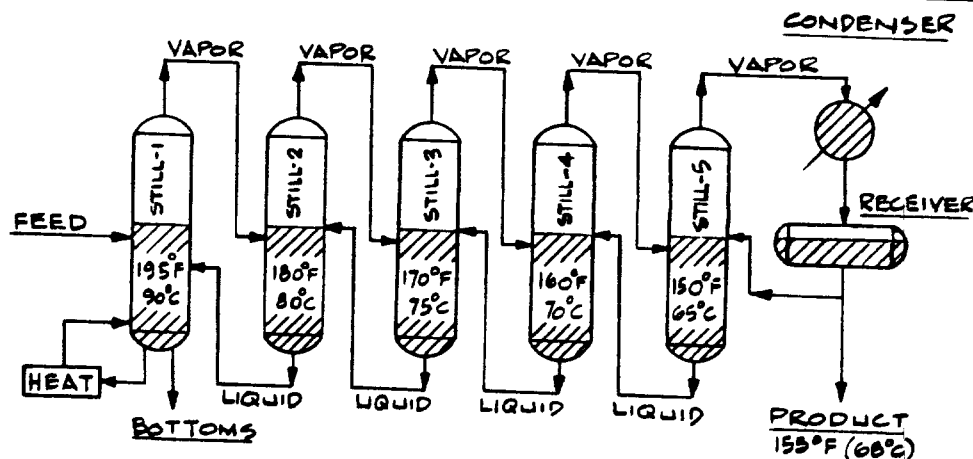
In the batch shell still process, the still is partially filled with a set feed called a batch. The feed is then heated to the temperature required to produce a specific product from the overhead vapors. This process is repeated each time for each product until the batch reaches the maximum temperature for the range of products specified. The feed remaining in the still is then pumped out, and the still is allowed to cool. It is then refilled, and the whole process is repeated. Not only is this process time consuming, but the product is not always of high quality. Exhibit 10-2 shows the batch shell still process, which was one of the earliest used for liquid mixture separation.

Continuous Shell

In the continuous shell still process, several shell stills are linked in series to form a battery. Fresh feed continuously enters the first still, which is kept at the lowest temperature for the lightest overhead product. The bottoms from the first still are fed to the second still, which is kept at the temperature for the next highest boiling overhead product, and so on. The number of stills required depends on the number of products needed. If the feed and the temperature of each still remain constant, the finished product is of satisfactory quality. Exhibit 10-3 depicts the continuous shell still process, which is an improvement over the batch shell still operation.

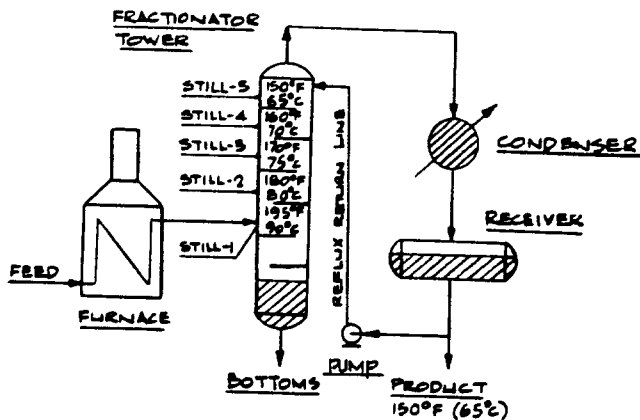
Fractional Distillation

Similar to the continuous shell still, the fractional distillation process is made up of several stills linked together in series. The main difference is that all the liquid condensate is returned to the upstream still. As the feed is partially vaporized in the first still, the va-

EXHIBIT 10-1 Crude Distillation of Products Across Temperature Range**EXHIBIT 10-2** Batch Shell Still Distillation Process**EXHIBIT 10-3** Continuous Shell Still Distillation Process**EXHIBIT 10-4** Multiunit Fractional Distillation Process

pors rise, travel through the overhead line, and come into contact with the liquid in the second still. Because the temperature of the liquid in the second still is lower than the incoming vapors from the first still, the vapors partially condense. At the same time, liquid from the second still enters near the top of the first

still. As vapors rise in the first still, they meet the incoming liquid from the second still. This causes vaporization of the incoming liquid from the second still and condensation of the rising vapors in the first still. The same reaction takes place in all the downstream stills. This process improves on previous operations in

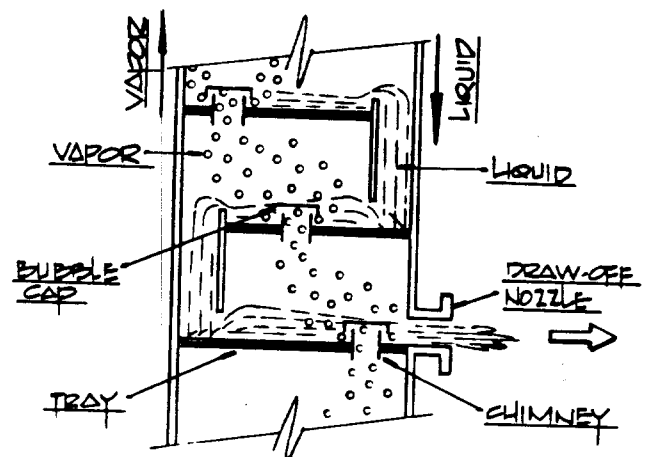
EXHIBIT 10-5 Fractionator Tower

terms of quantity, quality, and a reduction in the energy needed to heat the raw materials. Exhibit 10-4 illustrates the multiunit fractional distillation process.

All three process arrangements are satisfactory operations and play an important part in the development of the modern distillation tower. The final step in combining these operations into one single component is achieved by stacking the stills on top of each other and installing an internal device between each still to allow the liquid to flow down and the vapors to rise. This means that the single unit can function in a way similar to the multishell unit for less capital and operational cost. Exhibit 10-5 shows a single fractionator tower with the corresponding still numbers and temperature ranges of the multistill unit. The reflux return line controls the temperature of the fluids in the upper portion of the tower.

Vapor and Liquid Flow

One of the most common internal devices that allows the single tower to function similarly to the multistill unit is the tray, illustrated in Exhibit 10-6. Slots and holes in the trays allow the vapor to rise and the liquid

EXHIBIT 10-6 Vapor Liquid Flow

to flow down.

Rising vapors in the tower pass through slotted bubble caps and come into contact with liquid flowing around the caps. Liquid flowing down from trays above fall through downcomers and over and around the bubble caps en route to the next downcomer. In this manner, the light boiling fractions in the down-flowing liquid are vaporized by the heat from the rising vapors, and heavier boiling fractions in the vapor are condensed and flow down the tower. This process of vaporizing and condensing throughout the tower allows the feed to be separated into the required boiling-range fractions, which are drawn off from the side of the tower at the appropriate locations.

TYPES OF TOWERS

Towers are named for the service or type of unit they are associated with. For example, a stripper is used to strip lighter material from the bottoms of a main tower or a vacuum tower. It is generally used in a vacuum/crude unit for distilling crude bottoms residue under

EXHIBIT 10-7 Vacuum Tower and Stripper

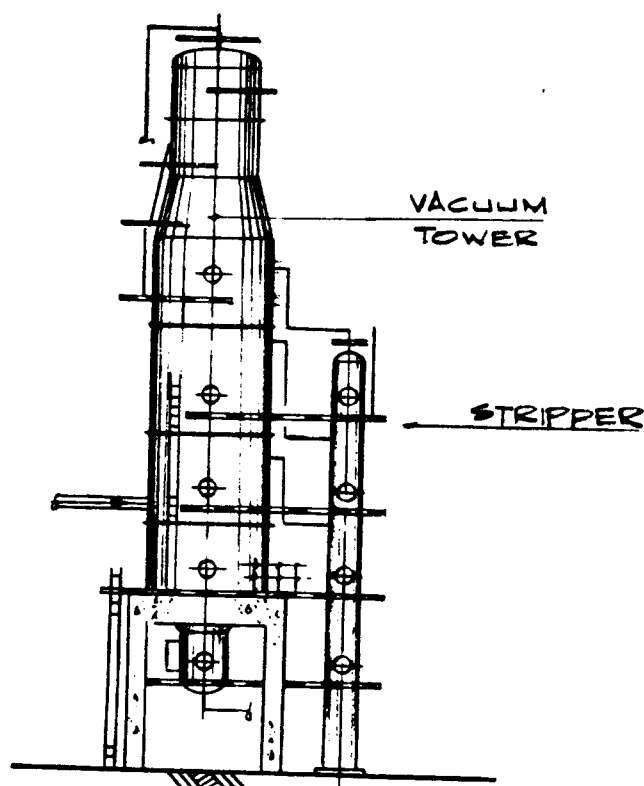
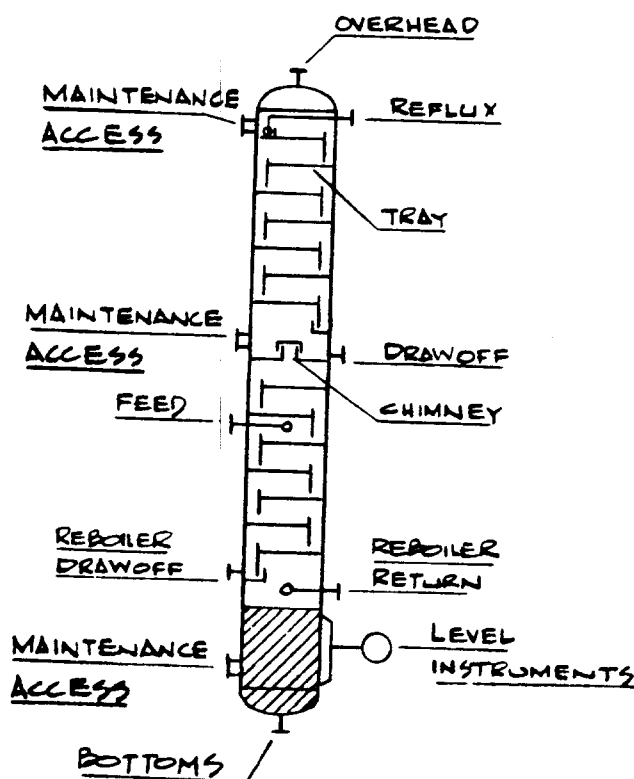


EXHIBIT 10-8 Trayed Tower



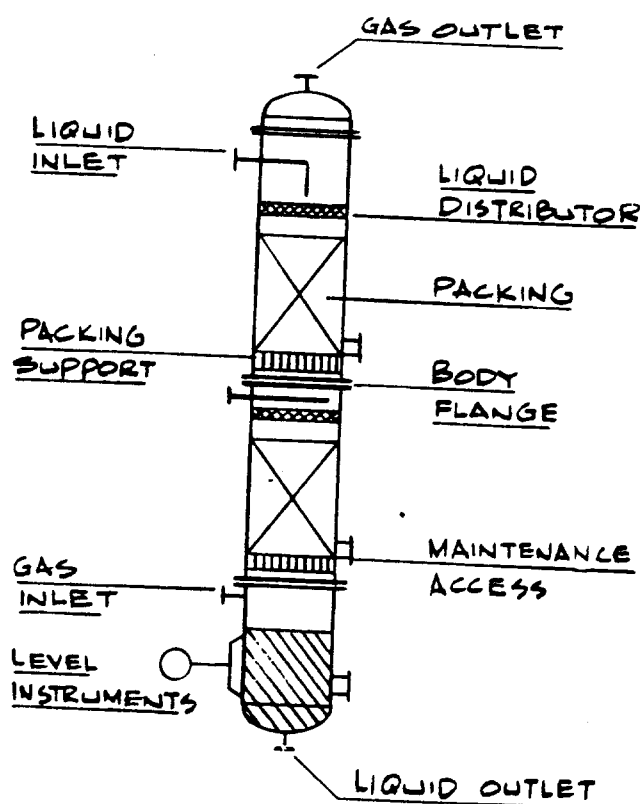
vacuum pressure. Exhibit 10-7 shows a typical vacuum tower and stripper.

From the outside, tower configurations are similar in appearance, varying only in dimension; some towers have swaged top and bottom sections. The principal difference among towers is the type and layout of the internal components that control the vapor-liquid contact.

This chapter describes the internal and external plant layout requirements for the two most common types of tower: the trayed and packed arrangements. Exhibit 10-8 depicts a typical trayed tower with some

of its associated components.

In a packed tower, instead of having trays, the units are packed with beds of metal rings. On entering the tower, the liquid passes through a distributor that routes the liquid evenly down through the packed beds of metal rings. Rising vapors passing through the beds come into contact with the descending liquid. In a manner similar to trayed tower operation, the liquid is partially vaporized by the heat from the vapors and the vapors are condensed by the cooler liquid. Exhibit 10-9 illustrates a typical gas-liquid packed tower and its principal components.

EXHIBIT 10-9 Packed Tower

DESIGN CONSIDERATIONS FOR TOWERS

Towers are not a standalone operation; they are usually located within a process unit adjacent to related equipment and in a suitable position for operator and maintenance access. A tower operates close to such related items as pumps, reboilers, drums, and condensers and should be positioned to facilitate an orderly and economic interconnection between itself and that equipment.

Within the conventional inline process unit, towers

and their related items are located on either side of a central pipe rack, serviced by auxiliary roads for maintenance access. In plants in which the related equipment is housed, the tower is often located adjacent to the building or structure containing the equipment. Exhibit 10-10 shows a process flow diagram of a tower and its related equipment, a typical plan arrangement of the same equipment, and the equipment in elevation.

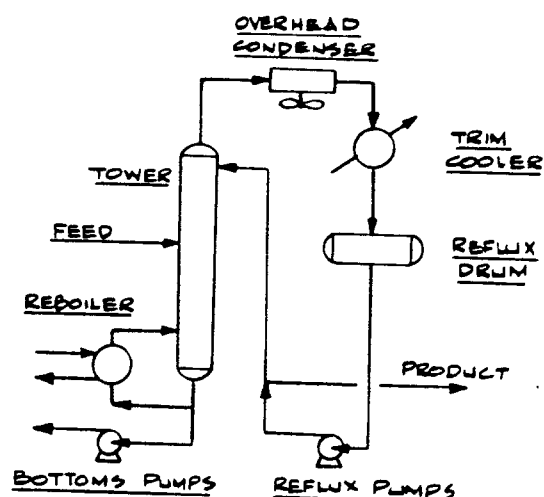
TOWER ELEVATION AND SUPPORT

Tower elevation is the distance from grade to the bottom tangent line of the vessel. Support is the means by which the vessel is retained at the required elevation. Exhibit 10-11 shows an example of elevation and support.

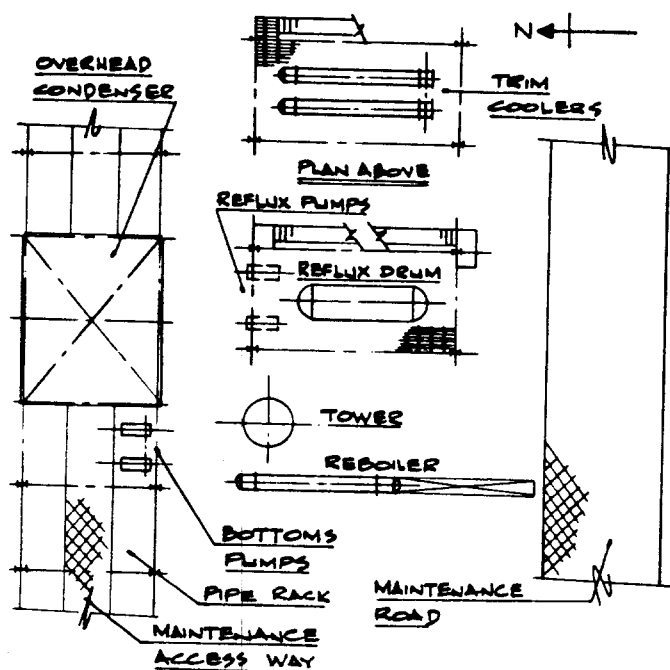
Although tower elevation must satisfy minimum NPSH requirements, it can be set by a combination of the following constraints—whichever produces the minimum tangent line elevation:

- NPSH (Exhibit 10-12).
- Operator access (Exhibit 10-13).
- Maintenance access (Exhibit 10-14).
- Minimum clearance (Exhibit 10-15).
- Vertical reboiler (Exhibit 10-16).
- Common access (Exhibit 10-17).

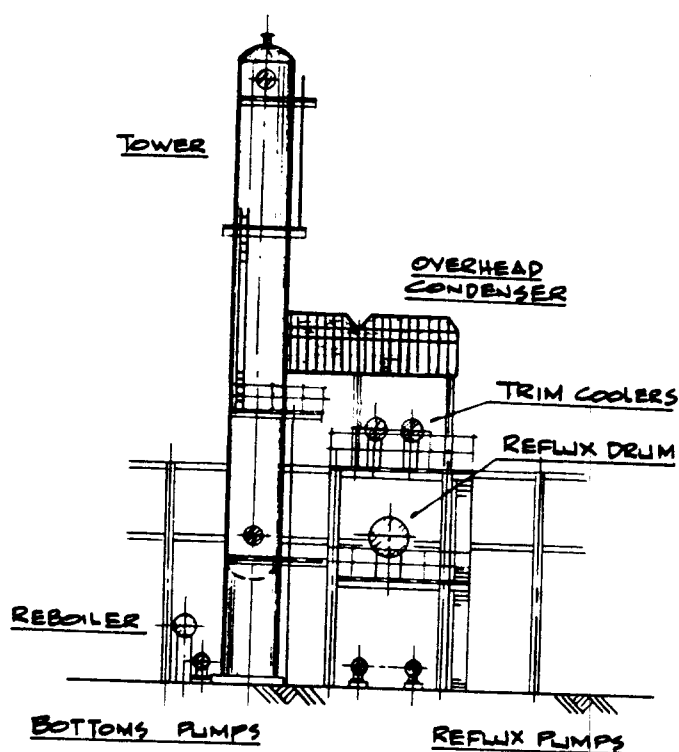
A skirt is the most frequently used and most satisfactory means of support for vertical vessels. It is attached by continuous welding to the bottom head of the vessel and is furnished with a base ring, which is secured to a concrete foundation or structural frame by means of anchor bolts. In most cases, the skirt is straight, but on tall, small-diameter towers, the skirt could be flared. Access openings are required in vessel skirts for inspection and, when possible, should be oriented toward the main access way. Exhibit 10-18 shows a typical skirt arrangement.



a. Process Flow Diagram



b. Plan Arrangement



c. Elevation

EXHIBIT 10-11 Considerations for Tower Elevation and Support

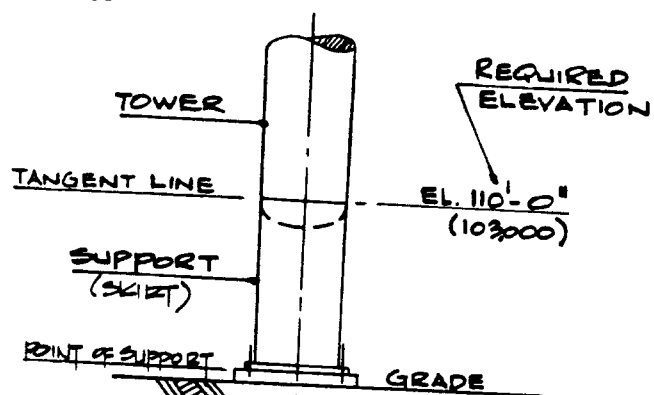


EXHIBIT 10-13 Operator Access

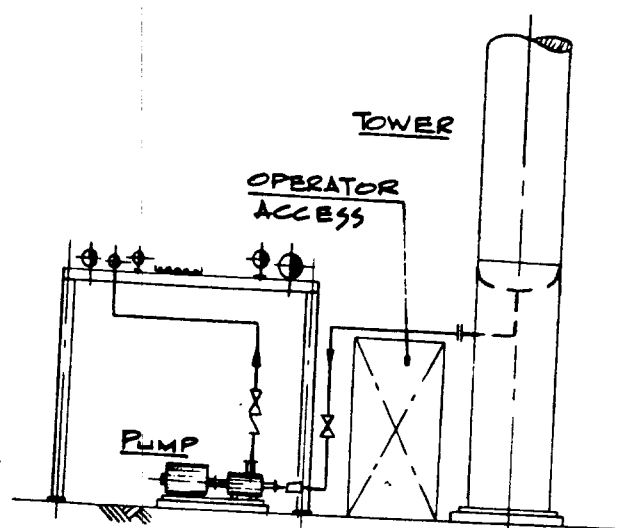


EXHIBIT 10-12 Net Positive Suction Head

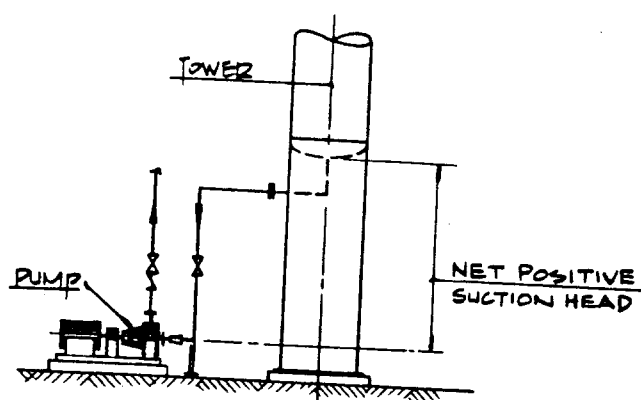


EXHIBIT 10-14 Maintenance Access

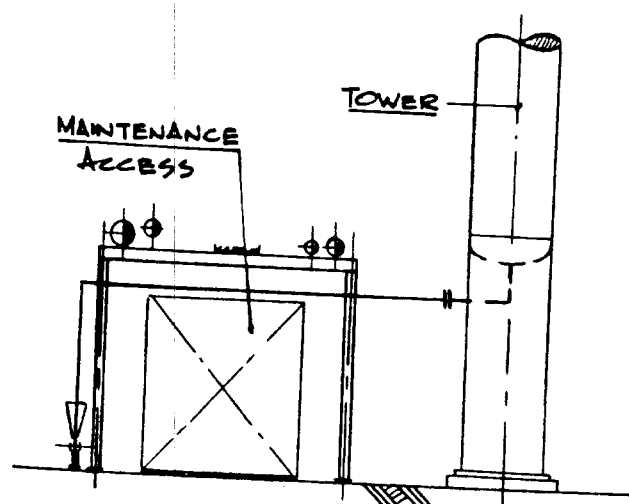


EXHIBIT 10-15 Minimum Clearance

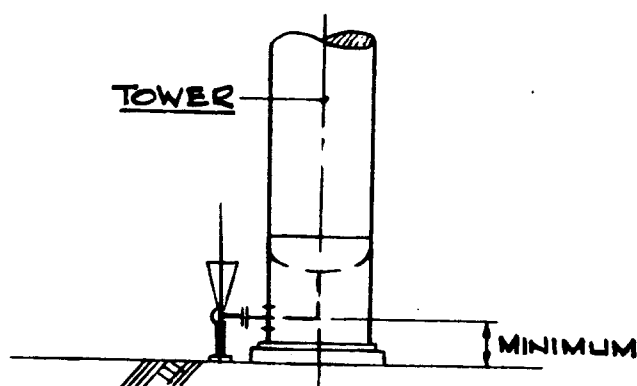


EXHIBIT 10-16 Vertical Reboiler

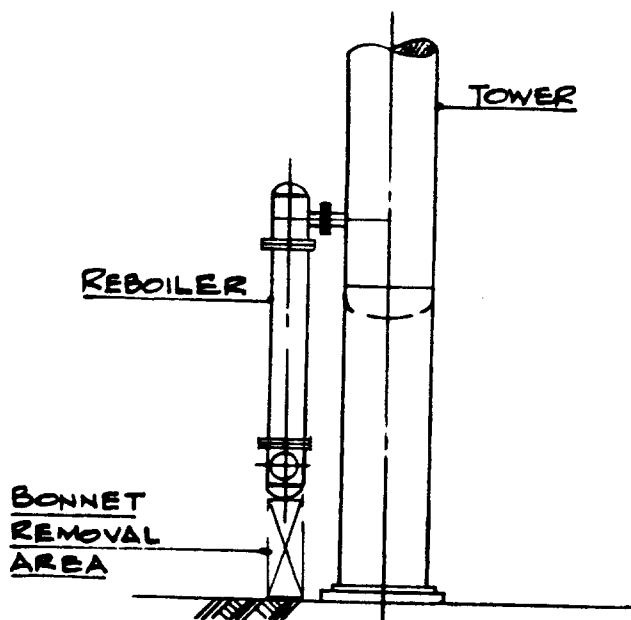
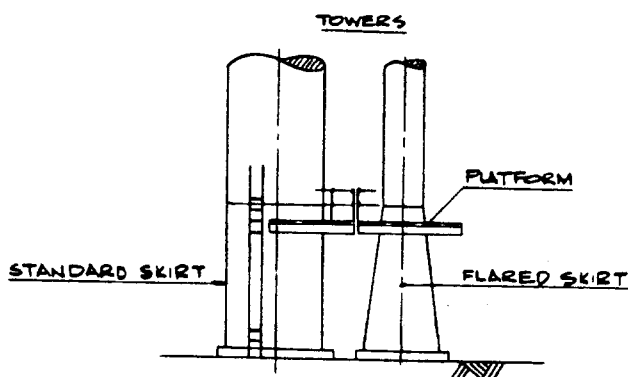


EXHIBIT 10-17 Common Access



The first step in tower layout is setting the bottom tangent line elevation. This step assists civil engineering in foundation design, vessel engineering in support design, systems engineering in line sizing, and rotating equipment engineering in pump selection. To set the elevation of a tower, the plant layout designer requires the following information:

- Tower dimensions.
- Type of heads.
- Support details.
- NPSH requirements.
- Bottom outlet size.
- Reboiler details.
- Foundation details.
- Minimum clearances.

For example, the tangent line elevation of the tower as shown in Exhibit 10-19 has been set using the following information and the guidelines in this chapter:

- Configuration—Exhibit 10-13 (operator access).
- Tower dimensions—4 ft (1,200 mm) in diameter by

EXHIBIT 10-18
Tower Skirt

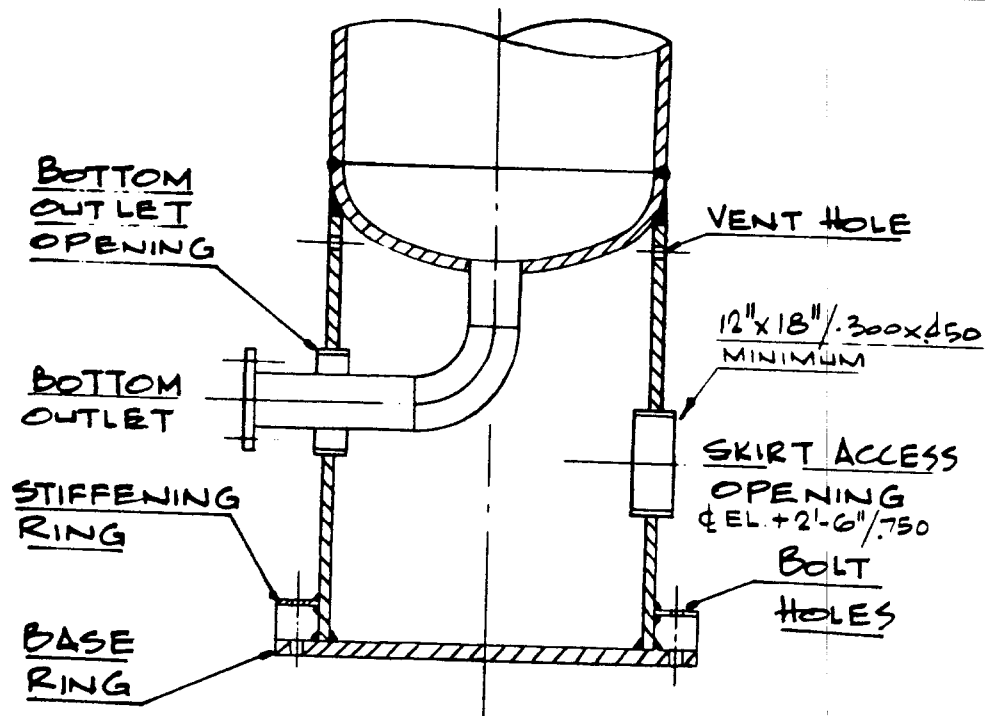


EXHIBIT 10-19
Tower Elevation Sketch

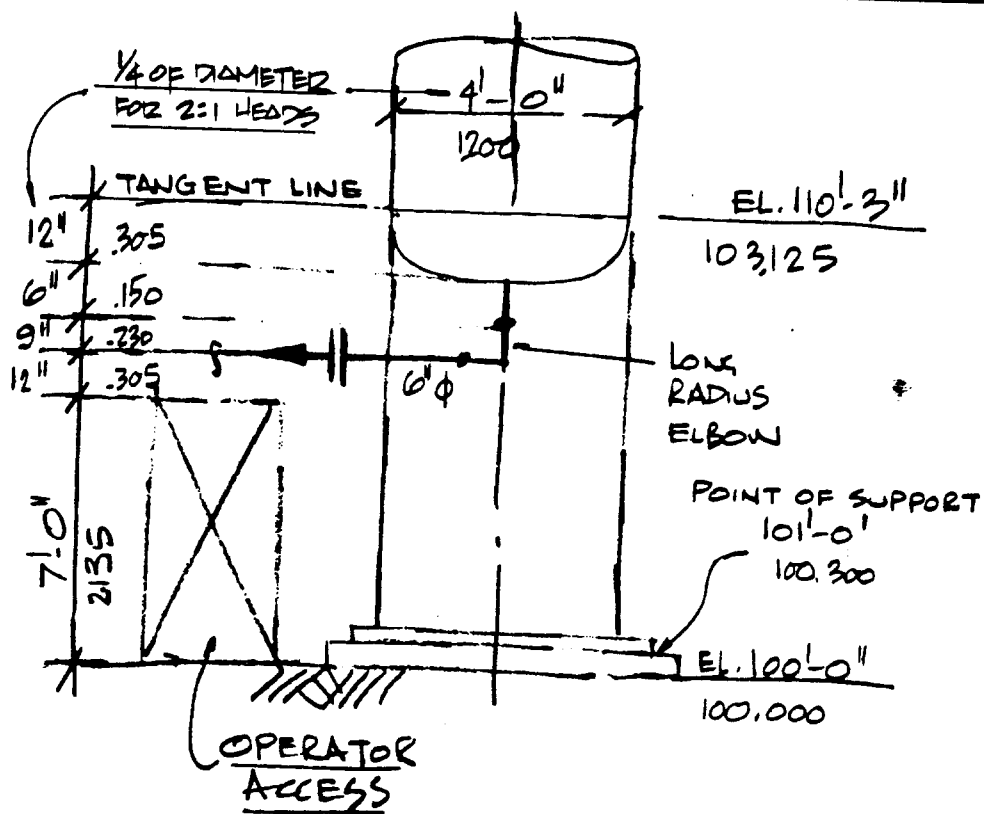
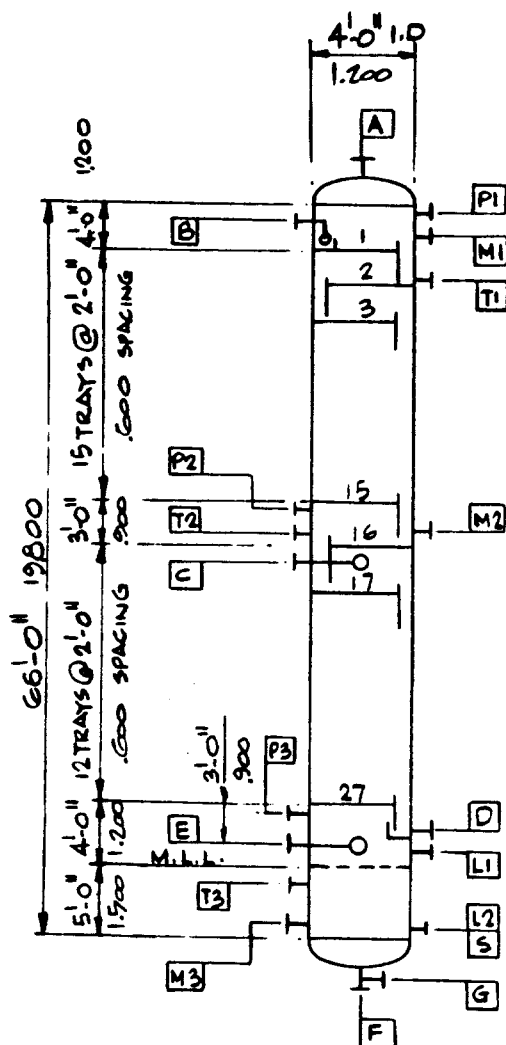


EXHIBIT 10-20
Process Vessel Sketch


NOZZLE SUMMARY		
SYMBOL	SIZE	SERVICE
A	18" 150° RF	VAPOR
B	3" 150° RF	REFLUX
C	6" 150° RF	FEED
D	10" 150° RF	REBOILER DRAW OFF
E	10" 150° RF	REBOILER RETURN
F	6" 150° RF	BOTTOMS OUTLET
P	1" 150° RF	PRESSURE
T	1" 150° RF	TEMPERATURE
L	2" 150° RF	LEVEL
S	1" 150° RF	STEAM OUT
M	24" 150° RF	MAINTENANCE ACCESS
G	3" 150° RF	DRAIN

ITEM #
T-100

60 ft (18,300 mm) in length.

- Type of heads—2 : 1 elliptical.
- Support—Straight skirt with base ring.
- NPSH—6 ft (1,800 mm) minimum.
- Bottom outlet size—6-in diameter.
- Foundation—Concrete point of support elevation of 101 ft (100,300 mm).
- Operator clearance—7 ft (2,100 mm).

A freehand sketch should be used for this exercise.

Although the minimum NPSH requirement was a key factor in elevating the tower in this example, the height was finally dictated by operator access clearance, which was the greater of the two dimensions. If the configuration shown in Exhibit 10-12 (NPSH) had been used, the tangent line elevation would be 108.5 ft (102,600 mm).

Tower Internals

Towers have a variety of internal devices for vapor-liquid contact and feed distribution that affect the exterior layout of the vessel. There is a wide range of designs for trays, which are the principal internal component of the trayed tower. The two most frequently used are the single-pass bubble cap tray and the double-pass bubble cap tray. Other trays (e.g., sieve or perforated trays) are similar in design to the bubble cap tray and do not affect the layout of the tower. Tray configurations and dimensions are furnished by process engineering and are included in the process release package. Exhibit 10-20 illustrates a process vessel sketch, Exhibit 10-21 shows the tray details, and Exhibit 10-22 depicts single-pass and double-pass trays.

Towers have the same tray configuration for the whole length of the tower. Some towers, however,

EXHIBIT 10-21
Tray Details

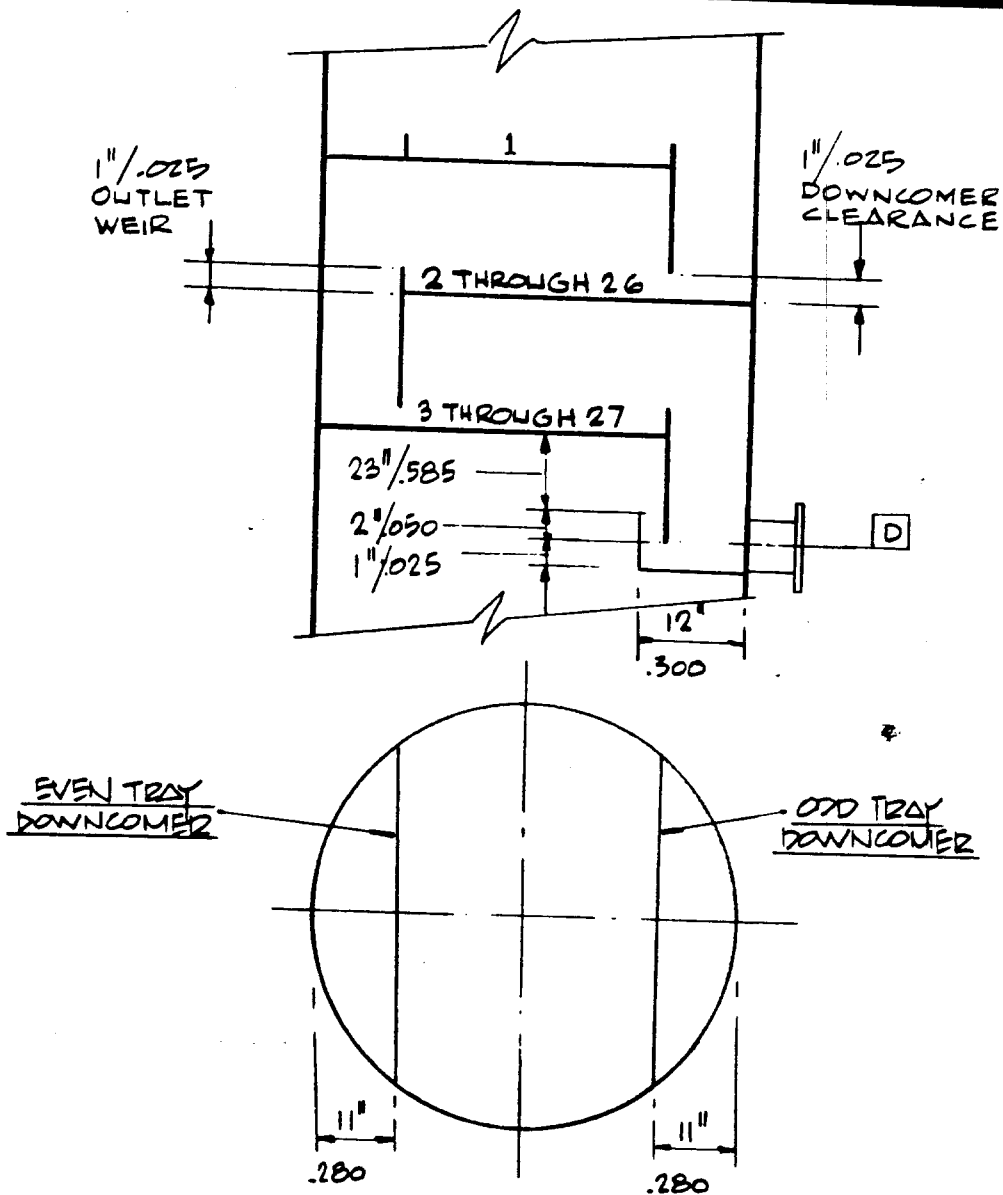
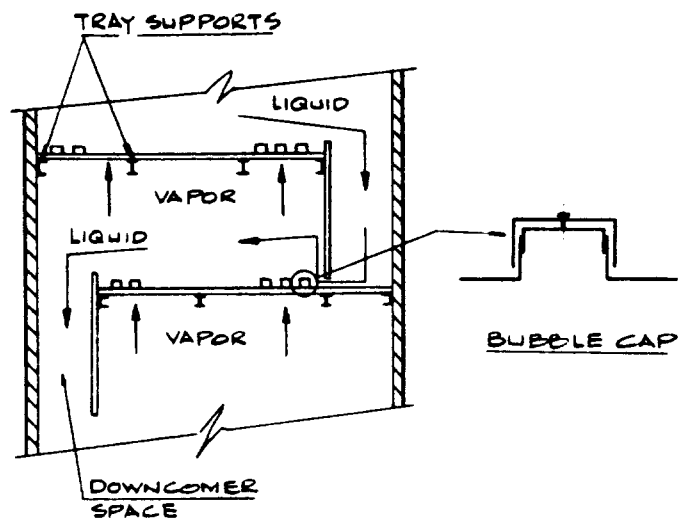
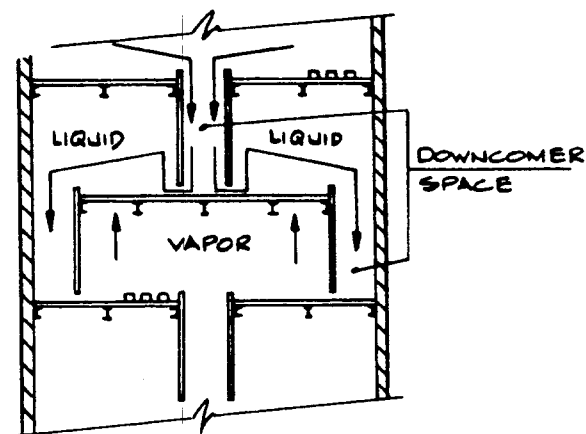


EXHIBIT 10-22 Examples of Downcomer Trays



a. Single-Pass Downcomer Tray



b. Double-Pass Downcomer Tray

EXHIBIT 10-23 Tower Transition Section

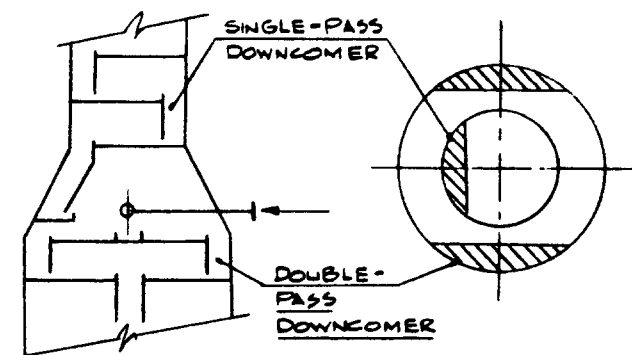


EXHIBIT 10-25 Opposing Downcomers

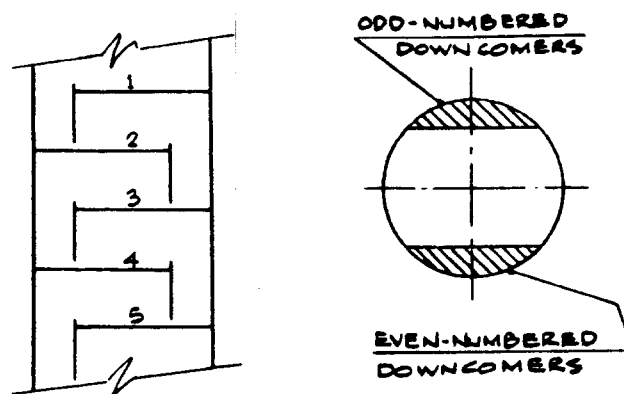


EXHIBIT 10-24 Chimney Tray Arrangement

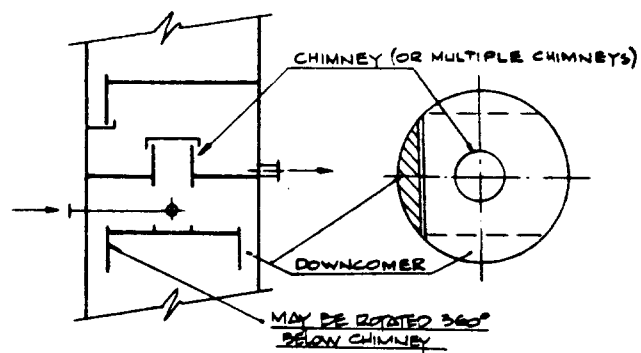


EXHIBIT 10-26 Reboiler Arrangement

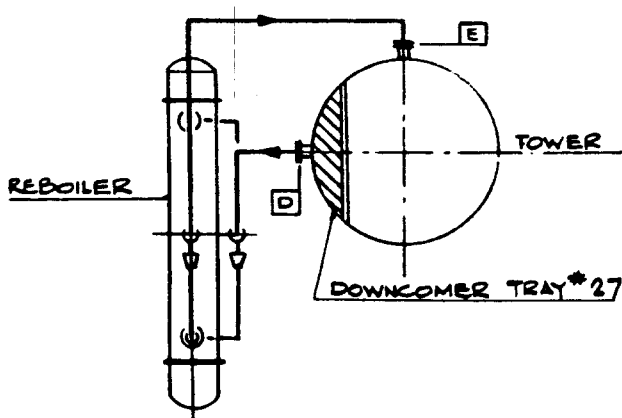
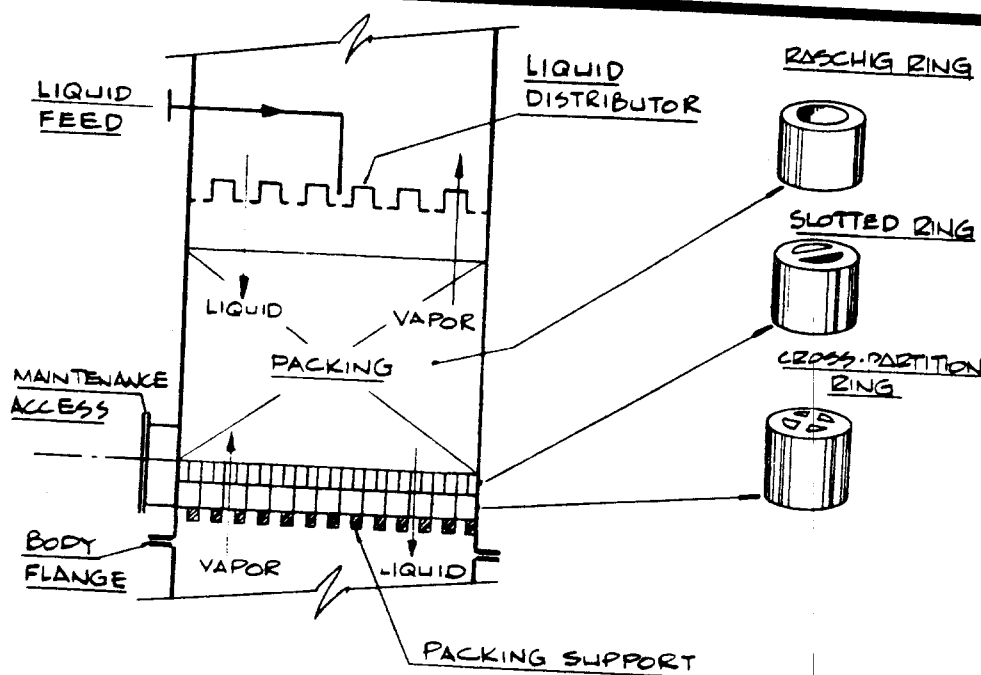
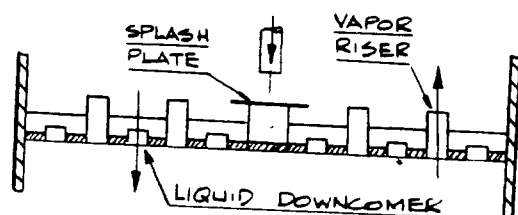


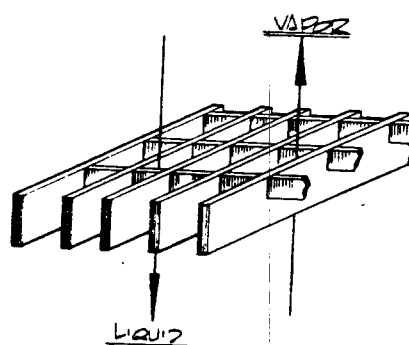
EXHIBIT 10-27
Packed Tower
Components



a. Packed Bed Section



b. Liquid Distributor



c. Packing Support Grid

especially those with enlarged sections, could change from single-pass to double-pass tray configurations. Exhibit 10-23 shows a typical arrangement at a tower transition section. The chimney tray, if specified, is another device that could change the tray configuration. The chimney tray is a solid plate with a central chimney section and is usually used at draw-off sections of the tower. Exhibit 10-24 identifies a typical chimney tray arrangement.

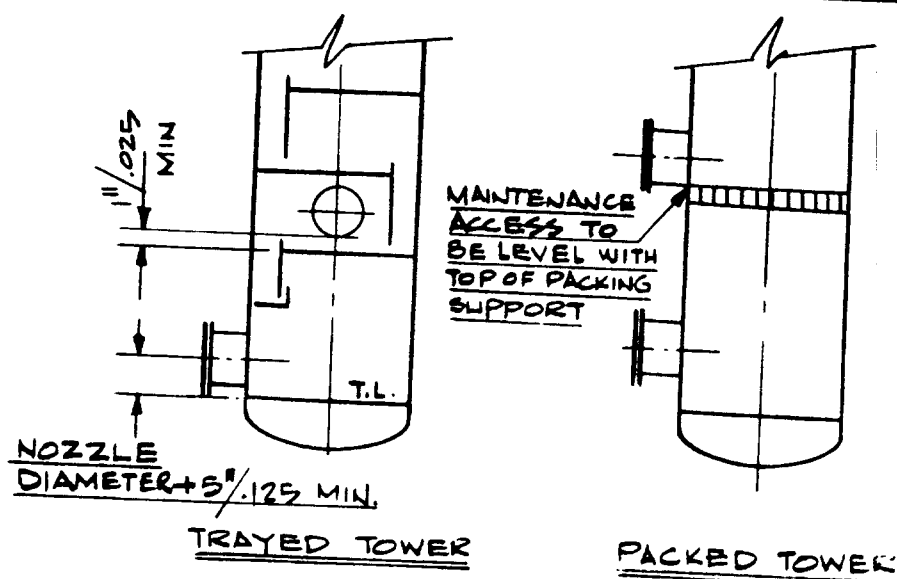
The plant layout designer must orient the trays along with the tower nozzles to suit the best exterior arrangement. The trays can be at any angle as long as the downcomers directly oppose each other. Exhibit 10-25 shows a typical example of opposing downcomers.

Two main items that influence tray orientation are maintenance access ways and reboilers. The process

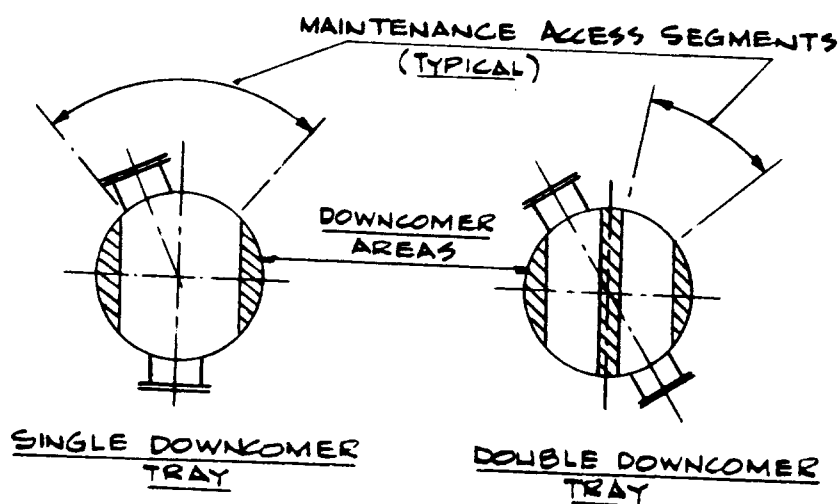
vessel sketch (Exhibit 10-20) shows that the reboiler draw-off nozzle is located directly below the downcomer of tray 27, and the plan arrangement (Exhibit 10-10b) indicates that the reboiler is located on the west side of the tower and that the maintenance road is south of the tower. Therefore, because the tower reboiler nozzle is generally on the same side as the reboiler and the maintenance access way is best located on the maintenance side, the trays are automatically positioned about a north/south centerline. Exhibit 10-26 illustrates a plan view of the arrangement.

The principal difference between trayed and packed towers is that the packed tower uses metal rings instead of trays for vapor-liquid contact. The metal rings are dumped or packed into specific sections of the tower, called beds, and supported by cross grid bars spaced to prevent the rings from falling

EXHIBIT 10-28
Elevation and Orientation
Requirements for
Maintenance Accesses



a. Maintenance Access Elevations



b. Maintenance Access Orientations

through. The supports are designed to allow vapor to rise and liquid to flow down. Liquid is fed into the vessel at the top of each bed through a liquid distributor. Unlike the trayed tower, there are no special considerations for orientation of the beds, the distributor, or the packing supports. Exhibit 10-27 shows these three packed tower components.

NOZZLE ELEVATION AND ORIENTATION

Nozzles must be elevated to meet the internal requirements of the tower and oriented for maintenance and

operational needs. Their position must also facilitate economic and orderly interconnection of piping between the tower and related equipment.

A maintenance access is usually located in the bottom; top, and intermediate sections of the tower and is used to gain entry to the tower during shutdowns for internal inspection and component removal. Maintenance accesses must not be located at downcomer sections of the tower. Care must be taken at sections of the tower that contain internal piping to avoid blocking the maintenance access entrance. Exhibit 10-28 shows typical elevation and orientation requirements for maintenance accesses.

Feed connections to trayed towers usually must be

EXHIBIT 10-29
 Reflux: Alternative
 Arrangements

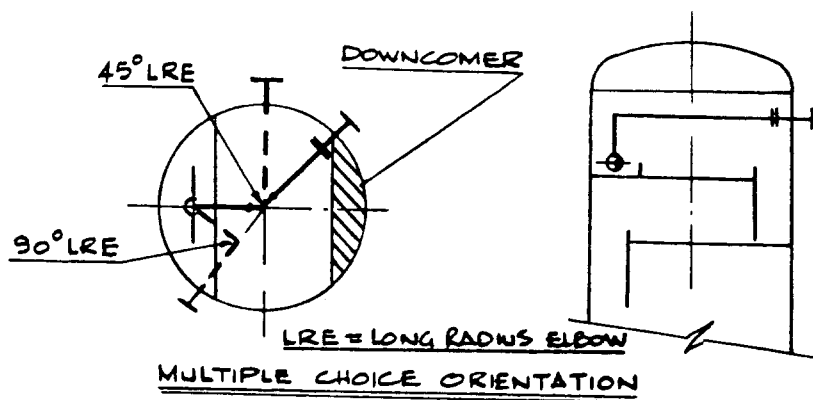
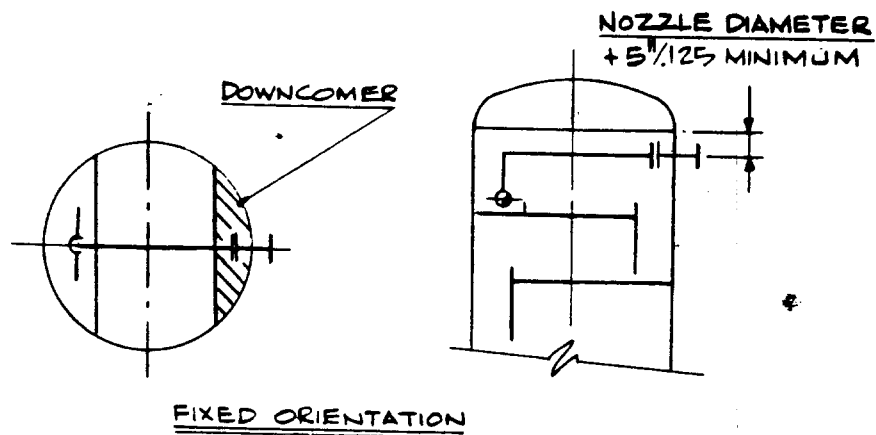
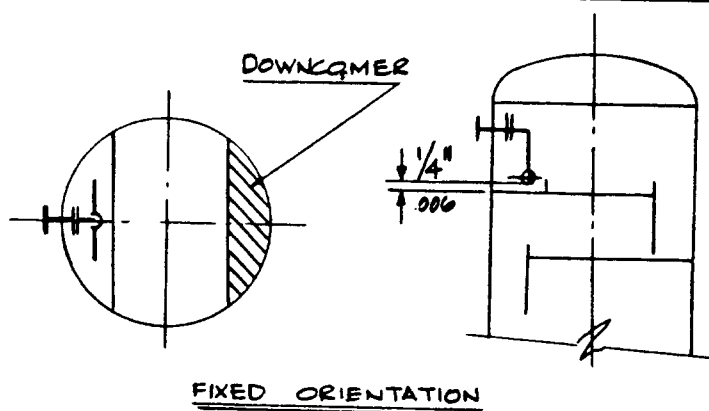
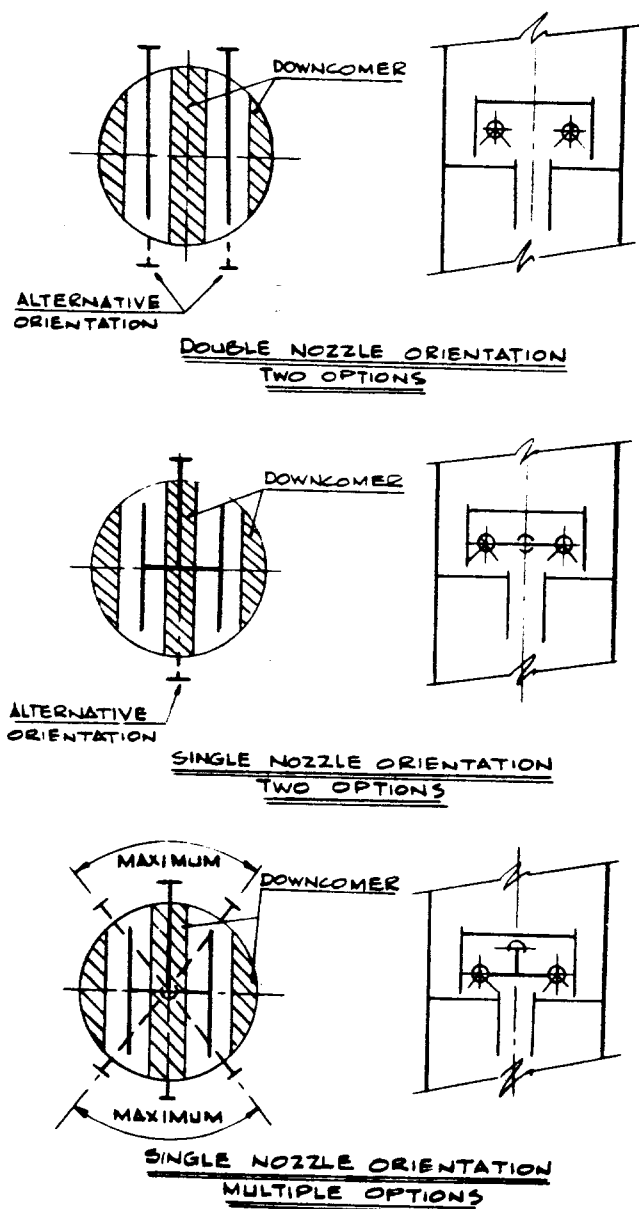


EXHIBIT 10-30 Feeds: Alternative Arrangement

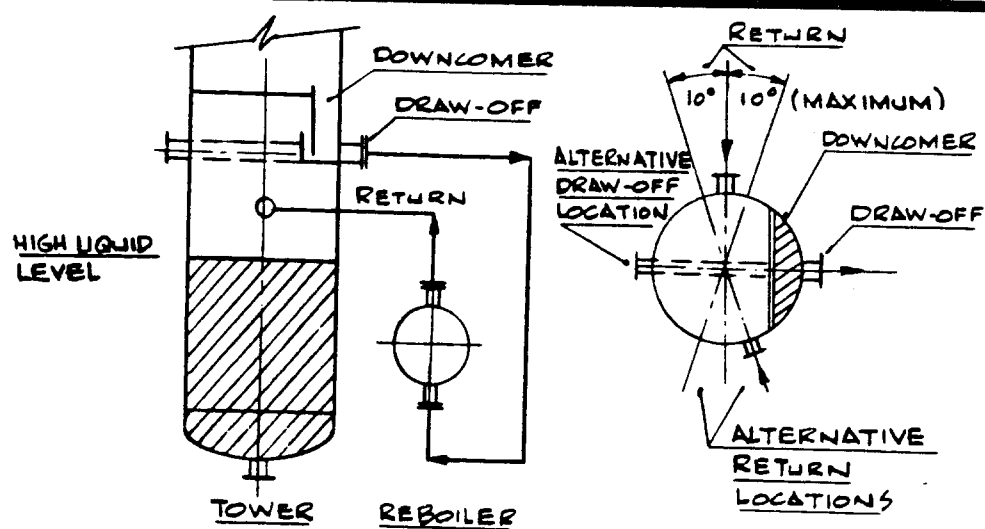
located in a specific area on the tray by means of internal piping, which can restrict nozzle orientation options. The restrictions are minimized by optional routing of the internal piping to facilitate the most economic exterior arrangement. Internal feed piping to packed towers is piped directly to the distributor and can be oriented at any angle. Exhibits 10-29 and 10-30 illustrate several options for internal feed piping.

If specified, reboiler connections are usually located at the bottom section of the tower. For the horizontally mounted thermosiphon reboiler, the draw-off nozzle is located just below the bottom tray. For the vertically mounted recirculating thermosiphon reboiler, the draw-off nozzle is located at the bottom head. For both systems, the return nozzles are located just above the liquid level. Exhibit 10-31 shows both of these arrangements.

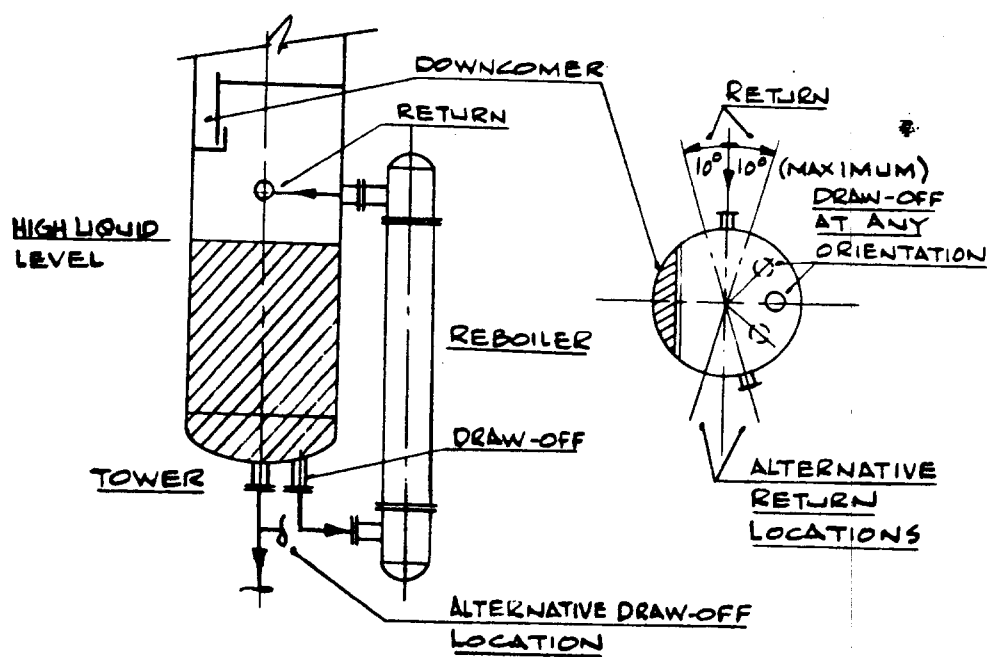
The vapor outlet is usually a vertical nozzle located on the top head of the tower. It is usually a single nozzle, but in certain cases (e.g., towers with very large diameters), more than one nozzle is specified. On large-diameter vapor lines, the vessel connection could be butt-welded instead of flanged. In addition, the vent and relief valve could be located on the top head instead of attached to the overhead piping. Exhibit 10-32 shows a typical top head arrangement.

The liquid outlet is located on the bottom head of the tower. If the tower is supported by a skirt, the nozzle is routed outside the skirt. As with the vapor outlet, more than one nozzle may be specified. The elevation of the nozzle is dictated by the constraints discussed previously in this chapter. The orientation can be at any angle, but generally it is dictated by pump suction piping flexibility. Exhibit 10-33 shows a typical bottom head arrangement.

Temperature- and pressure-instrument connections are located throughout the tower. The temperature probe must be located in a liquid space, and the pressure connection in a vapor space. Exhibit 10-34 shows the preferred location for both connections.



a. Horizontal Reboiler



b. Vertical Reboiler

EXHIBIT 10-31
Reboiler Connections

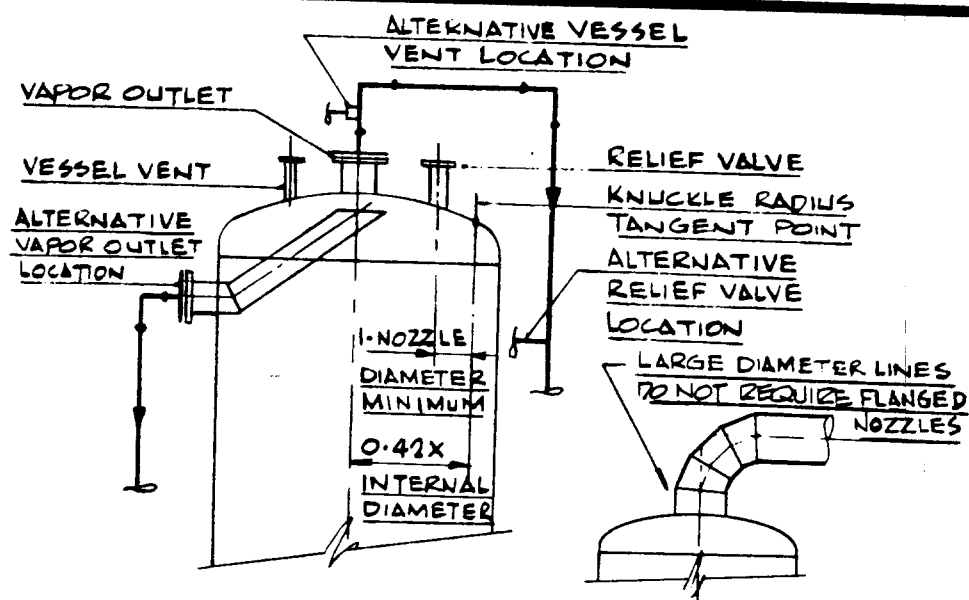


EXHIBIT 10-32
Top Head Arrangement

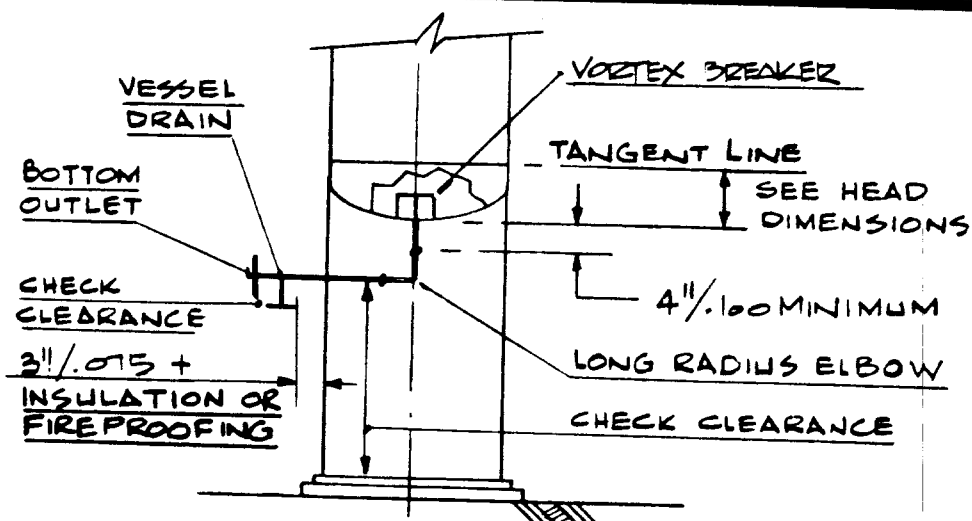


EXHIBIT 10-33
Bottom Head Arrangement

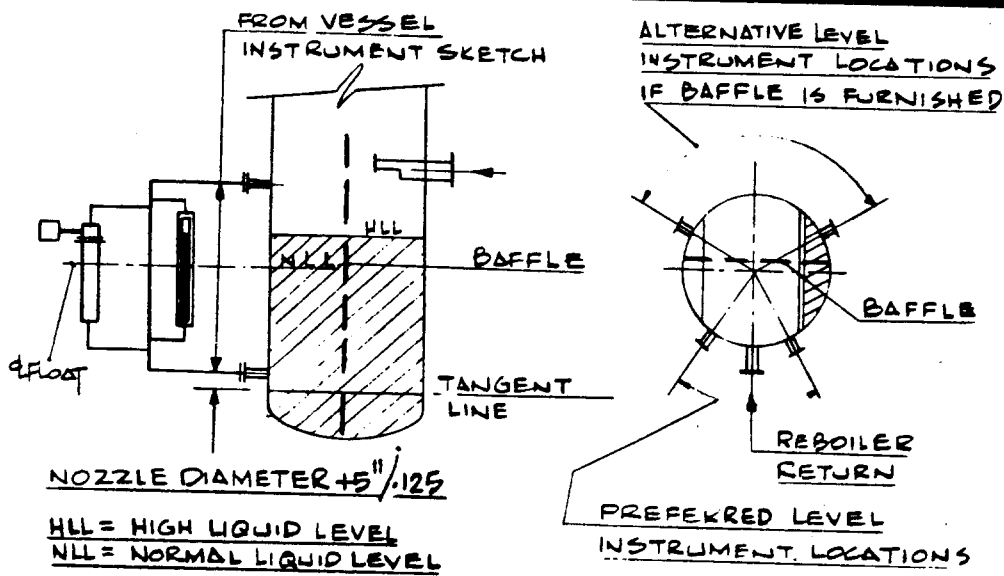
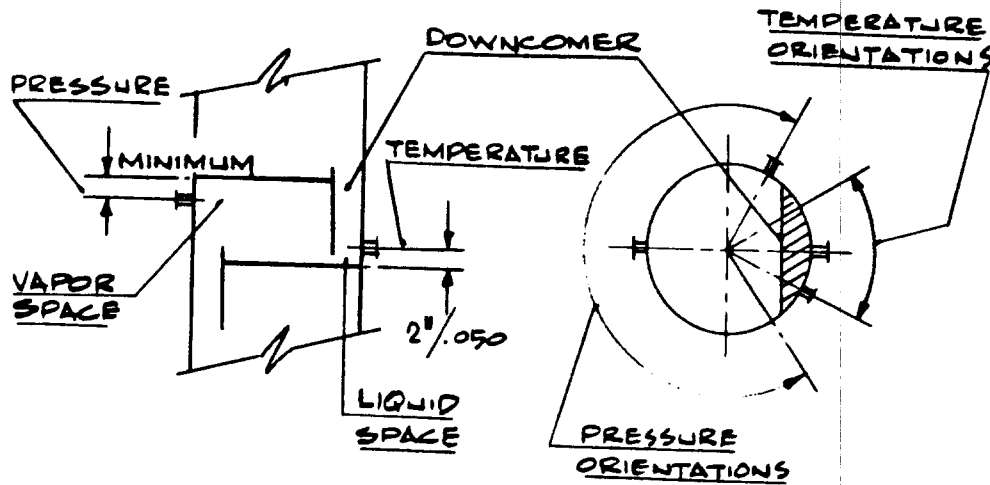
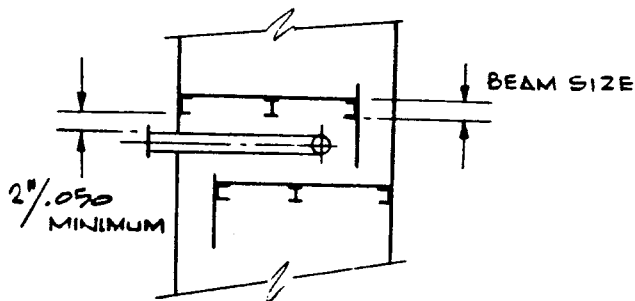
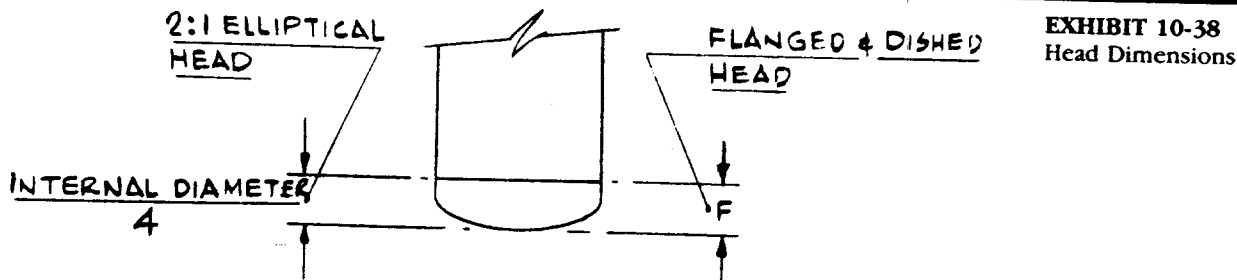
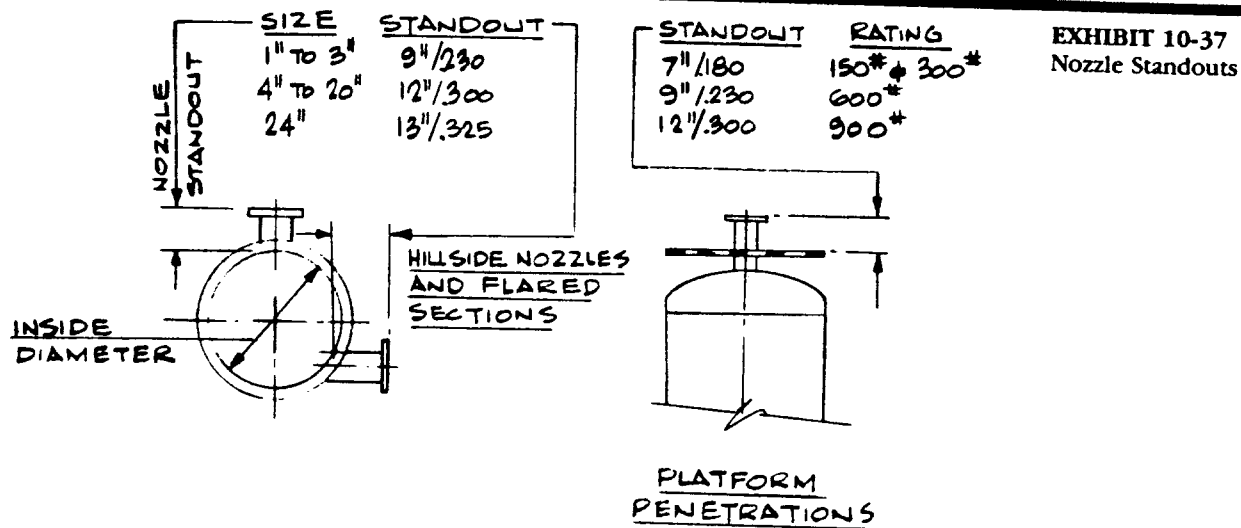


EXHIBIT 10-36 Tray Support Beam Sizes



TOWER DIAMETER	BEAM SIZE
3'-0" / 915	4" / 100
7'-0" / 2100	4" / 100
10'-0" / 3050	6" / 150
12'-0" / 3660	8" / 200
16'-0" / 4880	10" / 250
20'-0" / 6100	12" / 300



VESSEL INTERNAL DIAMETER		DIMENSION-F	
2'-0"	.610	4"	.100
3'-0"	.915	6"	.150
4'-0"	1.220	9"	.230
5'-0"	1.525	10"	.250
6'-0"	1.830	12"	.300
8'-0"	2.440	17"	.430
10'-0"	3.050	21"	.535
12'-0"	3.660	26"	.660
14'-0"	4.265	32"	.815

Level instruments are located in the liquid section of the tower, usually at the bottom. The elevation of the nozzles is dictated by the amount of liquid being controlled or measured and by standard controller and gauge glass lengths. This information is furnished on the instrument vessel sketch. Exhibit 10-35 illustrates level instrument requirements.

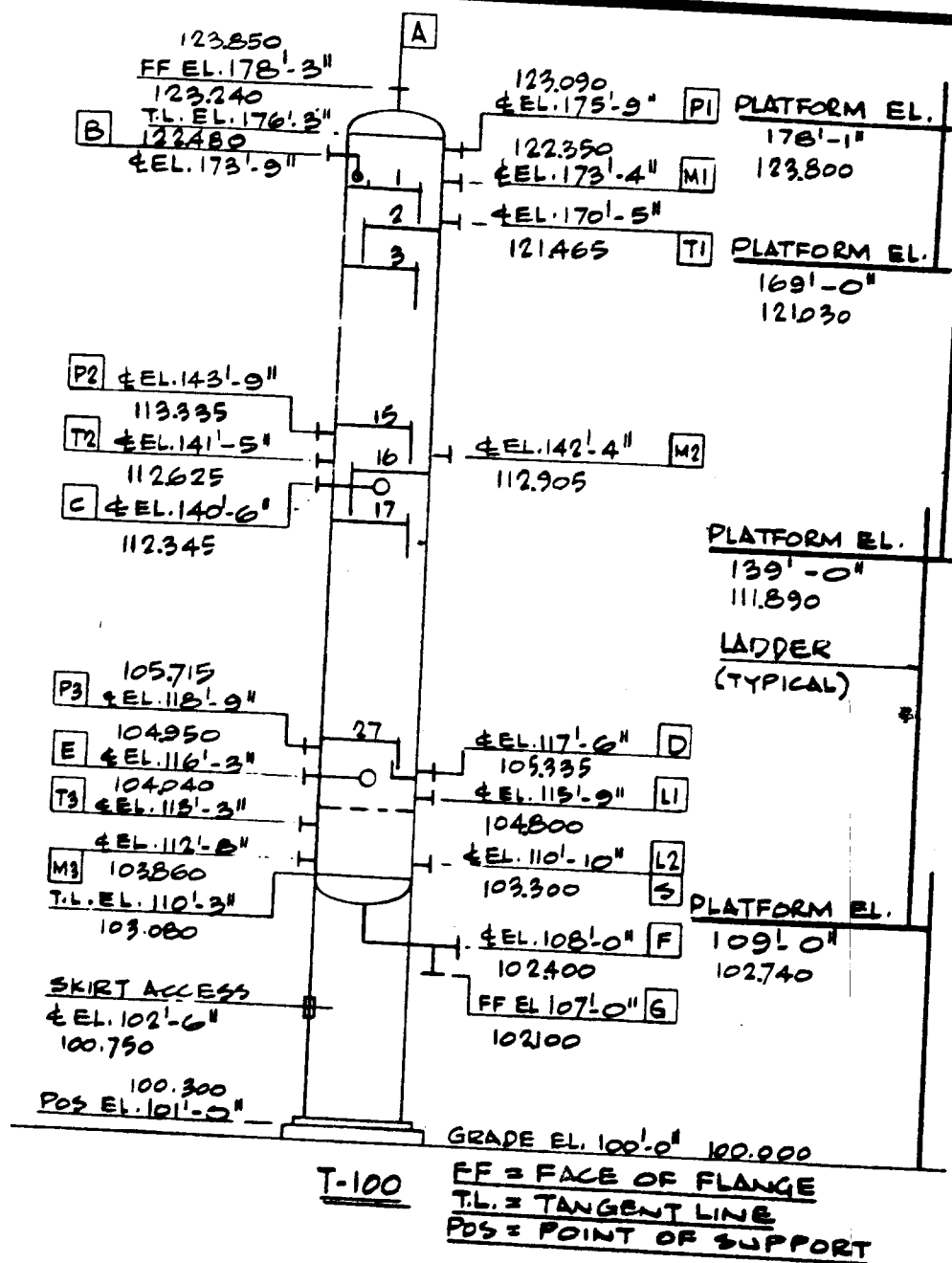
When nozzles, especially those with internal piping, are positioned, the plant layout designer must allow adequate clearance at tray support steel. Exhibit 10-36 illustrates approximate tray support beam sizes. Standouts, shown in Exhibit 10-37, are measured from the internal diameter of the vessel to the face of the

flange. To set top- and bottom-head nozzle elevations, the type of head must be specified. This information is highlighted in the process vessel data. The two most commonly used are flanged-and-dished and 2:1 elliptical heads. Exhibit 10-38 shows approximate dimensions for these heads.

As an example, the nozzle elevations shown in Exhibit 10-39 have been set using the following guidelines:

- Process vessel sketch (Exhibit 10-20).
- Tray details (Exhibit 10-21).
- Type of heads—2:1 elliptical.

EXHIBIT 10-39
Nozzle Elevations



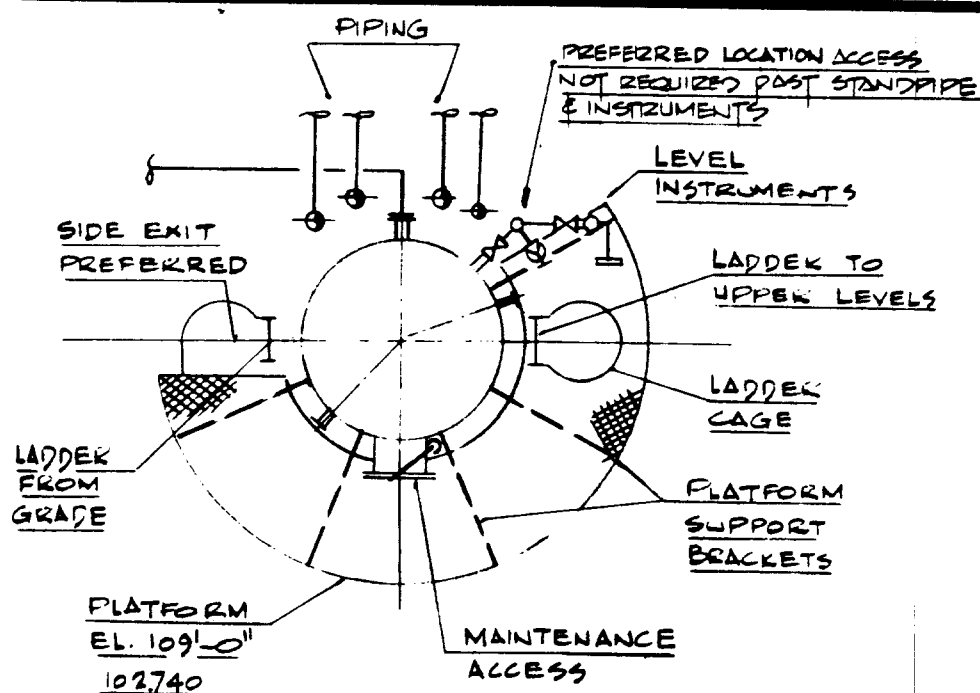


EXHIBIT 10-40
Typical Platform
Arrangement

- Bottom tangent line elevation (Exhibit 10-19).
- Nozzle summary (Exhibit 10-20).
- Instrument vessel sketch (Exhibit 10-58).
- Piping and instrumentation diagram (Exhibit 10-56).
- Plant layout specification—Chapter 2.
- Insulation—None required.

PLATFORM ARRANGEMENTS

Platforms are required on towers for access to valves, instruments, blinds, and maintenance accesses. Platforms are usually circular and supported by brackets

attached to the side of the tower. Generally, access to platforms is by ladder. Exhibit 10-40 depicts a typical platform arrangement.

Platform elevations for towers are set by the items that require operation and maintenance and by a maximum ladder run of 30 ft (9,150 mm). Exhibit 10-41 shows platform and ladder elevation requirements.

Platform widths are dictated by operator access. For intermediate platforms with no controls required and platforms with controls located to the side or the edge of the platform, the width must be a minimum of 3 ft (915 mm). At congested platforms with controls located over the platform, the width must be a minimum of 3 ft (915 mm) plus the width of the controls or

EXHIBIT 10-41
Tower Platform and
Ladder Elevation
Requirements

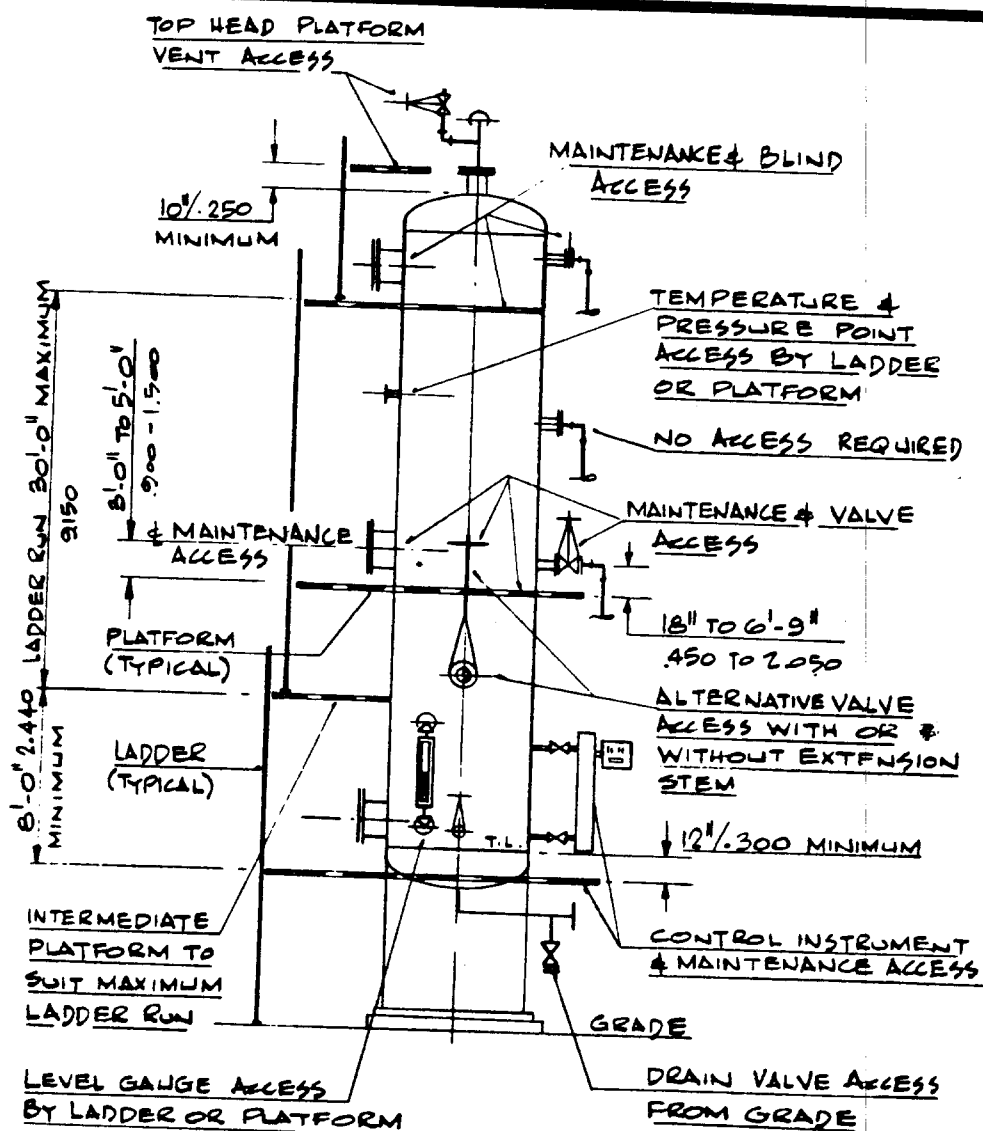
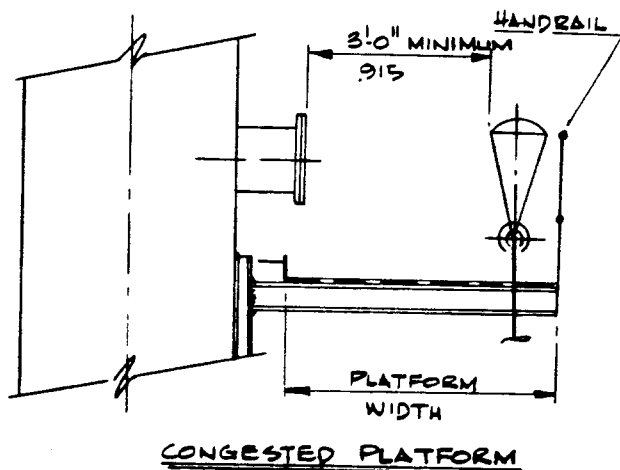
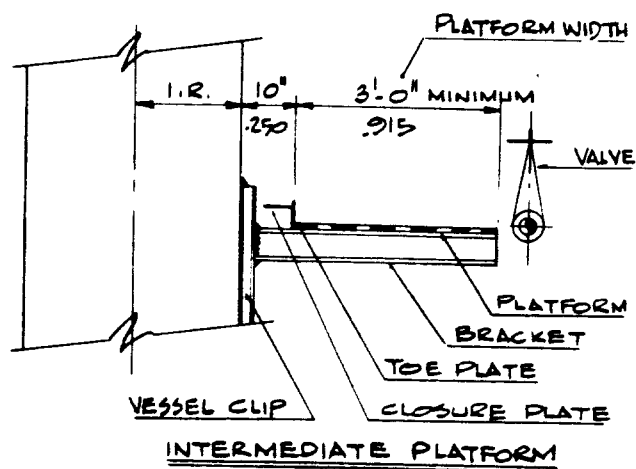


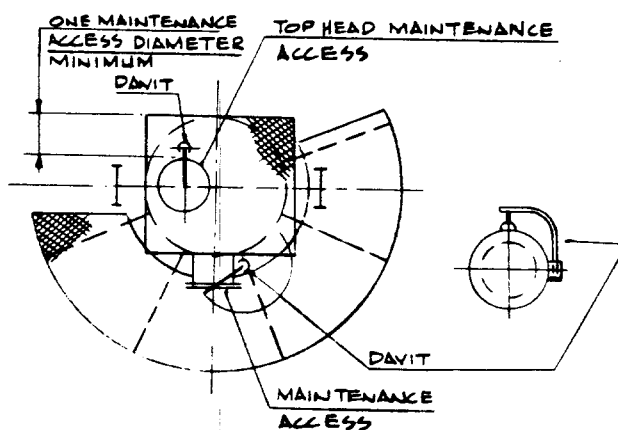
EXHIBIT 10-42 Platform Width Requirements



projections. Exhibit 10-42 shows these two arrangements.

At maintenance access platforms, adequate space must be provided to swing the maintenance access cover flange open for storage against the face of the tower. Top head-mounted maintenance accesses

EXHIBIT 10-43 Maintenance Access Arrangements

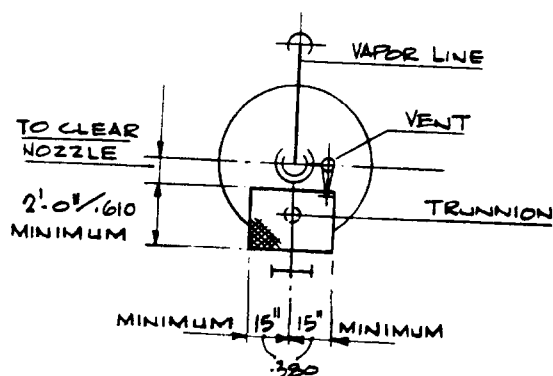


must be from three sides. Exhibit 10-43 displays typical maintenance access arrangements. Top head platforms are required for access to vents, instruments, and relief valves and are supported from the head by trunnions. Exhibit 10-44 shows typical top head platform arrangements. Access between towers, if layout permits, is provided by common platforming. The platform elevations can be within a maximum difference of 9 in (230 mm) but must be connected by mechanical joint. Exhibit 10-45 shows a common top head platform arrangement.

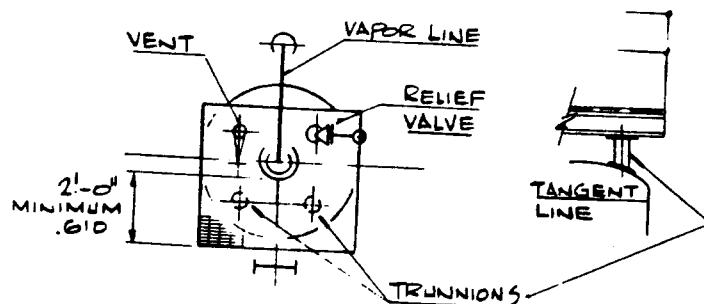
Brackets for side-mounted platforms are evenly spaced around the tower and, when possible, straddle both the main axes. Oddly angled brackets can be used for small platform extensions as long as the bracket clip does not interfere with the adjacent support. Exhibit 10-46 is an approximate guide to bracket spacing.

When a common ladder serves two or more platforms, the ladder rungs must be level with the platforms they serve. The platform elevations must be in even increments to suit the standard 12-in (300-mm) ladder rung spacing. Exhibit 10-47 illustrates this re-

EXHIBIT 10-44 Typical Top Head Platform Arrangements

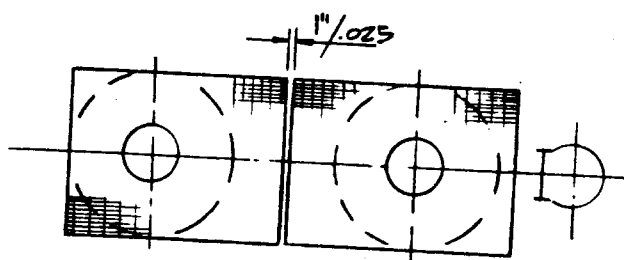


a. Minimum Top Head Platform



b. Multinozzle Top Head Platform

EXHIBIT 10-45 Common Platforms



quirement. Ladders at tower transition sections and at flared skirts may be sloped, if required, to a maximum angle of 15° from the vertical. Offsets in ladders should be avoided. Exhibit 10-48 shows a typical sloping ladder arrangement.

On very wide platforms or those that support heavy piping loads, knee bracing is required in addition to the usual platform steel, as illustrated in Exhibit 10-49. The potential obstruction immediately under the knee brace must be kept in mind during platform design.

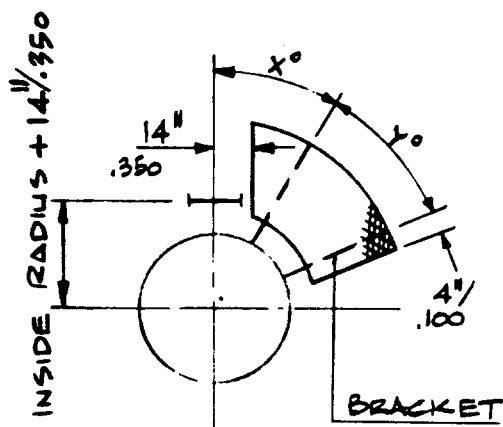
For example, the platform elevations shown on the process vessel sketch in Exhibit 10-39 are the minimum requirements for instrument, valve, and maintenance access. Exhibit 10-50 displays a platform arrangement for the tower using the information in Exhibit 10-39 and the guidelines in this chapter.

TOWER PIPING

Tower piping is located in conjunction with tray, nozzle, and platform orientation. When possible, the piping is grouped for ease of support and positioned to accommodate interconnection with related equipment and the pipe rack. Exhibit 10-51 shows the preferred areas of division for piping, platforming, and ladders.

Adequate space must be provided between piping and between the back of piping and the tower shell to facilitate the installation of pipe supports, which are attached to the tower. Exhibit 10-52 displays some typical supports for tower piping.

EXHIBIT 10-46 Bracket Spacing



VESSEL INTERNAL DIAMETER	X	Y
UP TO 4'-0" 1220	30°	60°
4'-0" TO 8'-0" 1220 2440	22½°	45°
8'-0" TO 17'-0" 2440 5180	15°	30°
17'-0" TO 25'-0" 5180 7620	11¼°	22½°

EXHIBIT 10-47 Ladder Rung Spacing

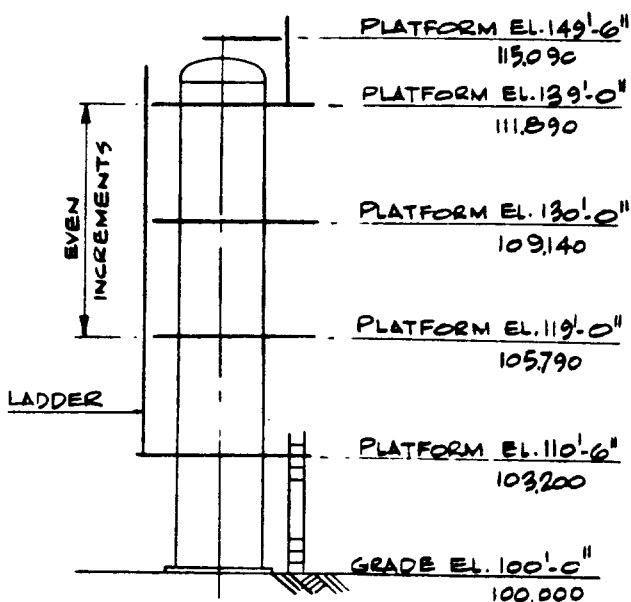


EXHIBIT 10-48 Sloping Ladder

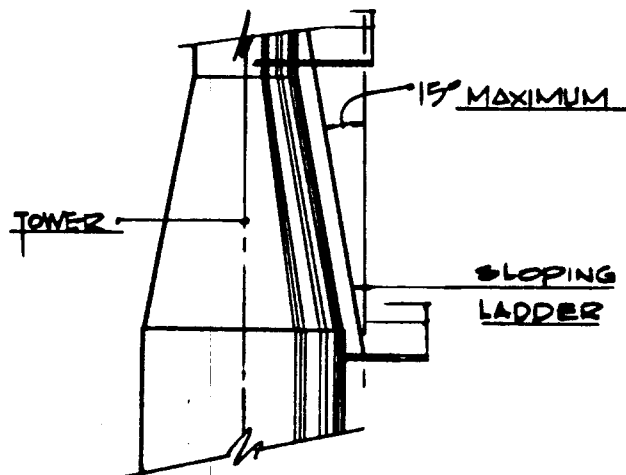


EXHIBIT 10-49 Platform Knee Brace

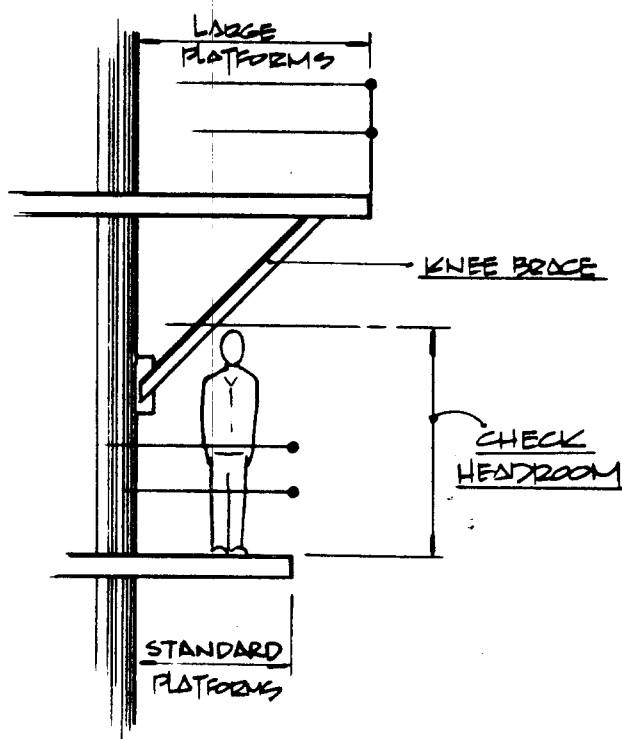


EXHIBIT 10-50
Platform Orientation

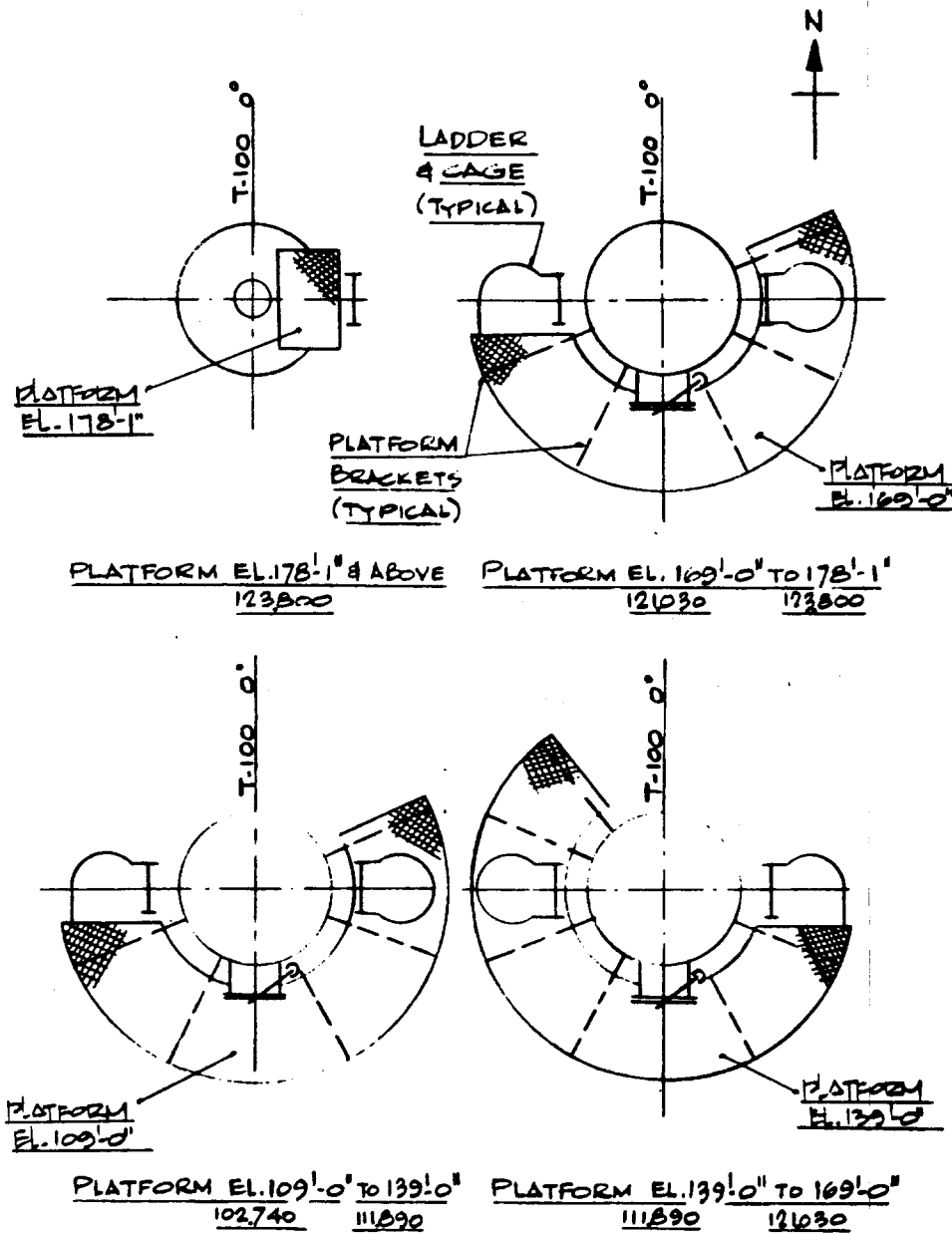
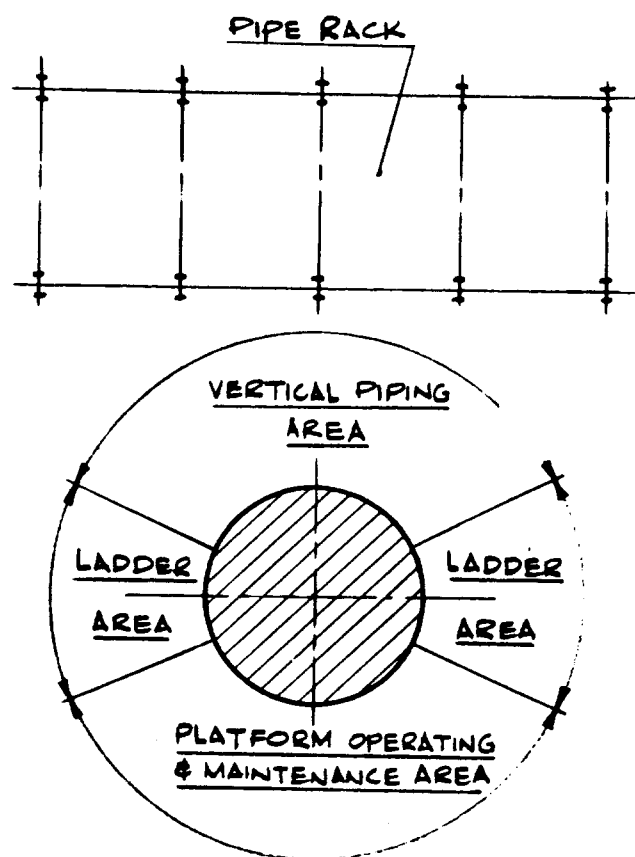


EXHIBIT 10-51 Tower Areas of Division



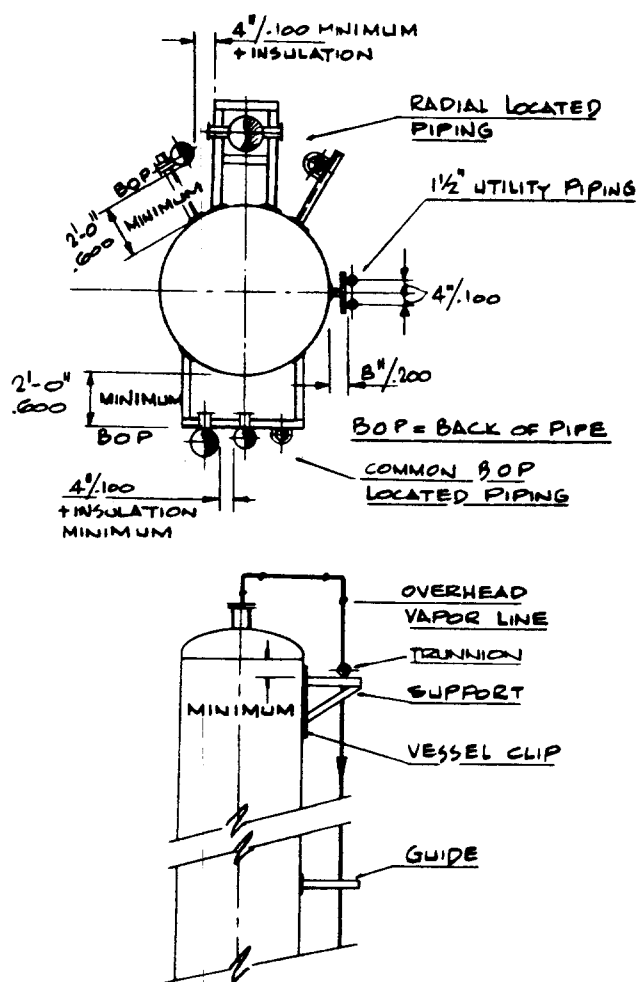
Tower piping should be arranged with sufficient flexibility to accommodate tower growth and to allow interconnection to equipment during regular operating conditions. Exhibits 10-53 and 10-54 show typical overhead vapor line and pump suction arrangements.

Relief valve systems that are open to the atmosphere are located at the top of the tower; closed systems are located a minimum distance above the relief header. Exhibit 10-55 shows a typical arrangement for both systems.

As an example, the piping arrangement shown in Exhibit 10-57 has been designed using the following information and the guidelines in this chapter:

- Process vessel sketch (Exhibit 10-20).
- Tray details (Exhibit 10-21).
- Nozzle elevations (Exhibit 10-39).
- Instrument vessel sketch (Exhibit 10-58).
- Piping and instrumentation diagram (Exhibit 10-56).
- Equipment arrangement (Exhibit 10-10b).
- Platform arrangement (Exhibit 10-50).
- Nozzle summary (Exhibit 10-20).
- Plant layout specification—Chapter 2.

EXHIBIT 10-52 Tower Piping Supports



TOWER INSTRUMENTS

Level, pressure, and temperature instruments control the operation of the tower and must be placed in a position that enhances operation and maintenance without obstructing operator access. Instrument requirements for towers are usually highlighted on an instrument vessel sketch furnished by the instrument engineer. Exhibit 10-58 is a typical instrument vessel sketch.

Level controllers, switches, and gauges are either located individually or grouped on a common bridge or standpipe. The controller must be operable from grade or a platform; gauges and switches may be operable from a ladder if no platform is available. Exhibit 10-59 illustrates arrangements for level instruments.

Like level gauges, temperature and pressure instruments can be operable from a ladder if a platform is not available at the required elevation. They can be read locally or in the main control room. Locally

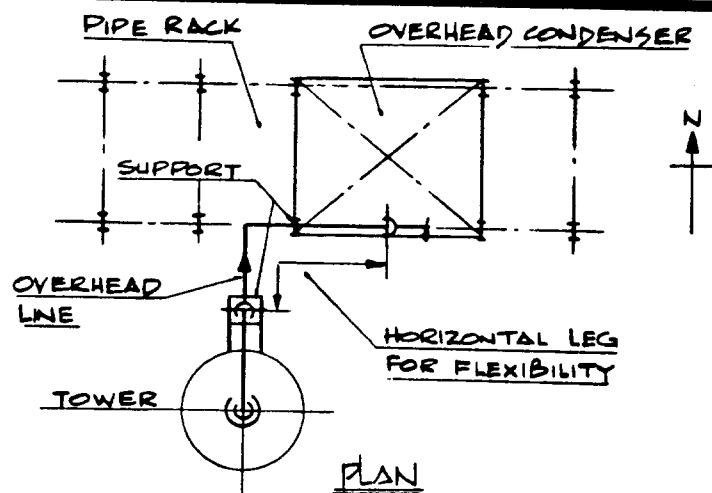
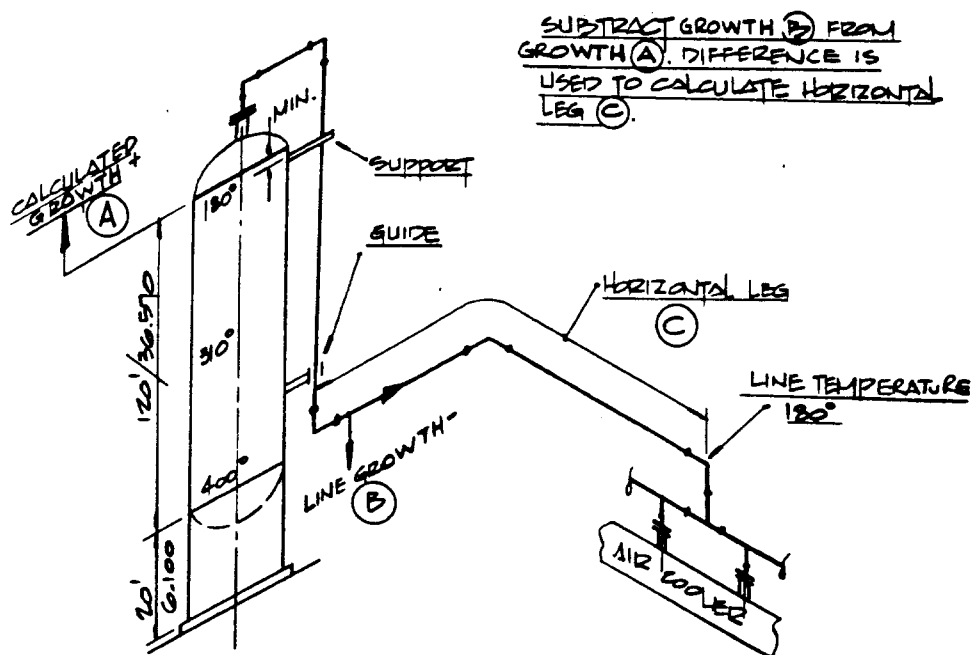
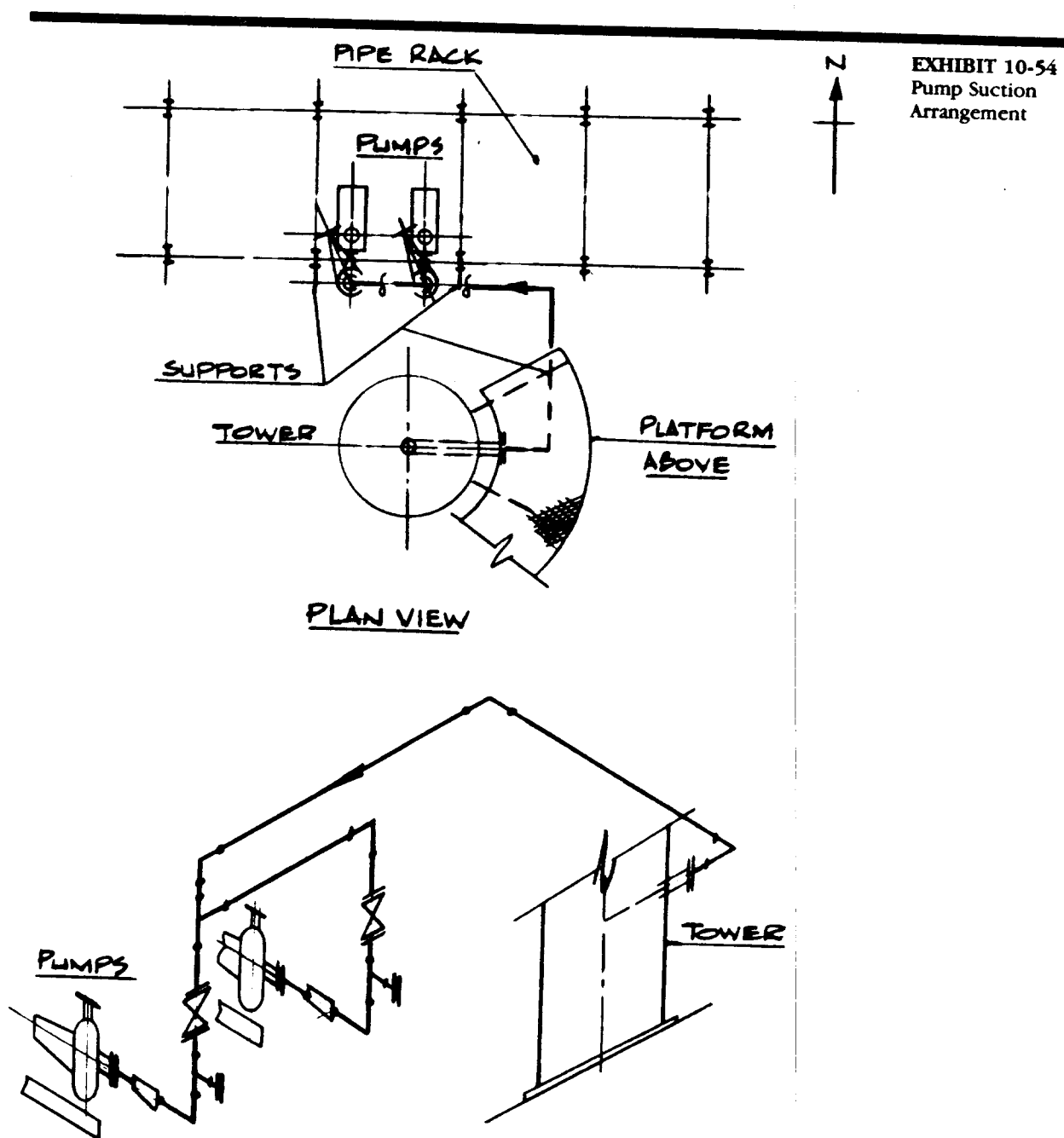


EXHIBIT 10-53
Overhead Arrangement





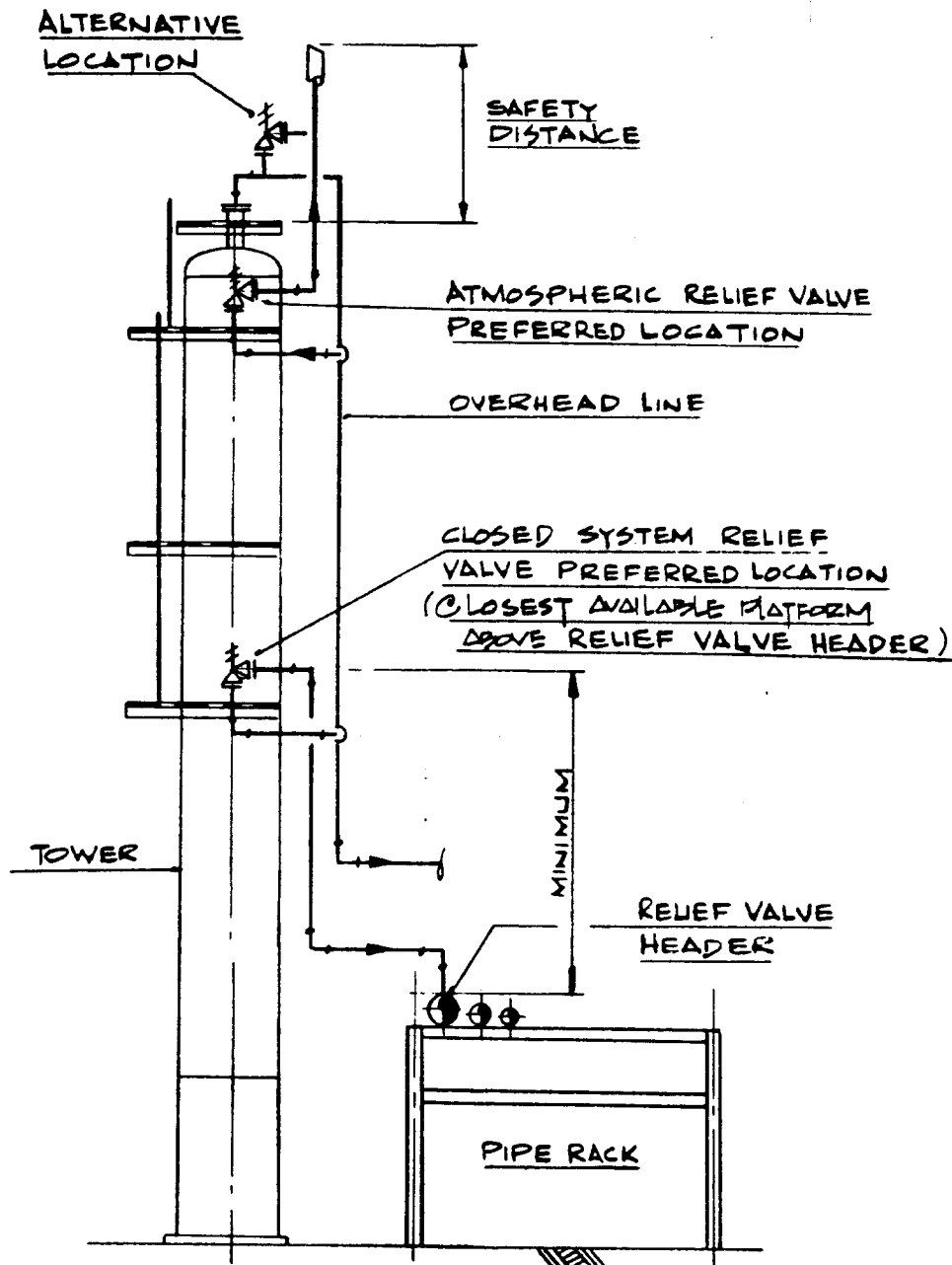
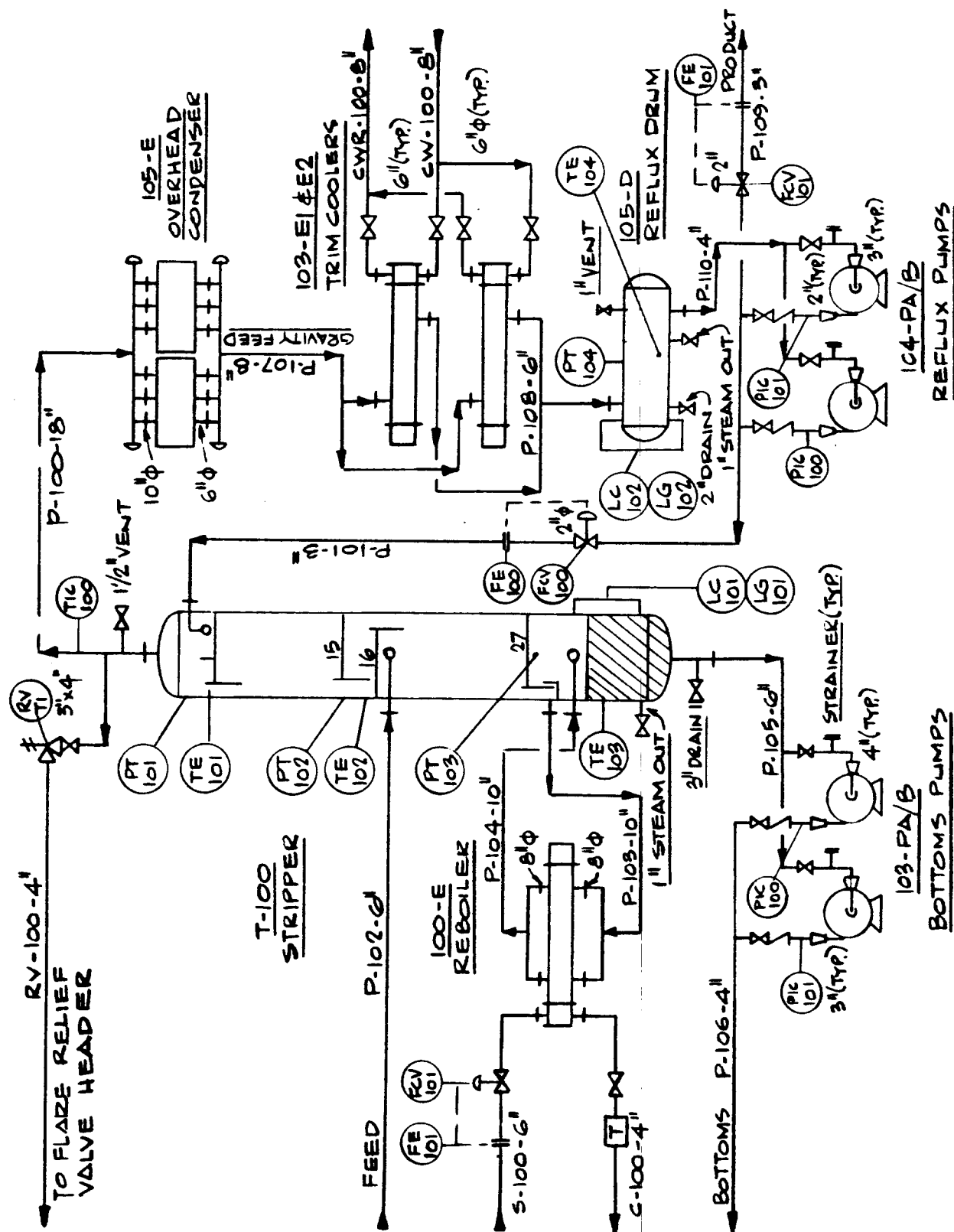
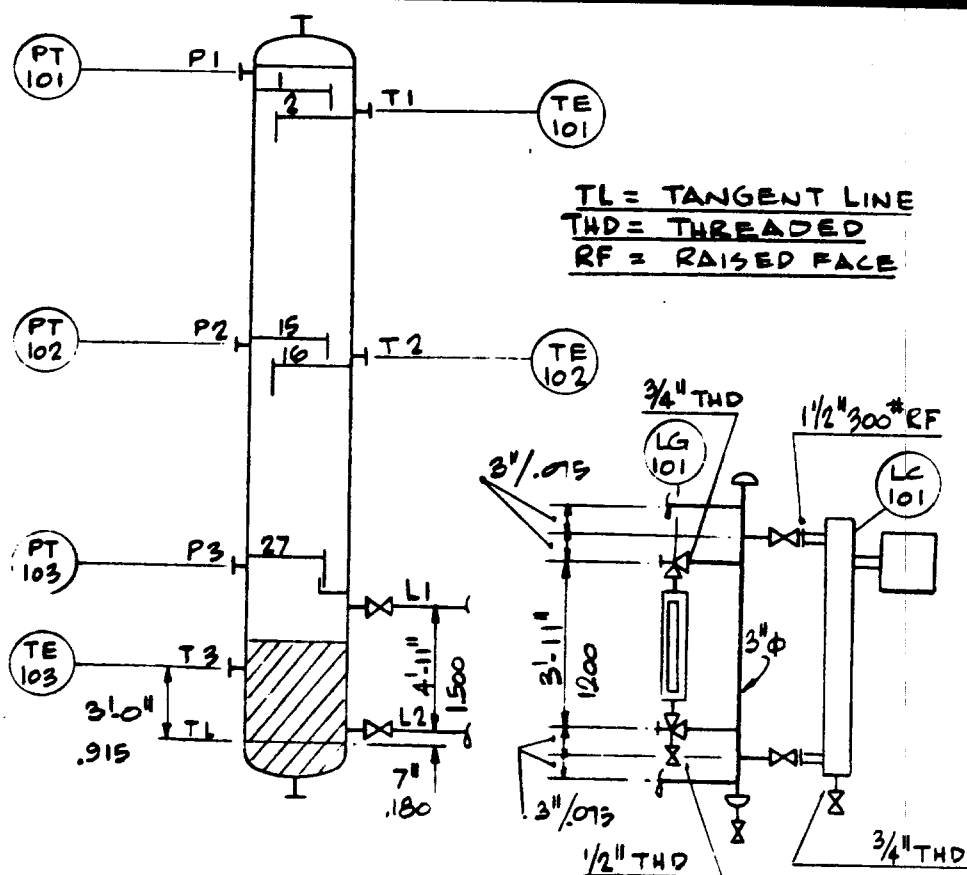


EXHIBIT 10-55
Relief Valve Systems

EXHIBIT 10-56 Preliminary Piping and Instrumentation Diagram





mounted indicators are available in a variety of styles, with straight or swivel heads that can be positioned for clear dial visibility. Exhibit 10-60 shows typical temperature and pressure connections.

The instrument arrangement shown in Exhibit 10-61 has been designed using the following information and the guidelines in this chapter:

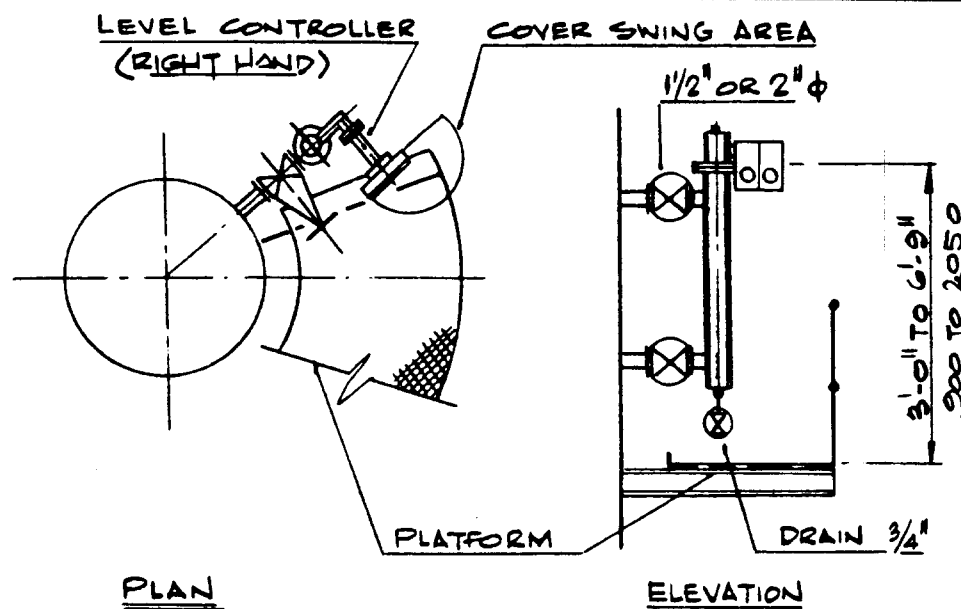
- Nozzle elevations (Exhibit 10-39).
- Instrument vessel sketch (Exhibit 10-58).

- Platform arrangement (Exhibit 10-50).
- Piping arrangement (Exhibit 10-57).
- Level instrument locations (Exhibit 10-35).

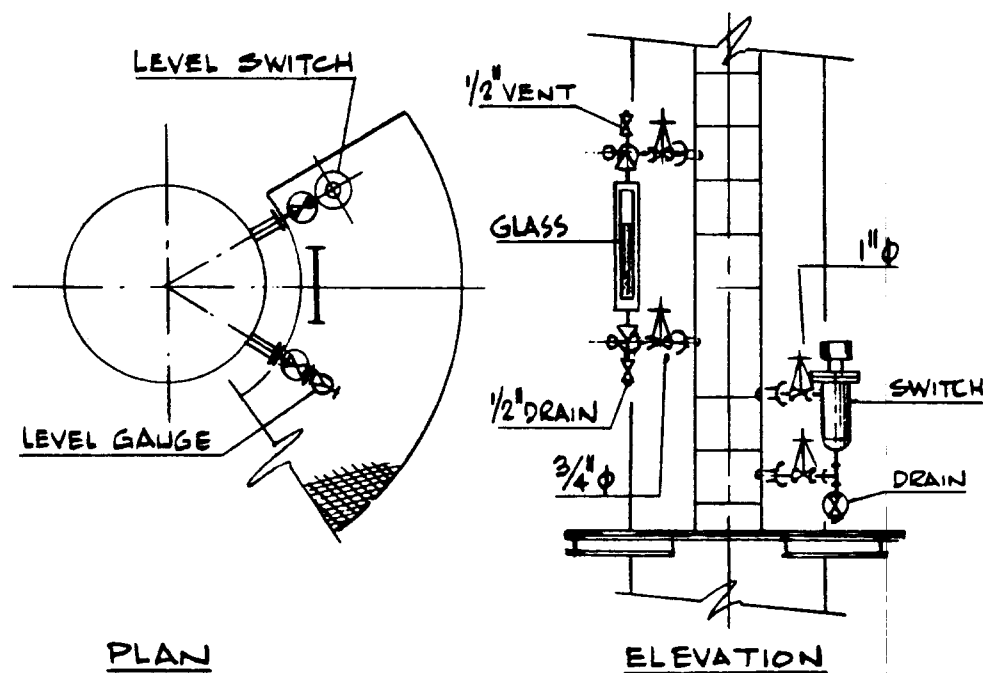
MAINTENANCE

Tower maintenance is usually limited to removal of exterior items (e.g., relief or control valves) and interior components (e.g., trays or packing rings). Han-

EXHIBIT 10-59
Arrangements for Level
Instruments



a. Single-Mounted Level Controller



b. Single-Mounted Level Gauge and Switch

dling of these items is achieved by fixed devices (e.g., davits or trolley beams) or by mobile equipment (e.g., cranes). When davits or beams are used, they are located at the top of the tower, accessible from a platform, and designed to lower the heaviest removable item to a designated drop area at grade. When mobile equipment is used, a clear space must be provided at

the back of the tower that is accessible from the plant auxiliary road. Exhibit 10-62 depicts a typical davit arrangement, Exhibit 10-63 shows a typical trolley beam arrangement, Exhibit 10-64 portrays a planned drop zone, and Exhibit 10-65 shows mobile equipment.

In certain cases, stiffening rings are specified as additional strengthening for the tower shell, especially

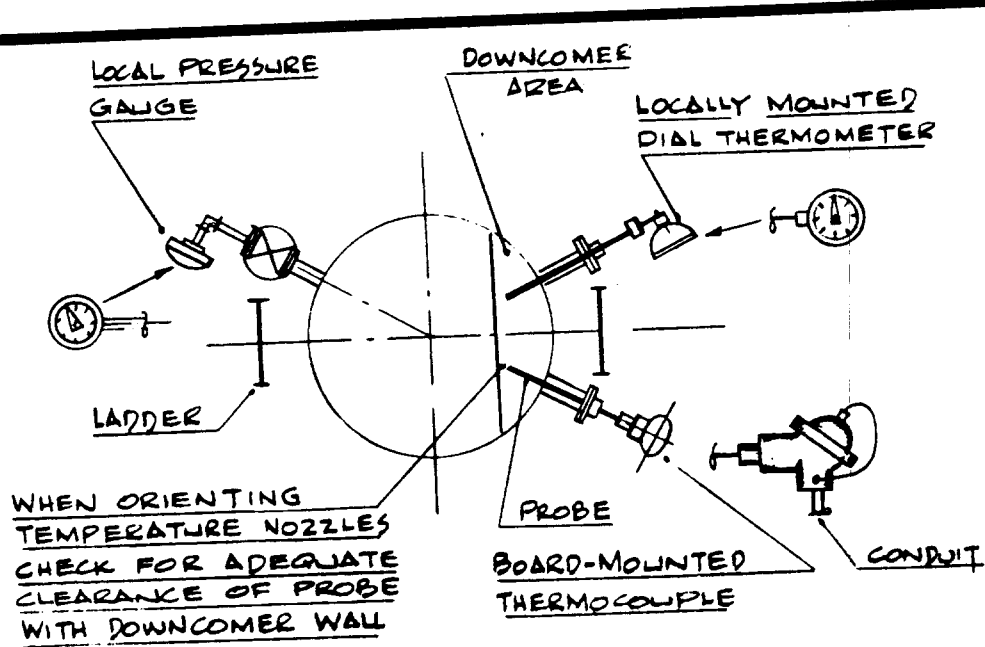
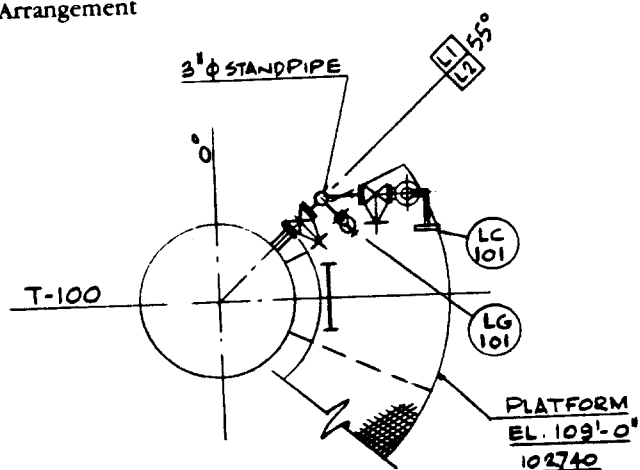


EXHIBIT 10-61 Common Bridle-Level Instrument Arrangement



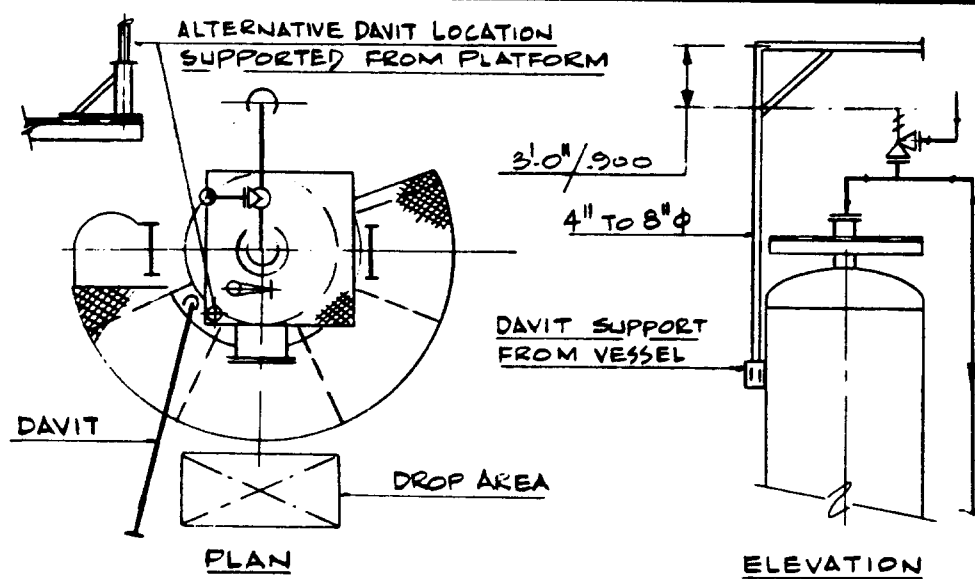


EXHIBIT 10-62
Typical Tower Davit
Arrangement

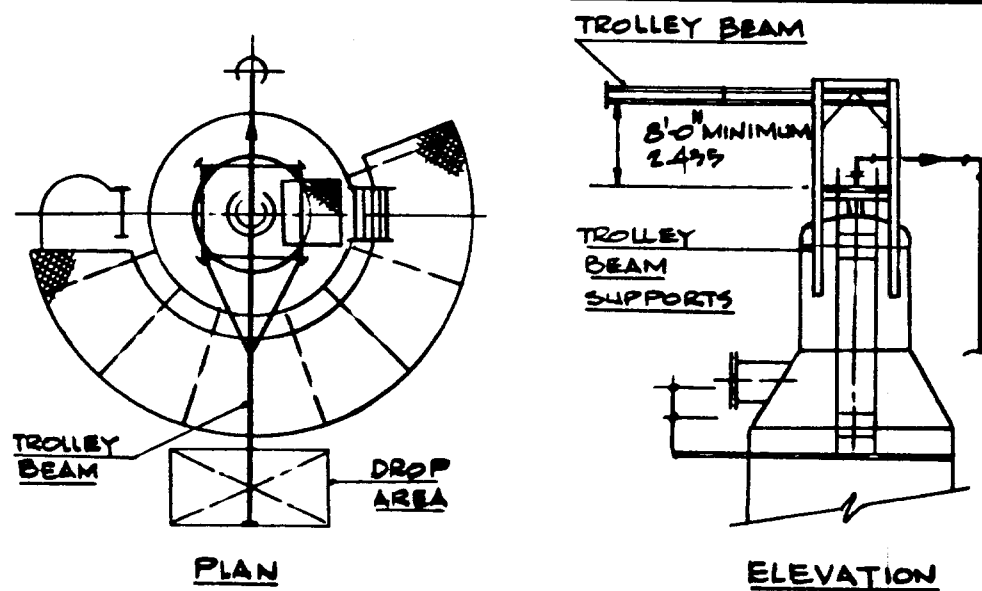


EXHIBIT 10-63
Typical Tower Trolley
Beam Arrangement

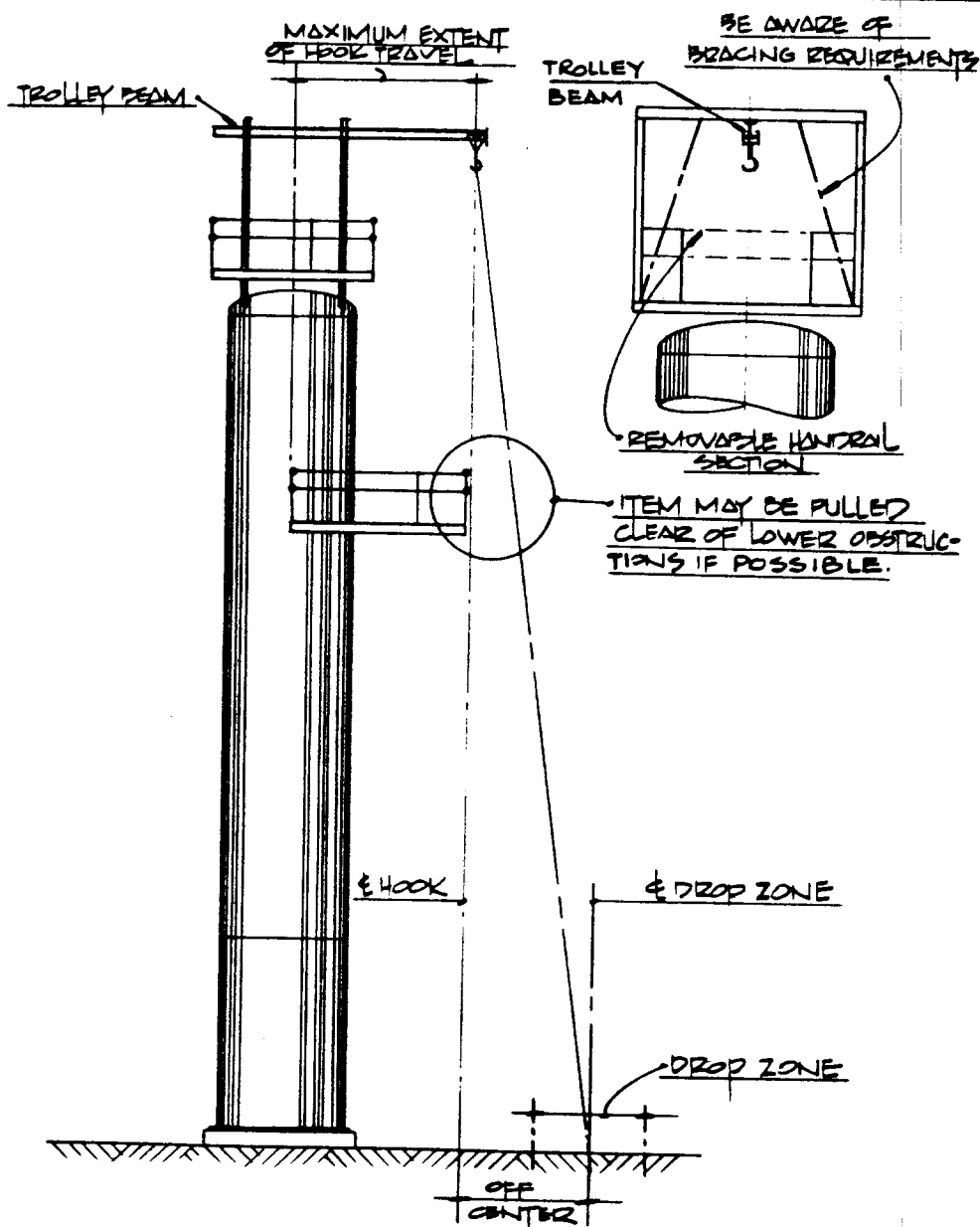
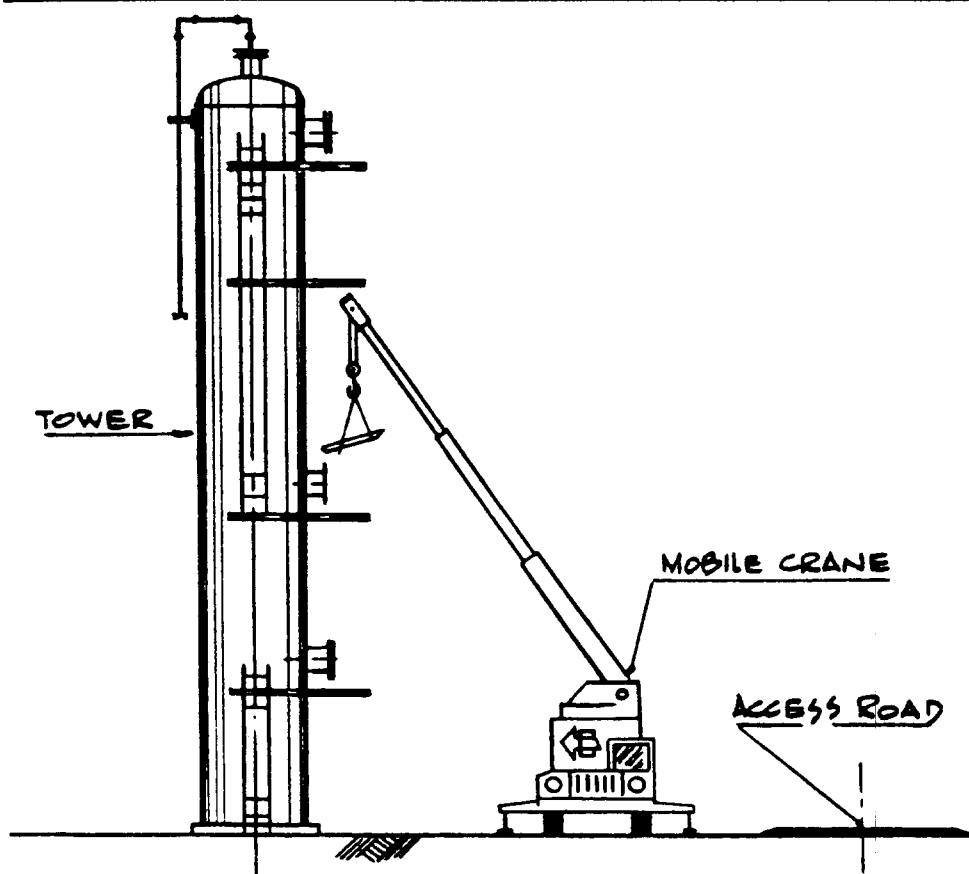


EXHIBIT 10-64
Planned Drop Zone

EXHIBIT 10-65
Mobile Equipment



for towers in vacuum service. Care must be taken in positioning the rings to allow adequate clearance at nozzles, platforms, ladders, and clips. A tower section with stiffening rings is shown in Exhibit 10-66. Because of size, towers can be shop fabricated in two or more sections for shipment in one piece or in sections for field welding. As with stiffening rings, allowances for clearances must be made between weld seams and attached fittings. The vendor's vessel fabrication draw-

ings show the location of weld seams; Exhibit 10-67 illustrates typical weld seams.

Utility stations are required at tower platforms that have maintenance accesses. Steam and air risers are the two services required and must be positioned during the tower layout stage so that adequate clips can be furnished for support. Exhibit 10-68 shows utility station requirements. Such towers as demethanizers operate under extremely cold conditions and sometimes

EXHIBIT 10-66 Stiffening Rings

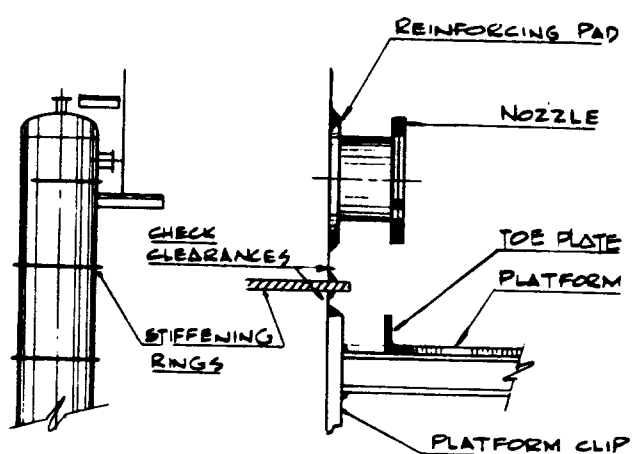


EXHIBIT 10-67 Tower Weld Seams

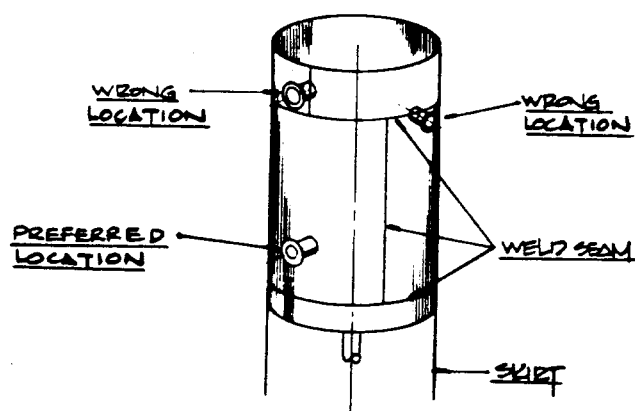
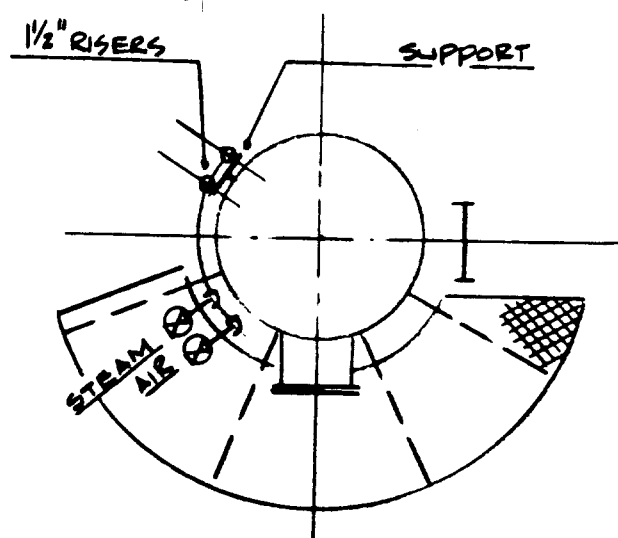


EXHIBIT 10-68 Utility Station Requirements



require increased standoff dimensions for nozzles, platforms, and ladders to clear extra-thick insulation and to prevent frost on supporting steelwork. Polyurethane insulators are usually furnished between trunnions and support brackets. Exhibit 10-69 shows typical cold-service tower requirements.

The dimensions, clearances, and guidelines highlighted in this chapter are an example of those to be used for tower arrangements. The plant layout designer, however, must be familiar with company and client tower standards before proceeding with tower layout and should coordinate the effort with such supporting groups as vessel, systems, process, and instrument engineering.

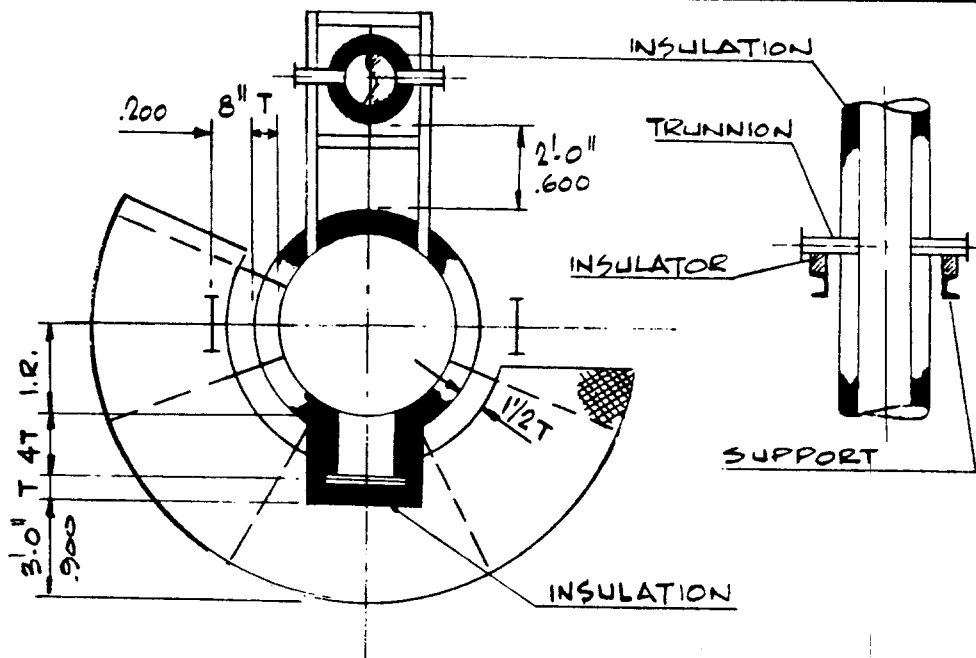


EXHIBIT 10-69
Cold-Service Tower
Requirements

T = INSULATION THICKNESS

Pipe Racks

A pipe rack is the main artery of a process unit. It connects all equipment with lines that cannot run through adjacent areas. Because it is located in the middle of most plants, the pipe rack must be erected first, before it becomes obstructed by rows of equipment. The corresponding piping drawings are also required early for the same reason. Pipe racks carry process and utility piping and may also include instrument and electrical cable trays as well as equipment mounted over all of these. This vital area requires considerable planning and coordination with other technology groups regarding construction because costs are so high.

This chapter explains what is required to finalize the pipe rack width, number of levels and elevations, and bent spacing and addresses pipe flexibility and access and maintenance concerns for each item located within the pipe rack area.

The primary data required for the detailed development of a pipe rack includes the following:

- Plot plan.
- Piping and instrumentation diagrams.
- Plant layout specification.
- Client specification.
- Construction materials.
- Fireproofing requirements.

ESTABLISHING WIDTH, BENT SPACING, AND ELEVATIONS

The first step in the development of any pipe rack is the generation of a line-routing diagram, shown in Exhibit 11-1. A line-routing diagram is a schematic representation of all process piping systems drawn on a copy of the plot plan. Although it disregards exact locations, elevations, or interferences, it locates the most congested piping bent in the pipe rack. Usually, the information available on early piping and instru-

mentation diagram issues covers only commodity, line number, and preliminary sizes.

Process flow diagrams provide insight to operating temperatures and identify the need for insulation. Once the routing diagram is complete, the development of rack width, bent spacing, and numbers of levels and elevations may proceed.

Bent Spacing

A pipe bent consists of a vertical column or columns and a horizontal structural member or members that carry piping systems, usually above headroom. The line sizes that are installed in the rack establish the bent spacing. Exhibit 11-2 is a typical pipe span chart and shows how far a particular line can span on the basis of size, schedule, liquid or vapor, and insulated or bare pipe. Pipe racks are tailored to a specific plant: pipe sizes in chemical plants are smaller than those found in refinery units. If a plant requires a 16-ft (4,900-mm) spacing, the variation in Exhibit 11-3 allows for a 32-ft (9,700-mm) spacing by adding intermediate bents supported from spandrels. Spandrels are horizontal structural members located along the longitudinal centerline that are used for structural stability, pipe support, or intermediate pipe bents. Doubling the column spacing as shown in 2A of Exhibit 11-3 may be required to cross roadways or avoid underground obstructions. The civil and structural engineers should be consulted to review the economics of the approach.

Setting the width of the pipe rack may then proceed. With the routing diagram, a dimensioned cross section is developed at the bent that will carry the most piping, which is bent No 12 in the example shown in Exhibit 11-4. Usually, pipe racks carry process lines on the lower level or levels, and the utility lines on the top level. Instrument and electrical trays are integrated on the utility level if space permits or on a separate level above all pipe levels. Any pipe rack design should provide for 20% future growth. When

EXHIBIT 11-1 Line-Routing Diagram

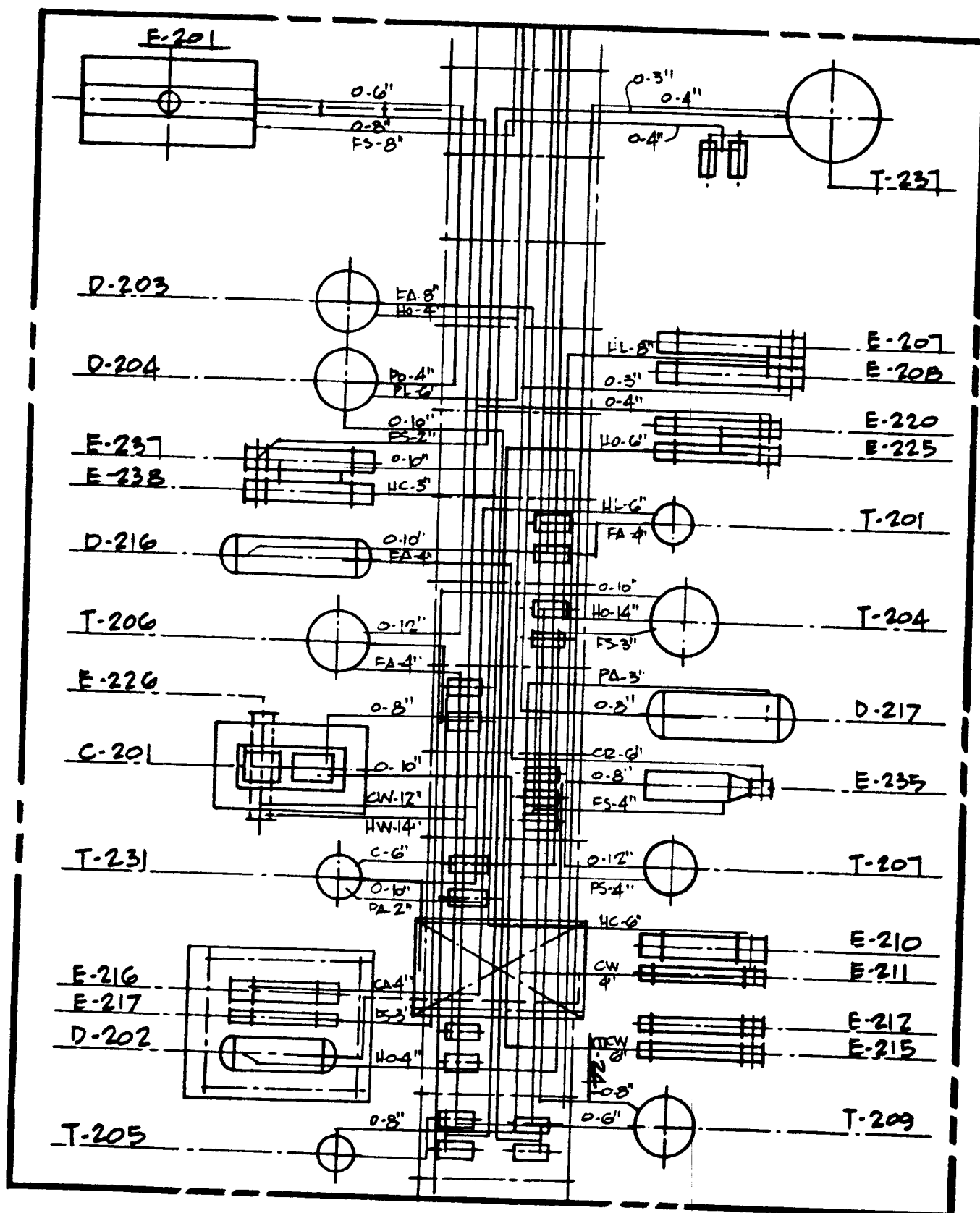


EXHIBIT 11-2 Basic Pipe Span Table

Size (inches)	Schedule (inches)	Corrosion Allowance	Vapor Line Insulation (Span)			Liquid Line Insulation (Span)			Bare Pipe (Span)		Size (inches)
			To 350° F	351° to 600° F	601° to 750° F	To 350° F	351° to 600° F	601° to 750° F	Empty (to 350° F)	Water Filled (to 350° F)	
3/4	40	0.05	12	11	8	12	10	-	14	13	3/4
1	40	0.05	14	13	10	14	12	9	16	14	1
1 1/2	40	0.05	18	14	14	17	15	12	19	17	1 1/2
2	40	0.10	18	16	11	17	15	11	21	18	2
2 1/2	40	0.10	23	19	16	19	18	15	25	21	2 1/2
3	40	0.10	24	21	18	21	19	16	26	22	3
4	40	0.10	27	25	22	24	23	19	29	25	4
6	40	0.10	33	31	28	29	27	25	34	29	6
8	40	0.10	39	36	33	33	32	29	40	33	8
10	40	0.10	44	42	39	37	35	34	46	38	10
12	3/8 w	0.10	47	45	42	39	38	36	49	40	12
14	3/8 w	0.10	49	47	44	40	39	37	52	41	14
16	3/8 w	0.10	53	50	47	42	41	39	55	43	16
18	3/8 w	0.10	56	54	50	44	43	40	59	45	18
20	3/8 w	0.10	59	57	53	46	45	41	62	46	20
24	3/8 w	0.10	65	62	58	48	47	43	68	49	24
3/4	80	0.10	12	10	-	11	10	6	14	13	3/4
1	80	0.10	14	12	10	13	12	9	16	14	1
1 1/2	80	0.10	17	16	14	16	15	13	19	17	1 1/2
2	80	0.10	19	17	14	18	16	13	21	19	2
2 1/2	80	0.10	22	20	18	20	19	17	23	21	2 1/2
3	80	0.10	24	22	20	22	21	19	25	23	3
4	80	0.10	27	26	23	25	24	22	29	26	4
6	80	0.10	34	32	30	31	29	28	35	31	6
8	1/2 w	0.10	39	37	35	35	33	32	40	36	8
10	1/2 w	0.10	44	42	39	38	37	35	45	39	10
12	1/2 w	0.10	47	45	43	41	40	38	49	42	12
14	1/2 w	0.10	50	48	45	42	41	40	51	44	14
16	1/2 w	0.10	53	51	49	44	43	42	55	46	16
18	1/2 w	0.10	57	55	52	47	46	44	59	48	18
20	1/2 w	0.10	59	57	55	49	47	46	62	49	20
24	1/2 w	0.10	65	63	60	52	50	49	68	52	24
1	XXS	0.25	14	13	10	13	12	10	15	14	1
1 1/2	XXS	0.25	17	16	14	16	15	14	18	17	1 1/2
2	XXS	0.25	20	18	15	18	17	15	21	19	2
2 1/2	160	0.25	21	19	17	19	18	16	23	21	2 1/2
3	160	0.25	24	22	20	22	21	19	25	23	3
4	120	0.25	27	26	23	25	24	22	29	26	4
6	80	0.25	33	31	28	28	27	26	35	29	6
8	1/2 w	0.25	38	34	33	32	30	40	34	8	8
10	1/2 w	0.25	43	41	38	36	35	33	45	37	10
12	1/2 w	0.25	47	45	41	38	37	35	49	39	12
14	1/2 w	0.25	49	47	44	39	38	37	52	40	14
16	1/2 w	0.25	52	50	48	41	40	39	55	42	16
18	1/2 w	0.25	56	53	50	43	42	40	59	47	18
20	1/2 w	0.25	59	56	53	45	44	42	62	45	20
24	1/2 w	0.25	64	60	58	47	46	45	68	48	24

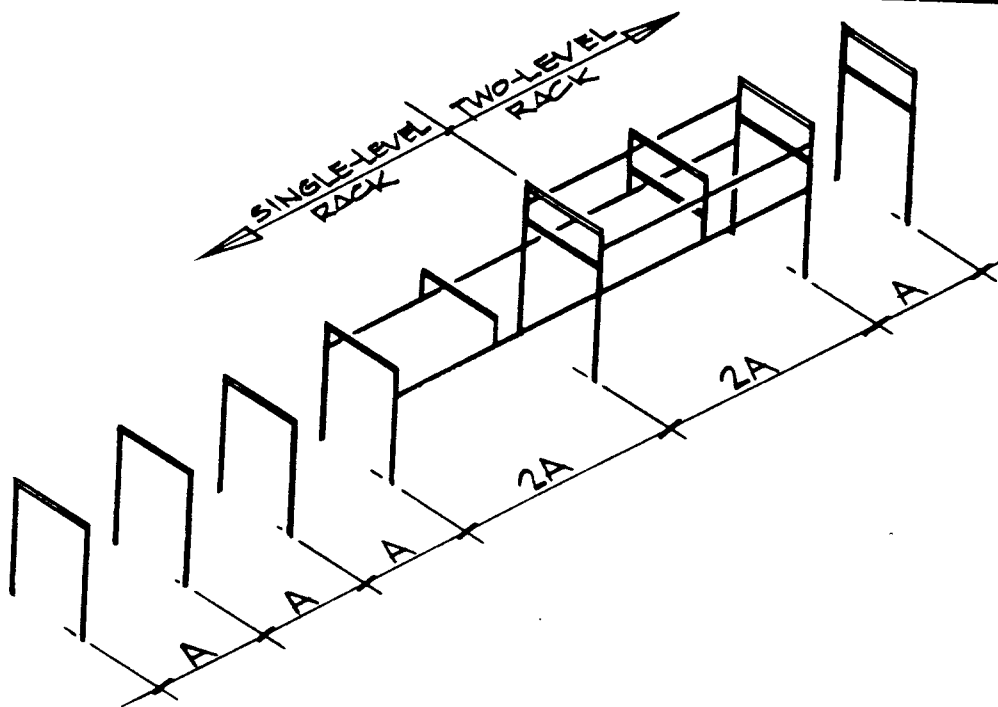


EXHIBIT 11-4
Pipe Rack Cross Section
(at Column 12)

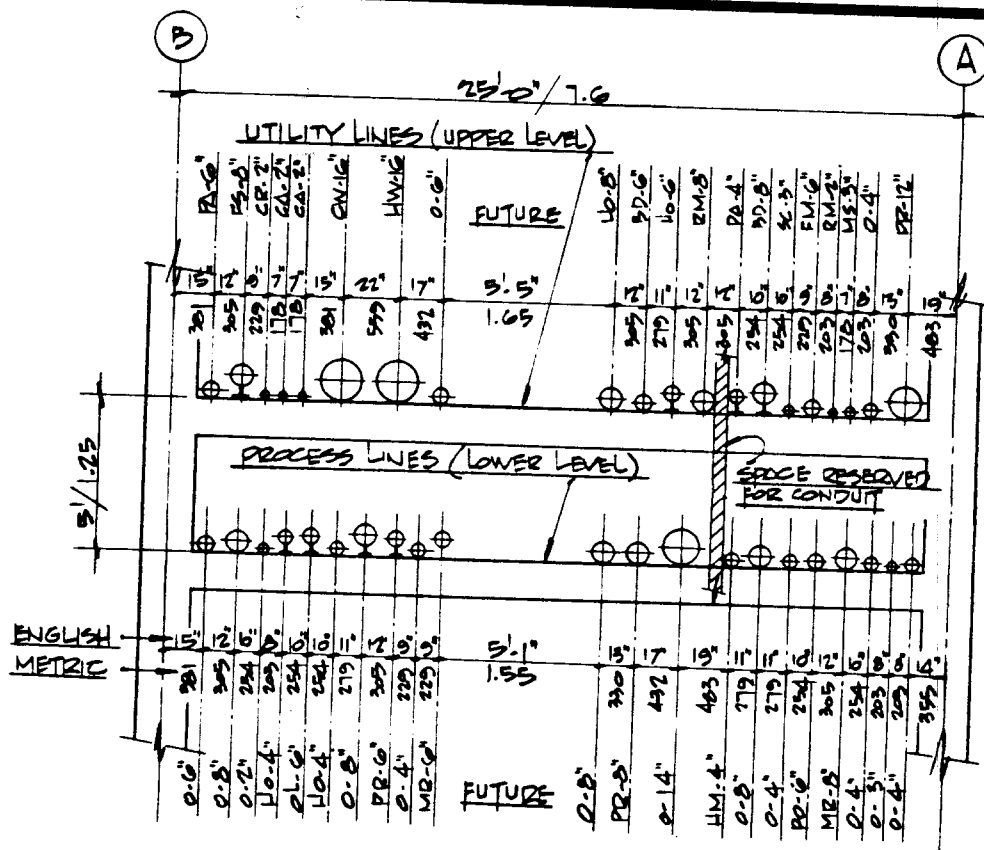
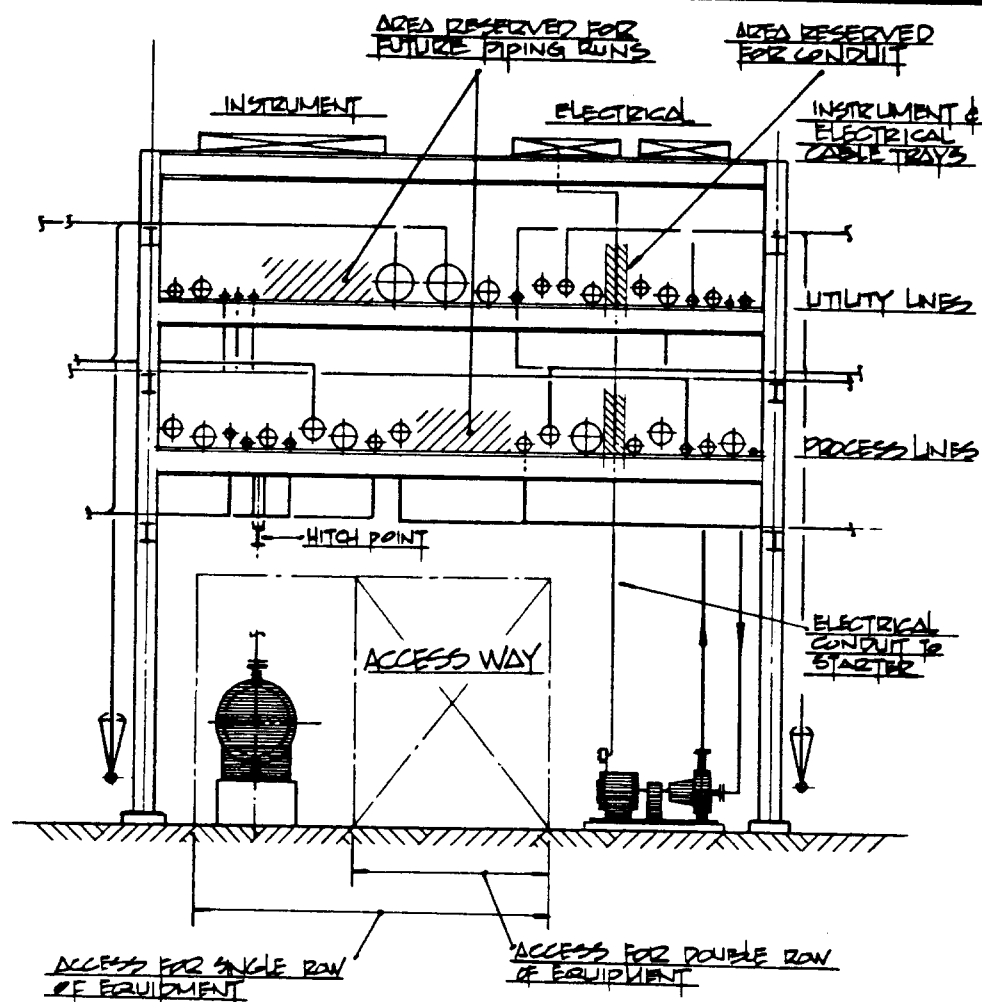


EXHIBIT 11-5
Pipe Rack Composite



the electrical conduit trays are located on the top level and a row of motor-driven pumps is located beneath the rack at grade, a 6-in (150-mm) slot should be provided to allow the conduit to run in the most direct manner and avoid running to the outside of the rack and back to the pumps. This feature is illustrated in Exhibit 11-5. Once future rack growth and conduit have been allowed for in the plan, the spacing may be set with the line spacing chart in Exhibit 11-6.

When flanges or flanged valves are required on two adjacent lines, the flanges are staggered as depicted in Exhibit 11-7. Thermal expansion or contraction must be accommodated, as shown in Exhibit 11-8. When all the distances have been established between all lines on each level, including allowances for future growth and conduit, the only remaining dimension to be set is the distance from the first line in the rack to the vertical column centerline. Column sizes are furnished by the civil/structural engineers.

The last step is to add up all the dimensions and round off to the next whole number—for example, 20

ft (6,100 mm) rather than 19 ft 3 in (5,850 mm). To illustrate, if the pipe requires a much greater area in the rack, the designer would work with the structural engineers to determine whether the pipe rack should be two 30-ft (9,150-mm) wide levels or three 20-ft (6,100-mm) wide levels. This decision affects the cost of the structure and pipe and must be made carefully.

After the bent spacing, rack width, and number of levels are established, the elevation of the levels must be set. As discussed in Chapter 2, the plant layout designer must know the minimum clearances to set the elevations. Plant roads, type of mobile equipment, and equipment located beneath the pipe rack can influence the pipe rack elevation. Usually, space is allowed below the pipe rack for equipment, with a minimum clearance of 10 ft (3,050 mm).

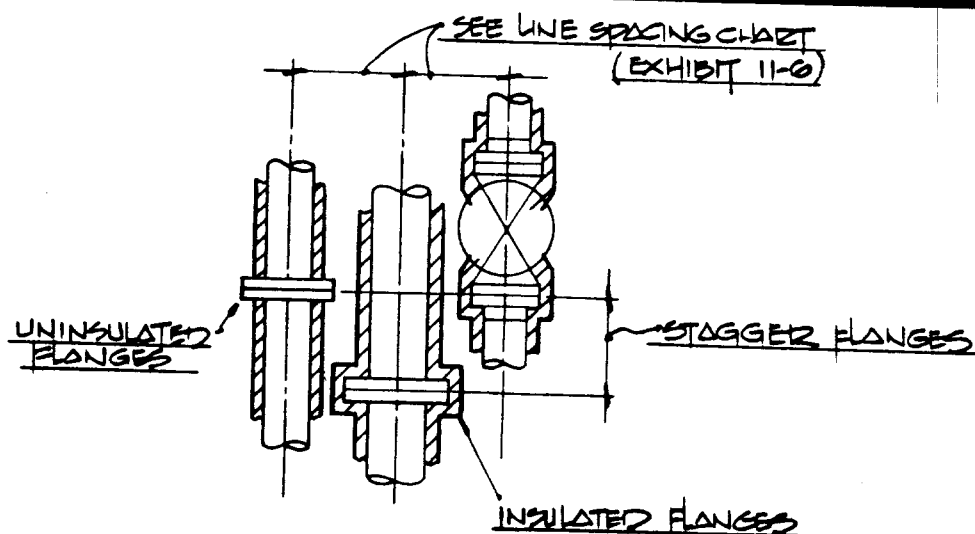
The next factor to consider is the dimension between the bottom of a line in the rack and the bottom of a branch as it leaves the rack. For example, if a review of the largest lines in the entire pipe rack indicates that there are two or three large-diameter

EXHIBIT 11-6 Line Spacing Chart

LINE SIZE		150# FLANGE														300# FLANGE													
		1	1½	2	3	4	6	8	10	12	14	16	18	20	24	1	1½	2	3	4	6	8	10	12	14	16	18	20	24
ADJACENT LINE SIZE	1	7	7	7	7	7	8	9	10	12	13	14	15	16	18	7	7	7	7	7	8	9	10	12	13	14	15	16	18
	1½		7	7	7	7	8	9	10	12	13	14	15	16	18		7	7	7	7	9	10	11	13	14	15	16	18	
	2			7	7	7	8	9	11	12	13	14	15	16	19			7	7	8	9	10	11	13	14	15	16	18	20
	3				7	8	9	10	11	13	14	15	16	17	19				7	8	9	11	12	13	15	16	17	18	21
	4					8	9	10	12	13	14	15	16	17	20					9	10	11	12	14	15	16	17	18	21
	6						10	11	13	14	15	17	17	19	21						11	12	13	15	16	17	19	20	22
	8							12	14	15	16	18	18	19	22							13	14	16	17	18	20	21	23
	10								15	16	17	19	19	21	23								15	17	18	19	21	22	24
	12									17	18	20	20	22	24									18	19	20	22	23	25
	14										19	20	21	22	24										21	22	23	24	26
16											21	22	23	25											22	23	25	27	
18												23	24	26												24	26	28	
20													25	27													27	29	
24														29														31	

NOTES:

- SPACING IS BASED ON RADIUS OF PIPE TO FLANGE + 1" / .025.
- SELECT LINE WITH LARGEST FLANGE DIAMETER, FIND ADJACENT LINE SIZE & READ ACROSS TO FIND CENTERLINE-TO-CENTERLINE DIMENSIONS, IN INCHES.
- ADJUST DIMENSION TO SUIT INSULATION THICKNESS.
- CALCULATE SPACING WHERE PIPE RACK REAL ESTATE IS LIMITED.
- ADJUSTMENTS TO SPACING FOR THERMAL EXPANSION OR CONTRACTION MUST BE MADE.

EXHIBIT 11-7
Line Spacing

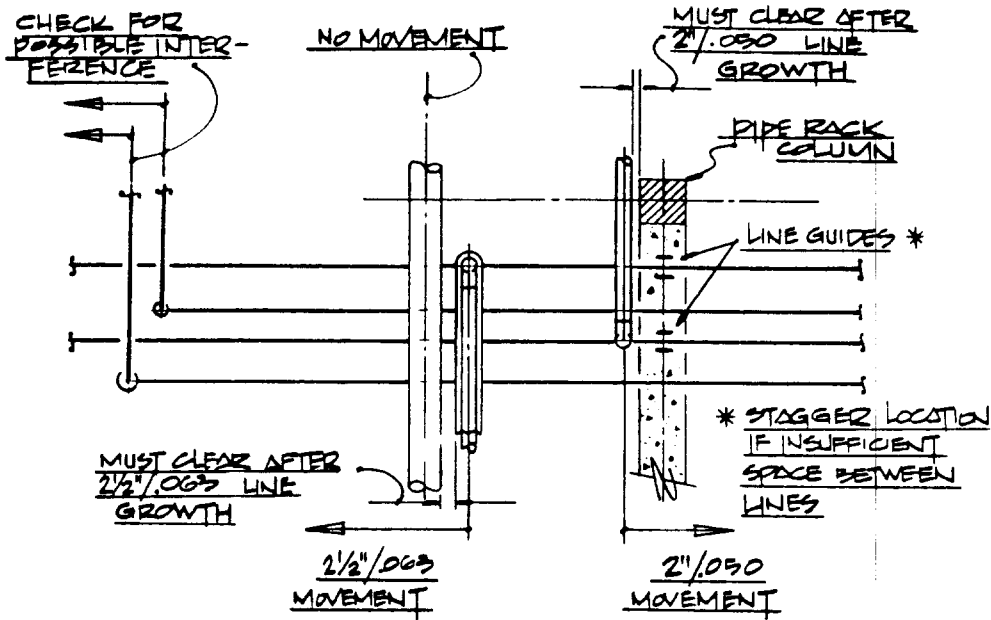


EXHIBIT 11-8
Planning for Line Growth

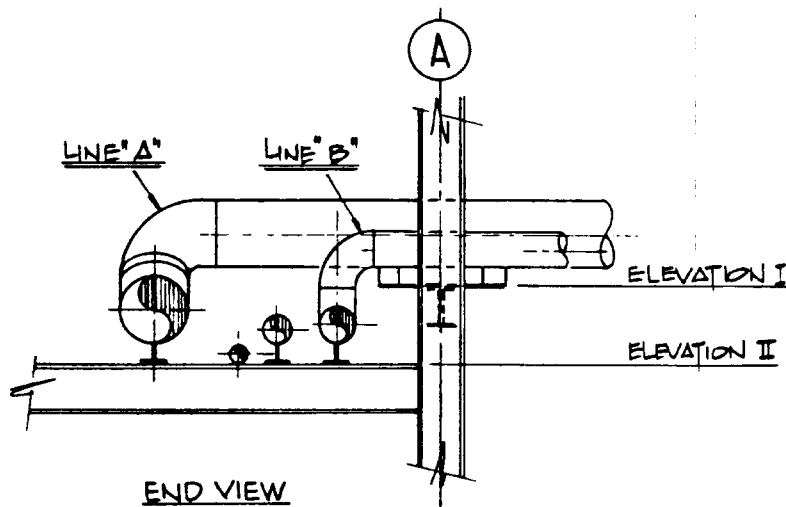


EXHIBIT 11-9
Large-Diameter Lines

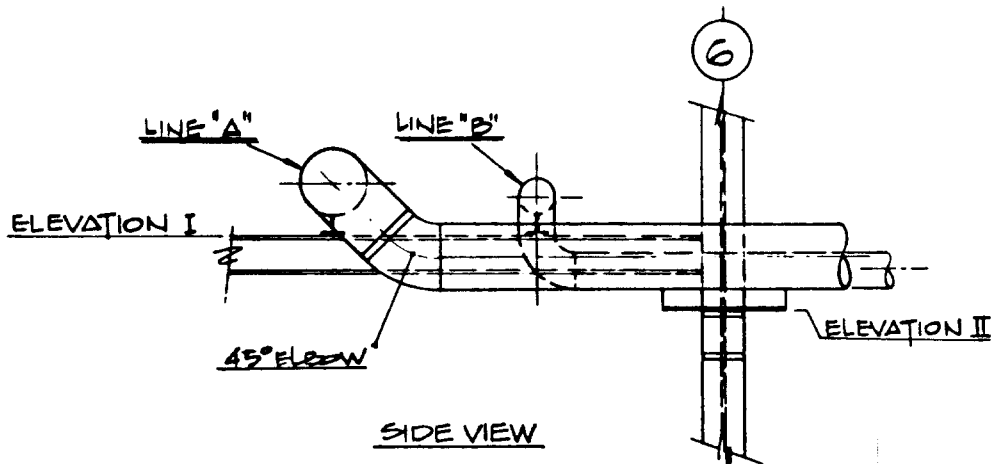
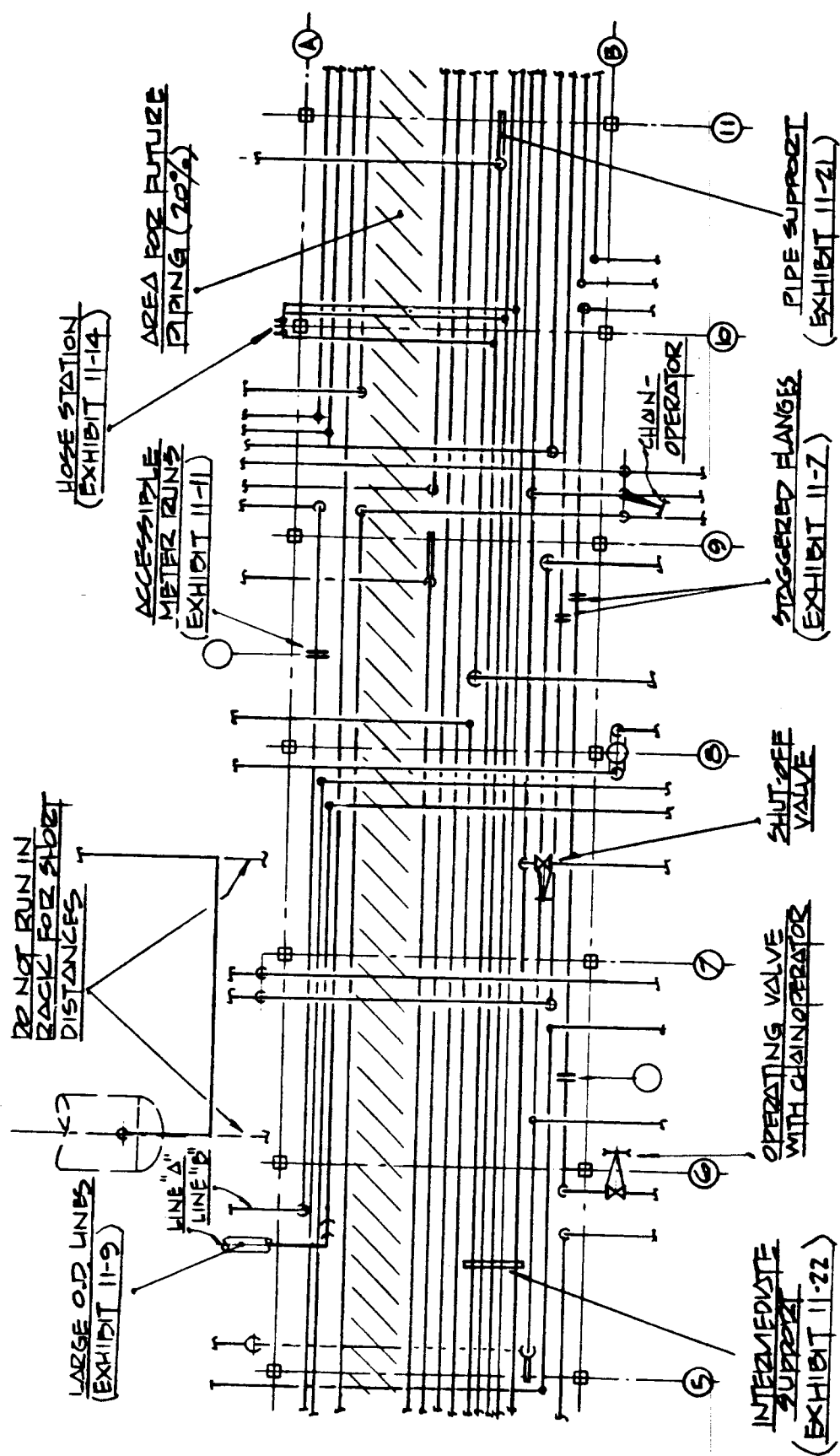


EXHIBIT 11-10 Pipe Rack Layout



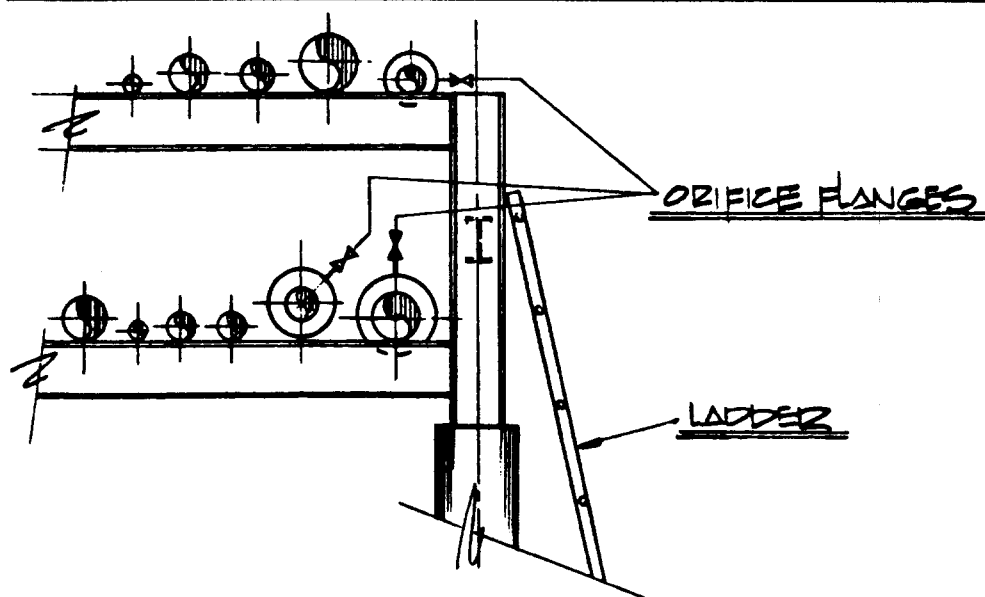


EXHIBIT 11-11
Pipe Rack Meter Runs

lines (e.g., 18, 20, or 24 in) and the remaining lines are 12 in, the exit level above and below the rack can be 3 ft (915 mm). The dimension from the end of a 90° butt-weld elbow to the centerline of a 12-in line is 18 in (457 mm). Exhibit 11-9 illustrates how to handle the large-diameter lines by using a 45° elbow or trimming an elbow to a more shallow angle. If the instrument and electrical conduit are installed on a separate level, the estimated dimensions of each tray must be obtained from the instrument and electrical engineers to ensure that adequate space is provided.

The design of the pipe rack is now complete with the exception of installing equipment over the rack.

SETTING LINE, VALVE, AND INSTRUMENT LOCATIONS

Many factors must be considered when locating each line, valve, and instrument in a pipe rack. Exhibit 11-10

is an example of a typical layout.

A common arrangement of a standard process unit pipe rack is one in which the process lines are on the lower level or levels. The utility piping is on the top level, which carries piping. Electrical and instrument cable trays are located on the top level with the utility piping or on a separate level above the utility piping, depending on the extent of cable tray area required. The plant layout designer must consult the electrical and instrument engineers early in the pipe rack layout to establish these requirements.

When locating lines in the rack, the plant layout designer should run the largest lines near the outside where possible to reduce the overall load on the supporting beams. Meter runs should be installed directly next to the columns so that access is available by portable ladder or mobile platform, as shown in Exhibit 11-11. Meter runs are located in the pipe rack only when absolutely necessary.

Many relief headers must be located above the top

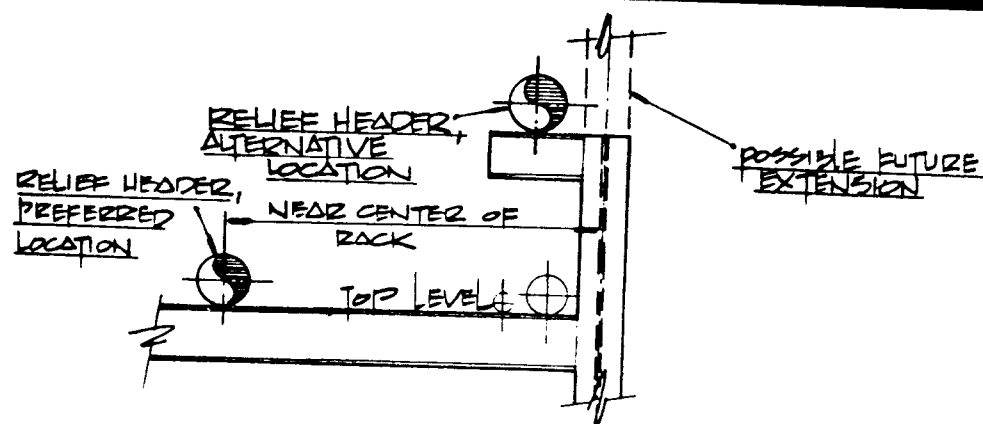


EXHIBIT 11-12
Relief Header Location

EXHIBIT 11-13 Alternative Pipe Rack Expansion

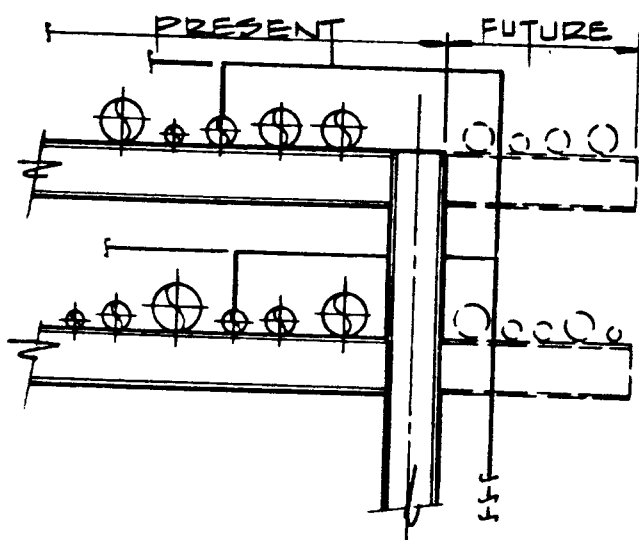
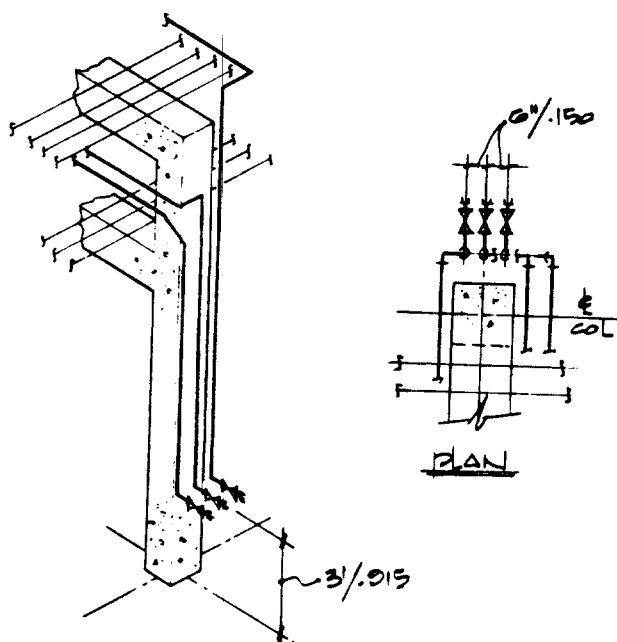


EXHIBIT 11-14 Hose Station at a Pipe Rack Column



level of the rack to allow the line to drain to the blow-down drum. The designer should avoid locating the line over the centerline of the column for support so that the columns can be extended for future rack expansion. Exhibit 11-12 shows a suggested location for the relief header that does not impede future expansion.

Shut-off valves at utility headers are located inside the rack area in the horizontal position, directly above the header if room permits. Operating valves must be accessible from platforms or by chain operators. The location of the valve must also permit the chain to fall free of obstructions that would hamper operation. An additional 20% of space must be allowed for future pipe rack growth. An alternative approach to such expansion is shown in Exhibit 11-13.

Because space in the pipe rack is limited once the design is set, it is important to route lines to avoid

dead spaces. The designer can minimize runs in the rack by consulting with the adjacent-area designers to identify which lines can run within the areas. Because the development of a pipe rack often includes swapping lines, it is advised that the designer draw the lines lightly until satisfied with the design. Once the layout is optimized, the line definition can be finalized.

A pipe rack composite is shown in Exhibit 11-5. This view highlights features mentioned previously and clarifies additional considerations. For example, the width of the access way is determined by the space needed to maintain the equipment located at grade below the pipe rack. For process or cost reasons, shell and tube exchangers may be located under a pipe rack in certain process units. Allowances must be made to

maintain such units (e.g., providing a hitch point over the channel end to facilitate its removal). Once again, it is extremely important to know exactly what kind of mobile handling equipment the plant will use.

The vertical drop of lines outside the rack, although usually 2 ft (610 mm), is once again set by the average line size in the unit. If the average line size is 2 in, a 12-in (300-mm) drop may be sufficient. This view also shows how the electrical conduit can be run directly to the pump starter switch.

Exhibit 11-14 shows a typical arrangement for a hose station. Battery limit valving for a single-level pipe rack is shown in Exhibit 11-15. The valves are staggered on either side of the catwalk, and hand-wheel extension stems are furnished when necessary to facilitate operation. Exhibit 11-16 also displays a single-level rack. Here, however, an elevation change is required between the process unit and the off-site pipe rack. This design has the block valves installed in the vertical portion of the line, which allows for relative ease of operation.

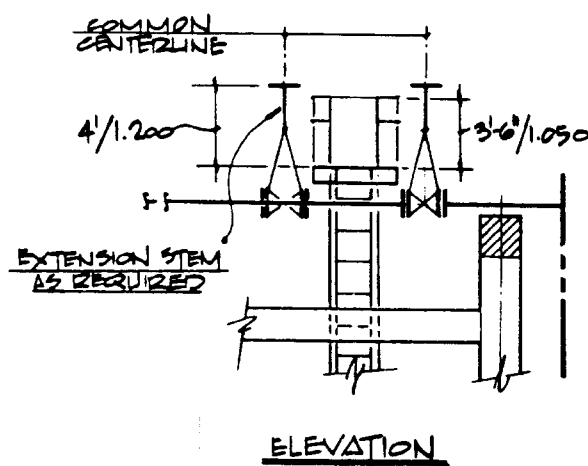
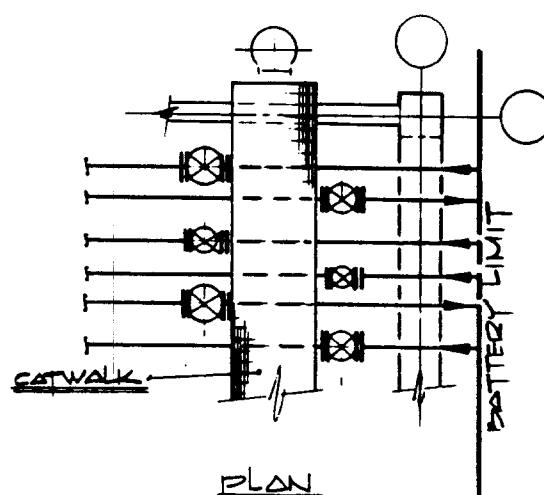
Exhibit 11-17 illustrates a two-level process unit pipe rack; the elevation change to the off-site area is either above or below the process unit pipe rack.

PIPE FLEXIBILITY AND SUPPORTS

Although conducting the final stress analysis is the responsibility of the mechanical or stress engineer, the pipe rack designer makes preliminary calculations using relevant books and nomograms to ensure that the design will not require major rework during the formal stress check. Exhibit 11-18 highlights the steps involved in making a preliminary flexibility check, which are discussed in the following sections.

Establishing potential flexibility problems The lines that would most likely require expansion loops should be defined. Steam headers in the top level of the pipe rack are such examples.

EXHIBIT 11-15 Battery Limit Valving: Single-Level Rack (Process/Off-Site Common Elevation)



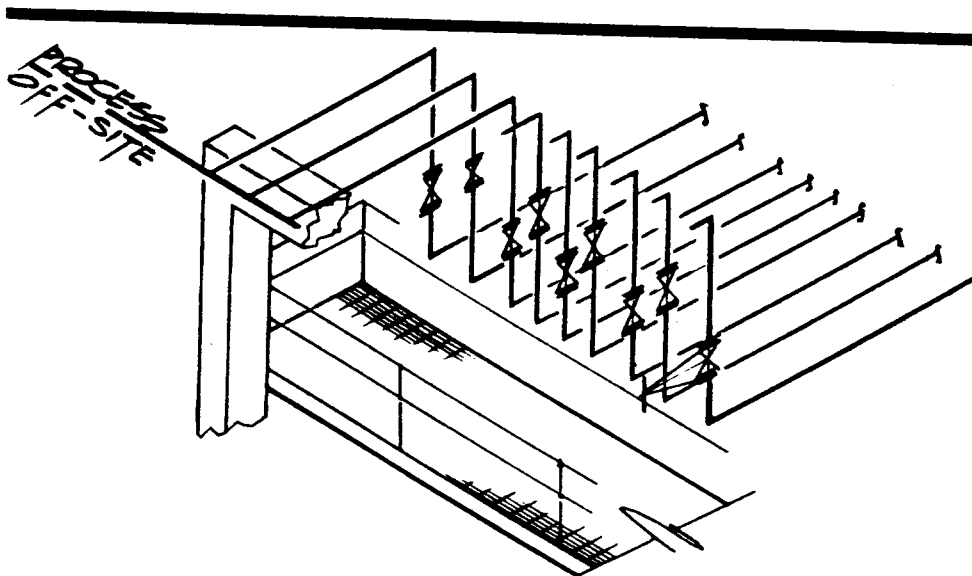
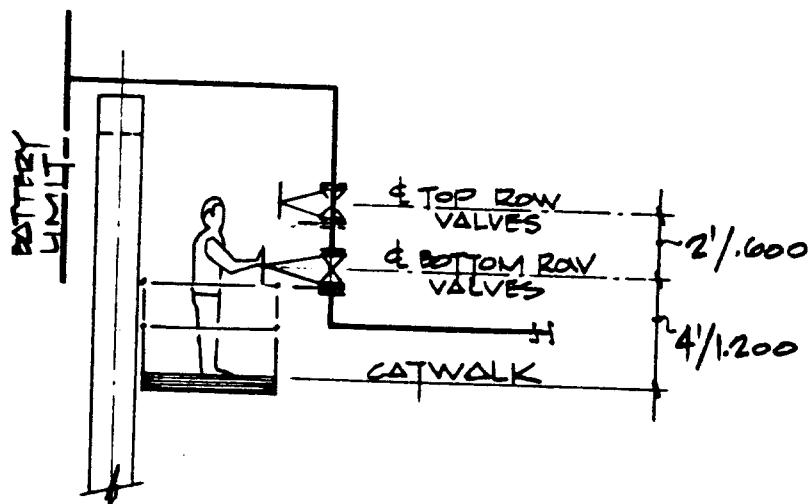


EXHIBIT 11-16
Battery Limit Valving:
Single-Level Rack
(Process/Off-Site
Elevation Change)



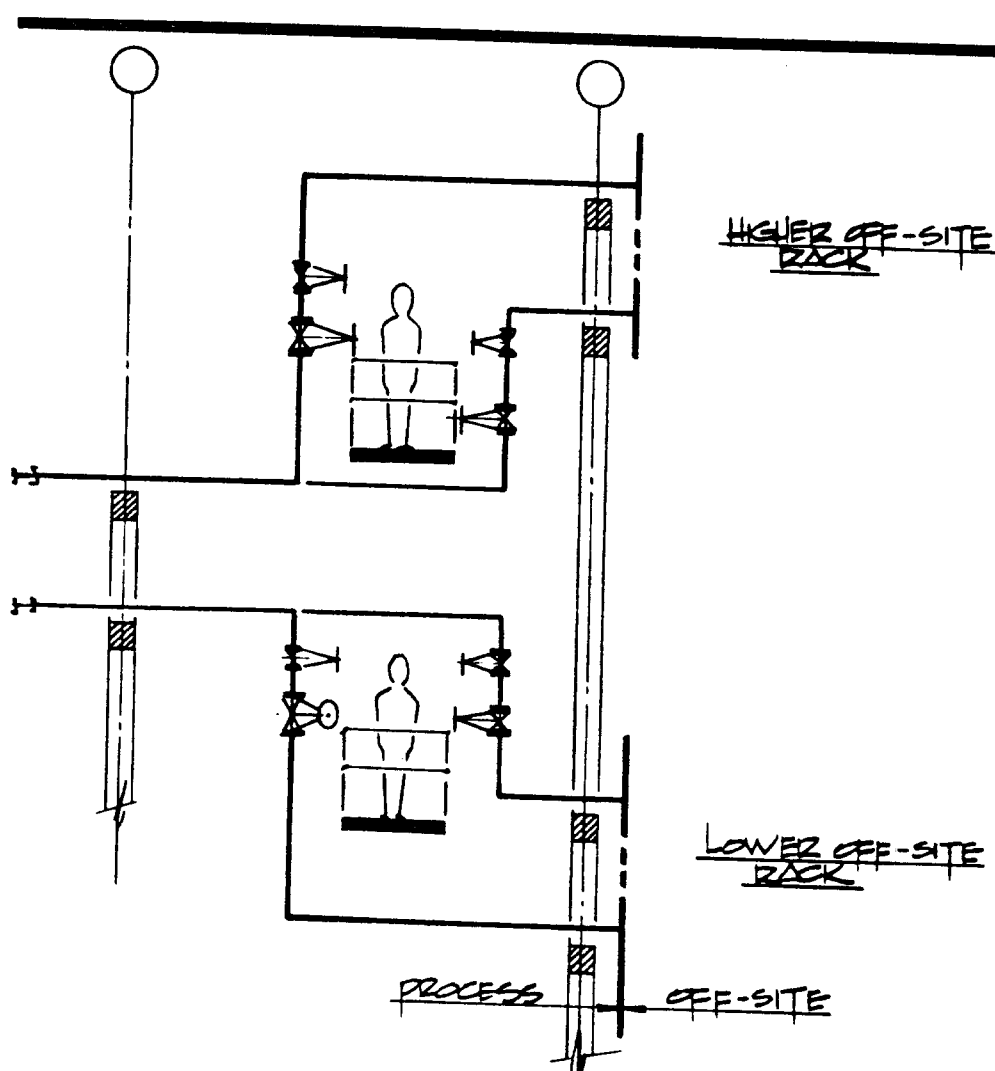
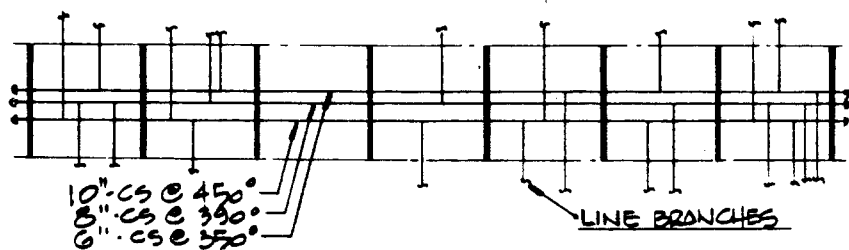
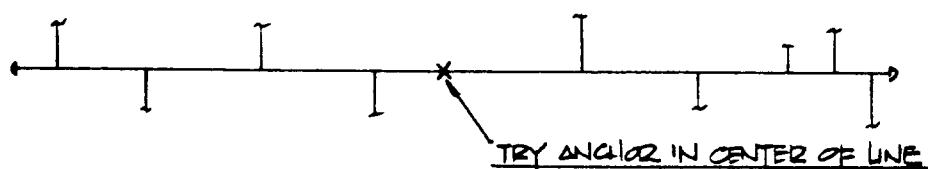
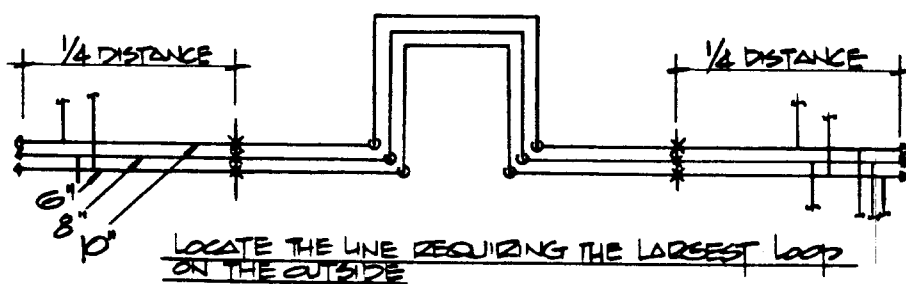


EXHIBIT 11-17
Battery Limit Valving:
Two-Level Rack
(Process/Off-Site
Elevation Change)

EXPANSION LOOPSEXHIBIT 11-18
Flexibility Check StepsSTEP I: ESTABLISH POTENTIAL FLEXIBILITY PROBLEMSMULTIPLY COEFFICIENT OF EXPANSION X LENGTH OF LINESTEP II: DETERMINE LINE GROWTH FOR THREE LINESSTEP III: DETERMINE WHETHER ONE ANCHOR POINT
WILL SUFFICESTEP IV: ARRANGE LINES IN PROPER SEQUENCE

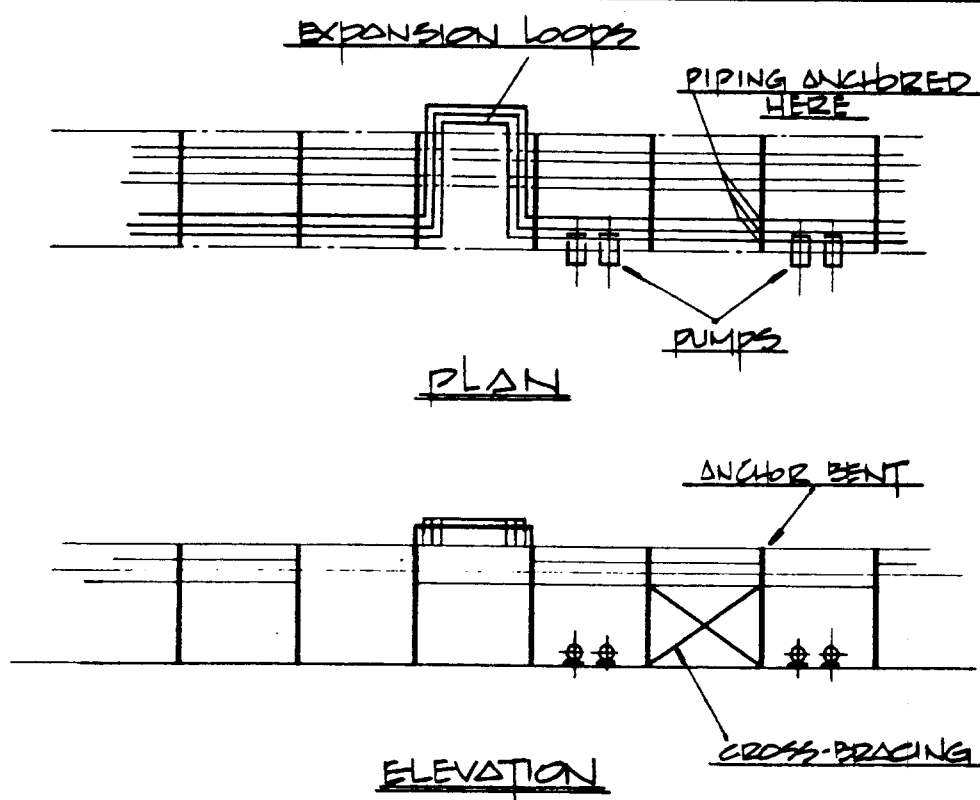


EXHIBIT 11-19
Pipe Rack Anchor Bent

Determining line growth The growth of such utility headers should be determined by multiplying the coefficient of expansion by the length of the line. The coefficient of expansion is based on a particular material operating at a specific temperature. Upset temperatures take precedence over operating temperatures.

Determining whether one anchor point will suffice Assuming that an anchor is located in the center of the header, the designer should calculate the growth of various branches to determine whether they have enough flexibility to absorb the header growth. If not,

two anchor points approximately one-quarter of the distance from each end of the header should be tried. Using the nomograms, the designer can calculate the amount of expansion leg required to satisfy all flexibility requirements.

Arranging lines in proper sequence The line that requires the largest leg must be located on the outside of the loop. Placing the headers along one side of the pipe rack allows the expansion loops to sit with a slight overhang along the adjacent side of the pipe rack. Exhibit 11-19 shows such an arrangement. As a

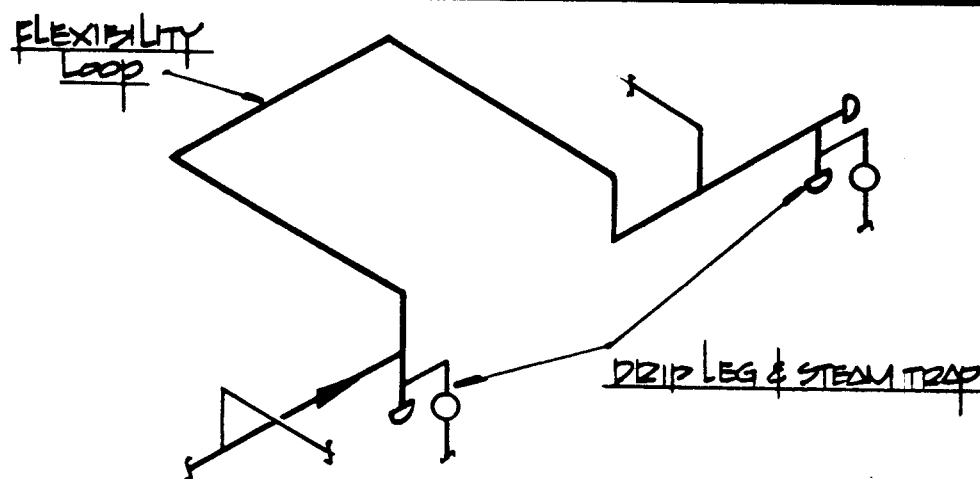


EXHIBIT 11-20
Steam Line Drip Legs

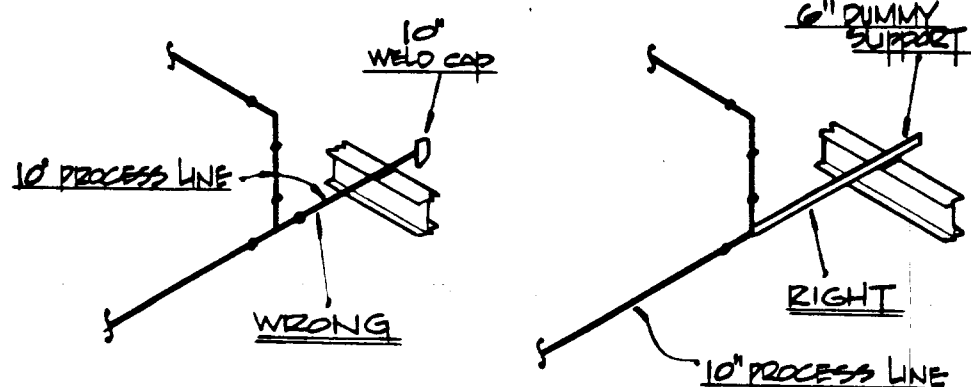
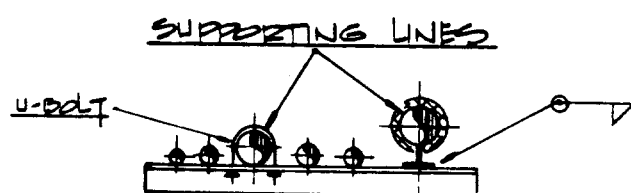


EXHIBIT 11-21
Proper Line Support

EXHIBIT 11-22 Intermediate Pipe Support



result of imposing stop loads on a particular bent, bracing may be required to grade, prohibiting the location of any equipment in that particular bay. A means of removing condensate build-up must be provided on either side of the expansion loop. The most common way to accomplish this is to add drip legs and traps, as shown in Exhibit 11-20.

Header growth causes another problem that is often not as obvious. The line spacing chart may have been used to set distances between lines, or lines may have been set close to a column. Exhibit 11-8 reveals that the movement of a line must not be restricted by

an adjacent line or column, because it will act as a line stop and could cause a problem. Enough space must be provided for the line to move its maximum distance and still have an ample clearance of 3 in (75 mm).

Exhibit 11-21 shows the correct way to support a line that has exceeded its allowable span. A common mistake is to extend the 10-in process line over the rack bent and cap it, when the line should have been run as if a support problem did not exist. A smaller piece of pipe or dummy leg could then be welded to the elbow for support (a hole should not be cut in the process line).

Exhibit 11-22 shows how larger lines in a pipe rack are used to support a group of smaller lines that may not be adequately supported because of the bent spacing. The uninsulated line is U-bolted to the supporting steel; the insulated line has its shoe welded to the steel. The smaller lines then rest on the steel. When an insulated line is used for support, the growth of the line at the proposed support point must be checked. Its growth could become restricted by this type of

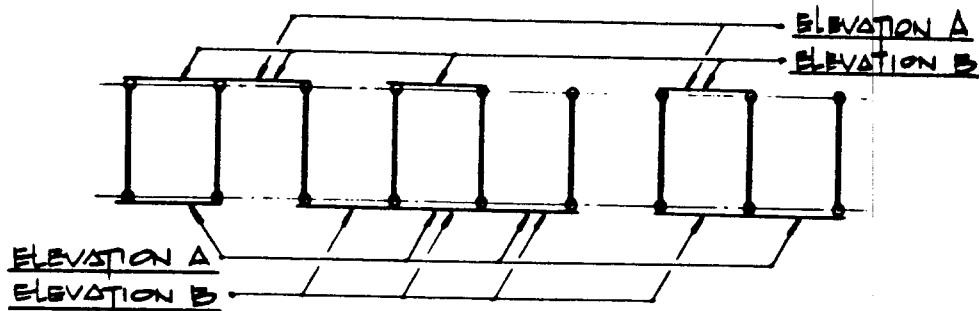


EXHIBIT 11-23
Pipe Rack Spandrel
Location

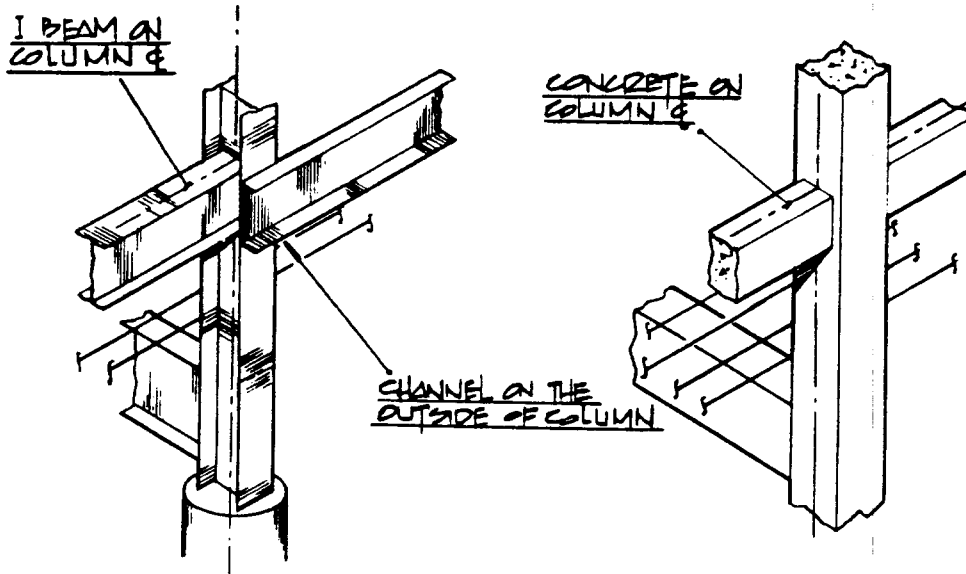


EXHIBIT 11-24
Pipe Rack Spandrel
Variations

support, and it may be better to use another line for this application.

STRUCTURAL CONSIDERATIONS

Most lines require support when leaving or entering a pipe rack. Structural members called spandrels are the most common means of satisfying this requirement. After all the lines have been run in the pipe rack, the plant layout designer must begin to locate the spandrels necessary to support all of these lines. Exhibit 11-23 shows how the requirement can be handled. If the structural engineers require additional spandrels for stability of the pipe rack, they should bring this requirement to the attention of the plant layout designer. Exhibit 11-24 shows some variations of spandrel design.

The plant layout designer should be aware that precast concrete pipe racks require structural members that are much larger than most designs. Exhibit 11-25 illustrates a precast column with an embedded steel

member for the spandrel support. The spandrel also has an embedded steel member that is bolted to the column and eventually grouted in. An installation sequence for a precast pipe rack is also shown in Exhibit 11-25.

Such equipment as drums and deaerators is often located above pipe rack columns. To avoid wasting valuable rack space with the large support columns, the inside face of the pipe rack column must line up with the inside face of the equipment support column, as shown in Exhibit 11-26. This approach also allows the feed-water outlet piping to run vertically down to the pump before the expansion loop is added.

Fireproofing of pipe rack columns is shown in Exhibit 11-27. If hydrocarbons are prevalent, it is common to fireproof the columns to a level just below the lower rack support beam. If air coolers or other equipment is located above a pipe rack, the fireproofing is extended to the equipment support beam. This issue must be reviewed with the client; allowances may need to be made for as much as 4 in (100 mm) of fireproofing.

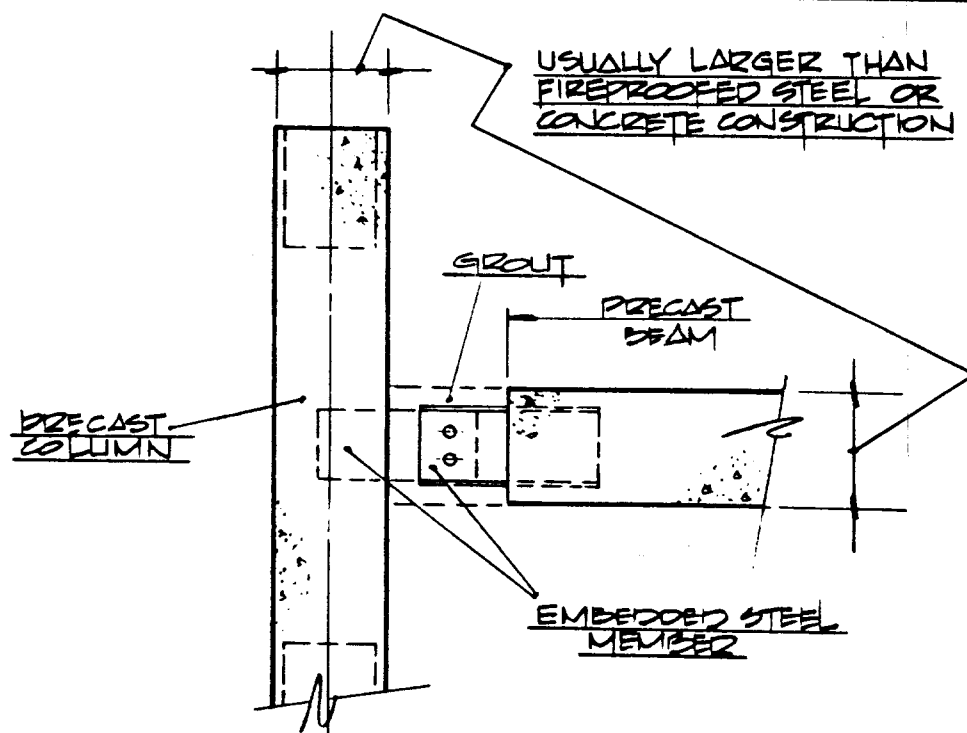
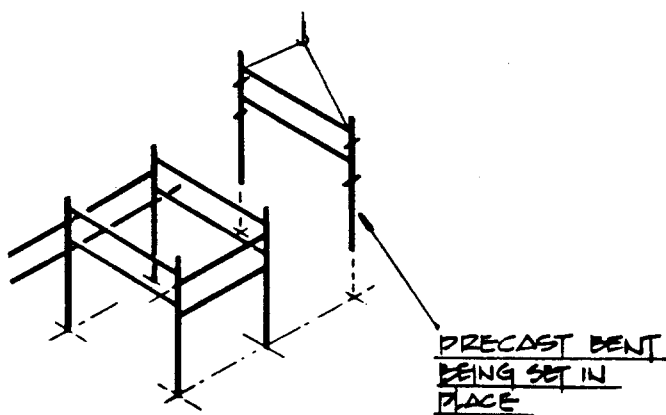


EXHIBIT 11-25
Precast Concrete Pipe
Rack Considerations

a. Precast Concrete Pipe Rack



b. Installation Sequence

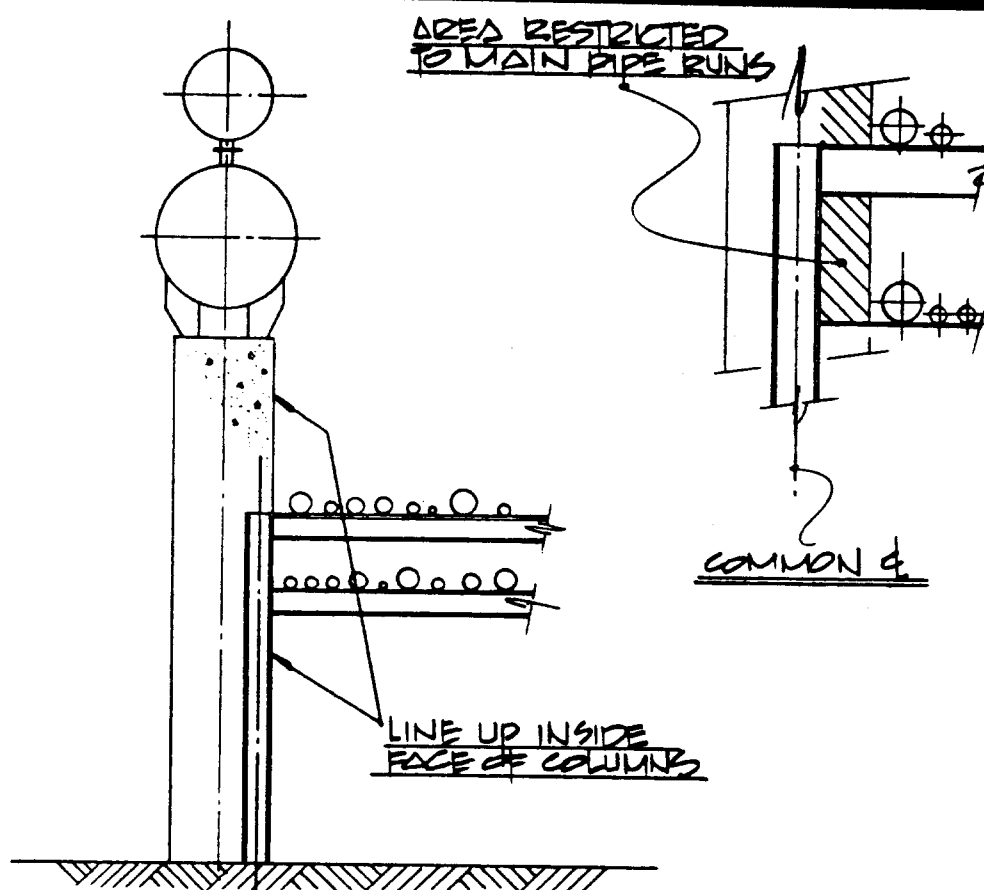


EXHIBIT 11-26
Equipment Support
Column Location

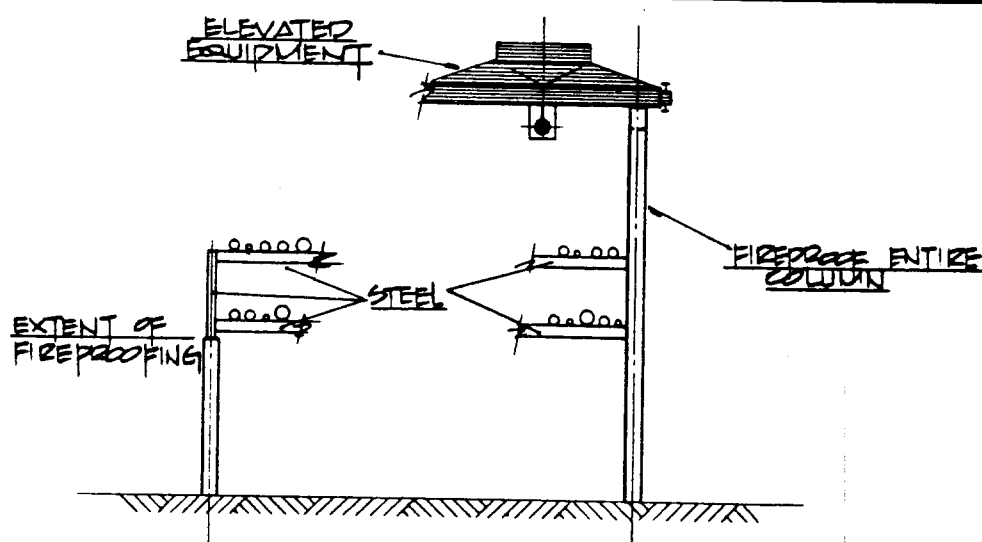


EXHIBIT 11-27
Fireproofing
Requirements

EXHIBIT 11-28
90° Pipe Rack Turns

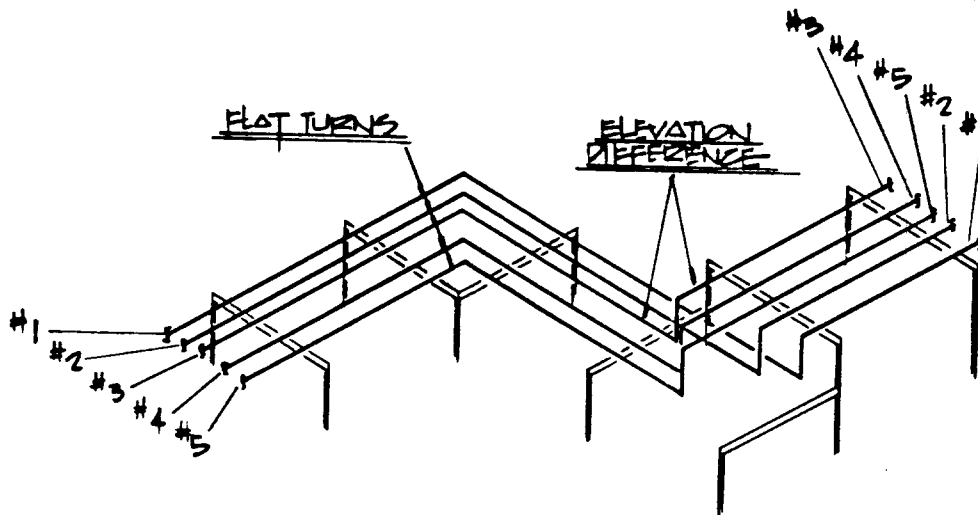
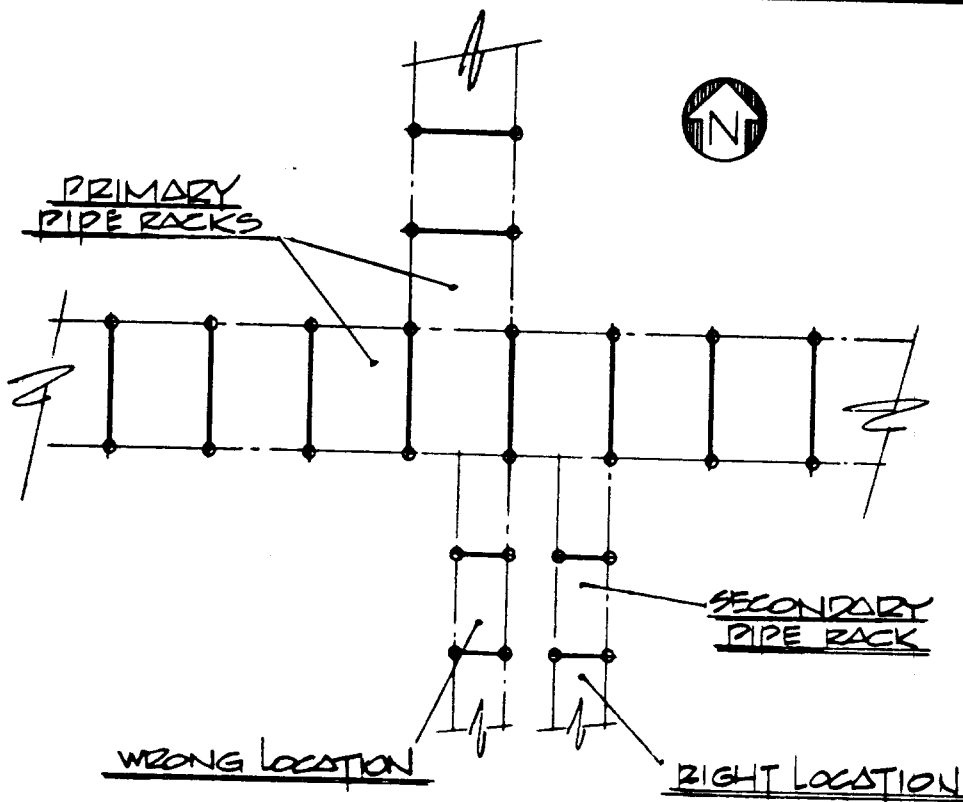


EXHIBIT 11-29
Rack Intersection



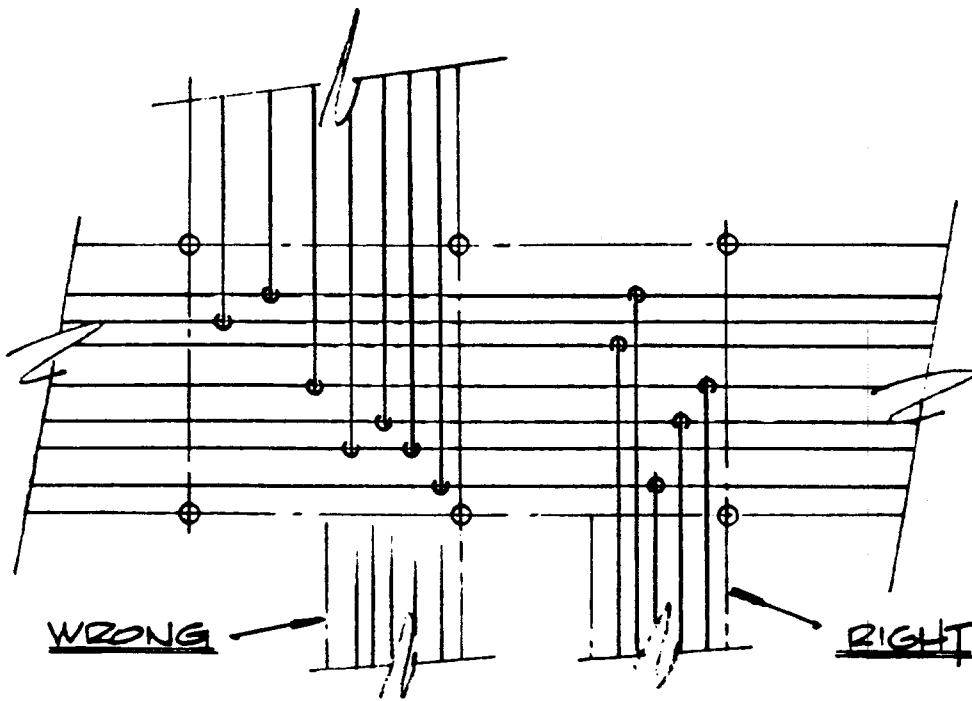
a. Rack Intersection Layout

OTHER CONSIDERATIONS

Occasionally, a situation arises in which a flat-turn pipe rack may be employed. This often happens near a dead-end area where the potential for problems is minimal. As shown in Exhibit 11-28, the line sequence

on the left side of the rack must remain constant as long as flat turns are used. A different elevation must be used at a 90° turn in the rack if the sequence must change, as shown on the right side of the diagram. This approach must be well thought out before it is used.

EXHIBIT 11-29
Rack Intersection (Cont)



b. Rack Intersection Detail

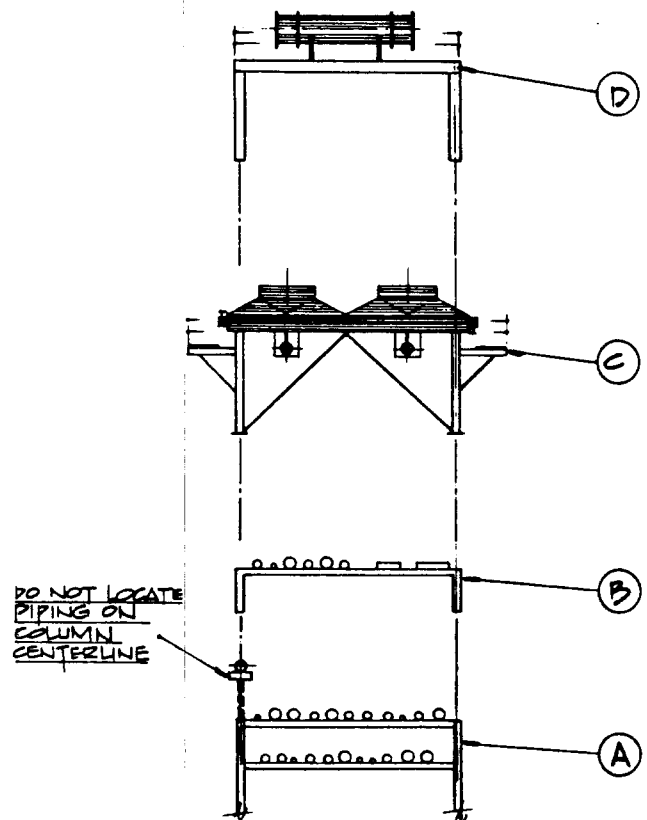
The secondary pipe rack intersection is shown in Exhibit 11-29. There is a right and a wrong way to set this location. Although it may seem more uniform to set the secondary rack directly south of the main north/south rack during the plot plan development stage, Exhibit 11-29 also clearly shows why this should be avoided. The lines heading north off the main east/west rack restrict the lines from the south from entering this common area. Therefore, the secondary rack should be shifted east one bay to eliminate the problem.

Alternative pipe rack expansion of the individual levels can be accomplished by adding a cantilever beam as required on the outside of the column. The only problem with this approach is that, if not planned for, the vertical risers commonly found outside the pipe rack use a considerable amount of the space of the extension, as shown in Exhibit 11-13.

Pipe rack additions are shown in Exhibit 11-30. Area A shows a standard two-level pipe rack, as planned. Because it is always possible for the pipe rack to be expanded in the future, the area over the columns must be kept free of piping and conduit. The future expansion may include another new level (B), an air cooler (C), or a series of shell and tube exchangers (D). The preferred location of a relief header above a pipe rack is illustrated in Exhibit 11-12.

Lighting panels and welding receptacles also must

EXHIBIT 11-30 Pipe Rack Additions



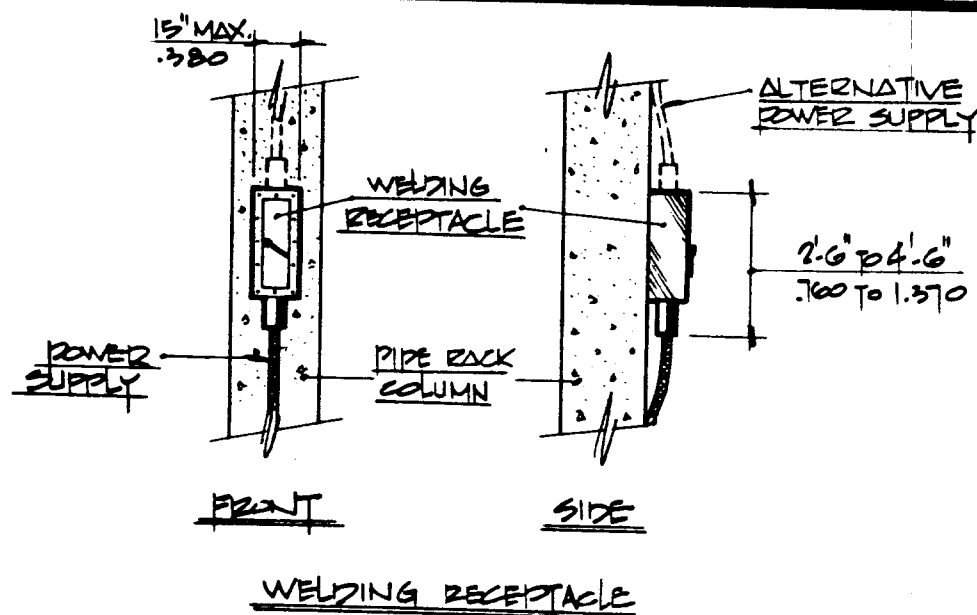
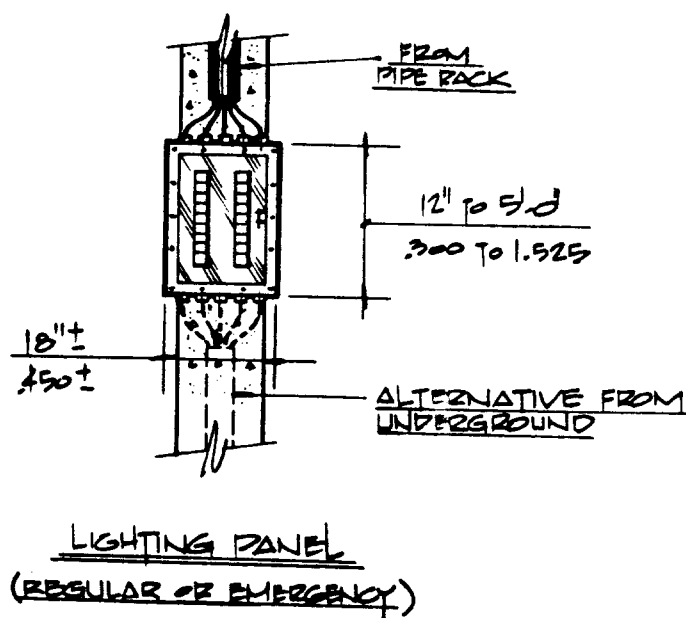


EXHIBIT 11-31
Lighting Panels and
Welding Receptacles



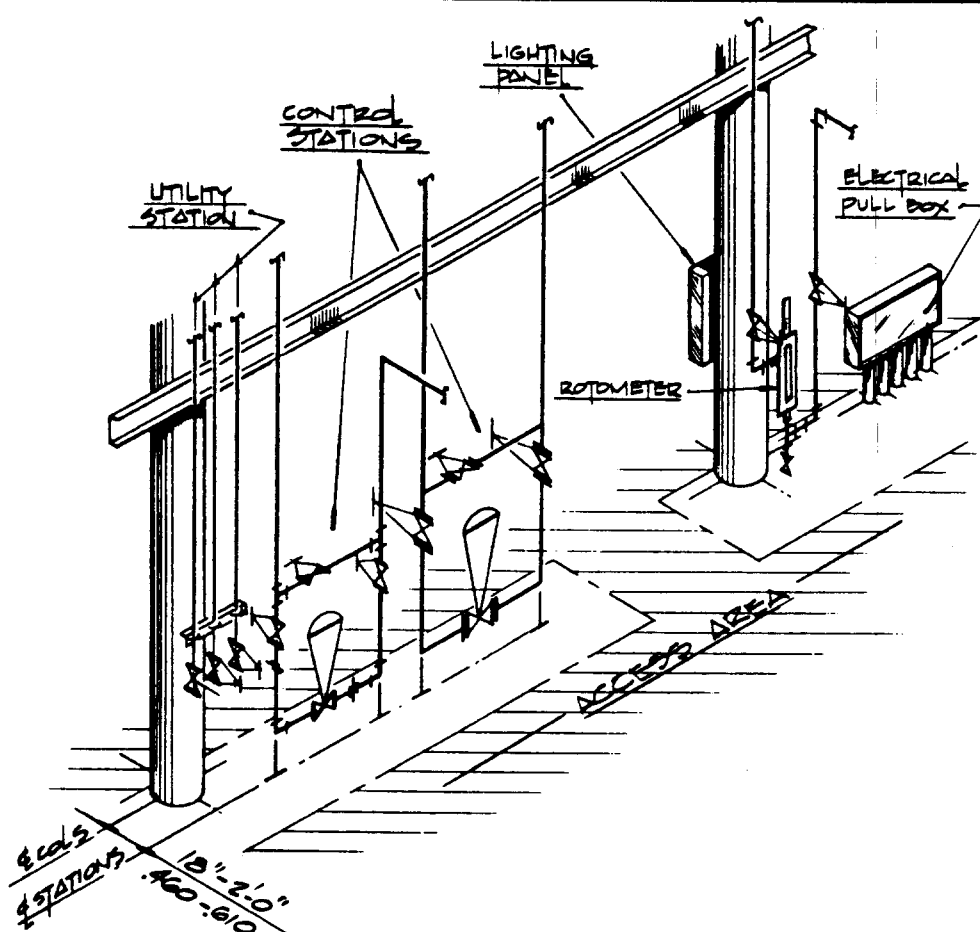


EXHIBIT 11-32
Operator Access

be planned for during the early stages of a pipe rack layout. They are mounted directly on pipe rack columns; their location must be recorded on the applicable documents. Electrical engineers designate where the regular and emergency panels are located; construction personnel select the preferred location for the welding receptacles (see Exhibit 11-31). When locating piping manifolds, control stations, instruments, and pull boxes along the pipe rack columns,

the designer should avoid blocking access from under the pipe rack to adjacent equipment areas by leaving clear space, as illustrated in Exhibit 11-32.

Overall pipe rack design must meet the current needs of a client as well as any expansion plans without making major modifications to existing facilities. Available space in the pipe rack must be considered valuable and used to the utmost advantage of present and future needs.

Structures

Structures are used in most industrial facilities to accommodate equipment and associated components to suit specific process, real estate, climatic, and client requirements. A structure can be designed to support one or two pieces of equipment or an entire process plant and can be open or enclosed. The principal objectives in the layout of structures are to optimize all available space and to support safety, maintenance, operation, cost, and constructability.

This chapter highlights the general requirements for structure layout. It covers the most common structural details and discusses equipment placement, maintenance, and operational considerations.

DESIGN FEATURES

Many design features must be considered before a structure layout is begun, including:

- Steel or concrete design.
- Open or enclosed structure.
- Siding requirements.
- Type of flooring.
- Access.
- Braced or rigid frame.
- Fireproofing requirements.
- Equipment maintenance.
- Type of roof.

After these basic parameters have been established, the layout may proceed. Besides real estate restrictions, allowable pressure drop, gravity flow conditions, and NPSH requirements may require equipment to be elevated; however, each piece of equipment must be set as close to grade as possible to minimize the overall height of the structure. If the structure is to be elevated, the following points must be addressed:

- Handrails are required around all operation and

maintenance platforms.

- Structures that contain equipment that does not need daily operator attention can be serviced by ladders.
- Equipment requiring regular operator attendance is serviced by stairways.
- Service to large structures may require an elevator or traveling belt lift.
- Because equipment may need to be removed for major maintenance (e.g., exchanger bundles), structural members or handrail sections may need to be removable.
- Monorails or hitch points may be required for maintenance.
- Main structures of concrete do not use bracing but should be constructed with a rigid frame design.
- When fireproofed steel construction is used, pipe support steel must be installed before the steel columns, beams, and braces are fireproofed. Otherwise, the fireproofing must be chipped away down to the steel member. This chipping is costly and should be avoided.

STRUCTURAL TERMS

Terms commonly used in structure layout are defined in the following sections.

Braced or rigid frames The design of any elevated structure must take into account the size and weight of the equipment to be supported and operation and maintenance requirements as well as wind load and earthquake zone considerations. Of these points, operation and maintenance play a large role in determining the need for a rigid or braced frame. A rigid frame design requires no additional horizontal or vertical cross bracing, permitting maximum access to equipment and piping. The plant layout designer must recognize frame requirements early in the development

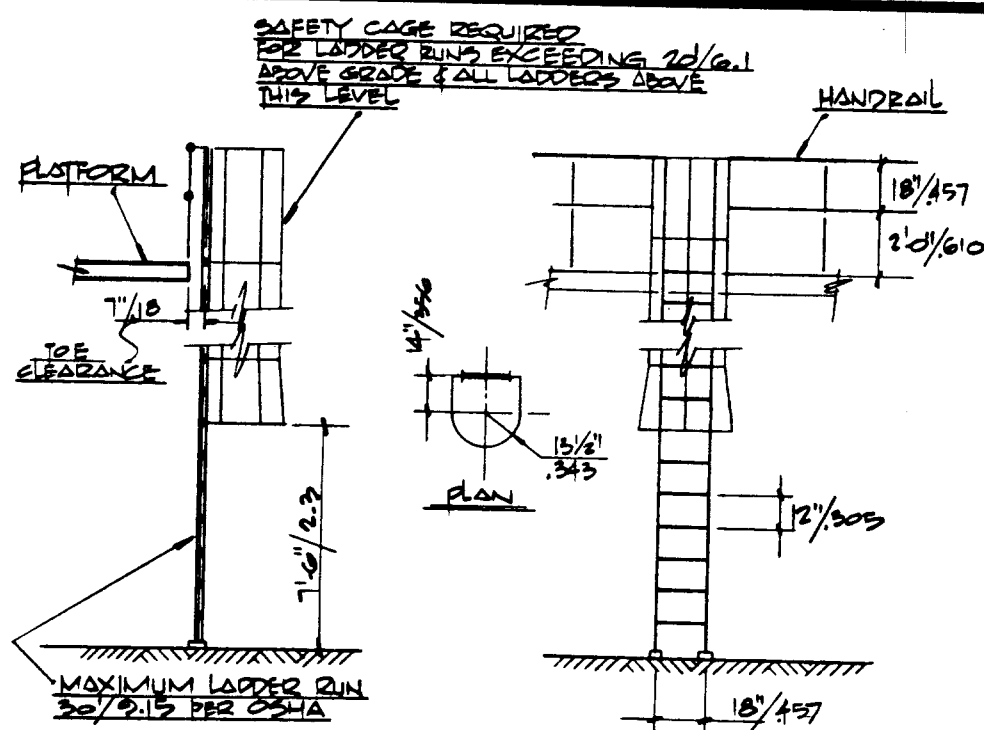
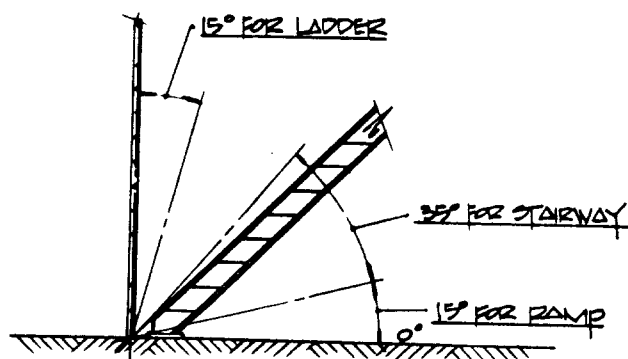


EXHIBIT 12-2 Preferred Positions for Ladders, Stairways, and Ramps



of a structure and consult with the structural engineer before proceeding with the design.

Equipment load This is the weight of equipment with all dead load attachments.

Dead load Dead load is the weight of all structural members within the structure, including the fireproofing.

Live load This comprises the superimposed loads on platforms or floors as a result of operation and maintenance. It is usually a minimum of 50 lb per square foot. Live load does not include the weight of equipment, piping, or storage of materials.

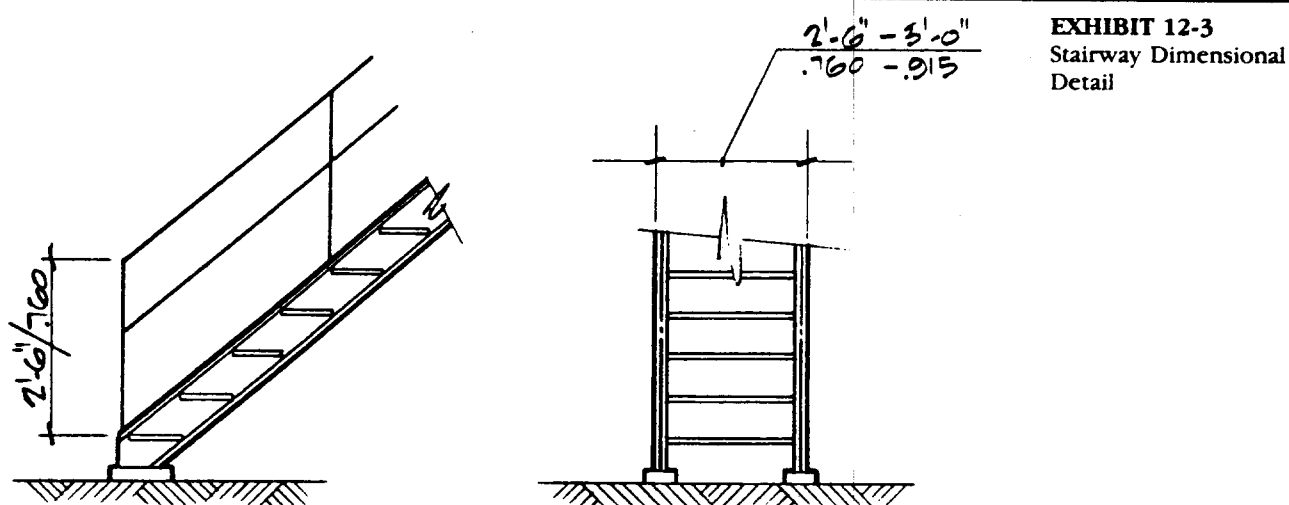


EXHIBIT 12-3
Stairway Dimensional
Detail

Pipe load Pipe load refers to the weight of all piping, valves, fittings, and insulation, including the weight of contents during test or regular operation, whichever is greater.

Earthquake load This is the specific seismic data for a particular site.

Wind load Measured in miles per hour, wind load is the force applied to a structure at a given site.

Exchanger bundle removal load This is half the weight of the tube bundle.

Thermal expansion load The effects of thermal expansion must be accommodated by equipment support structures and elements.

Pipe anchor load The force calculated to resist loading in anchored piping systems, the pipe anchor load is added to the thermal expansion loads of the equipment.

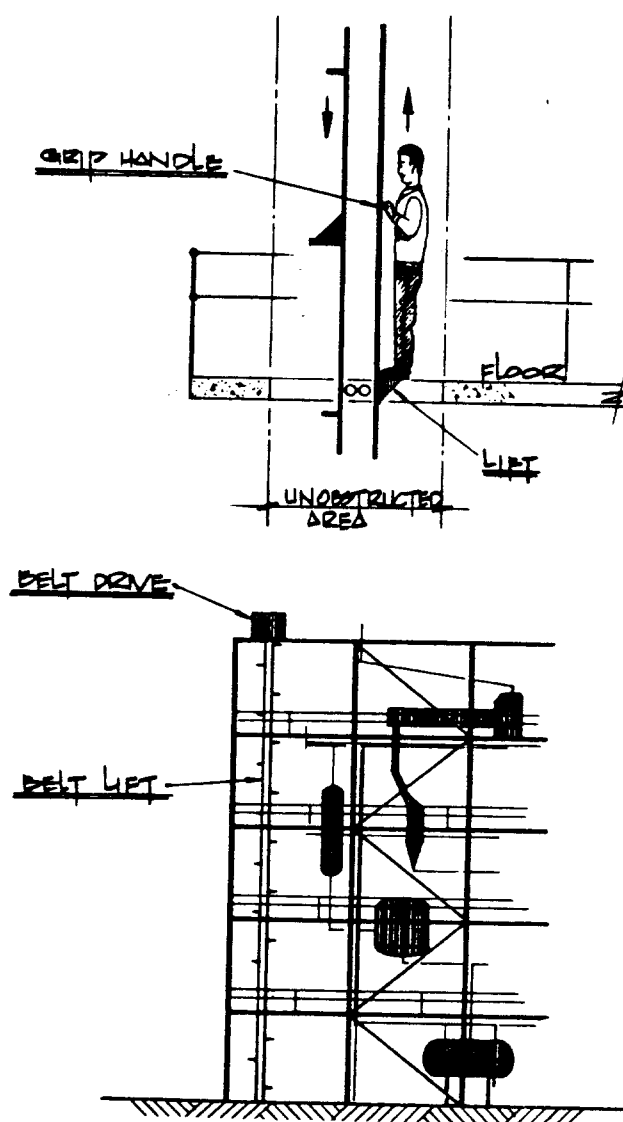
Dynamic loading This is the response of structures and their components to the cyclical loading produced by rotating or reciprocating equipment.

STRUCTURAL DETAILS

A typical ladder detail is shown in Exhibit 12-1. Ladders with elevations of a maximum of 20 ft (6,100 mm) above grade do not require a safety cage. An 8-in (200-mm) open area behind the ladder should be maintained for toe clearance. Any obstruction within this distance is a potential tripping hazard.

The preferred positions for ladders, stairways, and ramps are illustrated in Exhibit 12-2. It is recommended that ladders be run vertically to a maximum angle of 15°. Stairways should be limited to a maximum angle of 50° off the horizontal plane, but they should not be used for less than a 15° incline. Ramps should be limited to a 15° maximum incline. A stairway dimensional detail is shown in Exhibit 12-3. The

EXHIBIT 12-4 Traveling Belt Lift



location of the steps are usually set by the structural engineer.

Exhibit 12-4 shows a traveling belt lift. This device consists of an electric drive belt with steps and hand grips. It is constantly in motion at a slow rate. The lift provides rapid access to a large structure without the need for a standard elevator.

A grating platform is depicted in Exhibit 12-5. When this type of platform is used, the platform top-of-steel elevation does not include the thickness of the grating. Moderate pipe support loads can be imposed on this design; holes for piping should be banded for reinforcement. A deck plate platform is shown in Exhibit 12-6. This commonly used form of decking is $\frac{1}{4}$ in (10 mm) thick.

Fireproofed steel is shown in Exhibit 12-7. The plant layout designer obtains the required fireproofing thickness for particular structure at the outset of the design. Fireproofing thickness usually varies from 2 in (50 mm) to 4 in (100 mm). Bracing, illustrated in Exhibit 12-8, is fabricated from a variety of structural shapes or piping. Because the size of the gusset plates varies widely, final dimensional data must be obtained to check for possible interference between piping and steel gussets.

A concrete platform is illustrated in Exhibit 12-9. Like steel platforms, the concrete platform has a 4-in (100-mm) toe plate installed around its edge. A concrete platform for acid service is shown in Exhibit 12-10. Acid-resistant brick is used when specifically required, as shown in Exhibit 12-11. A curbed area is provided around the equipment most likely to leak during operation and maintenance. Shields are provided for flanges in acid service outside the curbed areas.

Exhibit 12-12 illustrates structural siding. Siding may be fabricated from lightweight aluminum or Lucite. Siding support steel should never be used to support piping. Piping may penetrate the siding through an opening slightly larger than the pipe or insulation, if applicable.

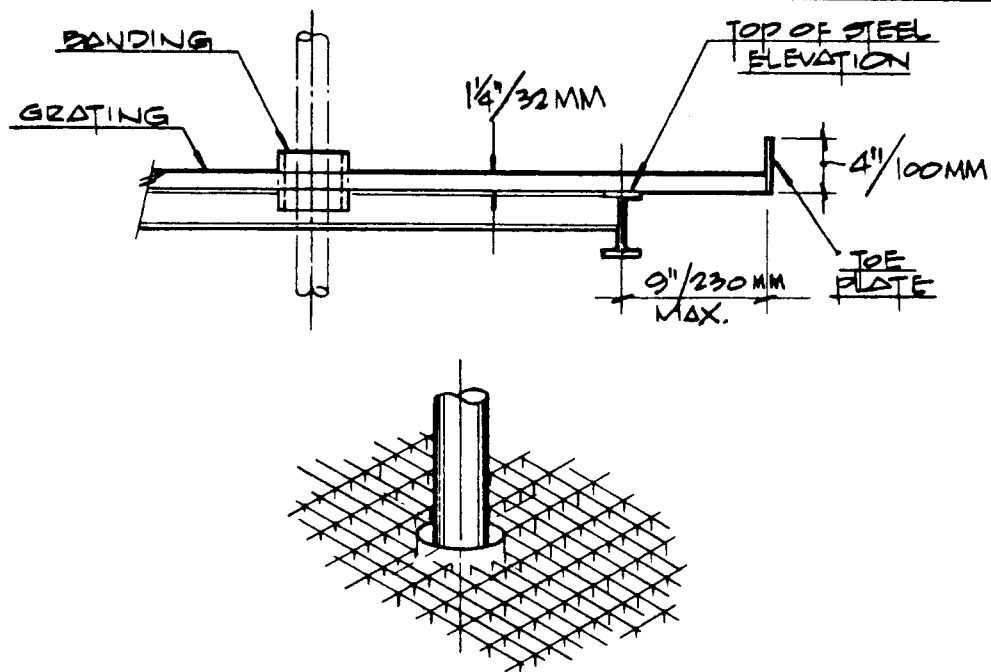


EXHIBIT 12-5
Grating Platform

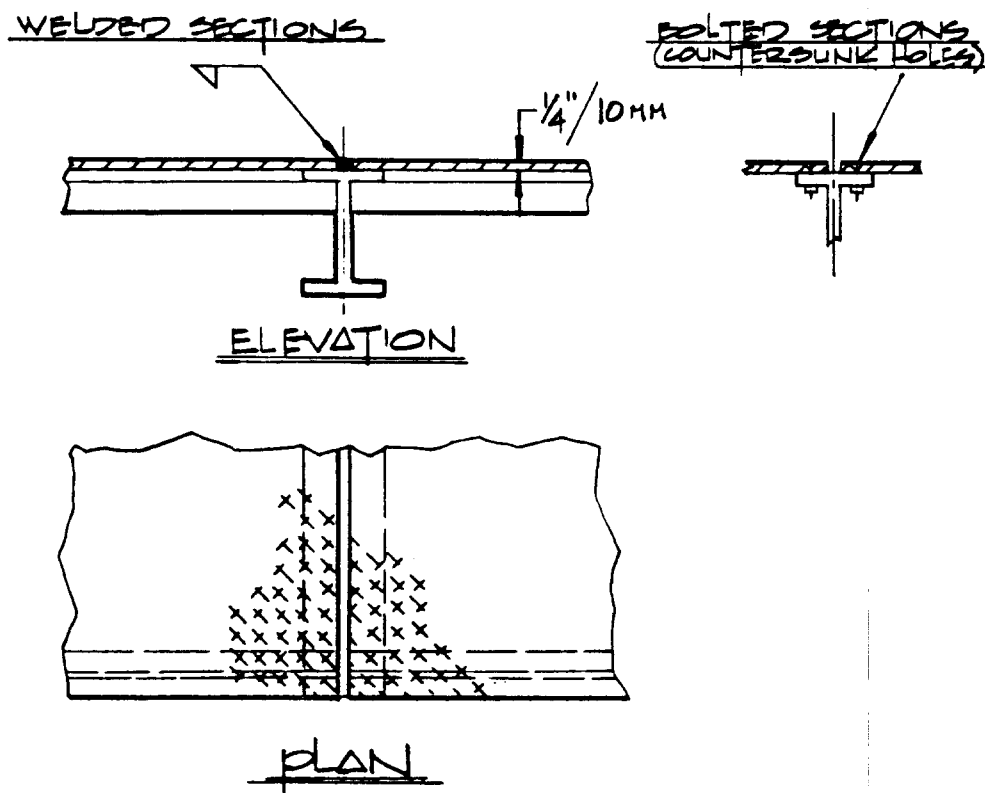


EXHIBIT 12-6
Deck Plate Platform

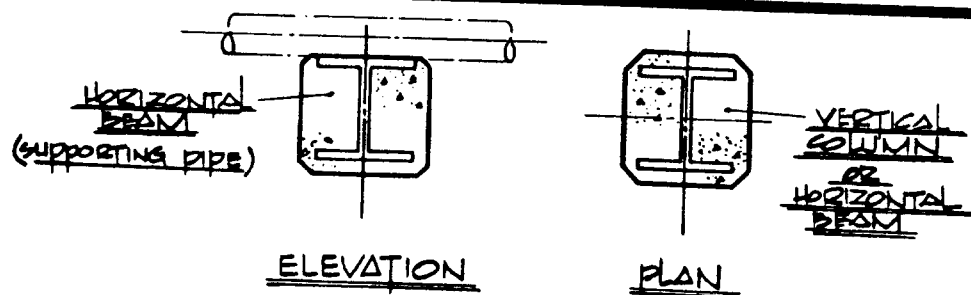


EXHIBIT 12-7
Fireproofed Steel

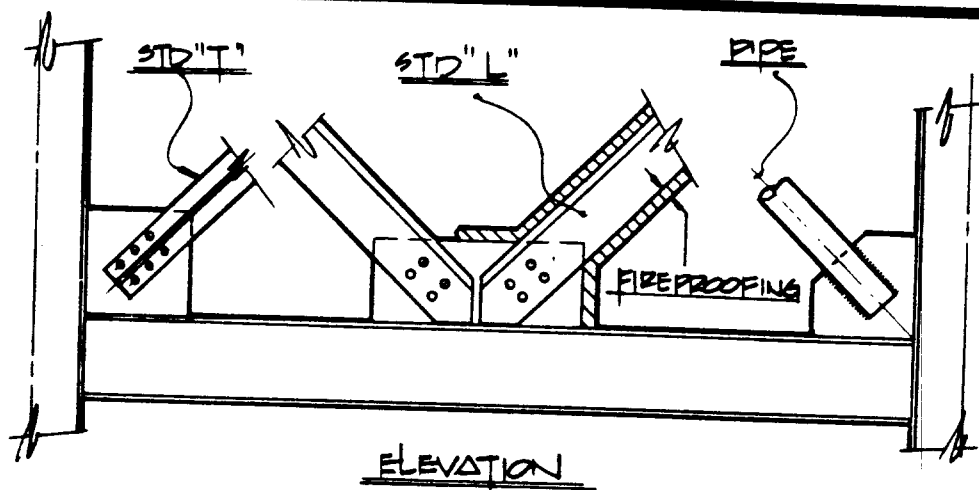


EXHIBIT 12-8
Bracing

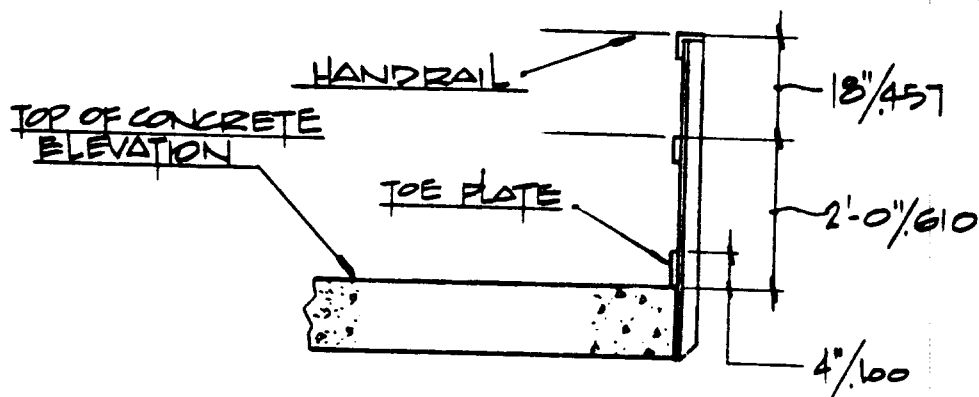


EXHIBIT 12-9
Concrete Platform

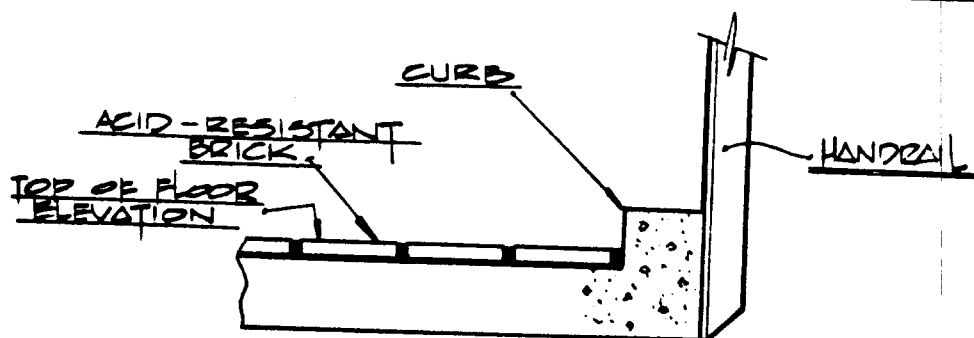


EXHIBIT 12-10
Concrete Platform for
Acid Service

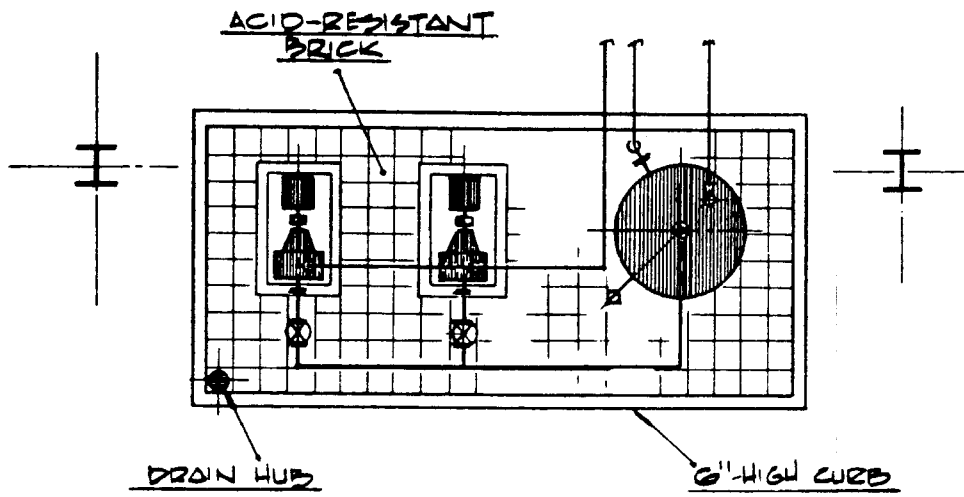


EXHIBIT 12-11
Acid-Bearing Equipment

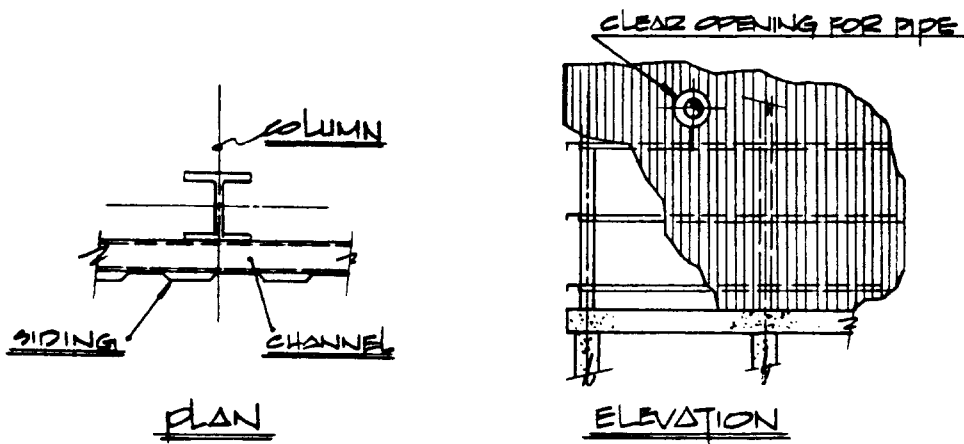
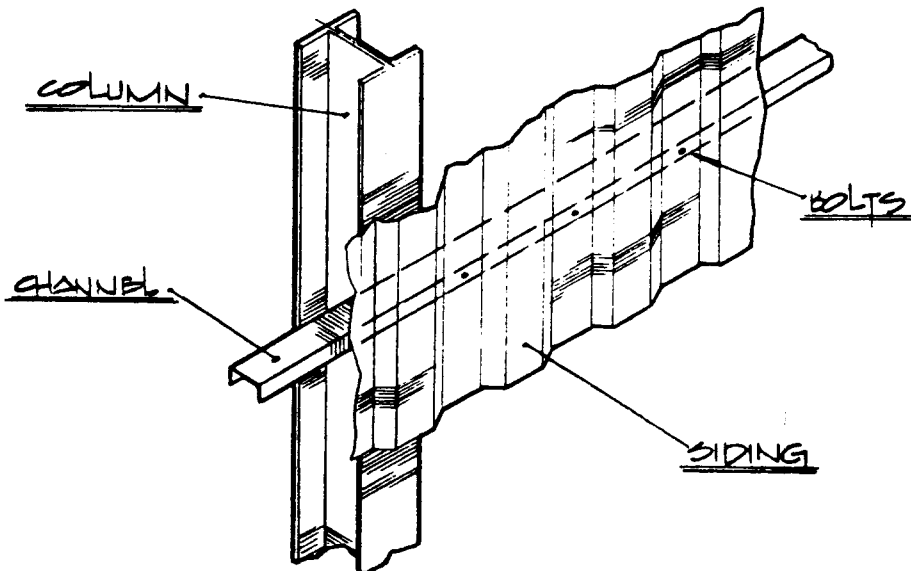


EXHIBIT 12-12
Structural Siding



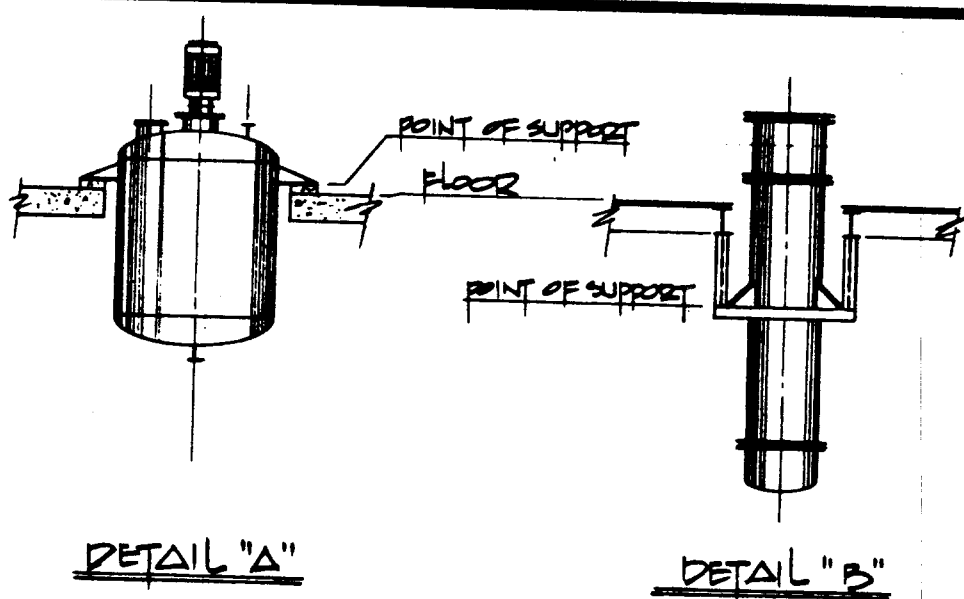


EXHIBIT 12-13
Equipment Supports

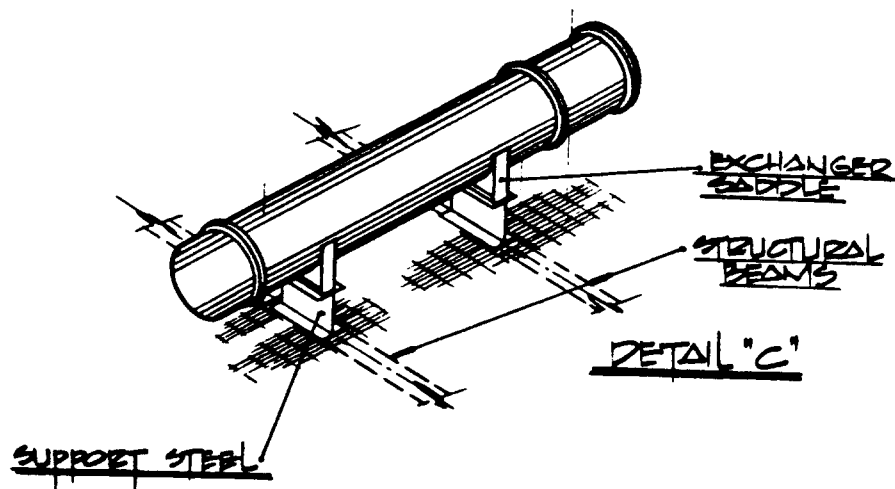


EXHIBIT 12-14
Monorail Layout

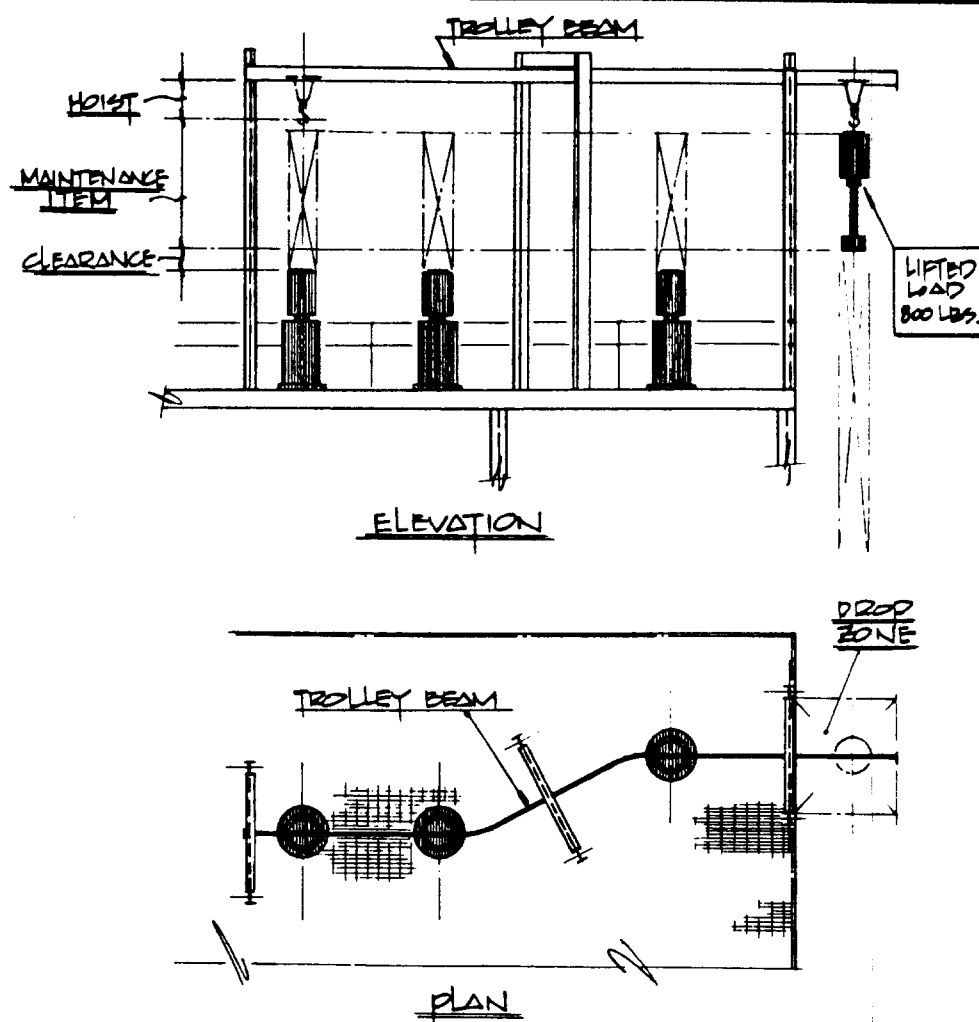


Exhibit 12-13 provides three variations of equipment support. Detail A is a kettle supported on lugs at floor level; the major portion of the vessel sits below the supporting floor. Detail B illustrates an exchanger supported by lugs below the floor, with a steel frame hung above the equipment to secure it at the required elevation. Detail C shows a common method of supporting horizontal equipment. In this application, the main structural steel members must be located under the saddles. Additional steel may be required between the supporting beam and the saddle to achieve the desired elevation, or the exchanger saddle may sit directly on the structural beam.

A monorail layout is depicted in Exhibit 12-14. When equipment requires constant maintenance, a monorail is often used to service it, not necessarily in a straight line. Client input is required before this feature is added, because mobile handling equipment may be an alternative to this approach. When a monorail is planned, the plant layout designer highlights the lifted load on the drawing to signify the maximum

load to be maintained by the monorail.

A pipe chase, shown in Exhibit 12-15, is usually found within a building or structure with concrete floors. The chase on each floor is lined up free of any obstructions and allows utility and process piping to run between all floors with minimal changes in direction. Individual lines should penetrate the floor at the desired locations and do not use a pipe chase.

SMALL STRUCTURES

Exhibits 12-16 through 12-20 show variations of small-structure design. The physical size of any structure should be strictly limited to the space required for equipment operation and maintenance. The first small-structure scheme, in Exhibit 12-16, illustrates a common approach, in which one piece of equipment is set above another to accommodate a gravity-flow system. Although the design appears reasonable, there may be an alternative to consider.

EXHIBIT 12-15
Pipe Chase Detail

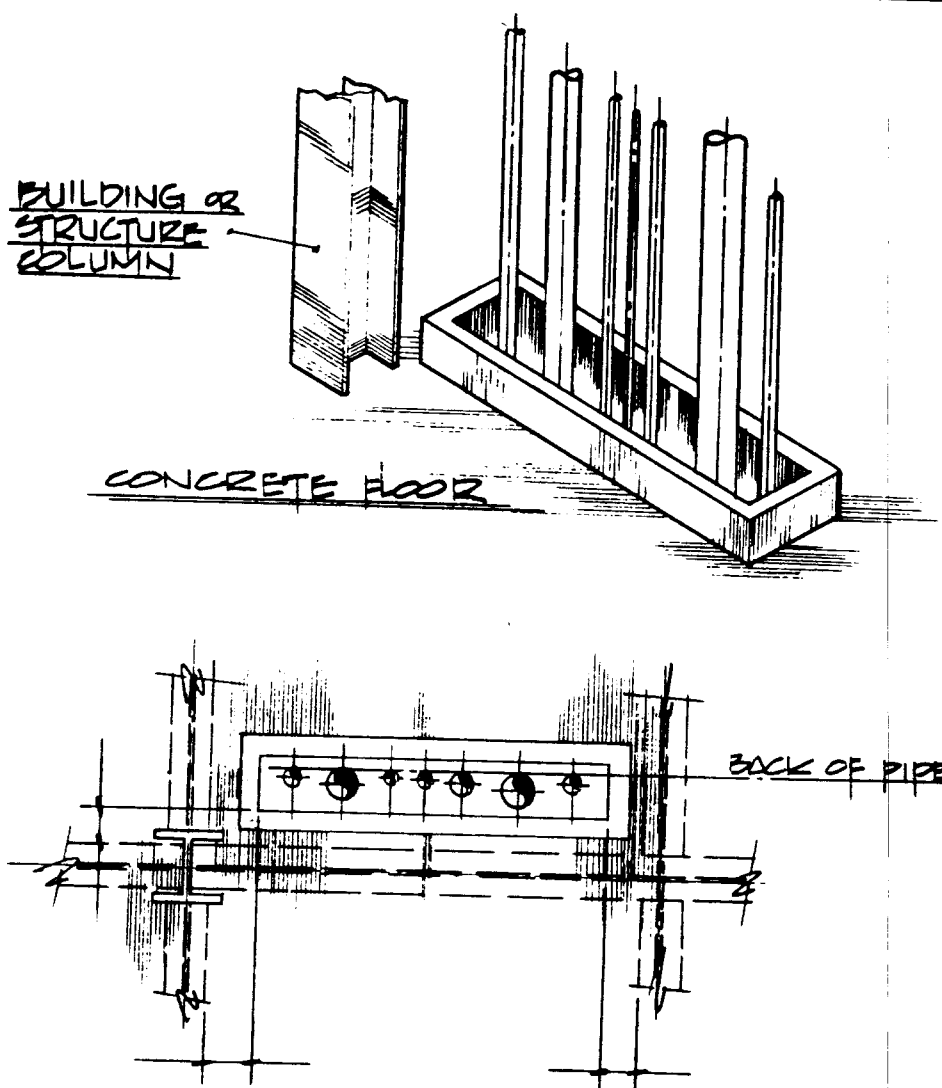
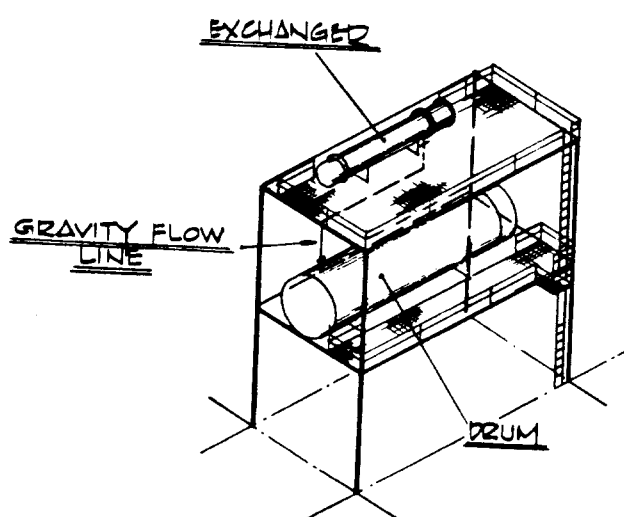


EXHIBIT 12-16 Small Structure



In Exhibit 12-17, the exchanger is set above the drum as in the previous design, but it is supported in a completely different manner. By consulting with the vessel engineer, the plant layout designer may be able to support the exchanger and platform from the vessel shell as shown, with the drum supported from concrete piers. This application should be considered whenever it is economically practical.

A single-level, one-bay structure is shown in Exhibit 12-18. In this design, the elevation of the upper-level platform is determined by the following conditions:

- The drum elevation must adhere to NPSH requirements.
- The platform on top of the drum must allow adequate headroom for operations personnel and space for the piping and for the structural beam.

A single-level, two-bay structure is illustrated in Exhibit 12-19. As previously mentioned, equipment sad-

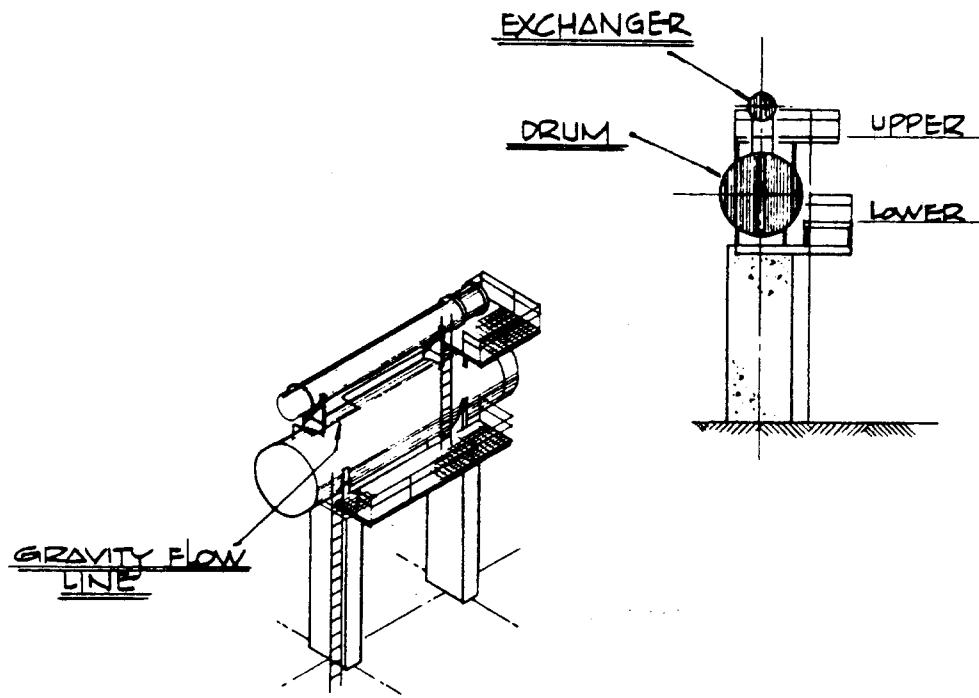


EXHIBIT 12-17
Alternative
Small-Structure Design

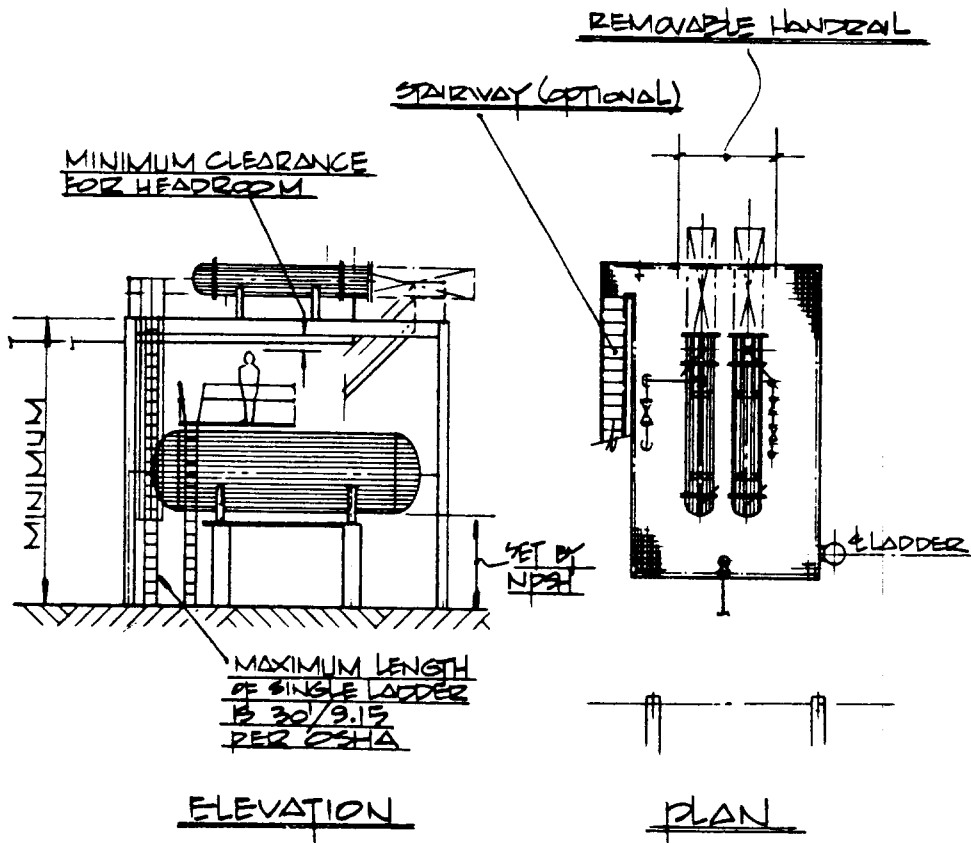


EXHIBIT 12-18
Single-Level, One-Bay
Small Structure

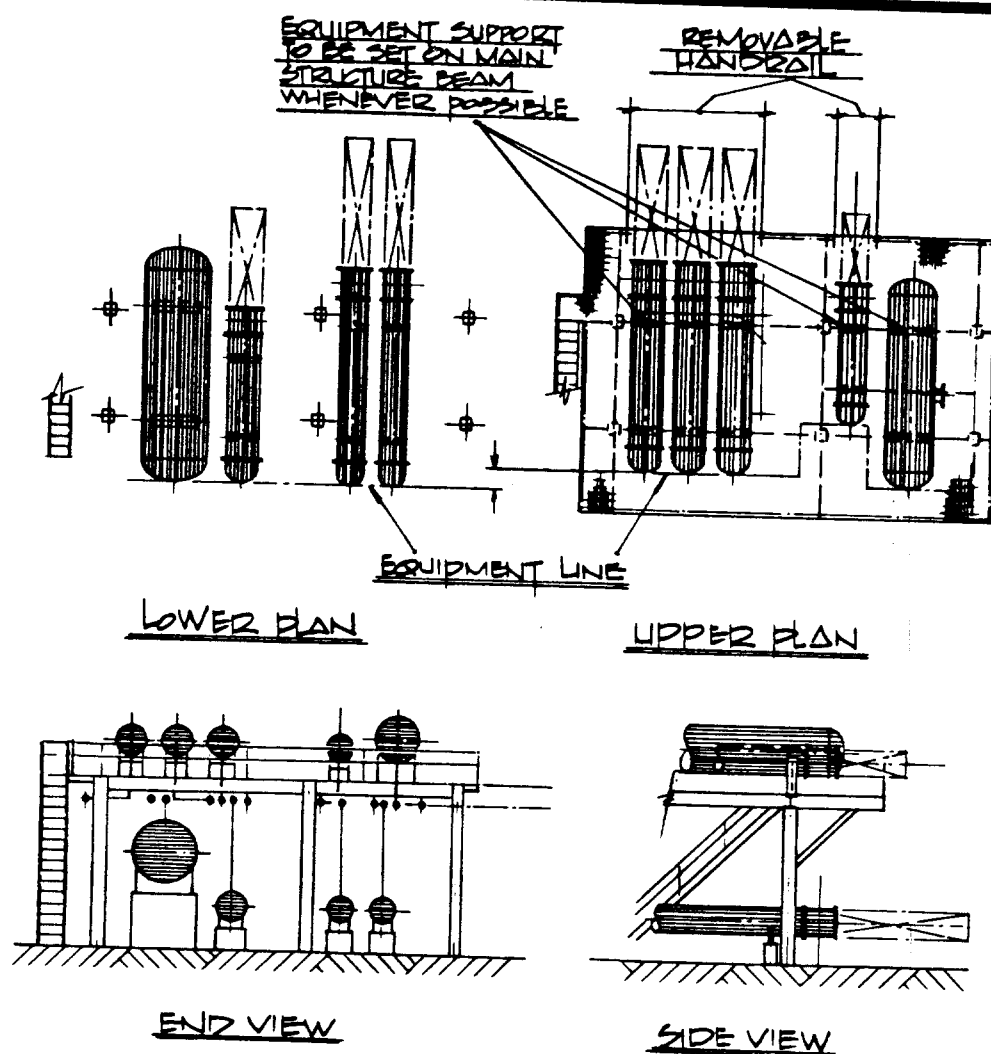


EXHIBIT 12-19
Single-Level, Two-Bay
Small Structure

dles are located on main structural beams whenever possible to minimize the need for additional steel. At grade, equipment is lined up along a regular equipment line; however, equipment in structures must follow an equipment line that accommodates the main support location, which may vary. Removable handrails must be provided in front of shell and tube exchangers when tube bundles must be removed.

A two-level structure is shown in Exhibit 12-20. The exchanger tube bundle maintenance on level I is the focal point of this exhibit. The size of the exchanger to be maintained determines the need for a tube removal structure. If such a structure is required, it should have a beam directly opposite the exchanger from which the bundle can be pulled. The structure must also have a trolley beam across the top of the upper level and directly over the exchangers. If a tube removal structure is not used, a trolley beam located directly over the channel end of the exchangers on level I

must project out to allow mobile equipment to pick up the bundle and lower it to grade.

MEDIUM-SIZED STRUCTURES

When designing a structure, a plant layout designer must often satisfy restrictive process conditions (e.g., a minimal pressure drop within a system). Exhibits 12-21 and 12-22 show how one equipment arrangement may satisfy that requirement. Preferably, the shell and tube exchangers (E1 through E6 in Exhibit 12-22) are set vertically in the structure, which uses the least amount of platform and may significantly reduce the area needed for the maintenance of the exchangers. Although the tube bundle removal structure is higher for the vertical configuration, the drop zone at grade is at its absolute minimum.

As illustrated in Exhibit 12-22, the platform area for

EXHIBIT 12-20
Two-Level Small
Structure

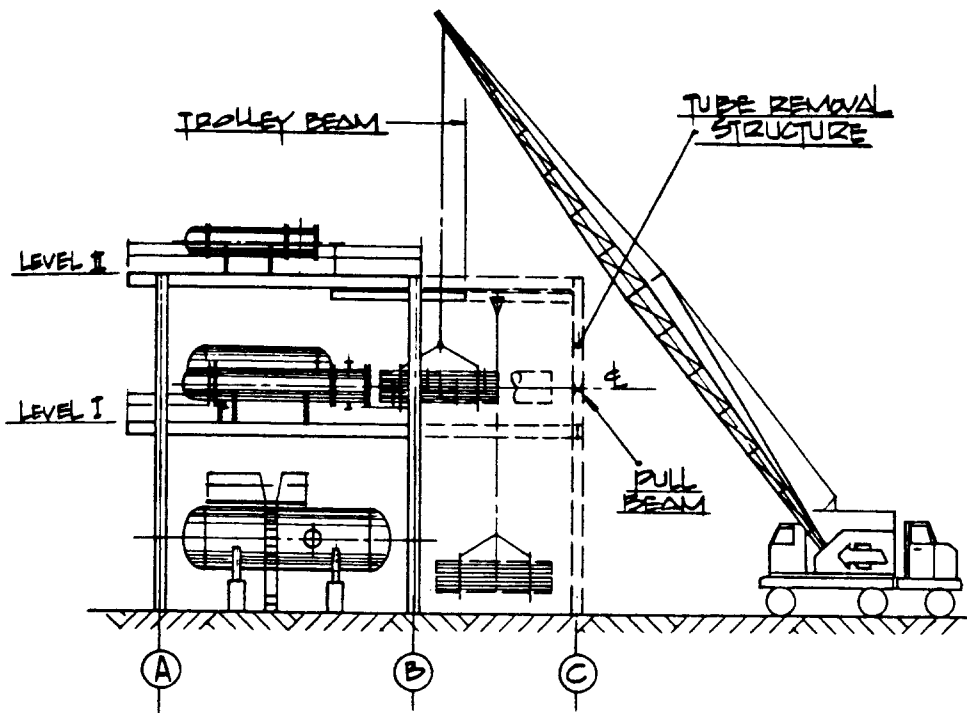


EXHIBIT 12-21
Horizontal Arrangement

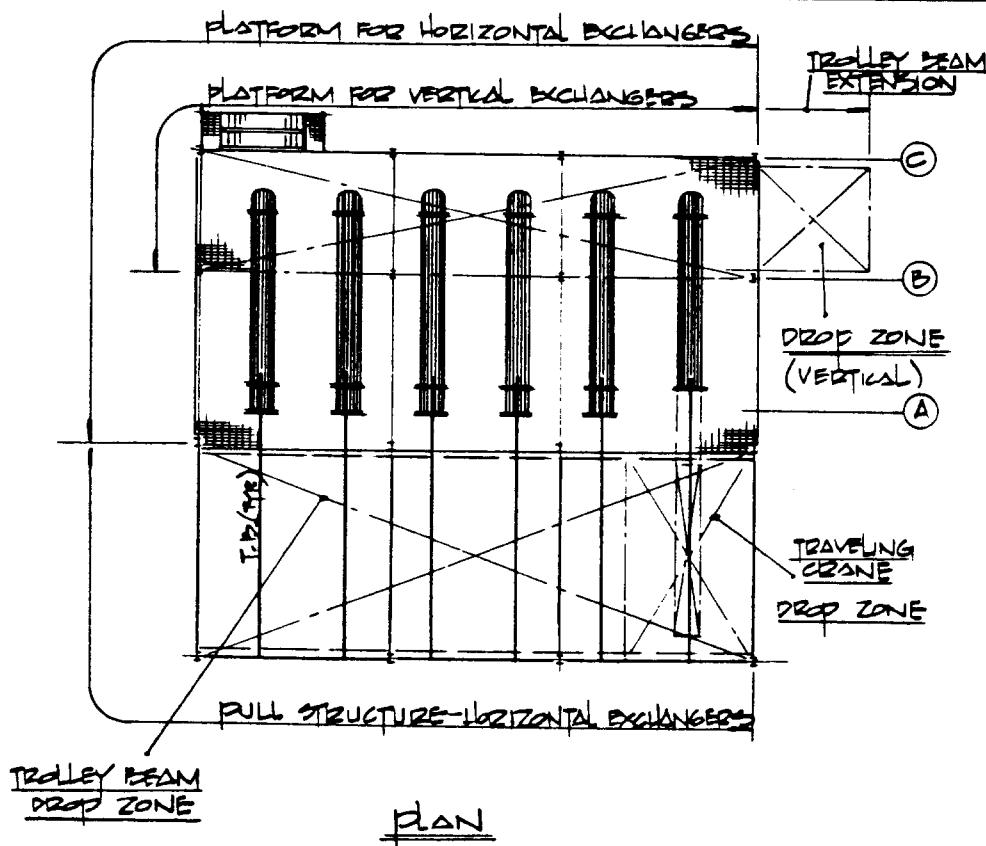
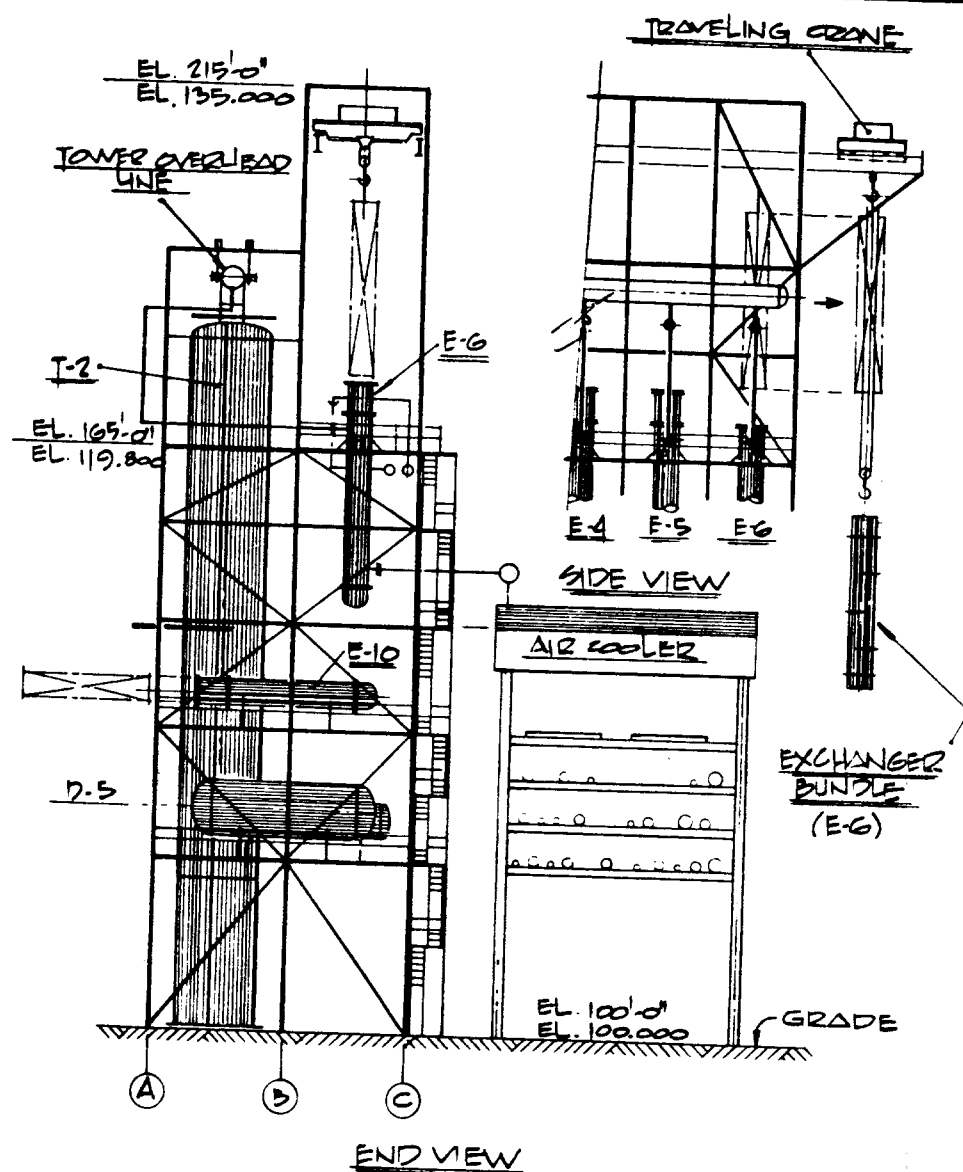


EXHIBIT 12-22
 Vertical Arrangement


the vertical layout is significantly smaller than for the horizontal one. If a traveling crane is used in the horizontal arrangement, a slightly larger drop zone is needed. If individual trolley beams are used over each exchanger, the area required at grade is significantly increased and can become a costly real estate problem. Solving it requires the participation of the structural engineer and the exchanger engineer.

LARGE STRUCTURES

Many process plants have equipment located in large structures. The reason these structures are preferred over grade-mounted installations is that a significant number of small pieces of equipment are used. Many

gravity-flow systems and a great deal of small piping need the natural support that a large structure can offer. Exhibit 12-23 illustrates a large structure. Factors that must be considered during the development of an equipment arrangement and piping layout in a process plant include:

- Finished grade within a structure should be 12 in (300 mm) higher than grade outside to avoid drainage problems.
- Pipe racks and electrical and instrument cable trays should be located in the same general area, preferably down the middle of the structure.
- Freestanding process towers should be located adjacent to the structure to facilitate operator access from the tower platforms to the structure.

EXHIBIT 12-23 Large Structure

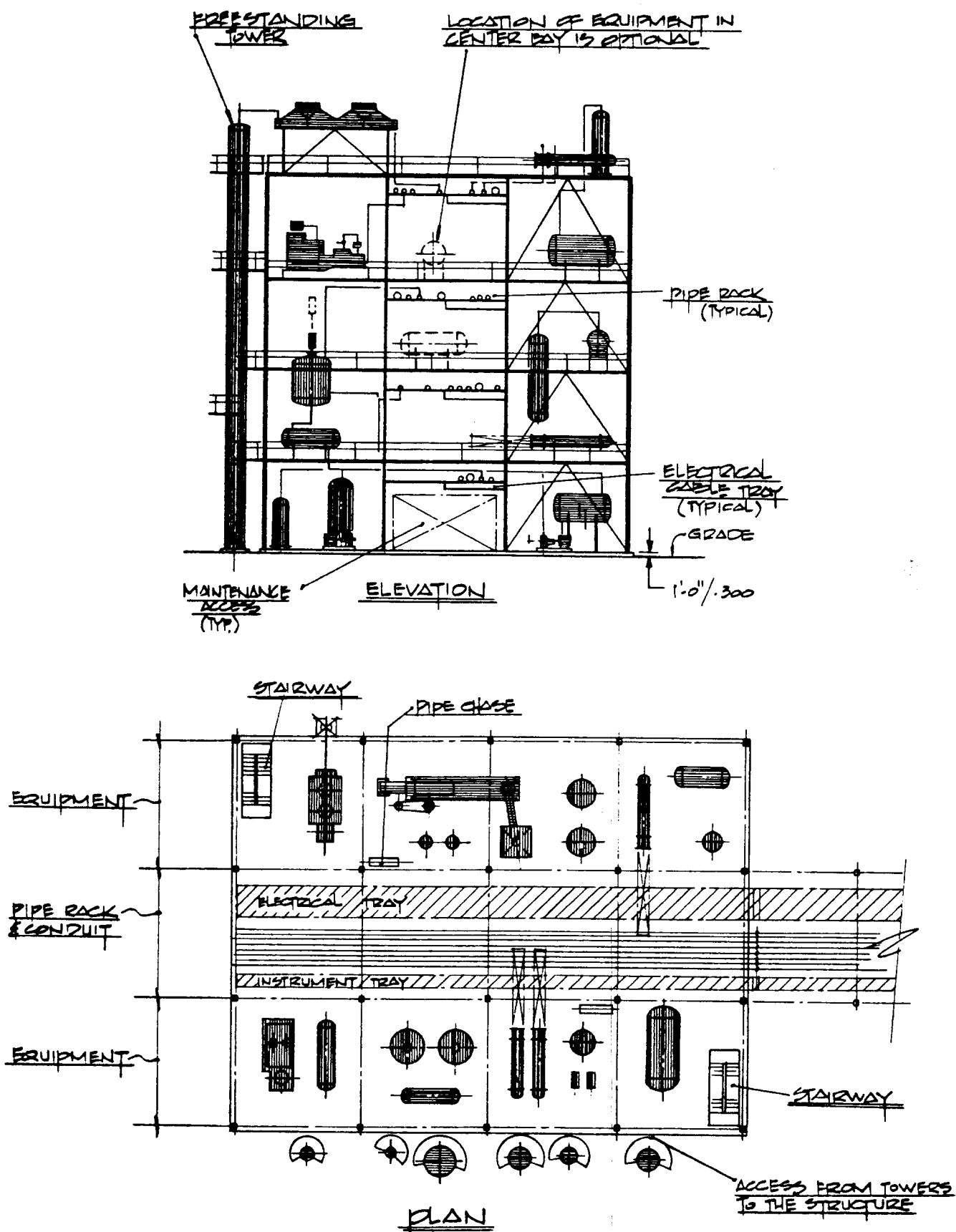
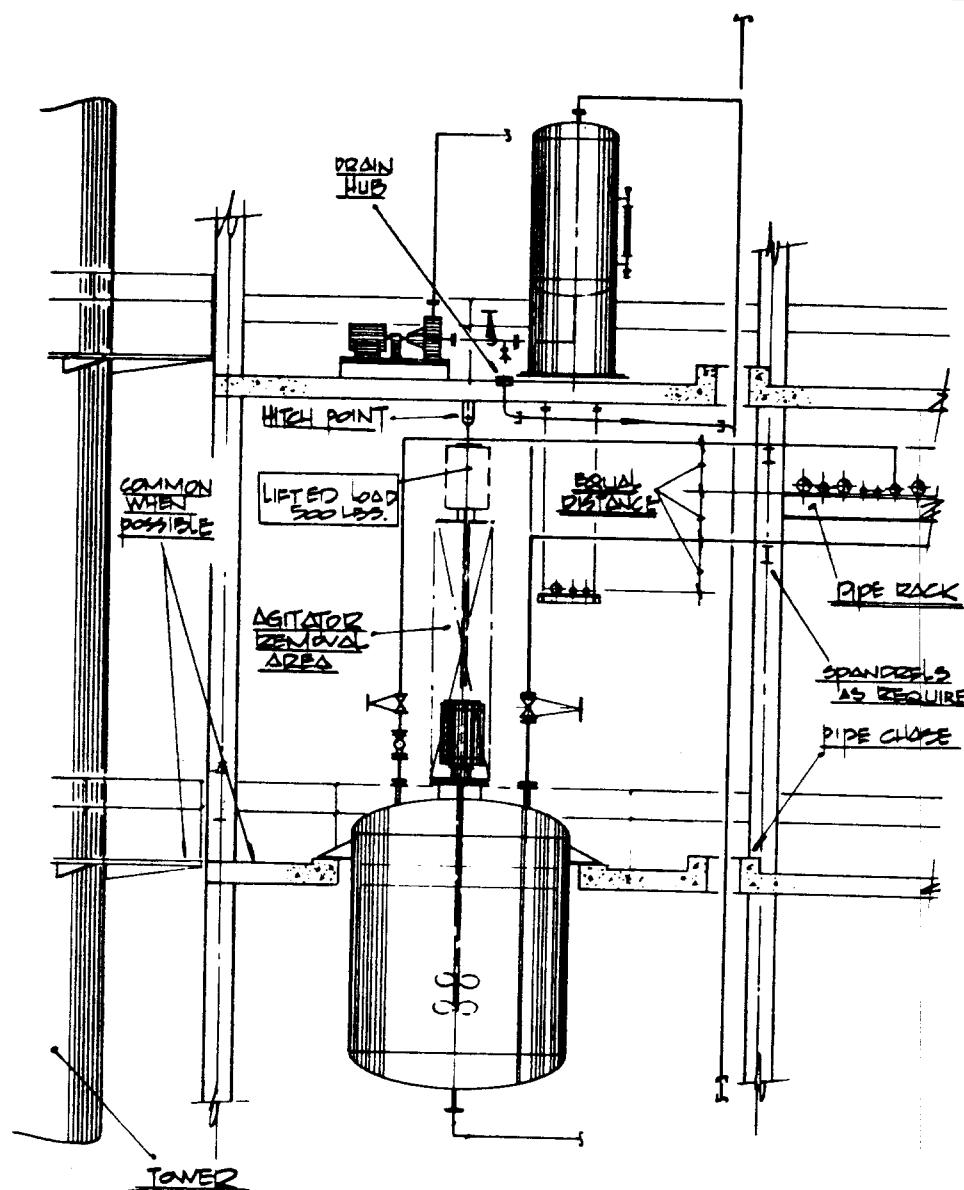


EXHIBIT 12-24
Structure Cross-Section



- A clear access way is needed for equipment maintenance or removal.
- Adequate clearance should be provided around all equipment for operation, maintenance, and safety.
- Adequate stairways and escape ladders are needed to meet OSHA requirements.

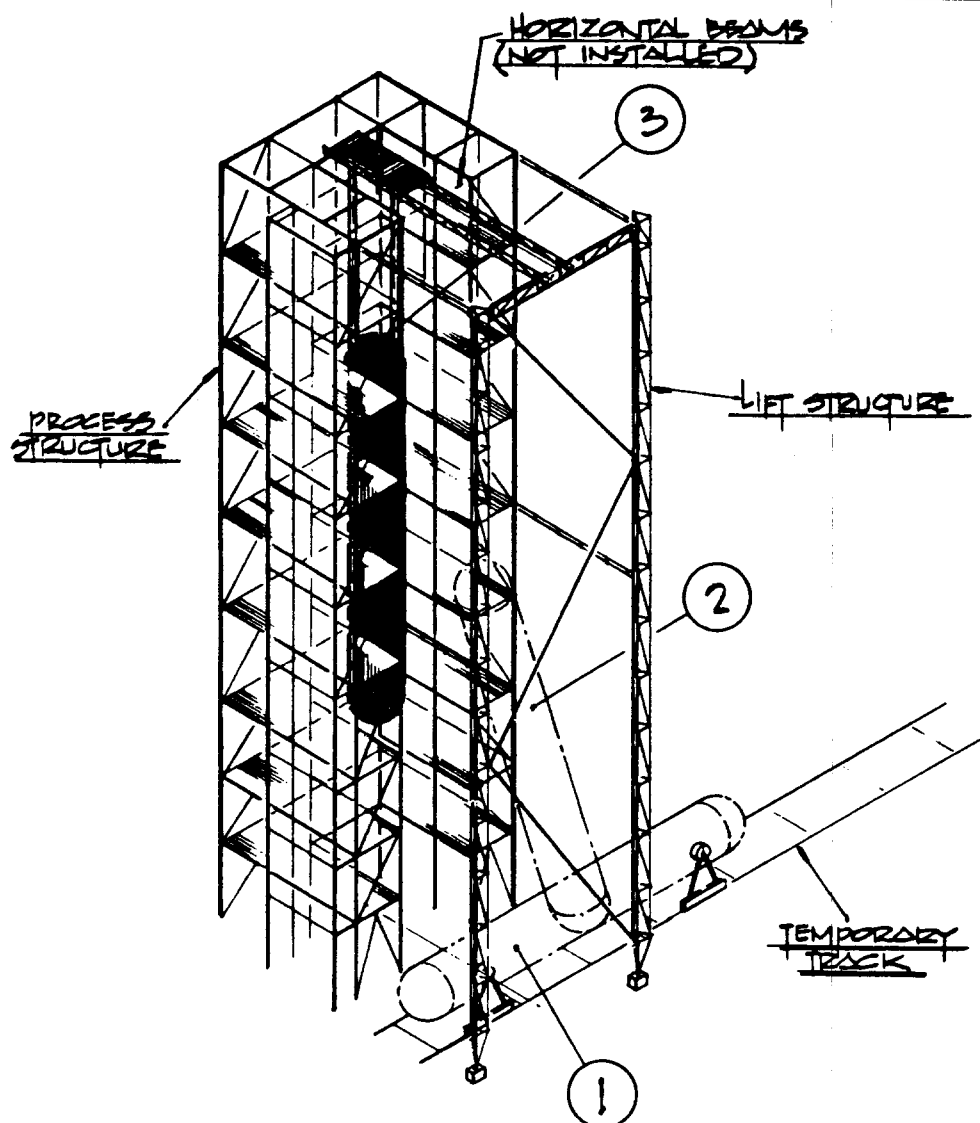
Open-sided and enclosed structures fall under different governing codes.

Hitch points and trolley beams are also required to facilitate maintenance. The lifted load requirement should be indicated on the layout drawing (as shown in the structure cross section in Exhibit 12-24) to show the maximum weight to be lifted at that point for the

structural engineer's information. Main pipe routing elevations must be established early. Flat piping turns should be used with caution. The use of pipe chases for grouped piping configurations should be considered for structures that have concrete floors to minimize individual holes through the floor.

When designing a large structure, the plant layout designer must observe how various pieces of equipment are erected during construction. Exhibit 12-25 shows one such sequence. The lift structure is erected adjacent to the process structure, and a temporary track is run between them. The vessel is brought into place and lifted off the rail. It is then raised to the desired elevation. With the outside beams yet to be

EXHIBIT 12-25
Setting Heavy Equipment
in a Large Structure



installed, the vessel is moved laterally into place; the beams are then installed. This is one method for setting large or heavy equipment in structures.

STAIR STRUCTURES

When complex equipment (e.g., a converter and fractionator in a fluid catalytic cracking unit) is designed, a stair structure with a vertical pipe rack must be located between both vessels, as shown in Exhibit 12-26. Although elevators are often used, client approval must be obtained before they are included. The optimum layout includes arranging the vessel platforms for easy access from the structure. Clearance between the vessel and structure platforms must accommodate the growth of the vessels, which should be calculated to satisfy safety concerns. This structure eliminates the

need to route lines and support them from their respective towers. The structure should be looked at as a vertical pipe rack and used to its maximum advantage to allow sufficient flexibility in the piping systems between the stationary structure and the movable towers.

DRILL STRUCTURES

Exhibit 12-27 illustrates two variations of the structure generally found in a coker unit. As can be seen, the main operating valve platform is the only platform supported from the elevated concrete deck in both arrangements. In one variation, the operator's penthouse is supported from the top of the vessel, along with the entire drill structure above the penthouse. This layout requires the coke drums to be designed to

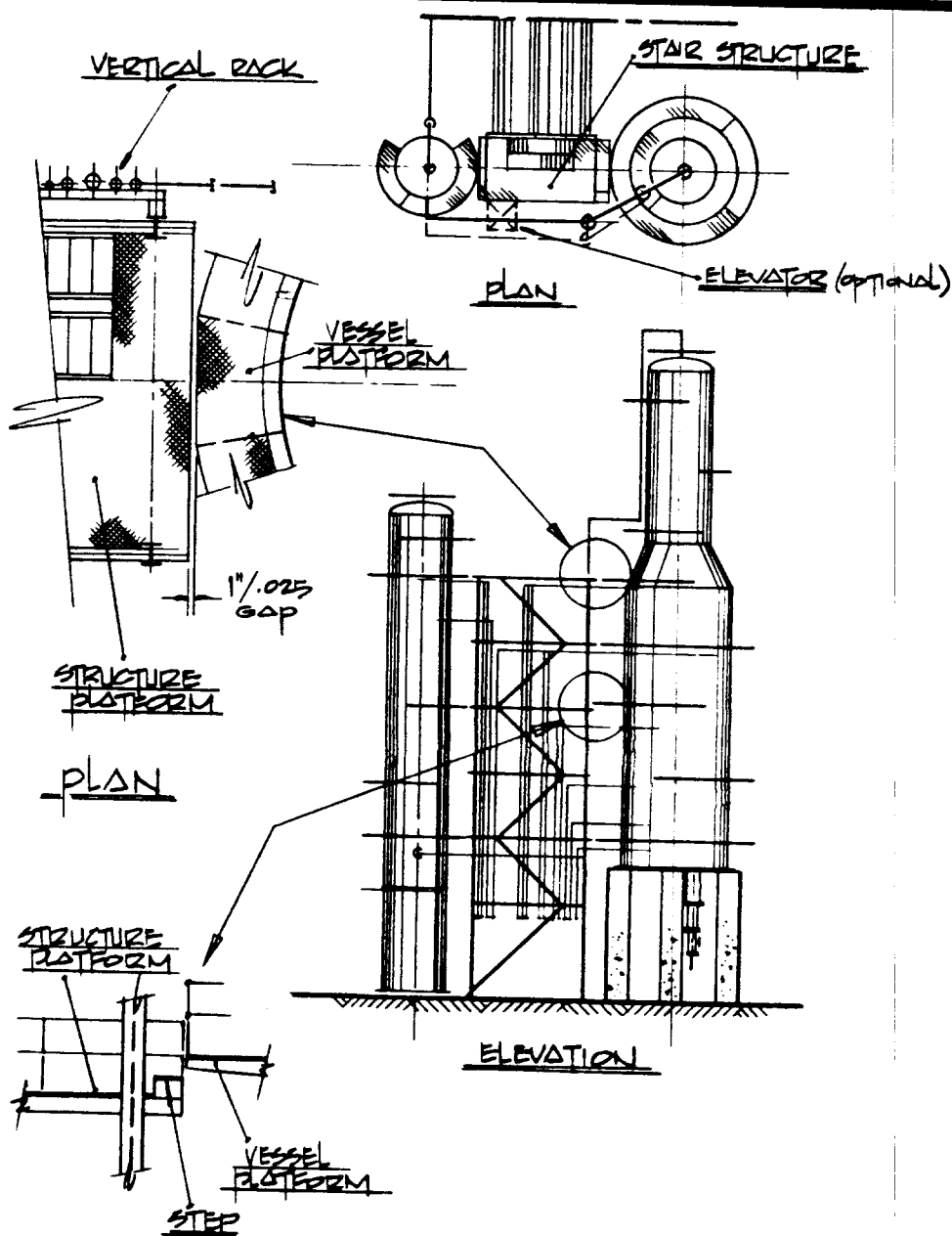


EXHIBIT 12-26
Stair Structure

EXHIBIT 12-27
Structures in a Coker
Unit

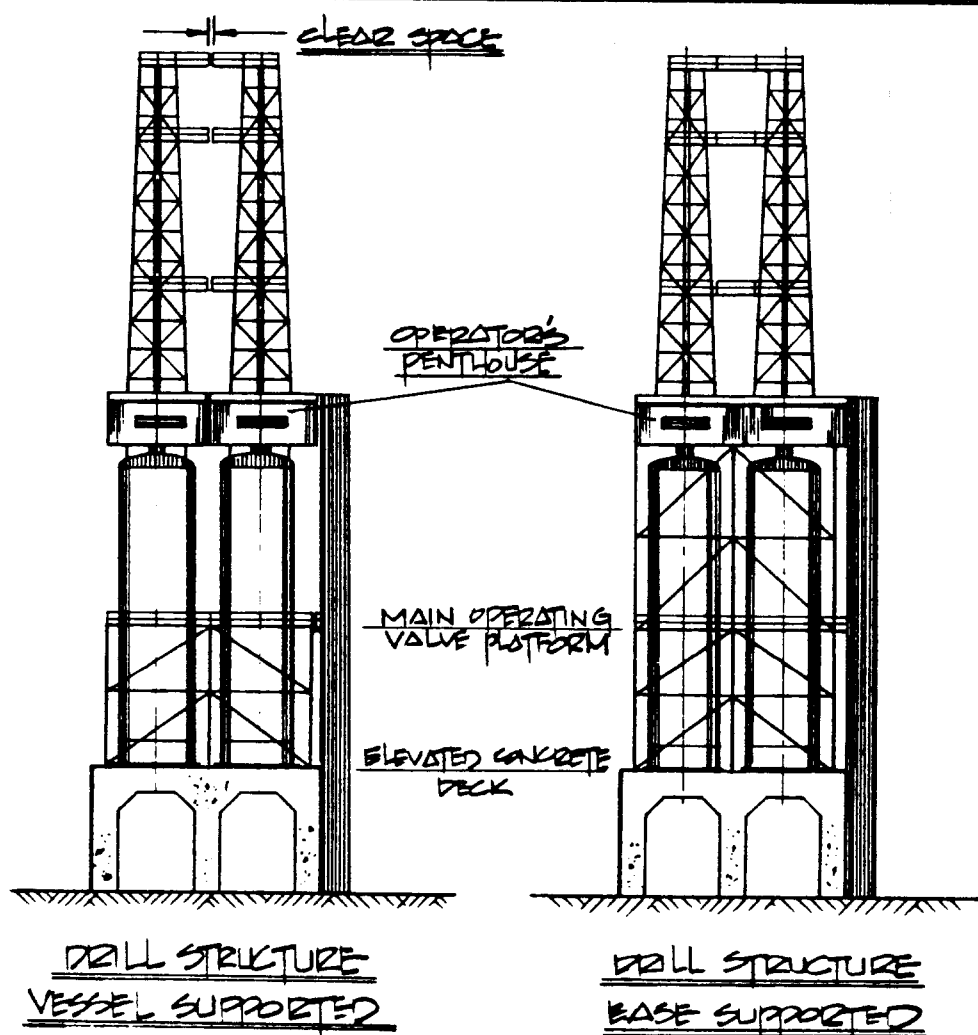
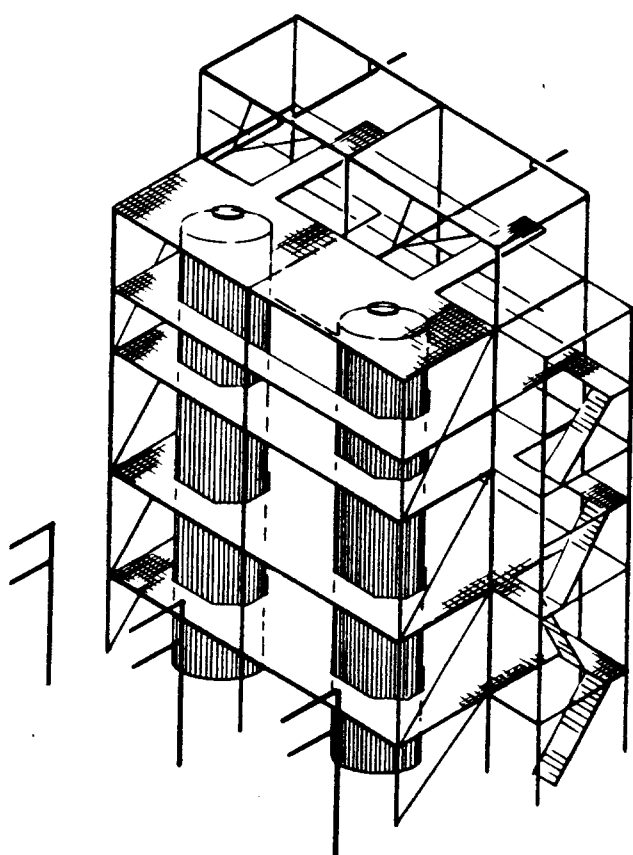


EXHIBIT 12-28 Operations Structure

support the penthouse and drill structures as well as the piping loads.

The alternative arrangement is one in which the entire structure is supported from the elevated concrete deck. Although the vessel wall can be thinner than in the first arrangement, this design requires more steel and greater attention to pipe support and flexibility because the tower operation is cyclic as a result of decoking requirements. The coke that builds up during operation is removed by high-pressure water flowing through a pipe rope supported within the drill structure. Before either of these arrangements is used, an economic study must be performed and reviewed by the client.

OPERATIONS PLATFORMS

Most large vertical vessels have platforms that are supported directly from the vessel shell. Some vessels have a great deal of associated piping and instrumentation; Exhibit 12-28 illustrates how much platform may be required for operation and maintenance. The top head platform is necessary for catalyst loading, and the monorail is used to hoist the catalyst from grade. At each level, the piping and instrumentation requirements need constant operator attention. Supporting large platforms from the vessels is often impractical, and a structure such as the one shown in this exhibit is best suited for support.

Underground Piping

Underground piping applies to any piping system located below grade. Buried or in trenches, underground piping systems within a processing complex consist of gravity flow drainage systems that carry process waste, spills, hydrocarbons to be reclaimed, and sanitary and storm water, along with pressurized water systems for process, fire, and drinking to meet the operational needs of the facility.

This chapter highlights the general step-by-step procedures to follow for each system when an underground piping layout is being developed. Local codes and regulations and specific client requirements govern the design of any underground piping system.

INDUSTRY STANDARDS

The following list represents the most commonly used industry standards for developing underground piping systems:

- ASTM A74—Cast iron soil piping and fittings.
- ASTM A120—Steel, black and hot-dipped, zinc-coated (galvanized), welded and seamless pipe, for ordinary use.
- ASTM A746—Ductile iron gravity sewer pipe.
- ASTM C425—Compression joints for vitrified clay pipe and fittings.
- ASTM C700—Vitrified clay pipe (extra strength, standard strength, and perforated).
- ASTM D1785—Polyvinyl chloride (PVC) plastic pipe (schedules 40, 80, and 120).
- ASTM D3034—Type PSM PVC sewer pipe and fittings.
- DIN 1230—Clayware for sewerage systems.
- SAS 14—Pipes of unplasticized plastic (polyvinyl chloride) for potable water.
- SAS 236—Clay pipes for draining sewage and water.

TERMINOLOGY

Terms used in underground piping systems are defined in the following section.

Invert elevation This term, usually associated with any underground line, refers to the elevation of the inside bottom of the sewer line, as shown in Exhibit 13-1. Because of the wide range of materials used in drainage piping systems with varying wall thicknesses, it is the constant that is used to set the elevation on construction drawings.

Sewer main This is the primary drain line in a system: it is separated into sections for safety reasons by sewer boxes.

Laterals Laterals are drain lines collecting from two or more sublaterals. They discharge into the sewer main through a seal.

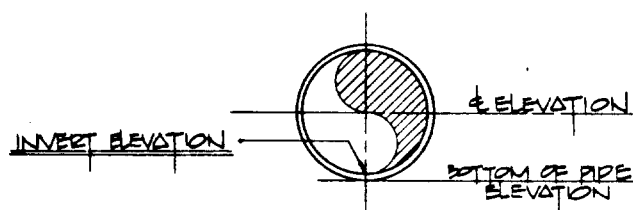
Sublaterals These collect branch lines and sealed sewer boxes into laterals.

Branches Branches collect all the various drain points within a plant (e.g., from catch basins and drain hubs) and tie into sublaterals.

Lift station This is an underground structure (e.g., a sump) used to pump effluent to a higher elevation, which may be in a gravity sewer system, or to the battery limit.

Catch basin This device is used to collect surface drainage, with an outlet liquid seal and sediment trap.

Cleanout A cleanout is a piping connection in a sewer system that is located at grade level for inspections or for cleaning the system.

EXHIBIT 13-1 Pipe Elevations

Drain hub Usually a 4-in open pipe connection located approximately 4 in (100 mm) above grade or platform in a concrete structure, a drain hub is used to collect drips or effluent from pumps, piping, or equipment drains.

Trench This is usually a three-sided concrete trough located in the ground whose top is flush with grade. It is used to house piping systems below grade and may require heat tracing or operator access.

Sewer boxes Used in oily water sewer systems, sewer boxes:

- Permit access for inspection and cleaning the sewer main.
- Allow a lateral to be sealed as it ties into a main sewer.
- Are required at intersections and changes of line size in sewer mains every 200 ft (61 m) in process units and every 400 ft (122 m) in off-site areas.
- Are sized to permit a worker to enter and inspect or remove any obstruction—They should have a minimum diameter of 48 in (1,200 mm).
- Do not require ladders as part of the design.
- Must have sealed covers in all sewer systems, with the exception of those in storm water sewers located in nonhazardous areas, which may have open grate covers—Sewer boxes located in hazardous ar-

as must have a 4-in vent line that discharges to the atmosphere at a safe location.

All lines entering sewer boxes within a process unit must have a 6-in (150-mm) minimum water seal. For off-site sewer boxes, a straight-through flow for sewer mains is permitted, provided that laterals from other areas do not enter the sewer box or mains. The inside top of the outlet line is installed at or lower than the elevation of the inside top of the lowest inlet line before sealing.

Seals These devices isolate the potential spread of fire from one area of a plant to another in a sewer system.

Angle of repose Concrete foundations must remain on undisturbed soil and must not be undermined by underground piping or conduit. In Exhibit 13-2, the angle of repose extends down at a 45° angle from the outer extremity of the foundation: nothing should be located within this area. Projects that use piles under foundations do not need to consider the angle of repose because the piles are carrying the load of the foundation, as depicted in Exhibit 13-3.

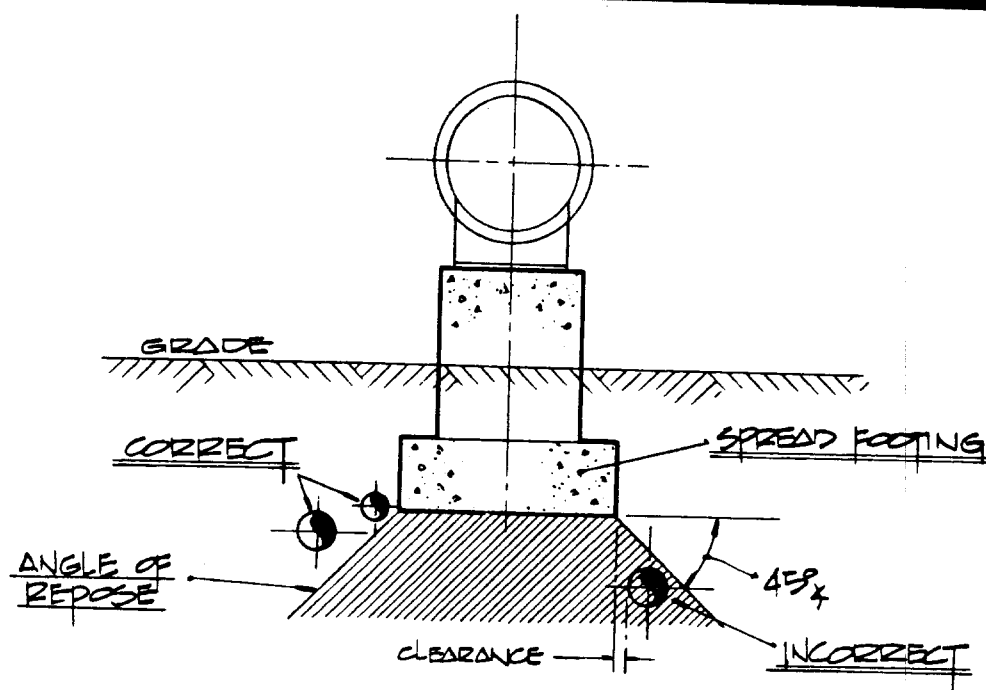
TYPES OF SYSTEMS

This section focuses on the various types of underground systems used in processing plants.

Uncontaminated Storm Water

This system generally collects all service water from process equipment areas, access ways, and roadways adjacent to such equipment. This collection is achieved through the use of area drains, catch basins, roof leaders, ditches, or swales. Spent process water is injected into this system if it is proved to be free of hydrocarbon contamination. In addition, the system must be sized to accommodate rain or fire water,

EXHIBIT 13-2
Angle of Repose



whichever is greater. In most cases, the latter will govern the line-sizing criteria.

Contaminated Storm Water

This system collects surface drainage from areas containing hydrocarbon-bearing equipment. This water must pass through a treatment facility before being discharged into an uncontaminated system or natural body of water (e.g., a river or stream).

Oily Water Sewer

This system collects waste, drips, and leaks from equipment and piping in areas that contain process equipment in noncorrosive services. The plant layout designer must consult with the systems engineer to

fully identify all such equipment and provide a drain hub at each item.

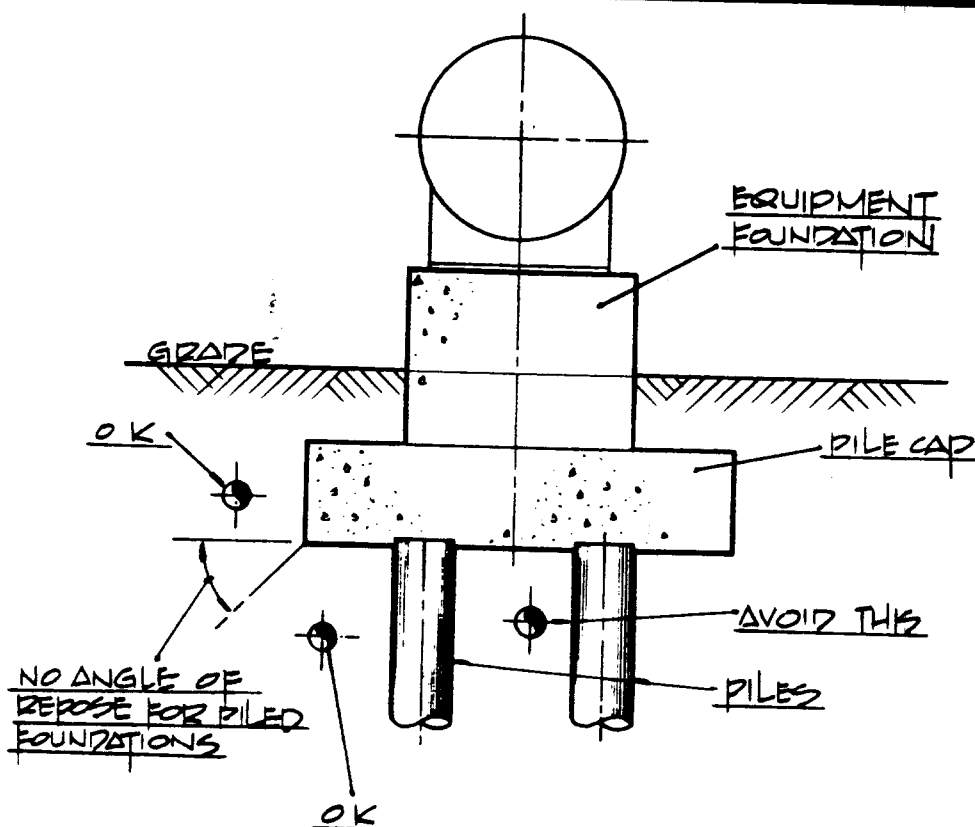
Chemical Sewers

This system recovers acid or chemical drains from equipment and piping as well as surface drainage around such equipment and piping through the use of curbed areas and drain hubs. This system may be routed to a sump for disposal or may be passed through a neutralization facility and discharged into an oily water system.

Combined Sewer

Process oily water sewers and storm water may be tied into a common system.

EXHIBIT 13-3
Pile-Supported
Foundations



Sanitary Sewer

This system collects raw waste from lavatories. If not discharged to the unit limit or lift station for disposal, it is routed to a septic tank or leaching field.

Blowdown System

This system picks up drains around boilers and steam drums and is run as a separate system, preferably to the battery limit. It is permissible to tie into a sewer box in the oily water sewer system as long as it is located downstream from any sewer box that collects

drainage from a furnace. This sewer box has an air-tight cover and vents to the atmosphere if located within a minimum distance of 50 ft (15 m) from a fired heater.

Pump-Out System

This system is shown on the piping and instrumentation diagrams. Although it does not need to slope, pockets must be avoided. Because it is common to pump out hot piping systems, adequate means must be provided to allow for line expansion or growth. Although trenches are generally used, buried pump-

out lines are covered with a mixture of sand and vermiculite.

Solvent Collection System

Many solvents are used to remove CO₂ from gas streams. These solvents are reclaimed in a separate drainage system and are also shown on the piping and instrumentation diagrams. The pipe is usually made of carbon steel and is run to an underground sump, where it is eventually pumped out.

Cooling Water

This system supplies water to such process equipment as surface condensers, coolers, and pumps through an underground header system.

Fire Water

This system consists of a loop around a process unit or equipment, with branches as required for hydrants or monitors, to protect the unit in case of fire.

Potable Water

This water is used for drinking, emergency eyewashes, and shower facilities.

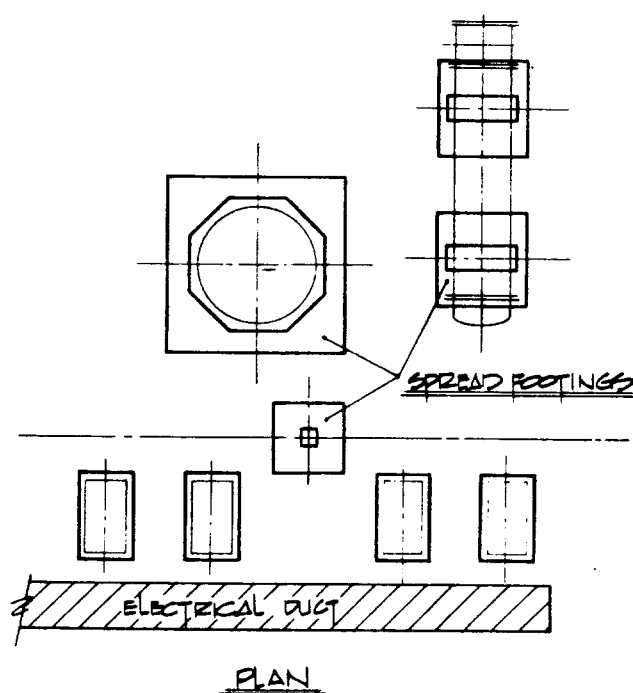
CONSTRUCTION MATERIALS

Materials selection is the responsibility of the piping specifications engineer and depends on service, operating pressure and temperature, durability, economics, and availability. Some of the materials and their uses commonly found in underground systems include:

- Carbon steel—For closed drain systems, cooling, and fire water.
- Stainless steel—For closed chemical drains.
- Cast iron (or grey iron)—Often used in handling storm and oily water drains. Cast iron is very resistant to corrosion. The hub and spigot design is fabricated in 5- and 10-ft lengths, which may be modified with a special cutting tool.
- Ductile iron—Has a higher stress value than cast iron. It is also used for hub and spigot as well as process water service.
- Concrete pipe—Used for surface drainage and for 15-in and larger pipes. Although it is available in smaller sizes, economics may limit its use.
- Fiberglass reinforced pipe—Used in corrosive service. It is limited to low-pressure and low-temperature systems. When fabricated, it is designed to meet very specific needs. For example, it may need to be able to withstand outdoor exposure or burying or may need to be sun retardant or made to project-specific dimensions.
- PVC pipe—Commonly used for corrosive service.
- Vitrified clay pipe—Used in gravity drain systems that handle sanitary or surface drainage. It cannot be subjected to any significant loads (e.g., under buildings, paved areas, or roadways). It generally has a maximum operating temperature of 200° F (93° C).
- Glass pipe—Used for floor drains in processing plants, especially for acid service.

OILY WATER AND STORM WATER SYSTEMS

The initial layout of any oily or storm water underground piping system usually takes place after the preliminary plot plan is generated. Even though some equipment locations may be tentative, the plant layout designer can begin to spot the oily water and storm water mains, locate sewer boxes, and establish the invert elevation of these systems at each end of the unit.

EXHIBIT 13-4 Below-Grade Obstructions

As with any piping layout, information for an underground gravity flow drain system is often less than what is required at the outset of a project. A list of the most preferred information includes:

- The underground specification.
- The plot plan.
- Above-ground piping studies.
- Local codes and regulations.
- The location of potential site obstructions.
- Local site data, including topographic information, maximum design rainfall, and frost depth.
- Electrical and instrument conduit locations if the

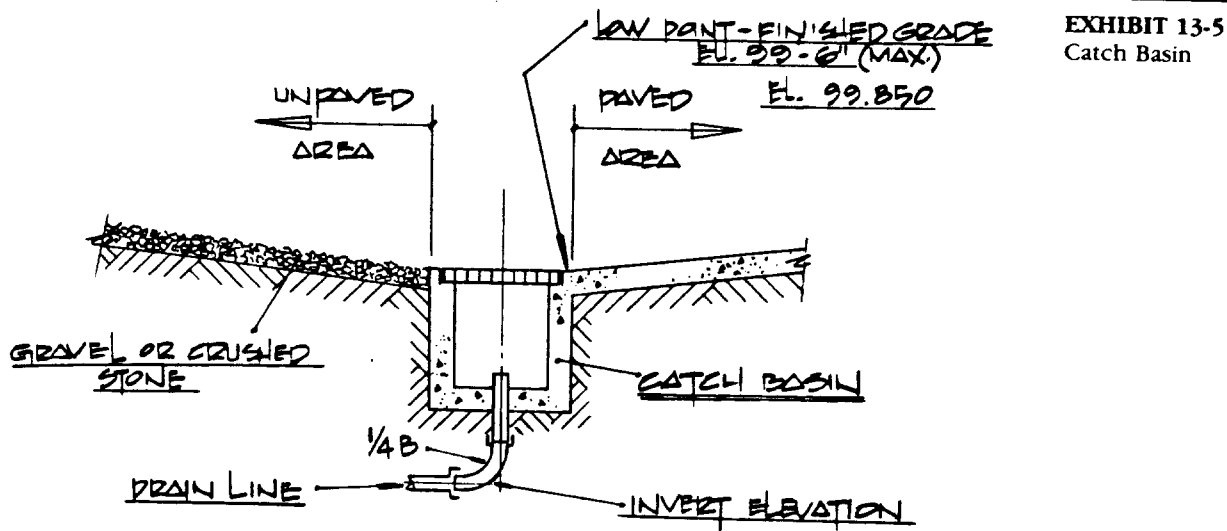
piping is routed underground.

- Fire water requirements.
- The type of system required (e.g., separate or combined oily and storm water system).
- The invert elevation of lines at the process unit battery limit, as preferred by the client.
- The extent of paving.
- The extent of pipe trenches that carry heat-traced drain systems.
- Preliminary foundation sizes and depths.
- Continuous process discharge that enters the system.

Using a copy of the plot plan, the piping designer should outline all underground obstructions, including equipment and structure foundations, proposed routing of major electrical and instrument ducts as developed by the electrical and instrument engineers, or any existing underground piping, trenches, and light pole stanchions. A typical example is shown in Exhibit 13-4.

A decision must be made on whether to route the oily and storm water drains as separate systems or combine them. A combined system is the most common. It requires seals to prevent the spread of hydrocarbon vapors or fire throughout the unit. A combined system must pass through a treatment facility outside the process unit before entering any outside body of water. Because the sewer must be run past the cooling water system, under the pipe rack, along with some electrical ducting and the major portion of the cooling system run outside the equipment, the combined oily and storm water sewer system is routed between the pipe rack columns and the equipment. The extent of all paving, curbed and diked areas, roadways, access ways, and equipment lay-down areas should be shown.

A high point of paving of 100 ft 1 in (100.025 mm) is set down the center of the area directly below the pipe rack before the unit is subdivided into areas serviced



by a single catch basin. The area under the pipe rack toward the center of the high point is included in each area run-off calculation. The suggested maximum area per catch basin is 5,500 sq ft (510 sq m) for paved areas and 3,500 sq ft (325 sq m) for unpaved areas.

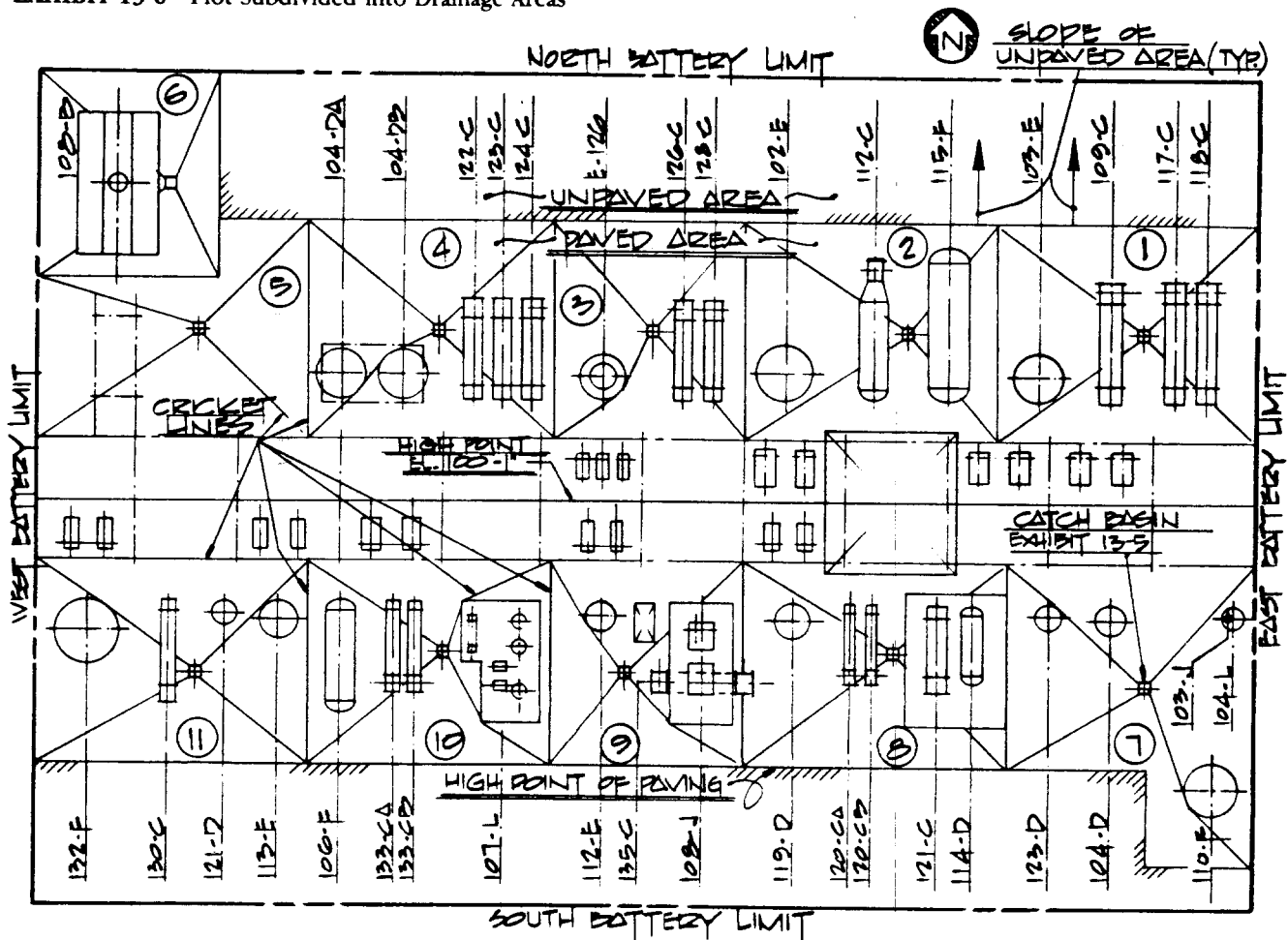
Cricket lines are drawn around each area to indicate the high point of paving or grade. The diagonal cricket lines from the corners of the area to the catch basin must slope at a rate of 1 in per 120 in; the maximum allowable drop should not exceed 6 in (150 mm). The maximum length of this diagonal cricket must not exceed 60 ft (18.25 m). Its length and elevation difference is calculated point to point and does not account for such obstructions as equipment foundations.

In paved areas with a high concentration of equipment, the allowable area per catch basin should not exceed 3,000 sq ft (270 sq m). When practical, these areas are arranged to collect drainage from common equipment. Catch basins are located as required, provided that the difference between the long and the short diagonal cricket line is no greater than 2 to 1.

When possible, catch basins are located near the center of the drainage area, preferably not under stairways, structures, or equipment. A typical catch basin is illustrated in Exhibit 13-5, and the extent of these areas is shown in Exhibit 13-6.

A tentative location and invert elevation of the drain system is established at the unit battery limit from the site data supplied by the client. If the information is unavailable, the end of the unit that the system exits should be obtained from the client. The west battery limit and an invert elevation of 94 ft 6 in (99.850 mm) is used as an example. The two sewer mains running east and west through the unit are located in the most direct route possible, with the depth of all underground obstructions on the way taken into consideration. The designer must avoid locating any line below the angle of repose of a foundation. Another concern is possible interference at the point at which any two underground lines intersect. It may not be obvious what the exact elevation of each gravity drain line is at the point of intersection. The following criteria determine the need for sewer boxes:

EXHIBIT 13-6 Plot Subdivided into Drainage Areas



- At the beginning and at the end of each main.
- At the intersection at which a branch line must be sealed from the header.
- At any change in direction or elevation in the main.
- Every 300 ft (91 m) for lines of 15 in and larger.
- Every 200 ft (61 m) for lines of 12 in and smaller.

Sewer boxes should be made of precast reinforced concrete pipe a minimum of 48 in (1,220 mm) in diameter. The system engineer establishes the need for sealed sewer boxes. Those containing clean storm or fire water do not require sealing, but toxic hydrocarbon-bearing run-off requires a sealed sewer box that is vented to a safe location, as shown in Exhibit

EXHIBIT 13-9
Minimum Cover for
Buried Piping

MATERIAL	HUB & SPIGOT EXTRA HEAVY / BELL & SPIGOT 50 th CLASS									
SIZE	4"	6"	8"	10"	14"	16"	12"	18"	20"	24"
H-10 LOADING 8000# WHEEL LOAD	1'-0"			1'-0"				1'-6"		2'-0"
H-15 LOADING 12000# WHEEL LOAD	1'-0"			1'-6"				2'-0"		2'-0"
H-20 LOADING 16000# WHEEL LOAD	1'-6"			2'-0"				2'-6"		3'-0"

MATERIAL	CORRUGATED METAL PIPE							
SIZE	12"	13"	18"	21"	24"	30"	36"	42"
GAUGE	16	16	16	16	14	14	12	12
H-10 LOADING 8000# WHEEL LOAD				6"				
H-15 LOADING 12000# WHEEL LOAD								
H-20 LOADING 16000# WHEEL LOAD				9"				

MATERIAL	EXTRA-STRENGTH CLAY PIPE									
SIZE	6"	8"	10"	12"	15"	18"	21"	24"	30"	36"
H-10 LOADING 8000# WHEEL LOAD	2'-0"	2'-0"	2'-0"				3'-0"			
H-15 LOADING 12000# WHEEL LOAD	2'-6"	3'-0"	3'-0"							
H-20 LOADING 16000# WHEEL LOAD	3'-0"	3'-6"	3'-6"				4'-0"			

LOADING	MINIMUM COVER FOR H-20 16000# LOADING ON CONCRETE PIPE									
SIZE	6"	8"	10"	12"	15"	18"	24"	30"	36"	42"
CONCRETE PIPE (C 14-42)	1'-6"	2'-0"	2'-0"	2'-0"	2'-6"	3'-0"	—	—	—	—
REINFORCED CONCRETE PIPE (C 7.5-41)	—	—	—	2'-0"	2'-6"	3'-0"	3'-6"	4'-0"	—	—
REINFORCED CONCRETE PIPE (C 7.6-41)	—	—	—	1'-6"	1'-6"	2'-0"	2'-0"	2'-0"	—	—

lows:

- Cast iron, concrete, and vitrified clay tile must be 4 in.
- Carbon and stainless steel and lined pipe must be line size, with a maximum of 3 in and a minimum of 2 in.

For ground cover for underground and gravity piping systems, the following information should be used in conjunction with the chart in Exhibit 13-9:

- Sewers, drain systems, and process water systems usually have a minimum of 12 in (300 mm) of cover, except when foundations (e.g., spread footings) or other obstructions located in nontraffic areas dictate otherwise.
- Process and fire water piping, without exception, have a minimum cover of 2 ft 6 in (750 mm).
- If cast iron, concrete, or clay tile pipe that passes under roadways and other tucking areas does not conform to minimum cover requirements for loading conditions, shown in Exhibit 13-9, the pipe must be encased in a suitable protective housing.
- The frost line is considered when elevations in freezing climates are established.
- Continuously flowing main water and sewer lines

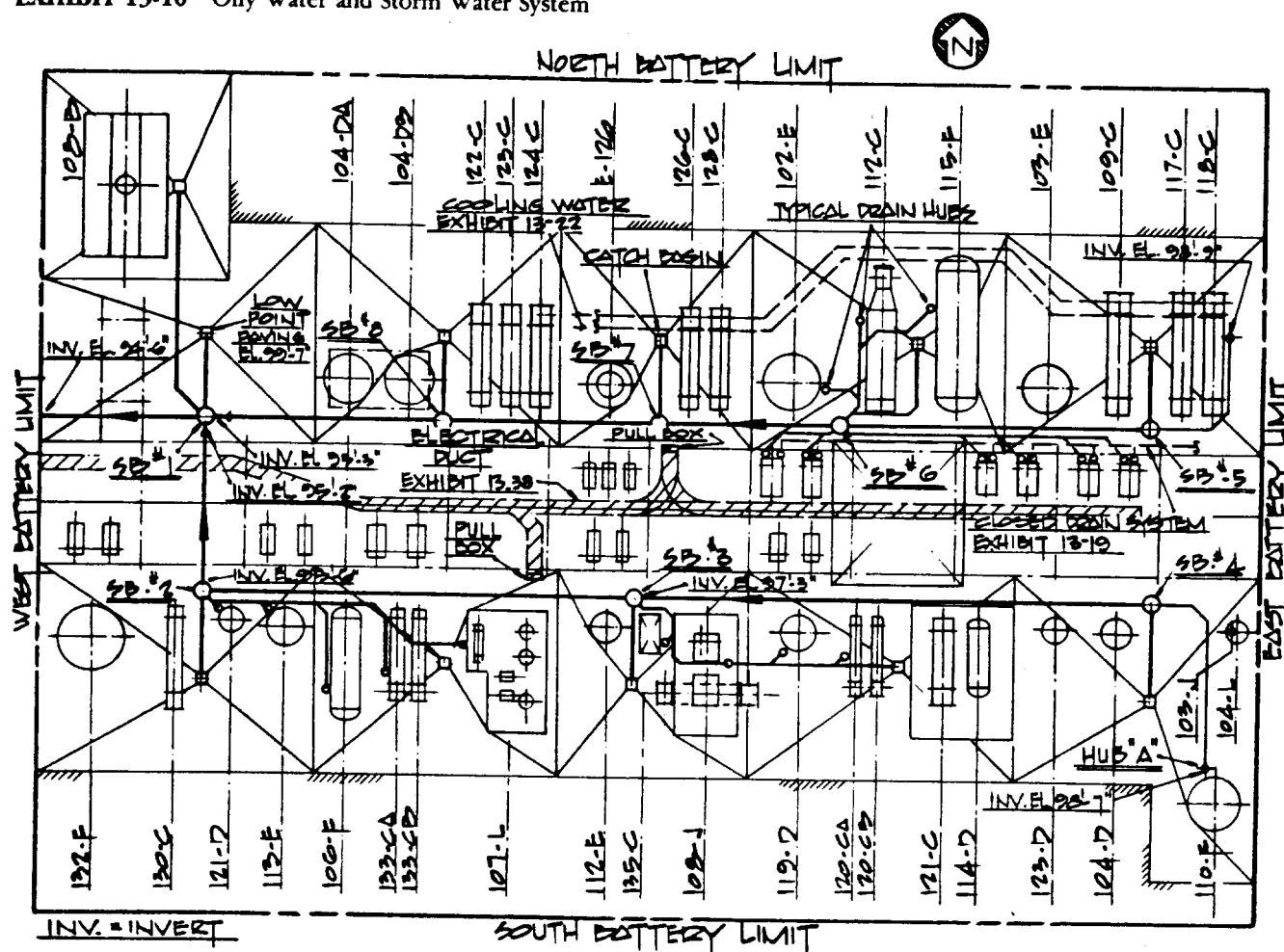
should be installed with the centerline of the pipe located at or below the frost line as indicated in the project data.

- Stagnant lines (e.g., fire water or cooling water not equipped with an antifreeze bypass) and lines with intermittent flow should be installed with the top of the pipe located at or below the frost line.
- Branch lines in water service with a constant flow may be installed above the frost line.
- Branch lines in sewer service are installed with the centerline at or below the frost line, with the exception of lines required only for housekeeping drains, which may be installed above the frost line—An example of a housekeeping drain is one in which the outlet from vessel-level instruments is collected and routed to a drain hub at grade.

The starting invert is set with the equipment drain located the greatest distance away from the ultimate point of disposal, hub A of Exhibit 13-10. This hub is set with a 12-in (300-mm) cover from the low point of paving to the top of the pipe.

As a rule, the slope of sublaterals is set to 1/4 in per foot (6 mm per 300 mm), and laterals are set at 1/8 in per foot (3 mm per 300 mm). All inverts are rounded to the nearest 1/2 in (10 mm) less than the calculated

EXHIBIT 13-10 Oily Water and Storm Water System



value as displayed in Exhibit 13-11.

The piping designer should locate the oily water drain hubs using the above-ground piping studies, setting each invert elevation and routing sublaterals, laterals, and headers. Each fitting (e.g., Y branches, $\frac{1}{8}$ bends, and $\frac{1}{4}$ bends) must be identified. Headers and laterals should be reduced, when possible, to 4 in

before cleanouts are installed. All laterals entering sewer boxes are sealed.

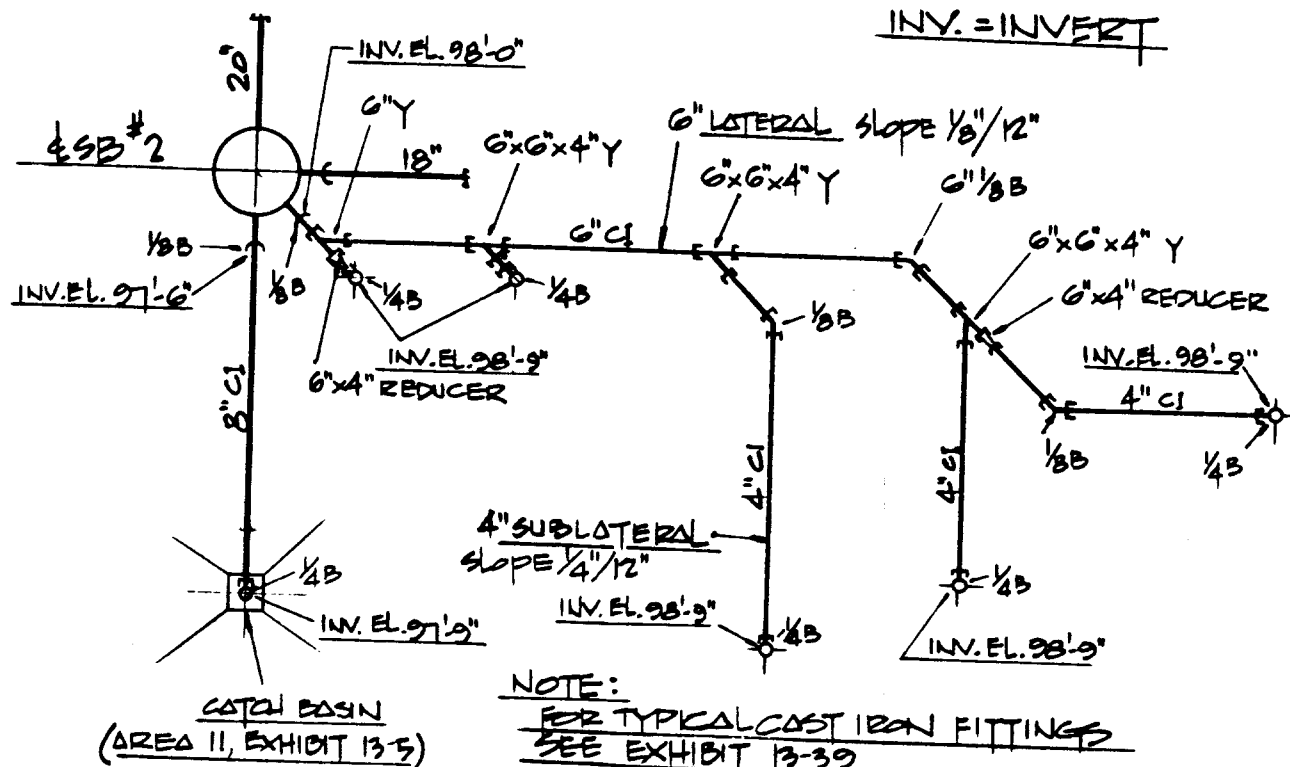
Oily or chemical lines should not be routed over the top of potable water lines. Local plumbing codes should be used for actual requirements. When oily and process systems drain to a sump or storage containment, the storage capacity is determined from the

1 DRAIN HUB AND LESS THAN 20' @ 0.100 RUN

= 4" LINE SIZE

2 OR MORE DRAIN HUBS OR MORE THAN 20' / 6.100 RUN = 6" LINE SIZE

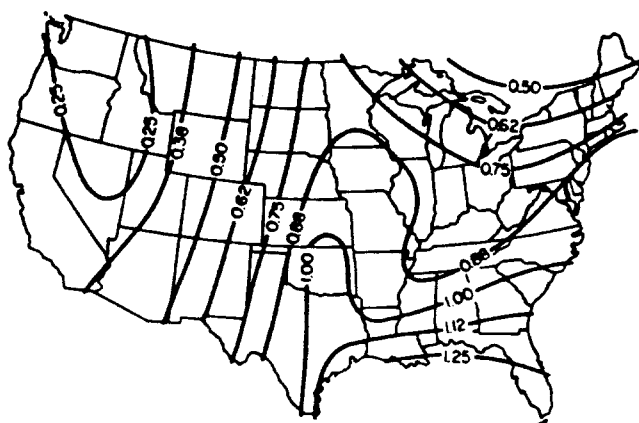
INV. = INVERT



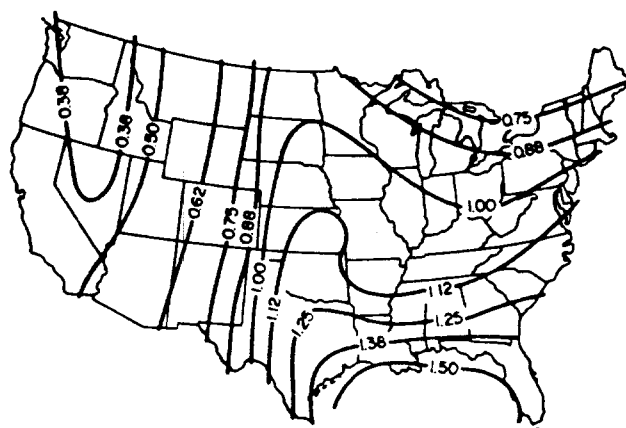
When all mains, laterals, and sublaterals have been routed, the line-sizing calculations can proceed. The system must be checked for excessive quantities of hydrocarbons that may suddenly discharge into the oily or storm water drain system as well as for any continuous discharge that exceeds 100 gallons (378.5 liters) per minute (gpm). (For simplicity's sake, the remainder of this chapter deals only with gallons.) These quantities are added into the line-sizing calculations and are furnished by the systems engineer. If excessive discharges are expected, it may be advantageous to run a separate branch line directly to the nearest sewer box. The outlet line of a sewer box is sized based on the total effluent into the sewer box from all sources.

This section outlines the criteria and formulas that are commonly used for developing line sizing for oily and storm water sewer systems.

Oily water and storm water sewers are sized to handle the calculated rainfall plus process water drainage or the fire water plus process drainage, whichever results in the greater quantity. Rainfall rates are obtained from the project design data, and process water drainage quantities are obtained from the systems engineer. When client input on fire water quantities is unavailable, a decision is made jointly by the systems and project engineers. When specific considerations (e.g., a deluge system) are not required, the fire water flow rate for each area is set at 1,000 gpm. The maximum fire water figured into line-sizing calculations for a process unit should not exceed 2,000 gpm. Local rainfall charts are reviewed before any line sizes are calculated.

EXHIBIT 13-12 Rainfall Intensity and Frequency

Fifteen-minute rainfall, in inches, to be expected once in two years.



Fifteen-minute rainfall, in inches, to be expected once in five years.

Eventually, the sewer line must be sized for a combination of rainfall and fire water. Sewers containing combined rainfall and process water are designed to run 75% full, which allows additional capacity for short but heavy rainfalls. This amount is calculated by multiplying the actual runoff rate by a factor of 1.1. For example, if the actual runoff rate were 1,500 gpm, that figure would be multiplied by 1.1 and the resulting 1,650 gpm would be used in the line-sizing calculation. Sewers containing combined fire water and process water are designed to run full. The following coefficients are used for surface drainage runoff:

- Rainwater, paved area—90% (0.9).
- Rainwater, unpaved area—50% (0.5).
- Fire water, all areas—100% (1.0).

Sewers running at the maximum flow rate are designed with a maximum velocity of 9 ft (2,700 mm) per second and a minimum velocity of 3 ft (900 mm) per second. The size of pipe depends on the coefficient of roughness, n , when run at a given slope. Although it is preferable to stay at the lower values of n for the most economical sizing, it is important to select the proper n value on the line-sizing chart. Based on these pipe types, the design value n is as follows:

- Clean, coated cast iron—0.012.
- Clean, uncoated cast iron—0.013.
- Concrete—0.013.
- Painted steel—0.013
- Vitrified clay tile—0.013.
- Galvanized iron—0.015.
- Corrugated steel—0.025.

The runoff rate for each area, as initially outlined in Exhibit 13-5, may now be calculated by using the modified rational formula:

$$Q = KICA$$

where:

- Q = the runoff rate in gpm (converting to cubic feet per second can be done by multiplying gpm by 0.00223)
- K = the conversion constant (0.01039 for flow in gpm)
- I = rainfall intensity for the storm duration in inches (or decimals of an inch) per hour, as shown in Exhibit 13-12
- C = the runoff coefficient
- A = the area of surface to be drained in square feet

For example, the runoff rate for a paved area can be calculated with the following data:

- Area = 80 ft × 75 ft (6,000 sq ft).
- Rainfall = 5 in per hour.
- Fire water = 1,000 gpm.
- Process water = 150 gpm.
- Pipe material = 4 in to 15 in, cast iron; 18 in and larger, concrete.
- Velocity = 3 to 5 ft per second.

Therefore, $K = 0.01039$, $I = 5$ in per hour, $C = 0.9$ (data was supplied), and $A = 6,000$ sq ft. The runoff rate in gpm (Q) is calculated as follows:

$$0.01039 \times 5 \text{ in} \times 0.9 \times 6,000 = 280 \text{ gpm}$$

The total area runoff is the total process water (150 gpm) plus the total rainfall runoff (280 gpm), or 430

FLOW FOR CIRCULAR PIPE FLOWING FULL
BASED ON MANNING FORMULA ($n = 0.013$)

EXHIBIT 13-13
Manning Formula

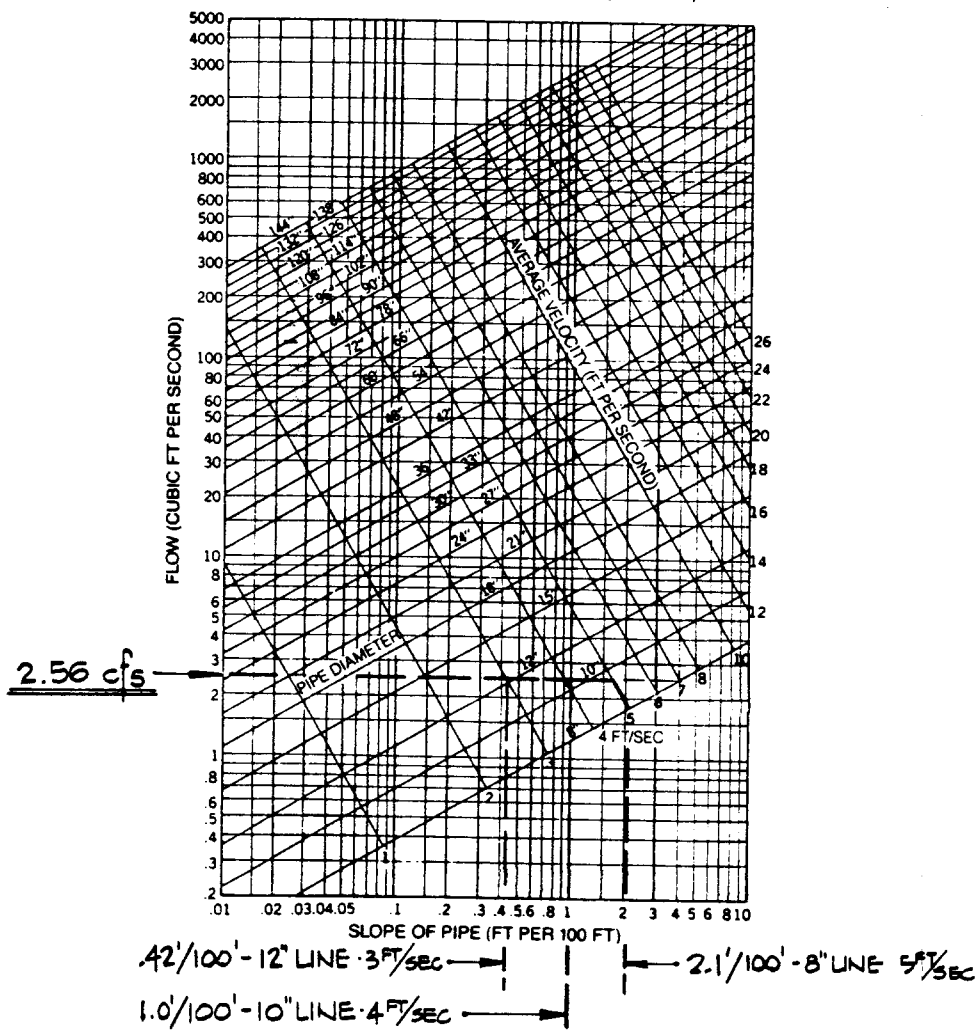


EXHIBIT 13-14 Calculation Chart

SEWAGE WATER/RAINFALL CALCULATIONS

AREA	SQ FT	GPM/CFS	REMARKS
1	3900	182 / .40	
2	5700	243 / .54	
3	6000	280 / .62	
4	4500	210 / .47	
5	3750	175 / .39	
6	4100	696 / 1.55	INCLUDES ADDITIONAL 500 GPM PROCESS WATER
7			
8			
9			
10			
11			
12			
13			
14			
15			

DESIGN DATA USED: K = .01030
C = .85 / HR
A = .0250

gpm. To convert 430 gpm to cubic ft per second (cfs), it is multiplied by 0.00223, yielding 0.959 cfs.

To calculate the total amount of water that would result if the pipes were running 75% full, 0.959 cfs is multiplied by 1.1, for a result of 1.05 cfs. The combined fire water and process water is:

$$1,000 \text{ gpm} + 150 \text{ gpm} = 1,150 \text{ gpm, or } 2.56 \text{ cfs}$$

The larger total of the two, 2.56 cfs, would be used for sizing.

Now that a flow rate of 2.56 cfs has been established, the actual line calculations can be developed through the use of graphs based on the Manning formula, illustrated in Exhibit 13-13. First, a line is drawn

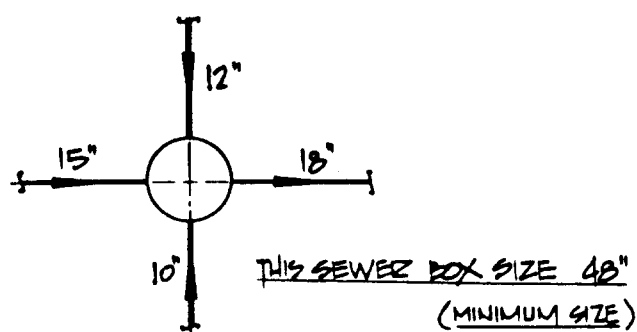
across the chart from left to right at the flow rate previously calculated, 2.56 cfs. As can be seen on the chart, several line sizes could handle the flow in the desired velocity range of 3 to 5 ft per second. A 12-in line would flow at 3 ft per second if the slope were set at 0.42 ft per 100 ft; a 10-in line would flow at 4 ft per second at a slope of 1 ft per 100 ft; and an 8-in line would flow at 5 ft per second if the slope were set at 2.1 ft per 100 ft. Higher velocities are attainable but at much greater slopes, which may not be practical. Therefore, the actual line-size selection must be made on the available slope within the system (from the farthest catch basin to the final invert elevation at the battery limit) and on the desired flow rate. It must be remembered that, in this example, the flow rate cannot be set at less than 3 ft per second.

The runoff rate calculated in each area of the unit must be recorded on a chart similar to the one shown in Exhibit 13-14. Because each section of sewer main is sized to handle the total accumulation that could possibly enter the line, it is important that all total flow-rate quantities are recorded not only for line sizing but for use during a mechanical check or audit of the system. Sizing gravity flow drain systems is a give-and-take situation. As the west battery limit is approached, it may be necessary to readjust some previously selected line sizes, flow rates, or slopes to avoid an underground obstruction or other gravity flow drain system within the unit. There are no absolutes, just many alternatives that must be explored before the line sizing of the oily and storm water drain system is finalized.

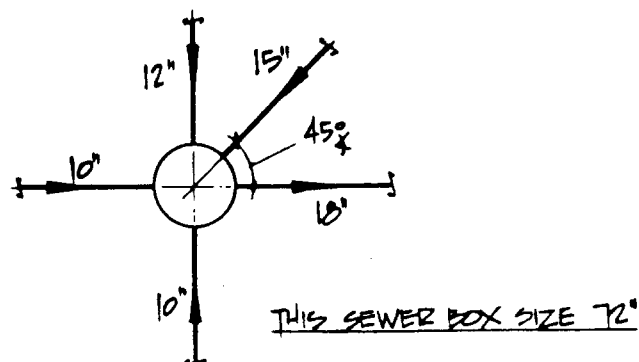
As the invert elevations of the main at the sewer boxes are confirmed, the actual elevations are recorded on the orthographic piping plan drawing, which is shown in Exhibit 13-7.

As the details for each sewer box become available (e.g., main inlet and outlet sizes and invert elevations, auxiliary inlet elevation, top and bottom elevations, and the diameter), the information is recorded on a sewer box schedule, as depicted in Exhibit 13-15. This

EXHIBIT 13-16 Sewer Box Sizes

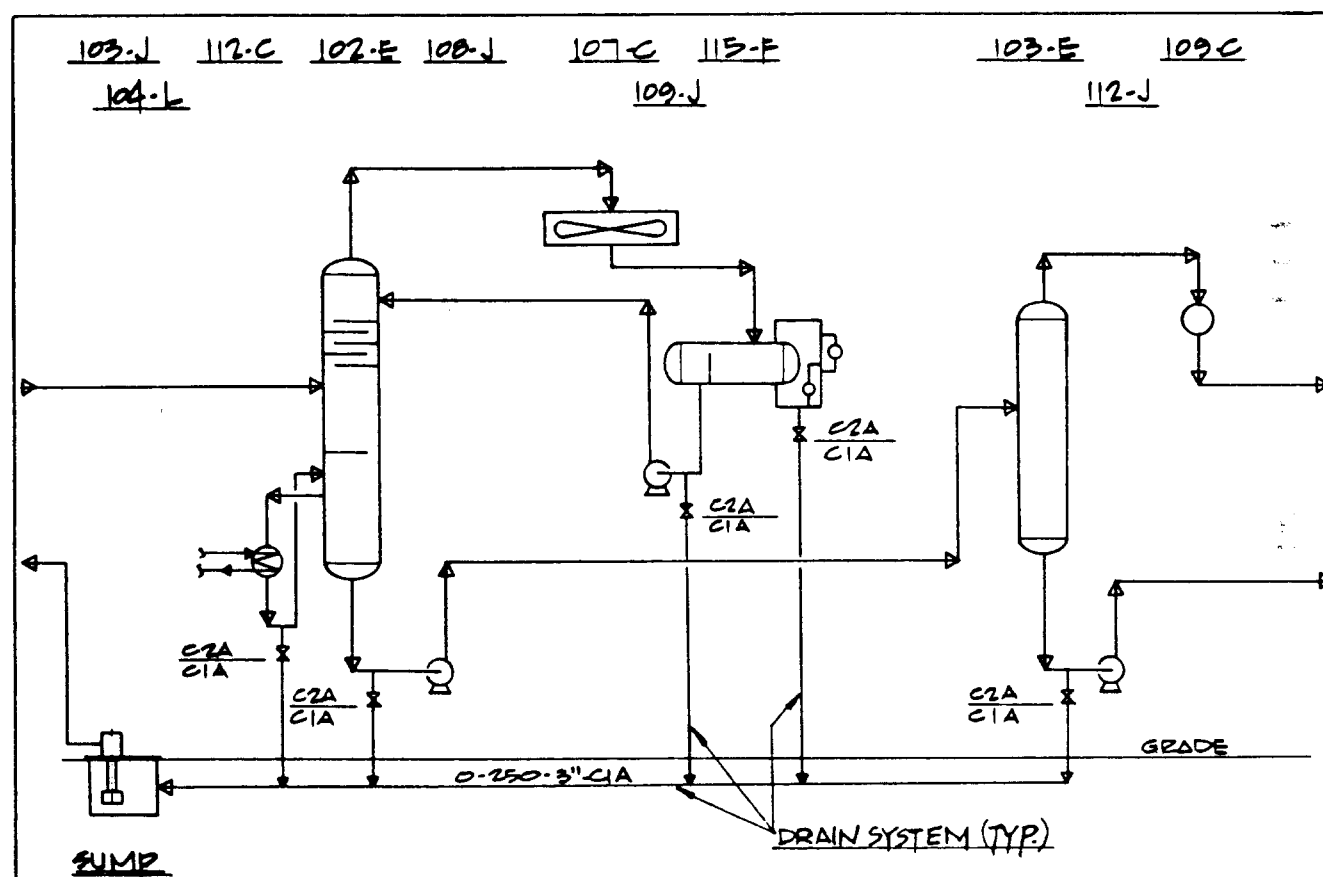


a. 90° Entry



b. 45° Entry

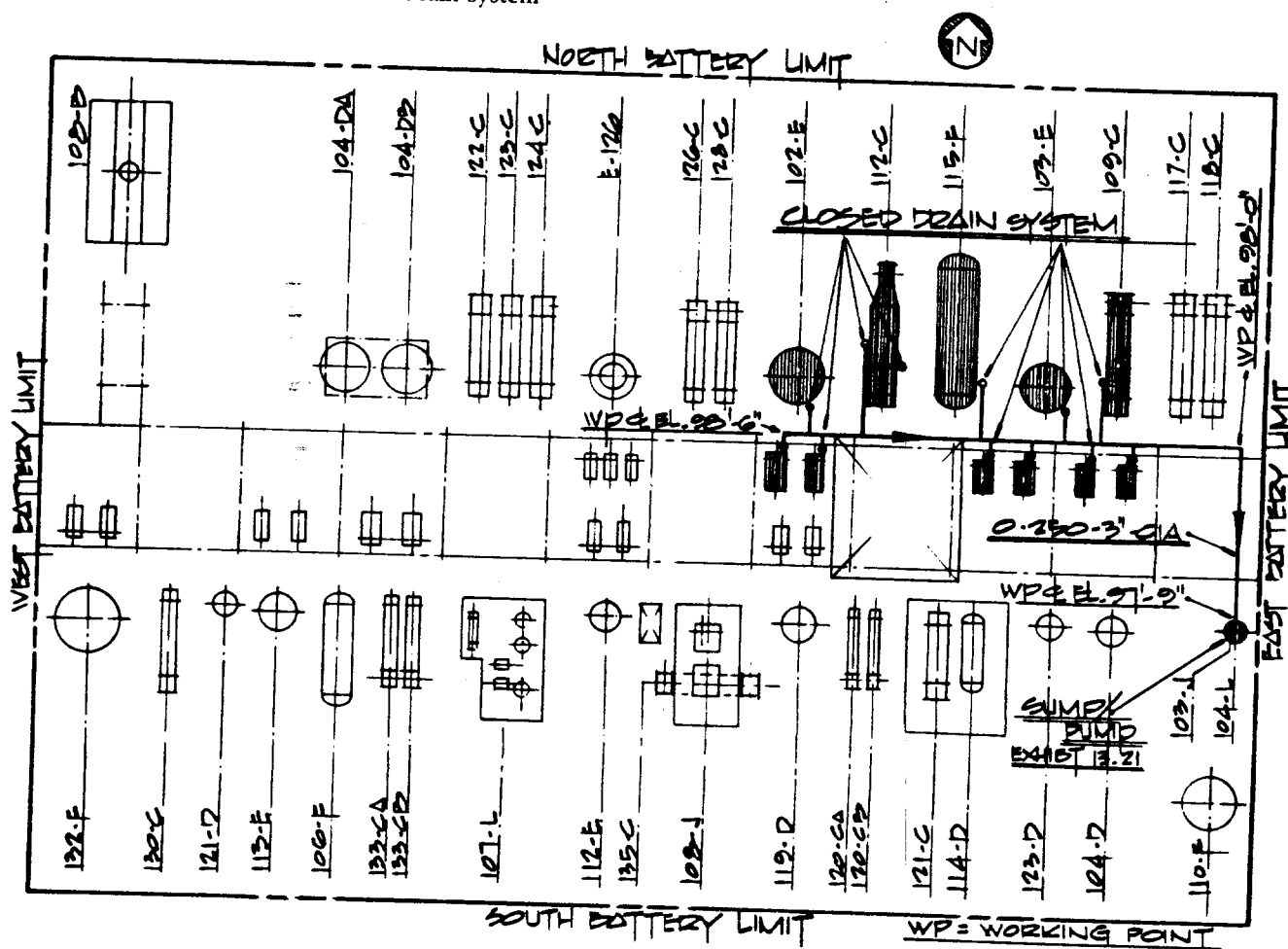
EXHIBIT 13-17 Process Drains: Closed System



limit, and at the point at which the header enters the sump. Exhibit 13-19 illustrates a typical cross section of what a closed or chemical drain system consists of. The large end of the hub, or reducer, is sized to suit the number of drain leads entering the hub. The remainder of the system is sized by the systems engi-

neer. A typical sump is depicted in Exhibit 13-20. The civil engineer sizes the sump on the basis of the quantity expected to be collected, as supplied by the systems engineer. The discharge of the sump pump is piped to an on-site storage tank or to a truck that is brought in periodically to remove the contents.

EXHIBIT 13-18 Plan for a Closed Drain System



PROCESS AND POTABLE WATER

Process and potable water are two common commodities found in most industrial plants. Some uses of process water include the following:

- Cooling water for temperature control of process streams in exchangers.
- Condensing steam exhaust in surface condensers of low-pressure steam systems.
- Chemically treated water used as boiler feed water.
- Cooling water for pump and compressor seals.

EXHIBIT 13-19
Closed Drain System:
Cross Section

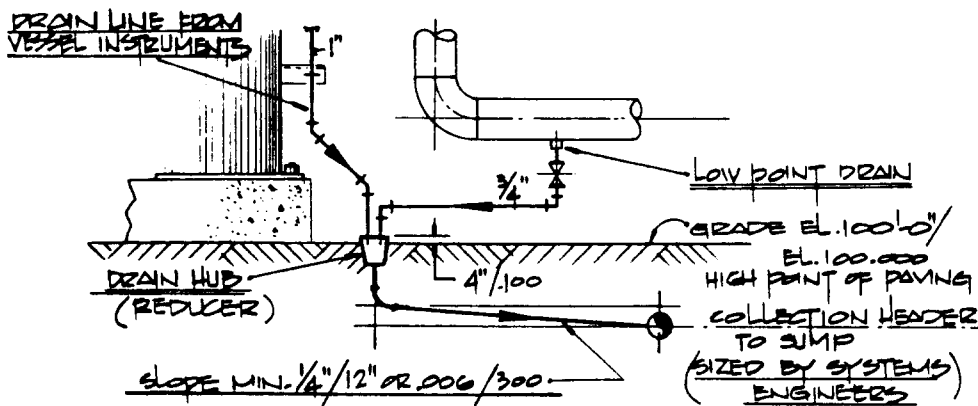
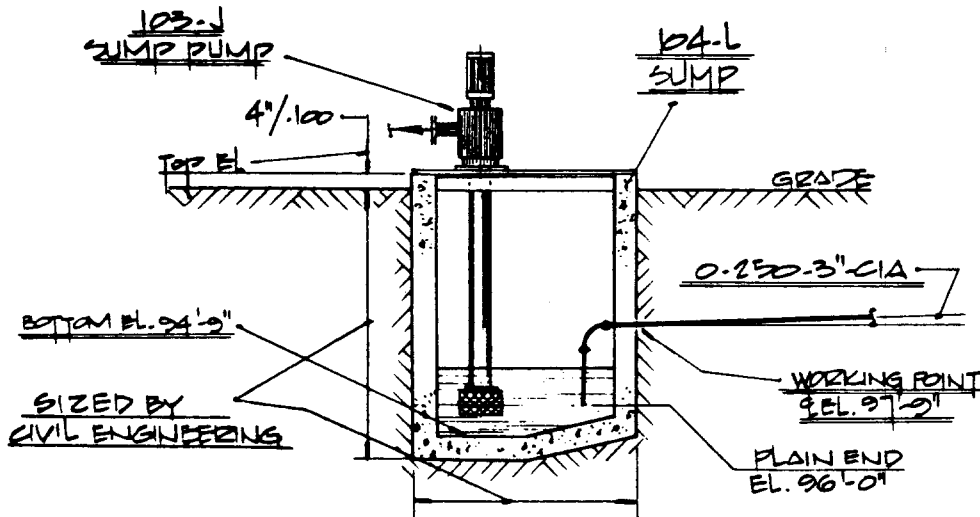


EXHIBIT 13-20
Closed Drain System
Sump



Potable or drinking water is used by plant personnel and also is supplied to emergency eyewash and shower installations.

The layout of a comprehensive pressurized water system follows some basic guidelines. In freezing climates, the centerline elevation of a water line should

not be set above the frost line as determined by the project design data.

Parallel cooling water and hot water return headers must be kept a minimum of 12 in (300 mm) from the outside of the pipe diameters. Running these two headers too close together may affect the temperature

EXHIBIT 13-21 Process Cooling Water and Potable Water System

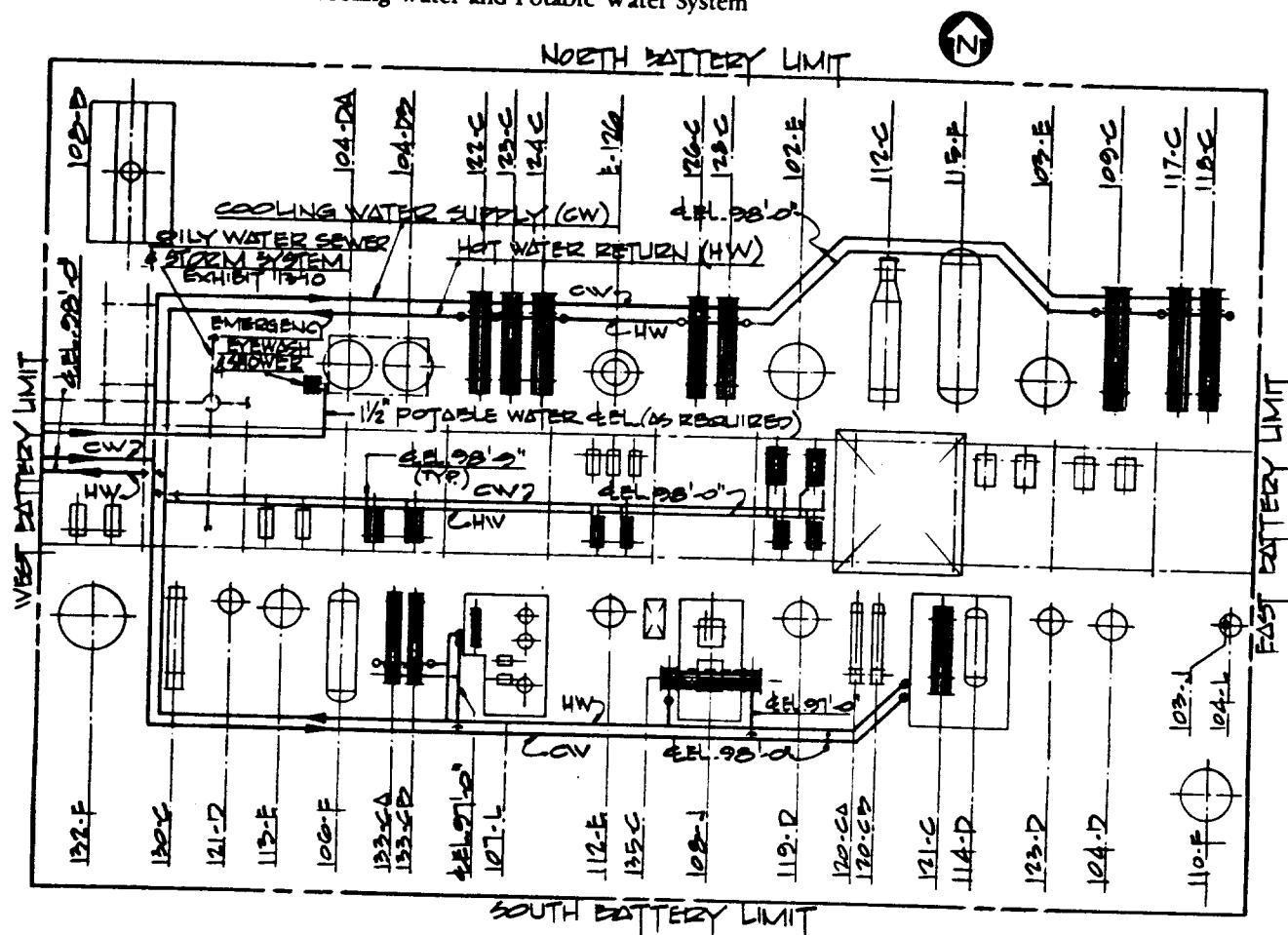
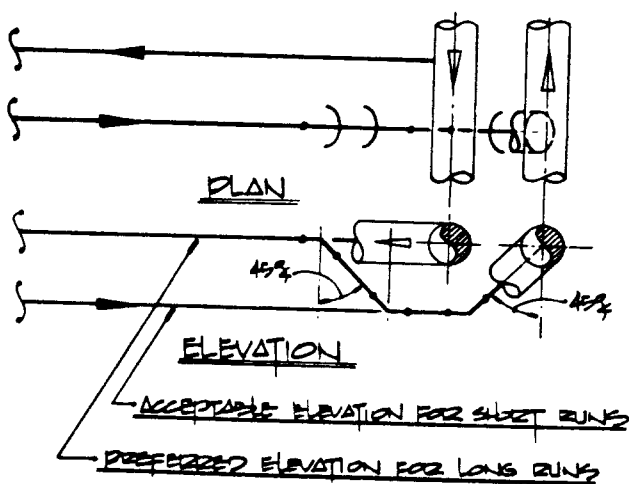


EXHIBIT 13-22 Cooling Water Crossover Piping



of the cooling water supply line, which in turn may hamper the ability to control the temperature of the process stream in the exchanger. As a pressurized system, the piping may run as required to clear any gravity flow drain system that crosses its path, by passing over or under the obstructing line.

An example of process cooling water and potable water layout is shown in Exhibit 13-21. As with most piping layouts, the lines are run in the most direct route possible to each of the water users (shown shaded in the exhibit). The locations where the cooling and hot water lines enter and leave the unit are usually set by the client or by the location of any existing supply and return headers. In this case, the west battery limit has been selected. Both lines run at the same elevation, as shown in Exhibit 13-22. When branch lines must cross over supply headers, they should return to the elevation of the higher branch line, unless the distance is so short that it would be impractical to do so.

Because the cooling water inlet nozzle is located on

EXHIBIT 13-23
Cooling Water at
Exchangers

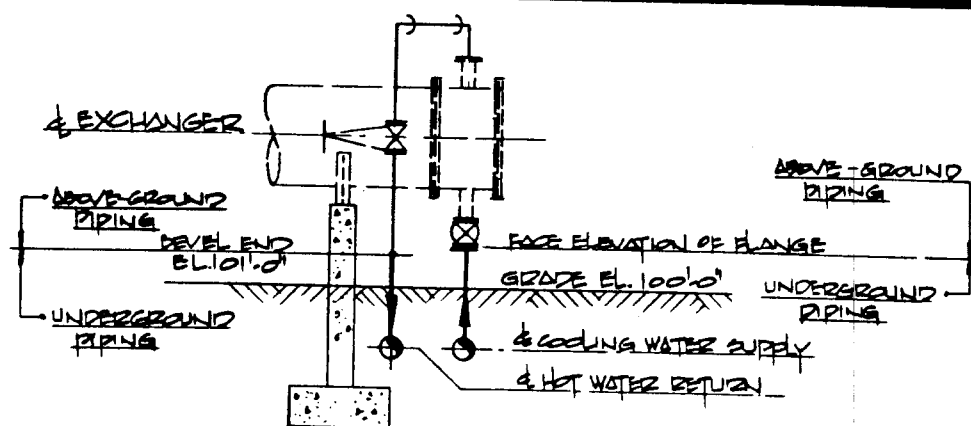
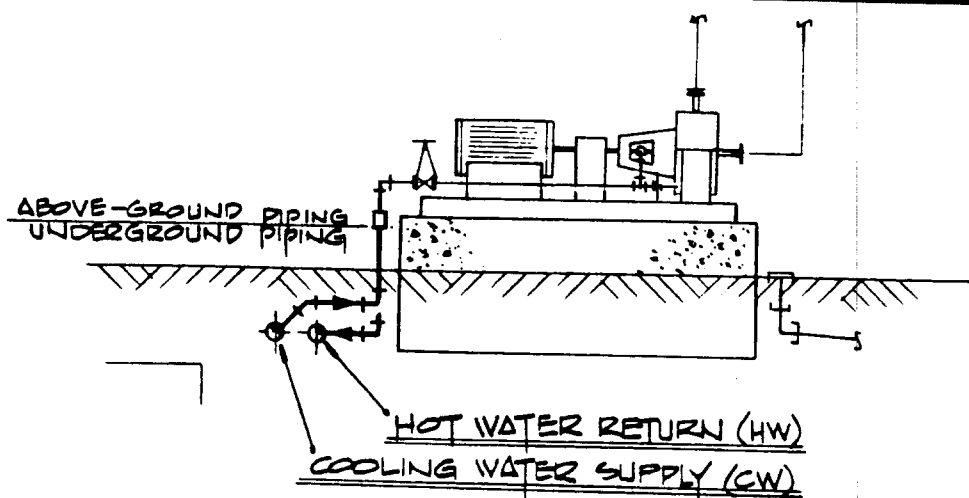


EXHIBIT 13-24
Cooling Water at Pumps



the bottom of the exchanger channel, the inlet header must be located directly under this nozzle, as illustrated in Exhibit 13-23. This arrangement allows for the most direct hookup. The underground portion of the fabricated pipe includes the flange to be bolted to the block valve; the hot water outlet line should terminate 12 in (300 mm) above grade with a bevel end. The above-ground piping takes over from this point.

If the water users are located in a structure, the underground portion of the lines should terminate with bevel ends 12 in (300 mm) above grade. Cooling and hot water headers to the pumps are run under the pipe rack, between the rows of pumps, as Exhibit 13-24 shows. A self-draining hydrant valve is used if the installation is in a freezing climate; this detail is displayed in item 8 of Exhibit 13-25.

The potable water line also enters the unit at the west battery limit and is run to the emergency eyewash and shower installation. A typical arrangement of this facility is illustrated in Exhibit 13-26. The underground portion of this line should terminate at a point

agreed to by both the above-ground and the underground plant layout designers.

FIRE WATER SYSTEM

Every industrial plant is protected by a fire water system that provides water to each piece of equipment through hydrants, monitors, or deluge spray systems. Each process unit has its own underground piping loop system, which is adequately valved to protect the system from a failure in any part of the line or isolation because of maintenance. Although each piece of equipment must be protected by one hydrant or monitor, client specifications often override this rule and require two sources of fire water for each piece of equipment. Basic fire protection equipment consists of fire hydrants, hydrants with monitors, grade-level and elevated monitors, hose reels, and deluge and spray systems.

All hydrants and monitors and their shut-off valves

EXHIBIT 13-25 Miscellaneous Details

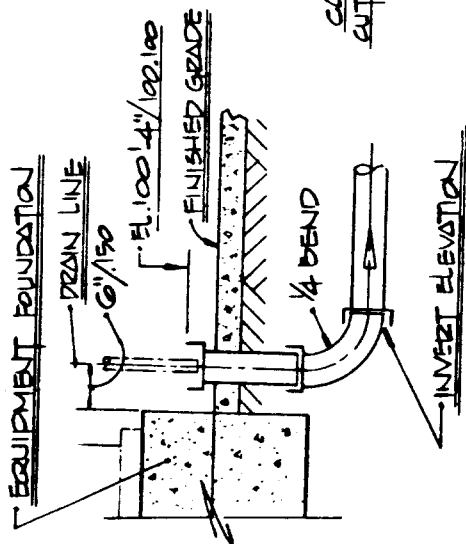
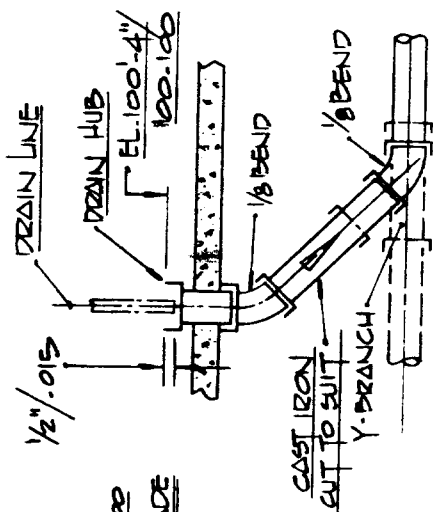
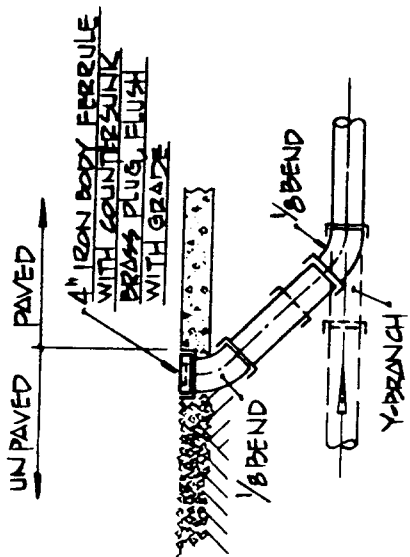
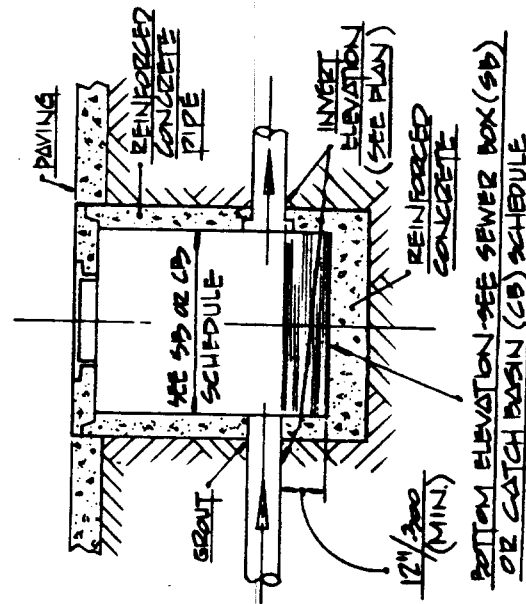
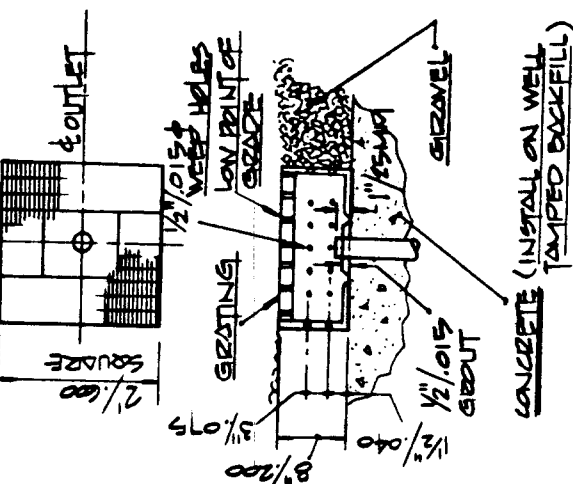
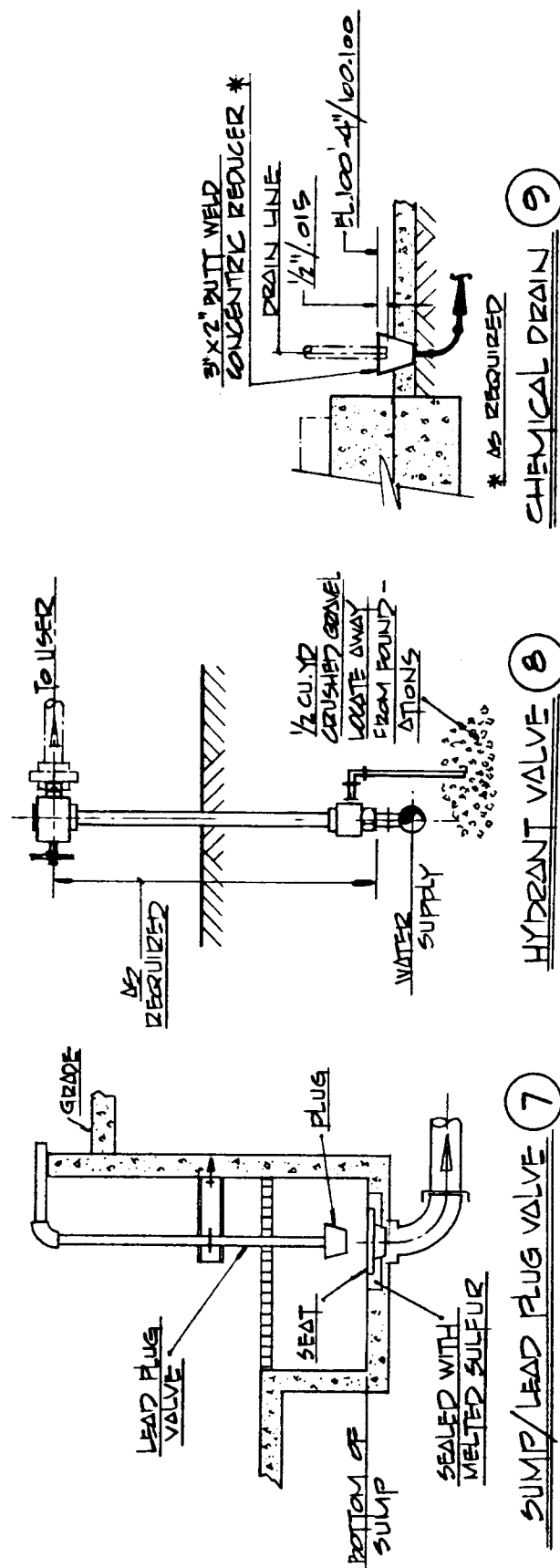
CAST IRON EQUIPMENT DRAIN 1CAST IRON IN-LINE DRAIN 2CAST IRON CLEANOUT 3CATCH BASIN 4IN-LINE SEWER BOX OR CATCH BASIN 5UNPAVED AREA CATCH BASIN 6

EXHIBIT 13-25 Miscellaneous Details (Cont)



Notes:

1. Typical equipment drain, with the top of the cast iron hub set at an elevation of 100 ft 4 in (100.1 m). Lines draining into this hub would terminate at a plain end elevation of 100 ft 3 1/2 in (100.085 m).
2. Similar drain hub tying into another drain line.
3. Cleanout connection in a cast iron piping system.
4. Catch basin in a paved area.
5. Inline sewer box or catch basin in which flow passes directly through the box.
6. Catch basin in an unpaved area.
7. Sump with a lead plug drain valve. Turning a handle allows the plug to fit into the seat, closing off the sump to its drain system.
8. A hydrant valve, which is commonly used for water in freezing climates.
9. Chemical drain hub, whose size is determined by the number of lines entering the hub as well as by its flow requirements.

EXHIBIT 13-26
Emergency Eyewash and
Shower

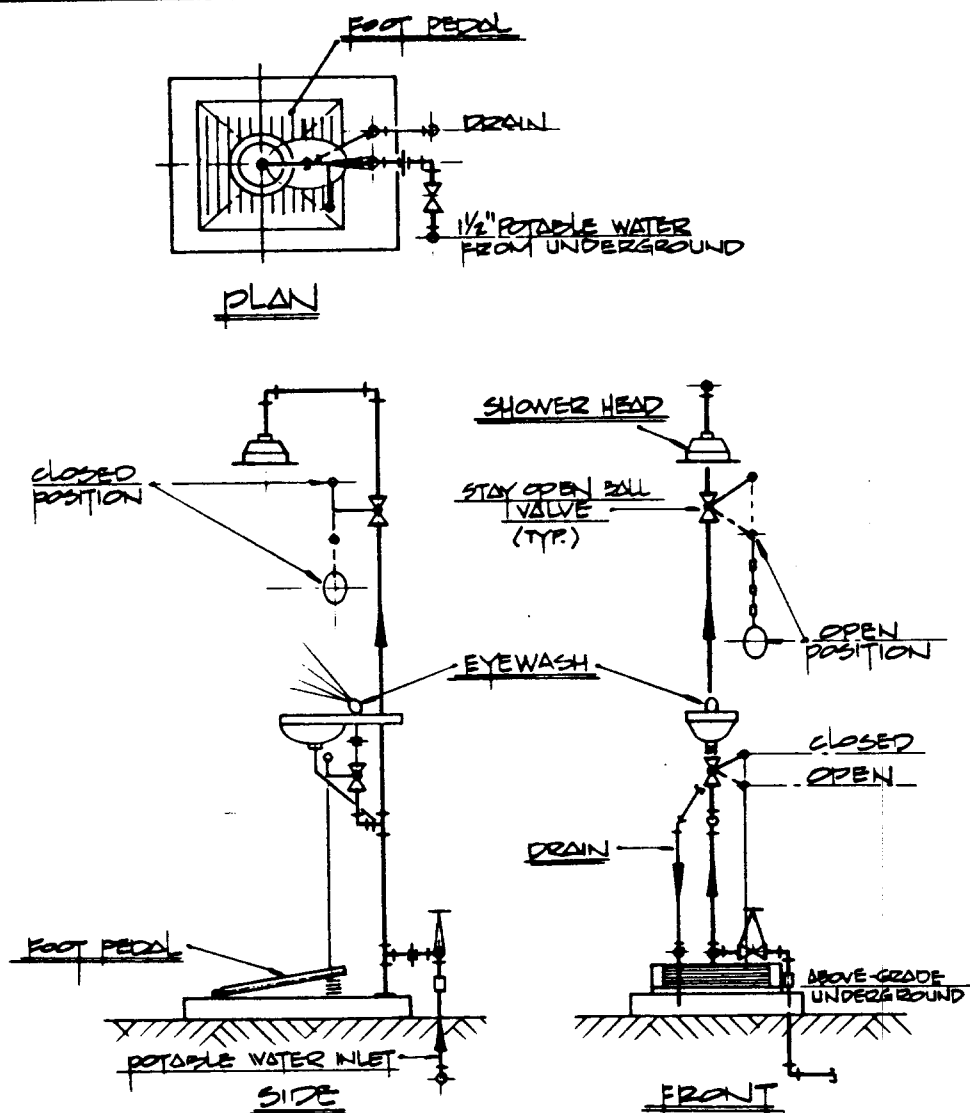
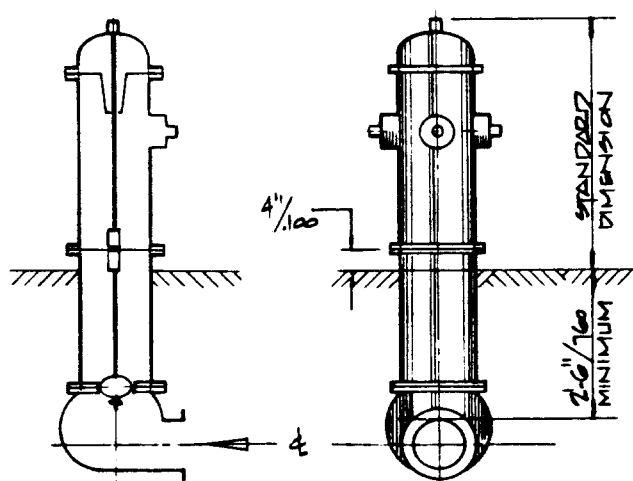


EXHIBIT 13-27 Typical Fire Hydrant



must be located a minimum of 50 ft (15 m) from a potential source of fire. A typical fire hydrant is shown in Exhibit 13-27. Although the hydrant dimension above grade is standard, the dimension below grade varies, depending on the proximity of the line to vehicular traffic and the potential for freezing. In cold climates, the centerline of the inlet to the hydrant must not be above the frost line, which is the lowest point below grade at which water freezes.

Exhibit 13-28 shows a typical hydrant installation. Proper drainage of the hydrant barrel after the hydrant is closed is essential to prevent freezing in cold climates. Drainage is provided by crushed stone around the base of the hydrant and extending above the lower barrel flange. The amount of crushed stone required depends on the nature of the soil. Loose sandy soil requires a smaller drainage bed than claylike soil, which absorbs water very slowly. The project civil en-

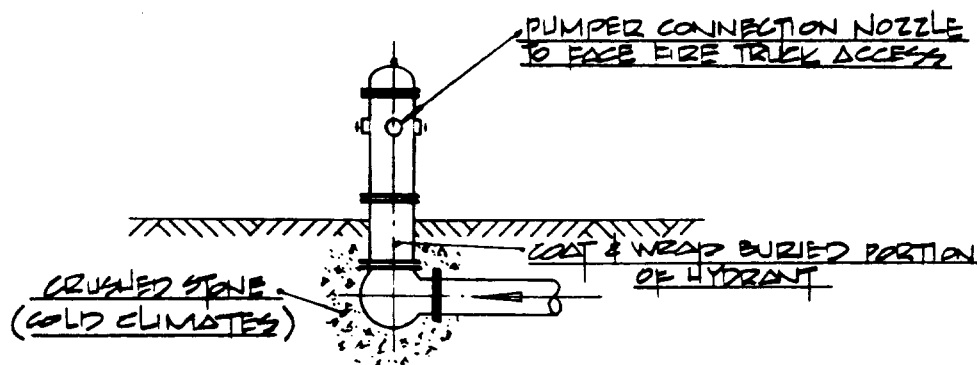


EXHIBIT 13-28
Hydrant Installation

gineer should be consulted before this detail is prepared. If the soil conditions prohibit the proper drainage around the hydrant, a drain to the nearest clean water or drainage ditch must be provided.

Exhibit 13-29 illustrates some additional features that the plant layout designer should consider when selecting and planning the installation of fire hydrants and monitors, including:

- Protecting the valve bonnet and extension stem with a buffalo box, which is a piece of pipe that sits on the valve and extends approximately 9 in (230 mm) above grade.
- When required, orienting the pumper connection nozzle toward the fire truck access way.
- If hydrants are vulnerable to damage, providing guard posts for protection.
- Coating and wrapping the buried portion of the hydrant.

If not specified by the client, a typical hydrant has a 6-in inlet line size with two 2½-in hose connections. Hydrant locations must permit clear access during a fire and be no more than 25 ft (7.5 m) from where a pumper may be required to hook up a suction hose. In remote areas of an industrial plant (e.g., around

tank farms or truck loading areas), hydrants are located every 300 ft (90.5 m).

Fire monitors are used to direct streams of water to burning pieces of equipment in a plant. Before monitors are selected and located, several factors must be considered. Fire monitors are lever operated, have a full 360° range, and may be locked in any desired position. They may be located at grade, approximately 4 ft (1,200 mm) above the ground, elevated to heights of 100 ft (30 m) or more, or mounted on a hydrant. The spray pattern of fire monitors depends on water pressure and flow rate. If vendor data is not available when preliminary fire water layouts are made, the chart in Exhibit 13-30 can be used to determine the effective fire water monitor range. This chart is based on a water pressure of 150 psi and a flow rate at the nozzle of 500 gpm.

Typical monitors are shown in Exhibits 13-31 through 13-33. The grade-mounted monitor shown in Exhibit 13-31 has the block valve located above grade, but it would be buried below grade in a freezing climate. The method of supporting an installation of this type is determined by the civil engineer.

A typical elevated monitor is displayed in Exhibit 13-32. When grade-mounted monitors cannot direct water to all pieces of process equipment because of

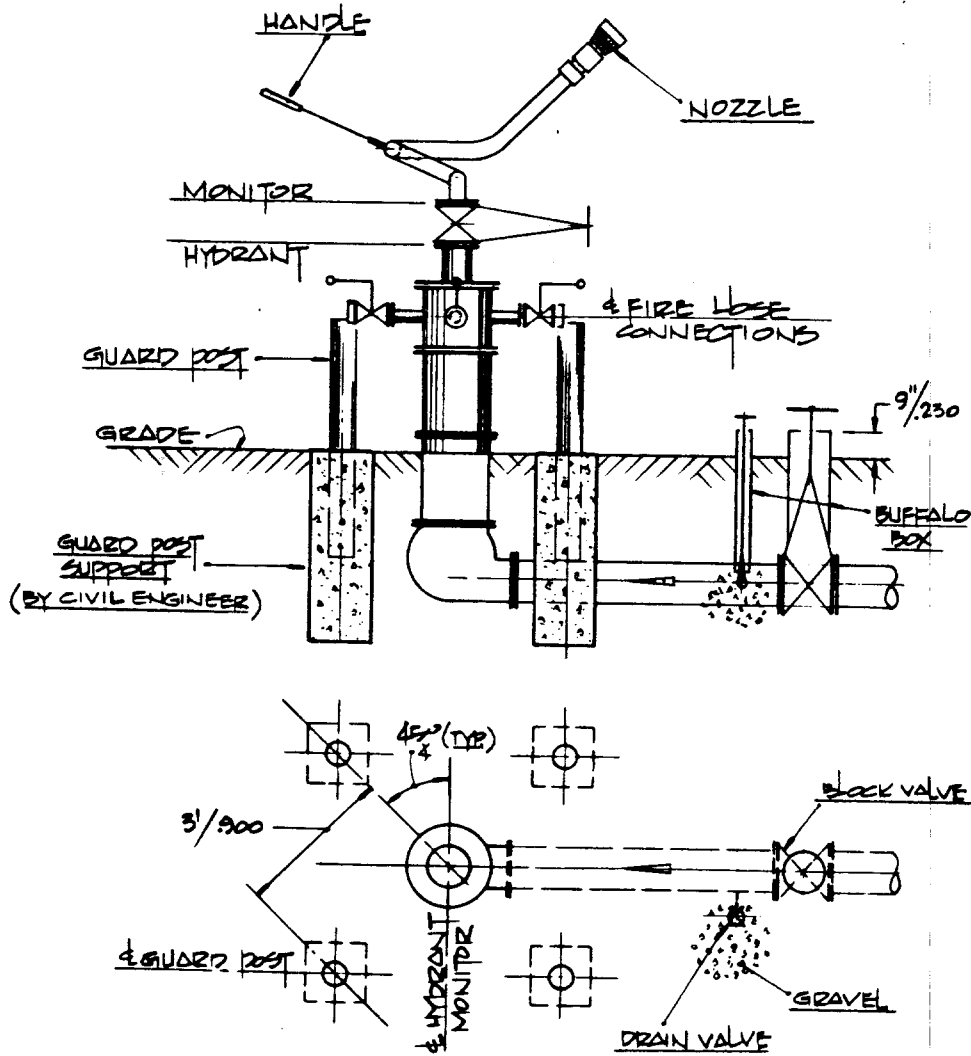


EXHIBIT 13-29
Hydrant and Monitor
Installations

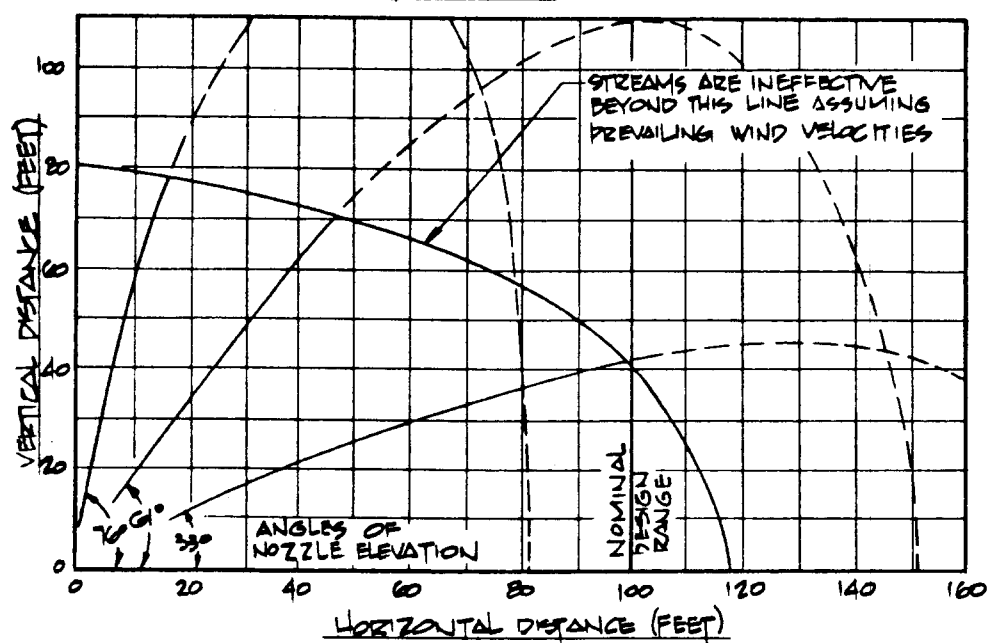
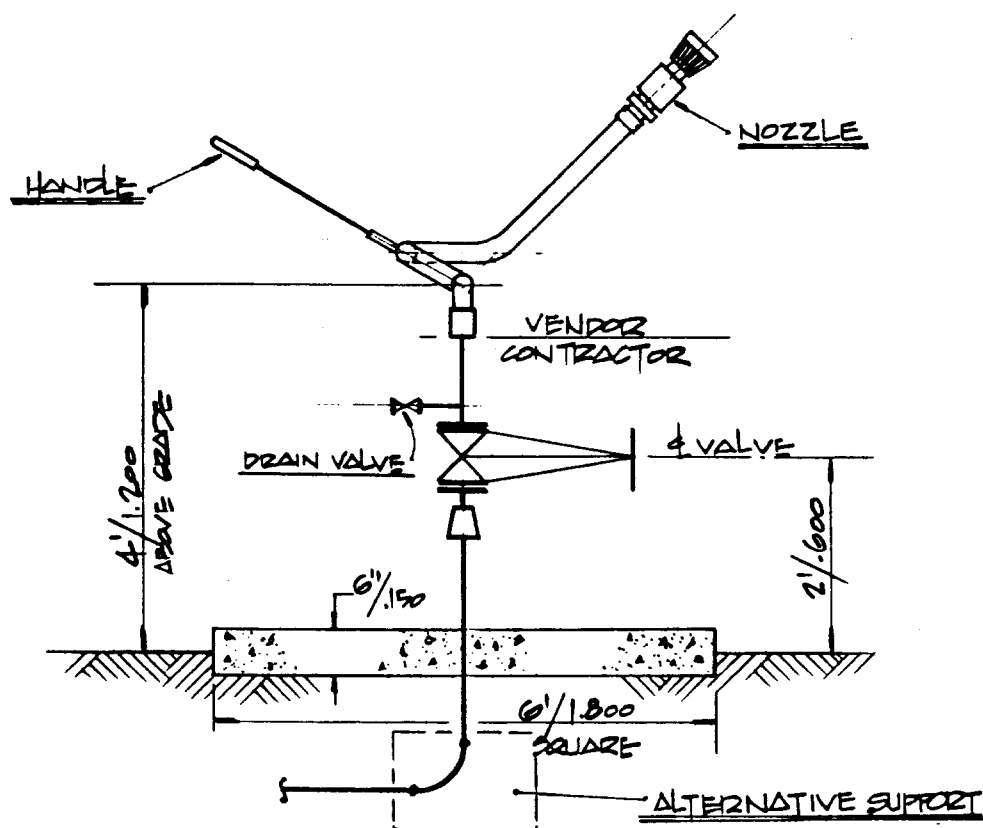
EFFECTIVE FIRE MONITOR RANGEEXHIBIT 13-30
Monitor Range ChartEXHIBIT 13-31
Typical Grade-Mounted
Fire Monitor

EXHIBIT 13-32
Typical Elevated Monitor

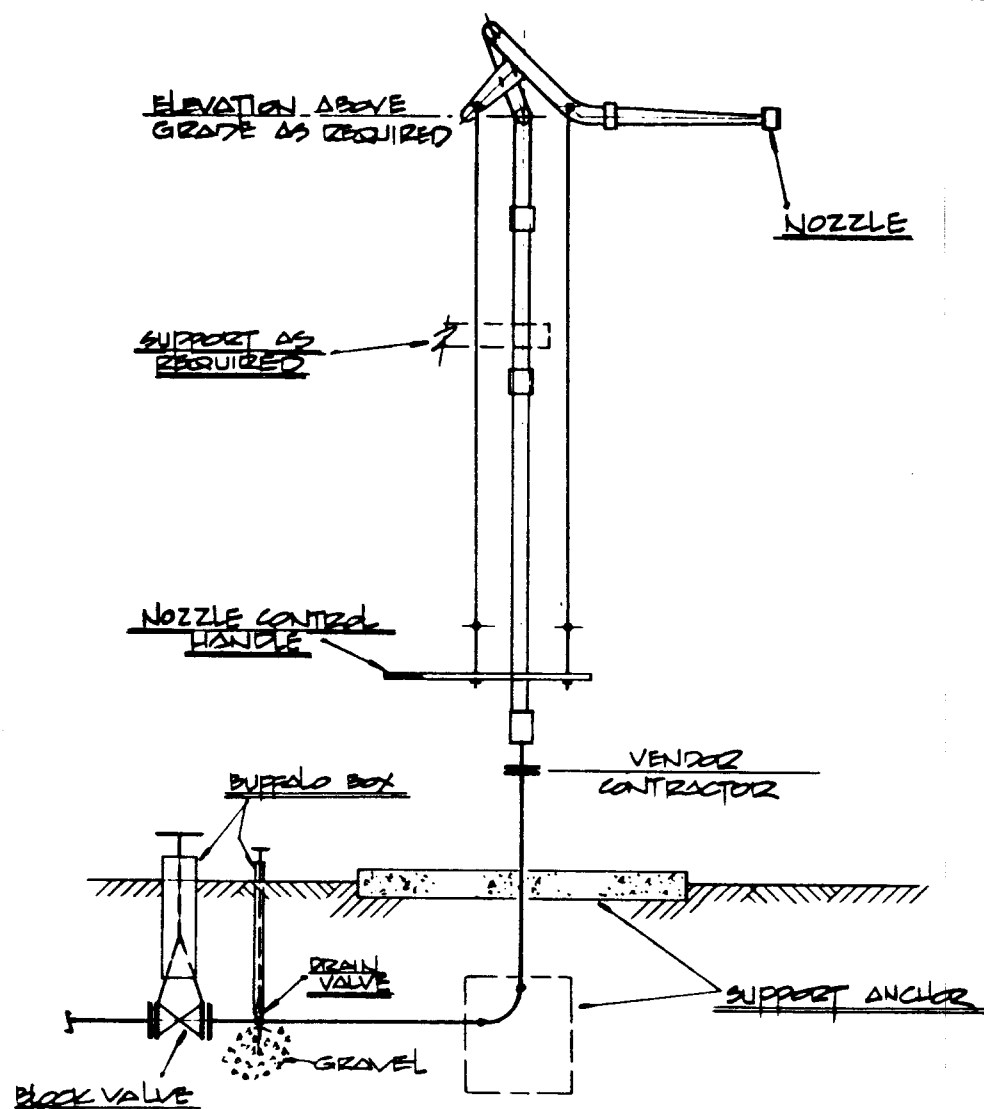
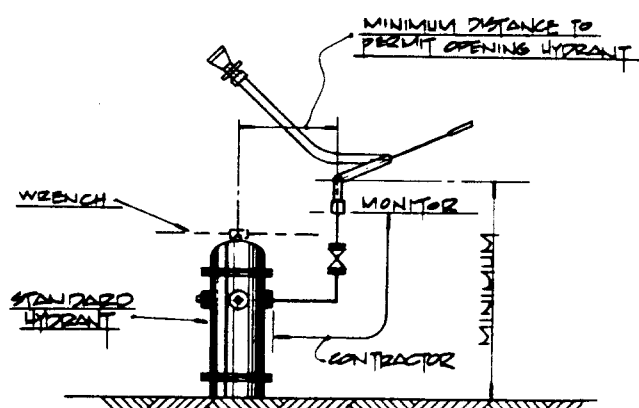


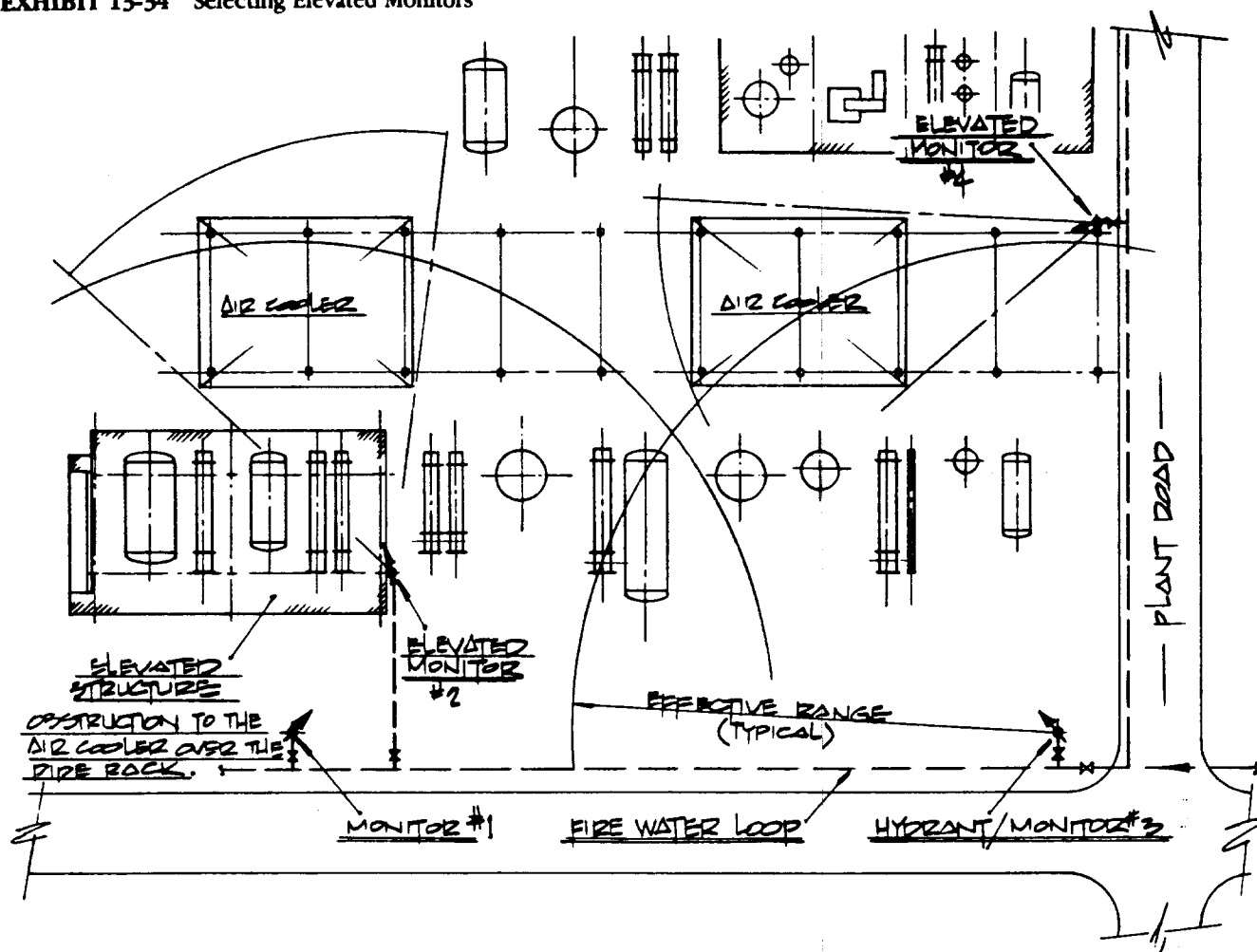
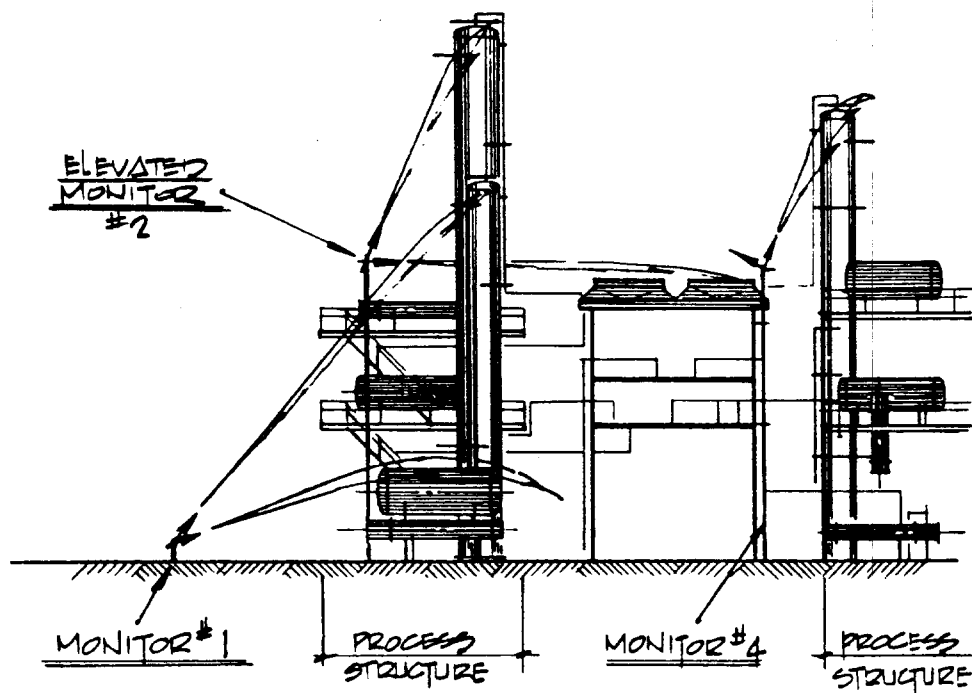
EXHIBIT 13-33 Typical Fire Hydrant with Monitor



obstructions (e.g., large structures), an elevated monitor may be required. Although nozzles can be set 100 ft (30 m) above grade, the vendor should be consulted before this design is finalized. The equipment arrangement drawing shown in Exhibit 13-34 is an example of how a large process structure blocks the fire water from monitor 1, which is directed at the air cooler located over the pipe rack. Therefore, monitor 2, supported from the process structure, may be directed at the air cooler and locked in position. As illustrated in Exhibit 13-35, monitor 4 may be required to cover additional air coolers or very large process towers.

Monitors and hydrants are the most common individual firefighting system components. The client, however, may request that a hydrant and monitor combination be used, as shown in Exhibits 13-29 and 13-33.

EXHIBIT 13-34 Selecting Elevated Monitors

EXHIBIT 13-35
Grade-Mounted and
Elevated Monitors

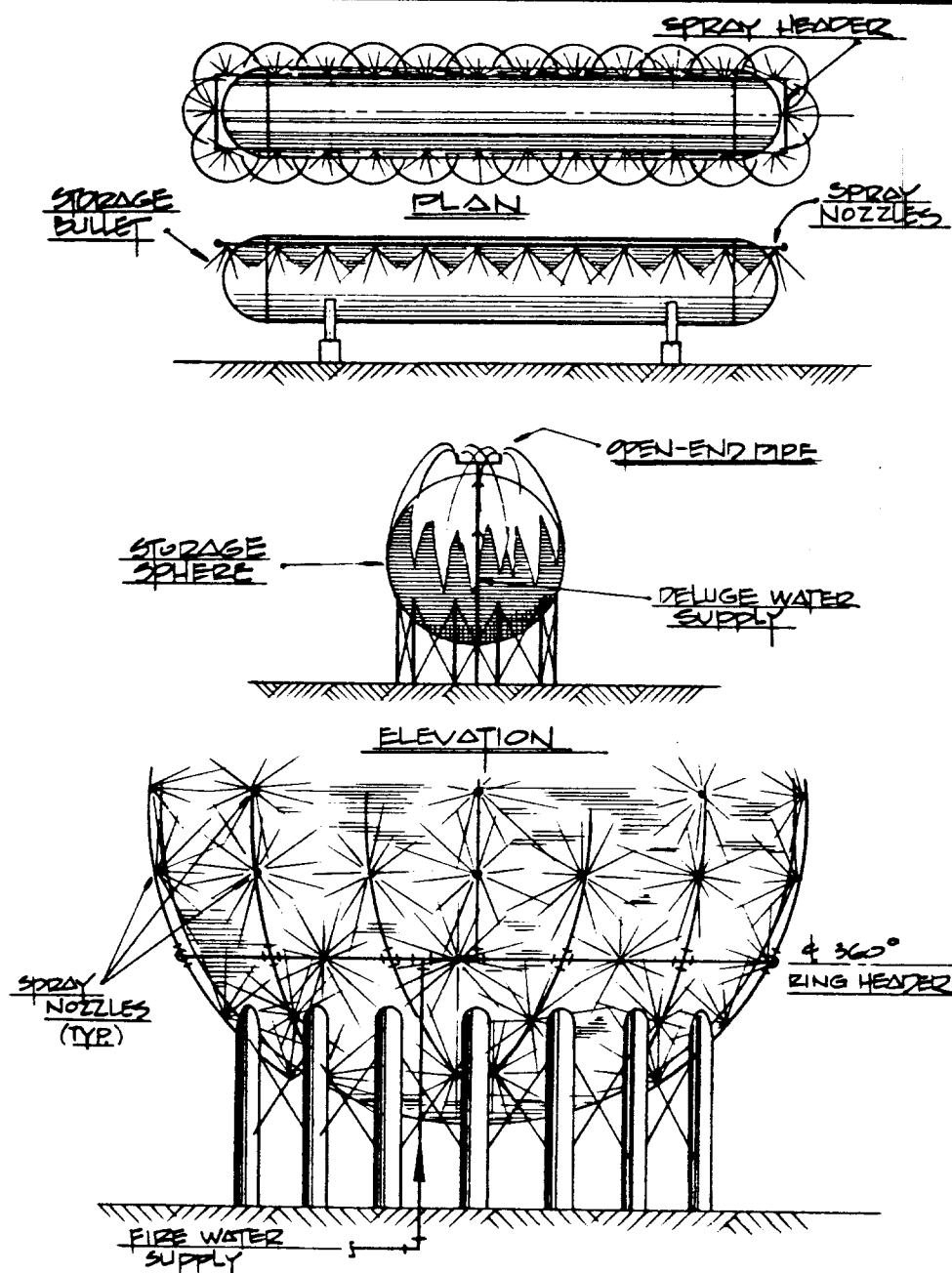


EXHIBIT 13-36
Typical Deluge and Spray
Systems

Deluge and Spray Systems

Deluge and spray systems are generally used when process equipment cannot be reached by fire monitors or requires a great quantity of water to protect it from a fire in the local area. Typical deluge and spray systems are shown in Exhibit 13-36. The storage bullet is protected by a ring header around the vessel, with spray nozzles equally spaced to provide appropriate coverage. Two storage sphere arrangements are shown in the exhibit. One has two open-ended pipe

connections that flood the sphere in the event of fire; the other has a horizontal 360° ring header and vertical leads that are approximately 6 in (150 mm) from the sphere shell, all with equally spaced spray nozzles. This type of fire protection is often subcontracted to companies that specialize in this particular service.

Fire Water System Layout

The layout of a fire water system in a process unit is usually accomplished in the following way:

EXHIBIT 13-37 Fire Water System Layout

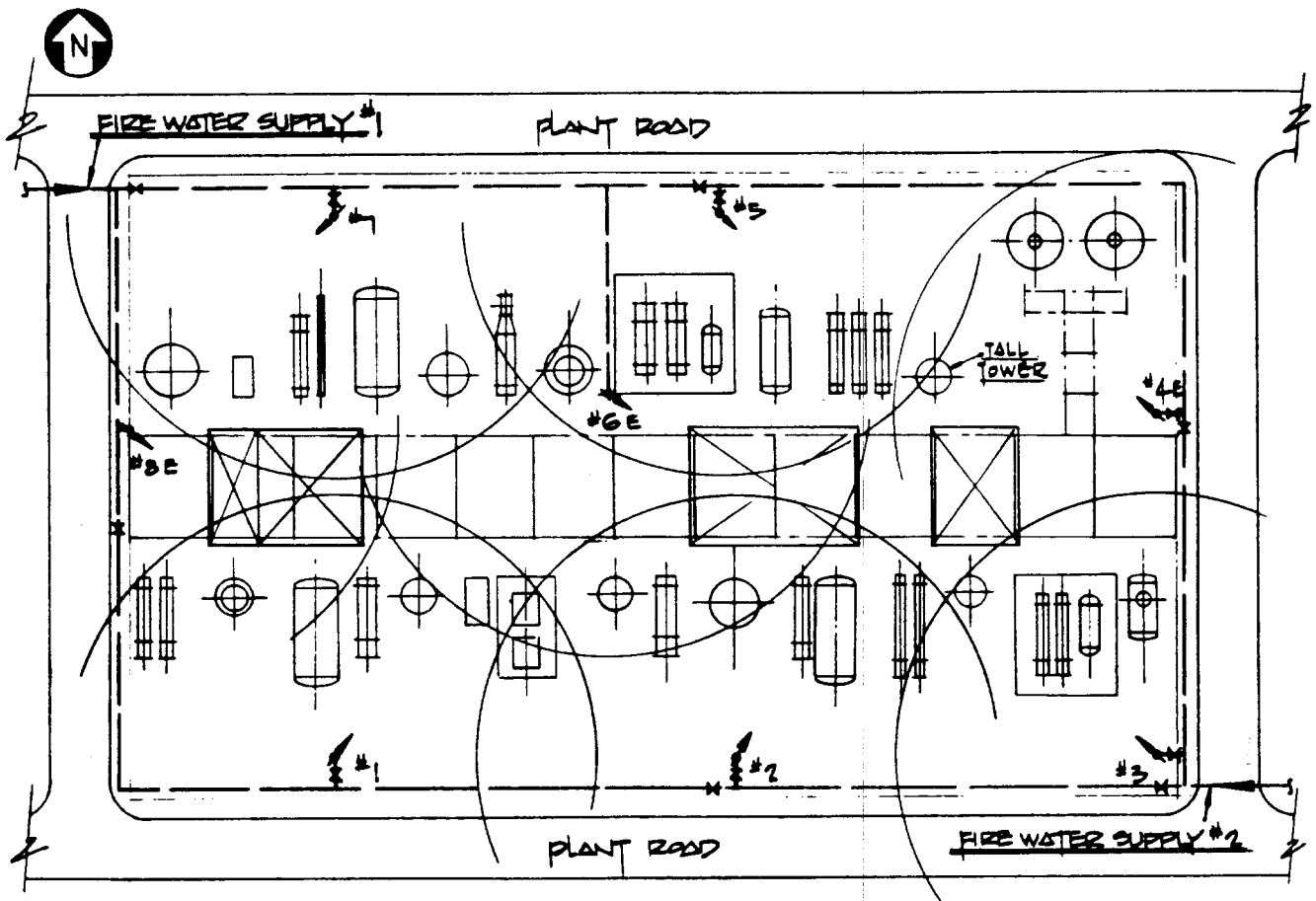
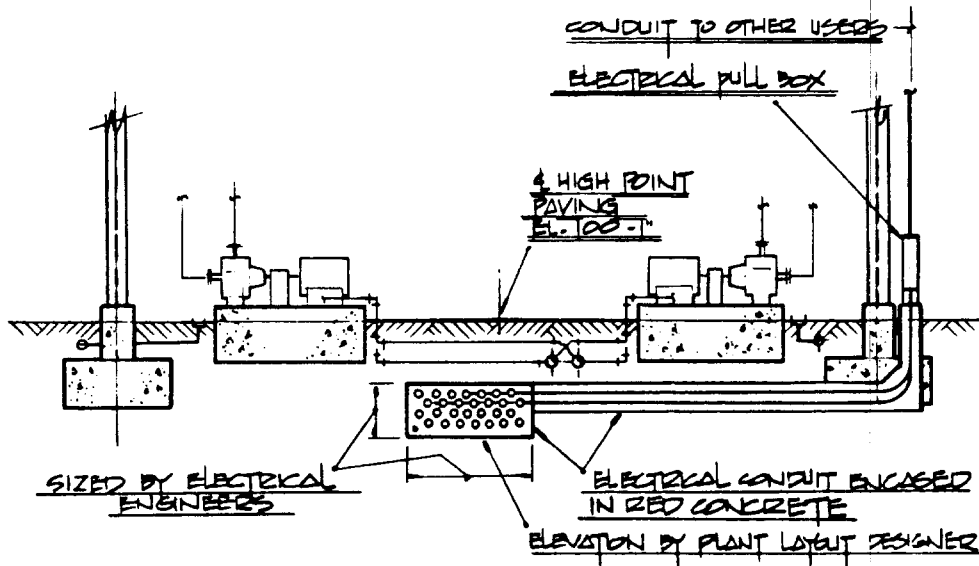
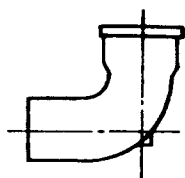
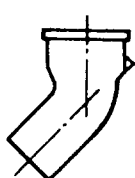
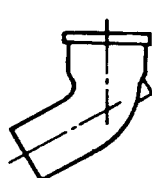
EXHIBIT 13-38
Underground Cable Duct

EXHIBIT 13-39
Cast Iron Fittings


a. Quarter Bend



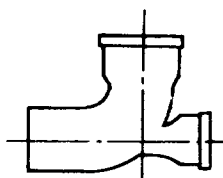
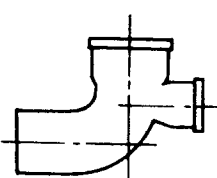
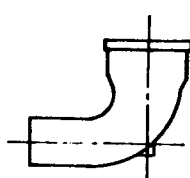
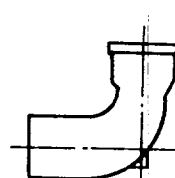
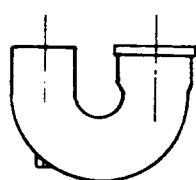
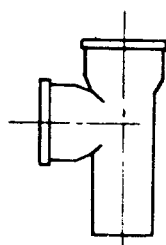
b. Eighth Bend



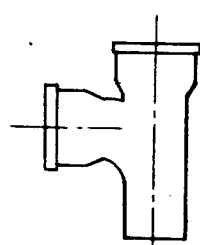
c. Sixth Bend



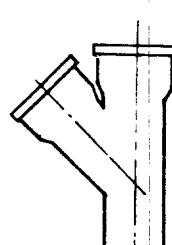
d. Sixteenth Bend

e. Quarter Bend
with Low Heel Inletf. Quarter Bend
with High Heel Inletg. Quarter Bend
Reducingh. Quarter Bend
Increasingi. Single Hub
Return Bend

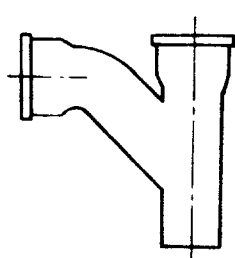
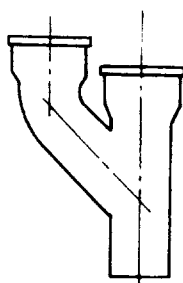
j. Straight Tee



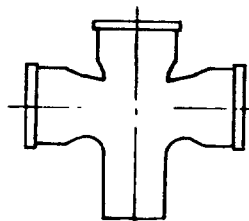
k. Sanitary Tee



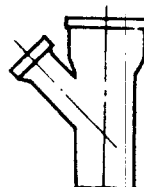
l. Sanitary Y

m. Combination Y
and Eighth Bend

n. Upright Y



o. Sanitary Cross

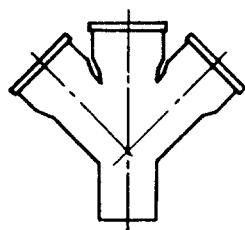


p. Tapped Y

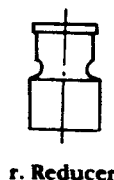
- A reproducible copy of the plot plan is used to prepare the initial layout, as depicted in Exhibit 13-37.
- A complete loop is drawn around the unit, with the line run along the edge of the plant road.
- To provide a margin of safety in the fire water system, the fire water loop is fed from opposite ends of the unit—Enough block valves are provided to ensure the overall firefighting capabilities of the system in the event of a rupture in the fire water loop. The number of valves placed in the header is subjective and is submitted to the client for approval.
- The effective fire water range is then established

through vendor data or the chart in Exhibit 13-30—If a compass is set to the maximum effective range, monitor 1 can be positioned showing its full coverage area.

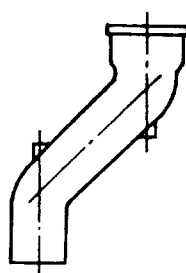
- Monitor 2 is located east of monitor 1 to cover all equipment not protected by monitor 1, and monitor 3 is located to cover equipment not protected by monitor 2.
- Monitor 4E is an elevated monitor that is trained on the air cooler over the pipe rack, the large process tower, or furnaces.
- Monitors 5 and 7 adequately cover the remaining

EXHIBIT 13-39
Cast Iron Fittings (Cont)


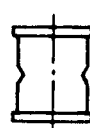
q. Double Y



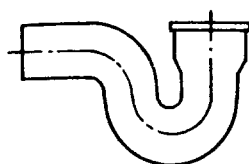
r. Reducer



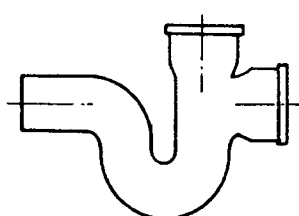
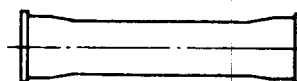
s. 45° Offset



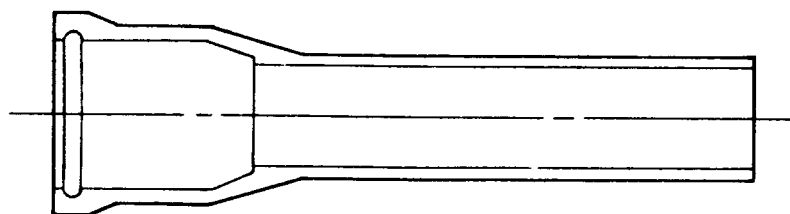
t. Double Hub



u. P Trap

v. Running Trap
with Hub Vent

w. Double Hub



x. Cast Iron Soil Pipe

equipment on the north half of the plot.

- Monitors 6E and 8E are elevated and can cover the air coolers over the pipe rack as well as the pipe rack itself.

Although each plant must conform to local firefighting rules and regulations, client interpretation of those regulations can produce vastly different fire water system layouts. Early consultation with each client is strongly suggested before a complete systems layout is developed.

UNDERGROUND ELECTRICAL AND INSTRUMENT DUCTS

At the outset of a project, a decision must be made on where the major electrical and instrument conduits will run—above ground in the pipe rack or buried below grade. If the underground route is selected, the plant layout designer must confer with the electrical and instrument engineers about the optimum layout of the ducts, where the conduits enter the unit, and

where best to locate the pull boxes. (There may not be a box per se, but it is the point at which the conduit exits the underground and serves all other users.) It is important that this space be left free of piping, equipment, or associated maintenance access. The conduit in Exhibit 13-38 is encased in red concrete for protection and located under the main pipe rack, between the two rows of pumps. Both the electrical and the instrument engineers are responsible for providing the estimated size of the duct, and the plant layout designer sets the elevation to best suit the gravity flow drain systems throughout the unit.

UNDERGROUND DETAILS

Variations of pipe fittings, catch basins, sewer boxes, trenches, sumps, and lift stations are only a sample of what a plant layout designer encounters in the development of an underground piping system. Available vendor data for fittings, catch basins, and sewer boxes must be used as a reference. Typical cast iron fittings are shown in Exhibit 13-39. The list of labels for these

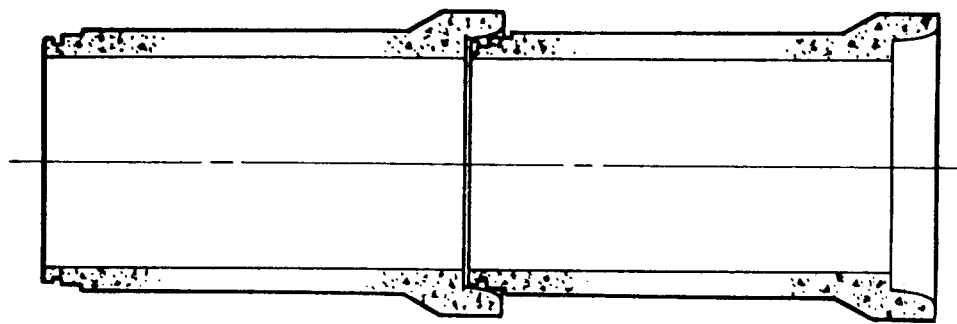
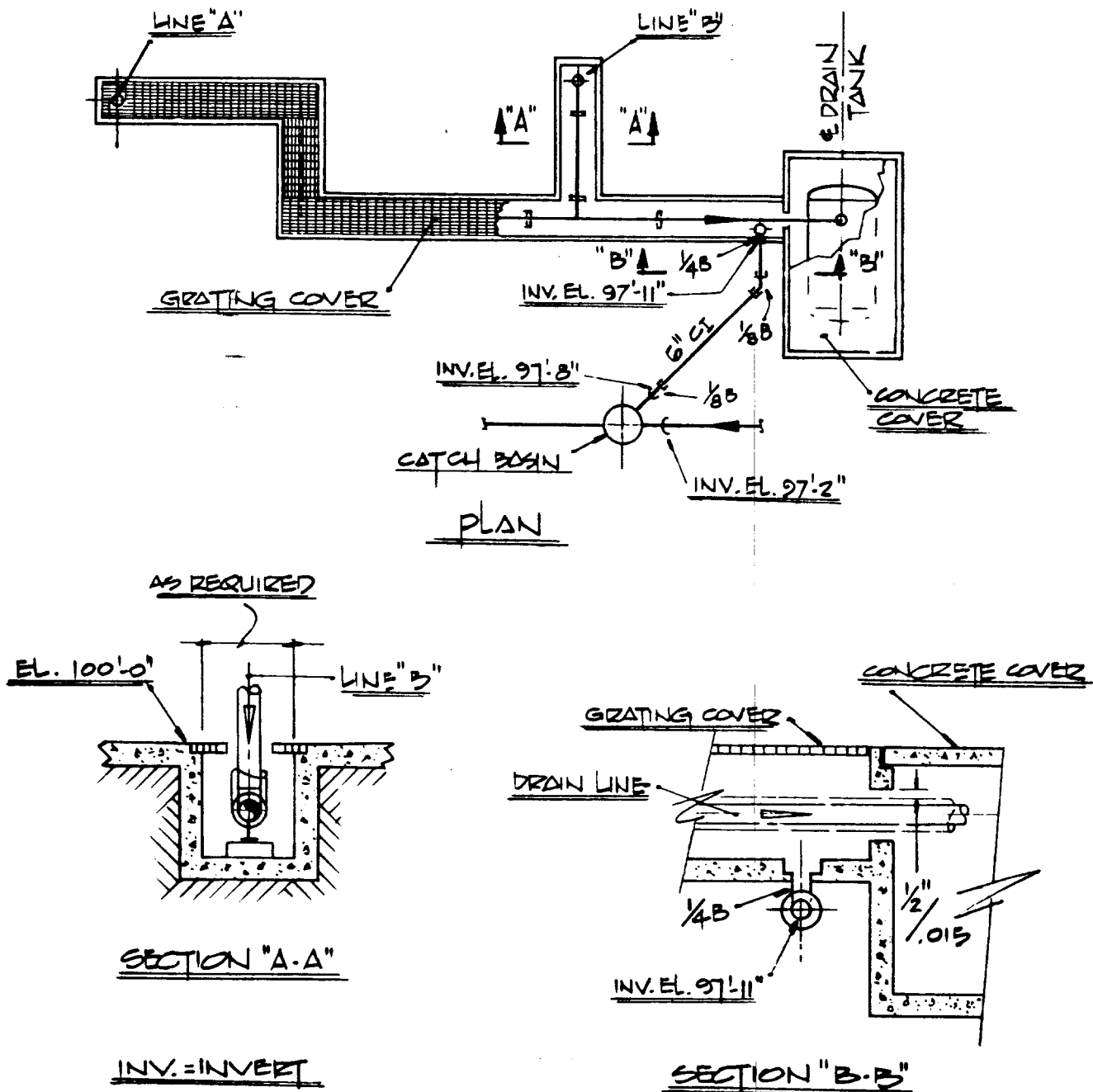


EXHIBIT 13-40
Concrete Pipe

EXHIBIT 13-41 Trench Piping



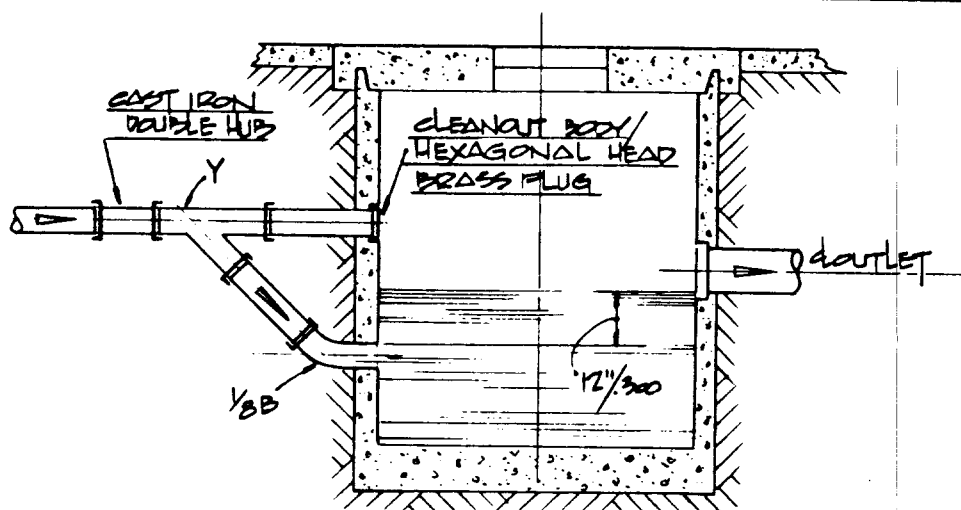


EXHIBIT 13-43
Sewer Box with Line
Cleanout

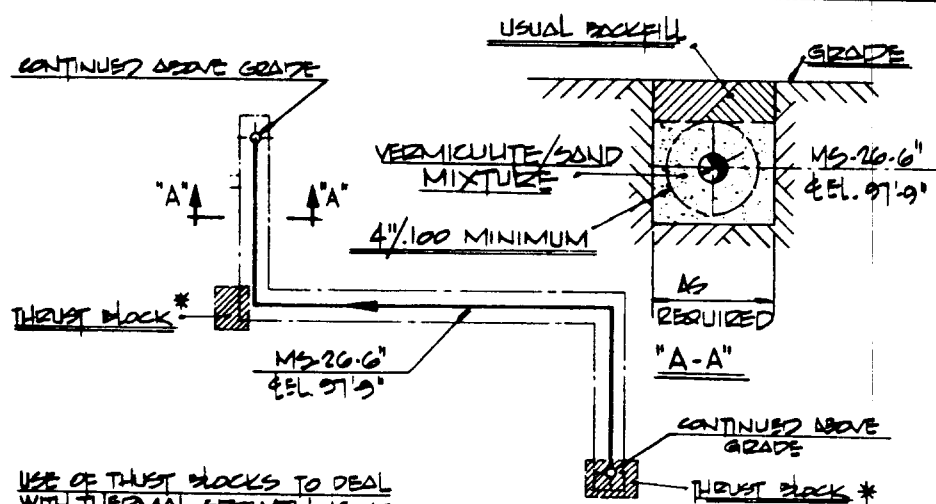


EXHIBIT 13-44
Buried Insulated Piping

* USE OF THRUST BLOCKS TO DEAL WITH THERMAL GROWTH IS AS REQUIRED BY STRESS/SUPPORT ENGINEER.

Exhibit 13-44 shows one way to bury a hot line underground. The line should be backfilled with a mixture that is equal parts sand and vermiculite, allowing for a thickness of at least 4 in (100 mm) around the entire line. The line is anchored as required by the stress engineer, through the use of concrete thrust blocks. This insulating mixture of sand and vermiculite allows the line to expand as necessary.

A diked area drain is shown in Exhibit 13-45. Because dikes are designed to hold the contents of a storage vessel in the event of a rupture, area drains must be kept closed at all times. A drain valve operates just outside the dike wall so that plant personnel can see when the contents have been drained and the valve may be reclosed.

When gravity flow drain systems are developed, it may be impractical to continue with the required

slope or impossible to tie into existing plant facilities without the installation of a pump in the system. A lift station is shown in Exhibit 13-46. It basically consists of a concrete sump (sized by systems engineering) and a vertical pump. The discharge line of the pump is run as desired because it is now a pressure system.

DOUBLE CONTAINMENT— UNDERGROUND SYSTEMS

New and more stringent environmental laws throughout most of the world are impacting many operating process plant underground systems. As an example, in the United States, the Environment Protection Agency has promulgated several standards applicable to the transfer of waste operations in refineries. The NESHAP

EXHIBIT 13-45
Diked Area Drain

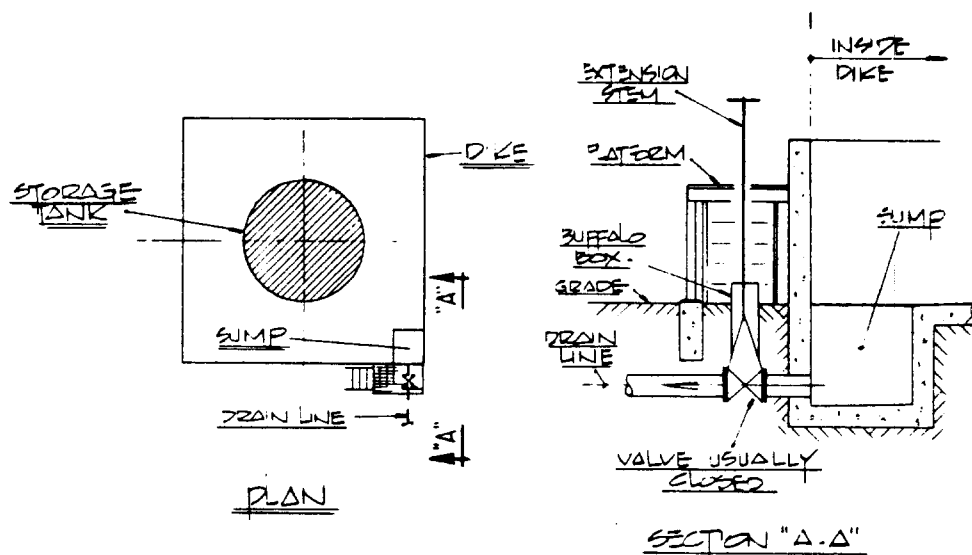
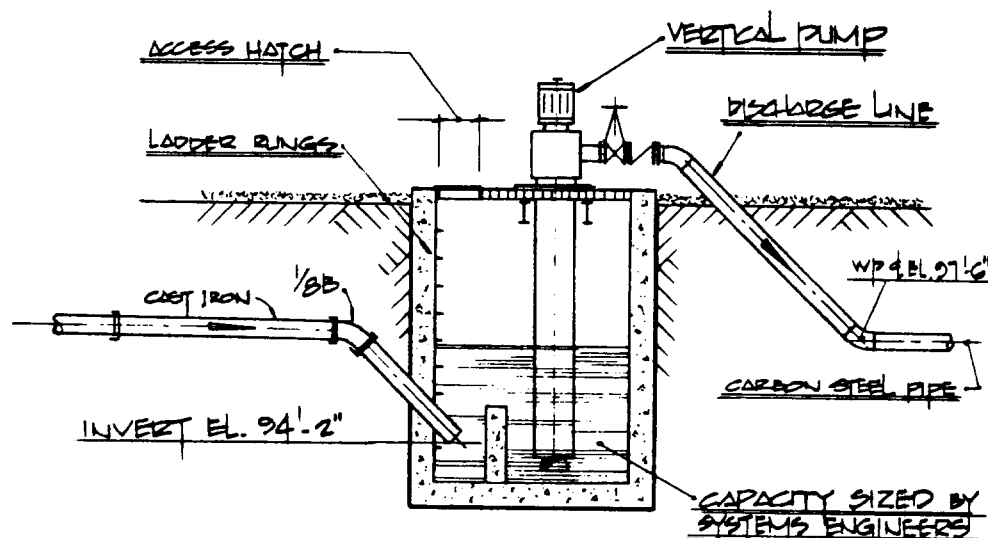


EXHIBIT 13-46
Lift Station



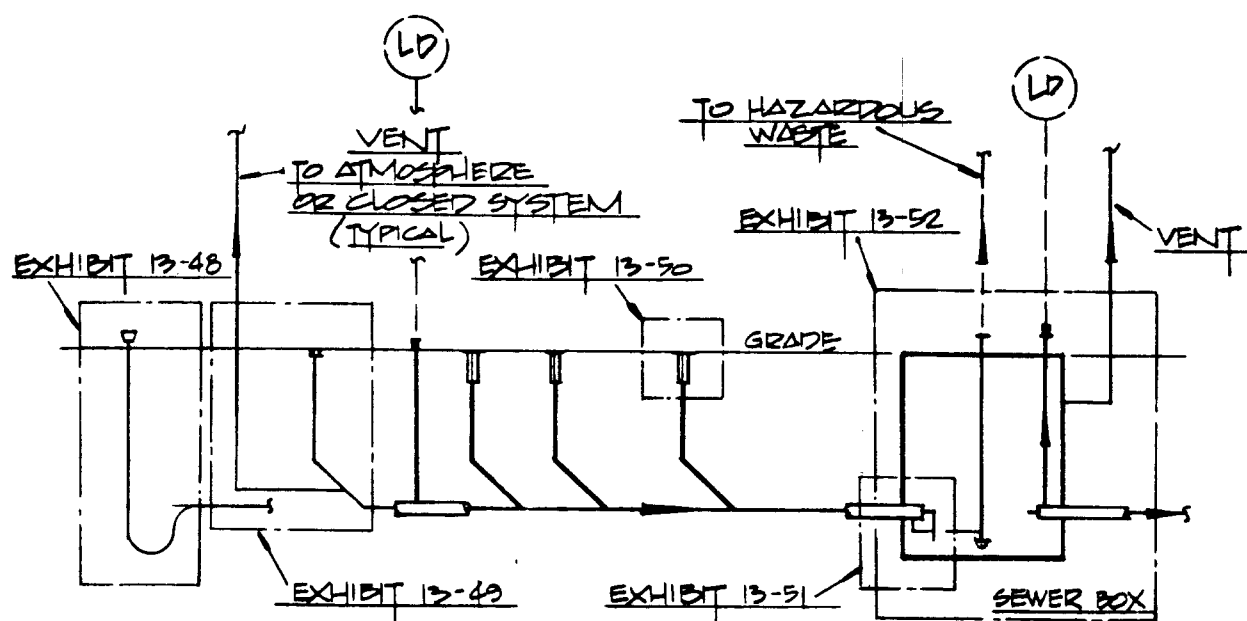
(National Emission Standards for Hazardous Air Pollutants) standard for benzene are likely to impact many refineries. If determined to exceed the allowable content of benzene in waste water systems, some form of change must occur in the design of effluent waste systems.

Process drains normally run below grade may be pressured to remote treatment facilities through above-ground piping. Another solution is possibly to double-contain the gravity flow drain system carrying the contaminant. It is suggested all local environmental laws be thoroughly reviewed by the operating company before any decision is made on this vital matter. Should double-containment be the selected means of satisfying such regulations, the following exhibits are some suggested ways of dealing with the layout.

FABRICATION

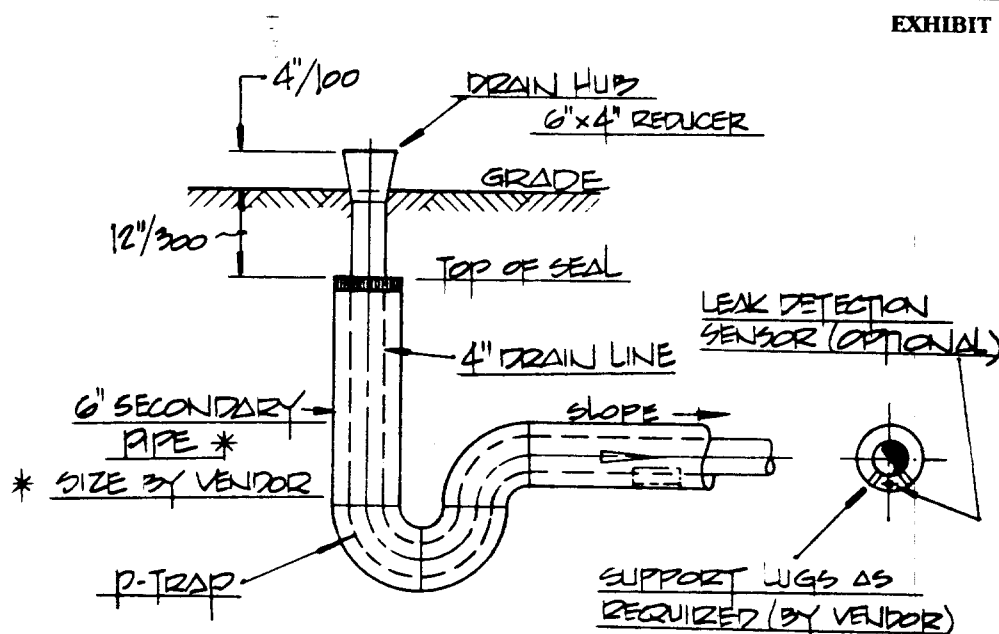
Many shop fabricators are capable of supplying prefabricated components of these systems. However, because of the numerous material combinations one may be faced with, consideration should be given to working with vendors who specialize in providing this service. FRP, lined, and PVC pipe are just a few examples of available prefabricated double-containment piping systems. Primary drain lines, sometimes called carrier pipes, come fully fabricated with supports within the secondary pipe or containment line. This service greatly reduces field installation time that can translate into significant cost savings.

Exhibit 13-47 is a composite schematic sketch of the various containment features covered in the following



Key:
LD Leak detection

EXHIBIT 13-48 Drain Hub with P-Trap



exhibits. Exhibit 13-48 is a drain hub with a P-Trap. The secondary containment line should be sealed to the drain line approximately 1 ft/300 below finished grade because it is not likely that any liquid entering the drain pipe would ever reach this elevation. As with many aspects of underground systems, it is important to understand client philosophy on providing a vapor seal. Solutions may include use of a P-Trap, Running Trap, Sewer Box seal, or insertion of a commercially available seal into the effected drain hub.

Because it is possible to suck the water seal out of a P-Trap caused by the introduction of variable flow rates downstream, it is important to vent underground drain systems properly. Exhibit 13-49 shows how the vent is branched off the clean-out line. The vent line may discharge into the atmosphere or closed system for disposal.

Exhibit 13-50, a commercially available component, is a suggested means of effectively providing a seal to new or existing underground systems. It comes in

EXHIBIT 13-49 Vent Branched Off Clean-Out Line

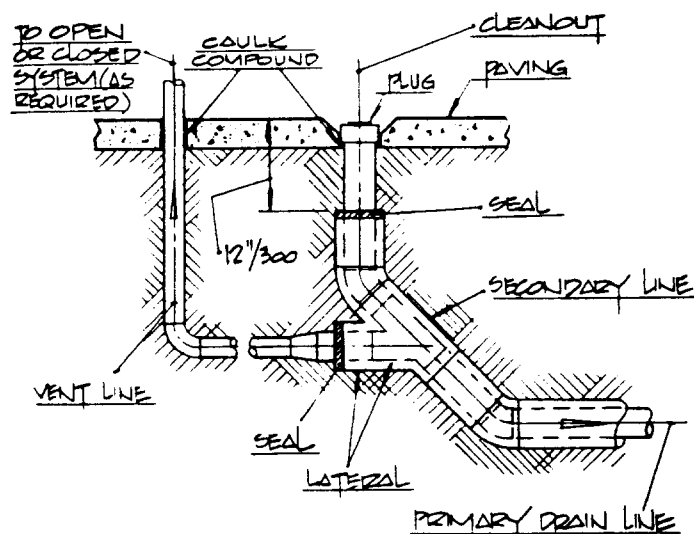


EXHIBIT 13-50 Vertical Pipe Trap

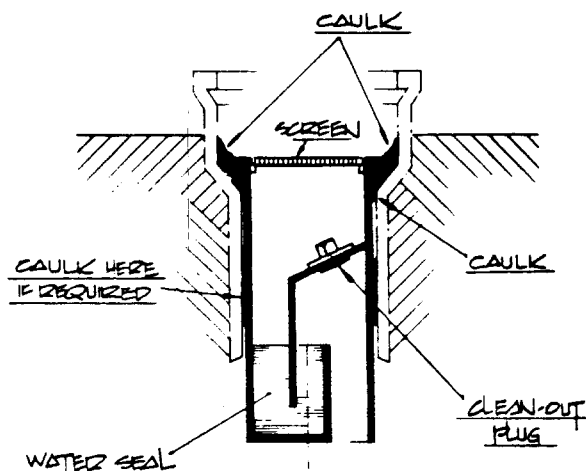


EXHIBIT 13-51 Sewer Box—Inlet Line

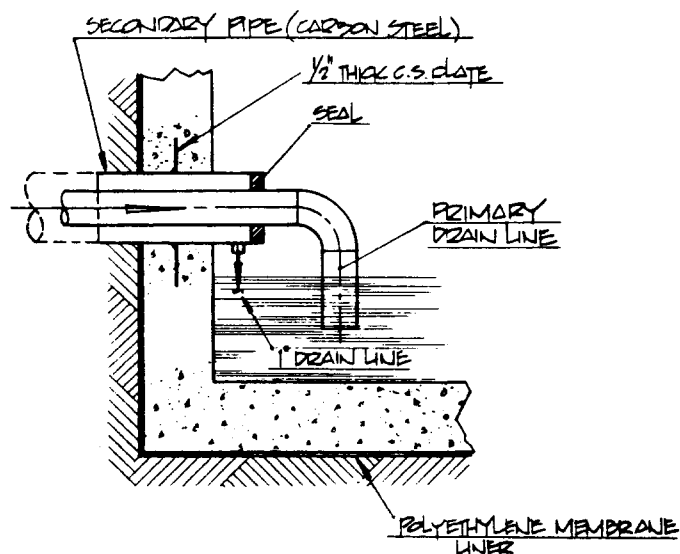
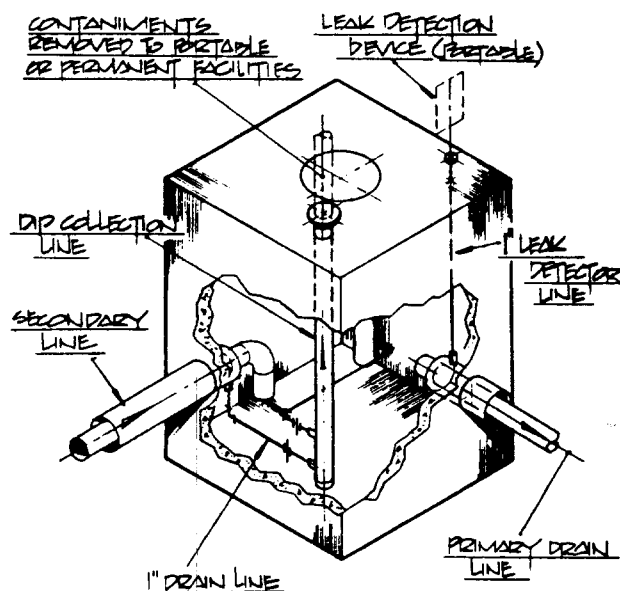


EXHIBIT 13-52 Sewer Box



varying sizes and is inserted into a hub and sealed with a caulking compound. A clean-out plug is provided to flush out any debris that may collect in the system.

Exhibit 13-51 highlights a number of features for a designer to consider. A prefabricated section of pipe is imbedded into the concrete wall. A $\frac{1}{2}$ in/015-thick plate is welded to the secondary line to act as a water seal. A 1-in drain line is provided to remove any leaked material from the containment line. The exterior wall of the sewer box is covered with a polyethylene membrane liner that acts as a condary containment barrier.

Exhibit 13-52 shows one means of dealing with any

spilled liquids or vapors that may have entered the secondary containment pipe. An internal dip collection line is precast into the sewer box, and should be large enough to permit cleaning if required. A 1-in vapor leak detector line should be run from the top of the effluent carrier pipe, through the top of the sewer box. A portable leak detection device can routinely be attached to check the integrity of the system. Permanent detection devices are also available.

These few sketches are just some examples of how the new and changing environmental laws may impact the design of underground piping systems.

UNDERGROUND COMPOSITE

Exhibit 13-47 is a composite of the various underground piping systems discussed in previous sections of this chapter. The circled numbers refer to details shown in Exhibit 13-25. Shop-fabricated piping systems are the only underground lines assigned line numbers. All other piping is fabricated and installed from information supplied on this drawing. When preparing this drawing, the plant layout designer should double-check the following:

- All above-ground piping layouts to ensure that all drain points have been picked up.
- Coordination of the locating dimensions, interface point, flange size, rating and elevation, and bevel end schedules and elevations.
- All spread footing sizes and elevations to ensure that a foundation has not been undermined by entering the angle of repose.
- Spacing provided between lines and cover.
- The data transferred from the drawing to the sewer box schedule to be used by the construction contractor.
- All line-size calculations from the data recorded in Exhibit 13-14.
- All piping interface points between the new facility and any existing piping at the site.
- The issued construction piping and instrumentation diagrams to ensure that all lines have been accounted for on the underground piping plan.

Instrumentation

Instruments play an important part in the operation and control of modern process plants. Instruments indicate, record, and control such process and utility flows as liquid volume, temperature, and pressure conditions within equipment and piping systems. Although the instrument engineer is responsible for designing the instrumentation to operate and control the plant, the plant layout designer must understand the system to position the associated controls.

This chapter highlights the general requirements for the layout of instruments. It also discusses what information is required to locate, operate, and maintain the most common types of instruments associated with these facilities.

Instruments give information about the internal conditions of piping and vessels and, when required, about control temperatures, pressures, liquid levels, and process flow. Temperature, pressure, and level gauges are regarded as locally mounted systems and are placed in piping systems and on vessels to facilitate visual readout. Instruments can also be monitored from a control panel adjacent to the components or

from a panel within the control room. This is achieved by a mechanical, pneumatic, or electrical connection from the instrument-sensing element. These arrangements are referred to as local and distributed control systems. Exhibits 14-1, 14-2, and 14-3 show typical piping and instrumentation diagram arrangements for these systems.

TYPES OF INSTRUMENTS

Most process plants have many instrument components that must be incorporated into the design by the plant layout designer. The most common are vessel level instruments, pressure and temperature indicators, control valves, and flow elements.

Control valves are installed in piping systems to automatically control the flow of process and utility gases and liquids. This control is achieved by commands from the sensing elements through transmitting and controlling devices. The body of the valve is similar in design to the conventional globe valve and

EXHIBIT 14-1 Locally Mounted System

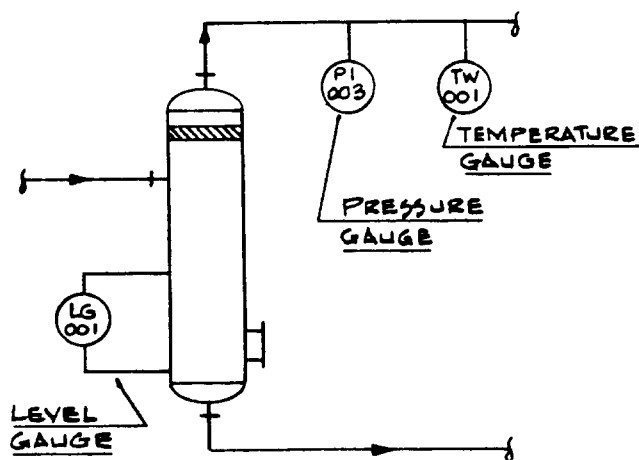
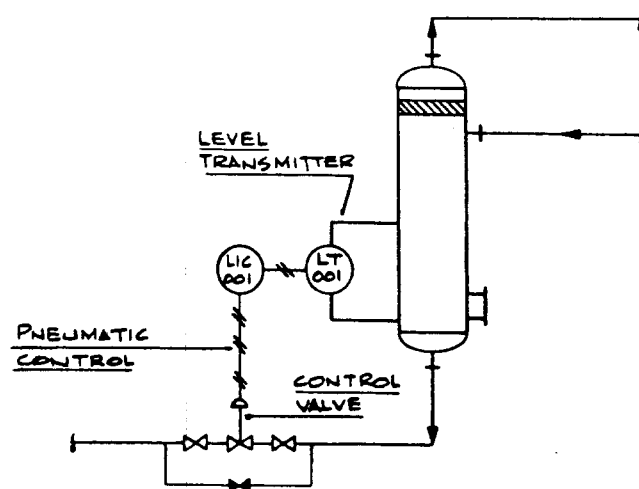


EXHIBIT 14-2 Local Control System



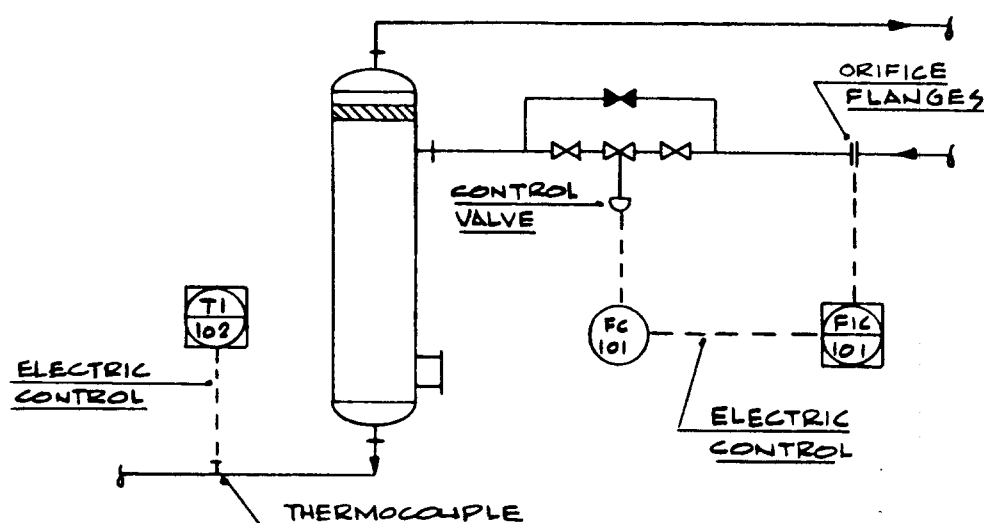
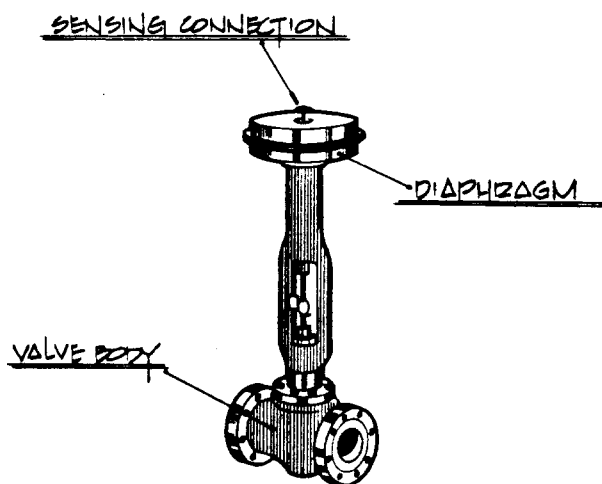
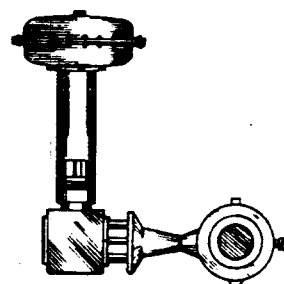


EXHIBIT 14-3
Distributed Control
System

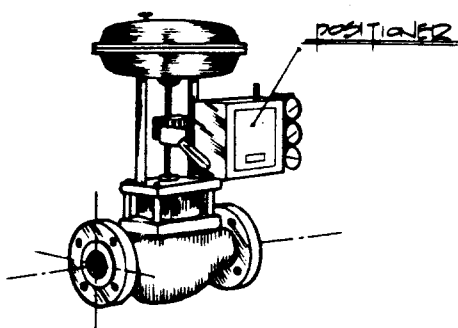
EXHIBIT 14-4 Control Valves and Accessories



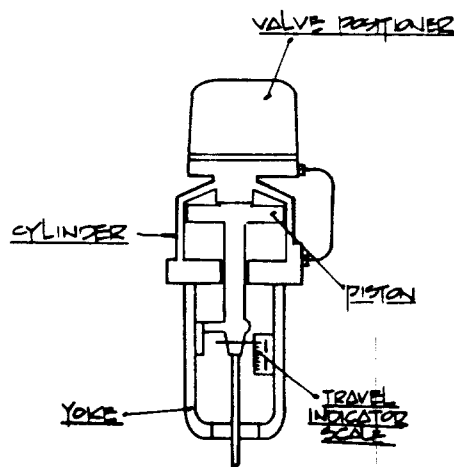
a. Typical Diaphragm Control Valve



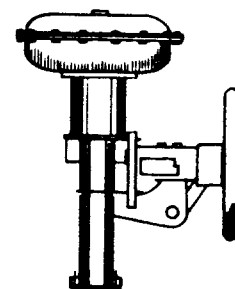
b. Butterfly Control Valve



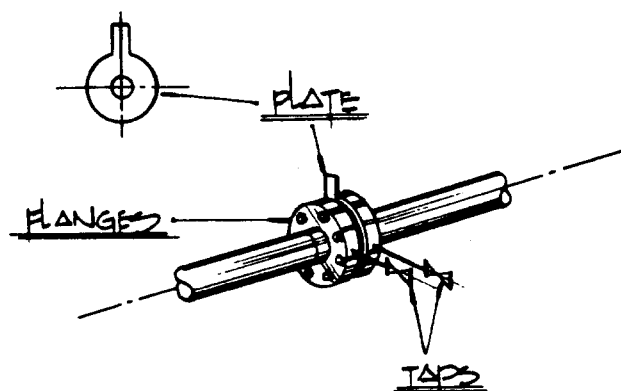
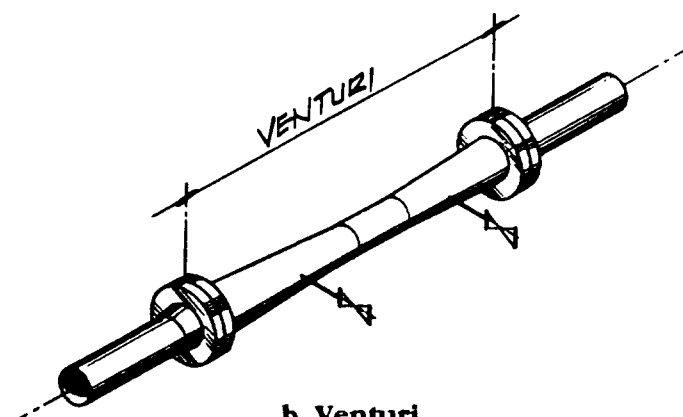
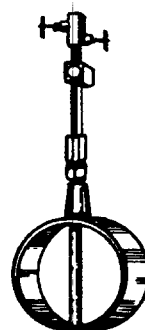
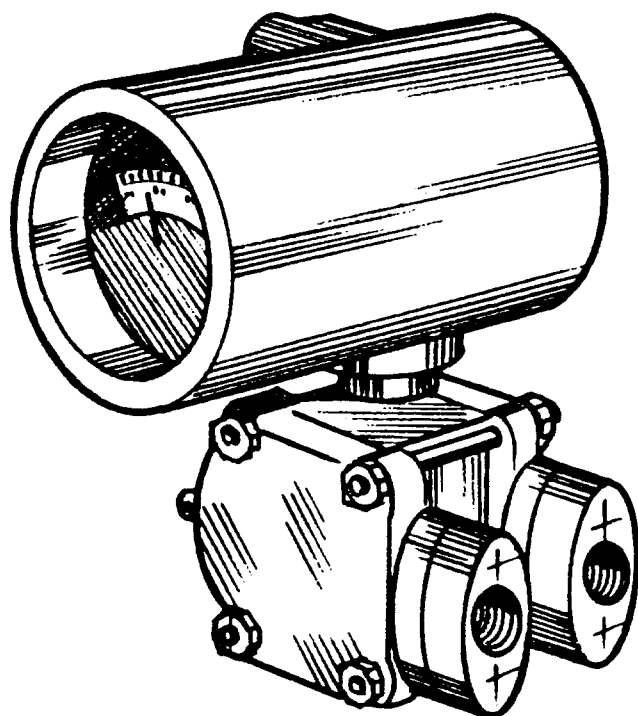
c. Control Valve with
Valve Positioner



d. Double-Acting Piston Actuator

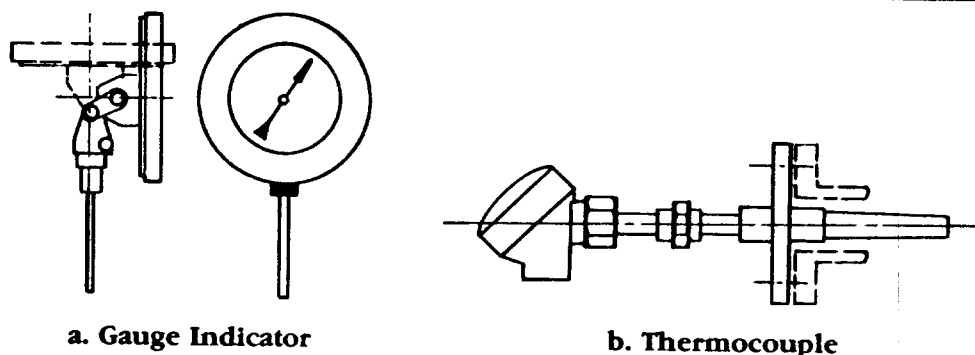
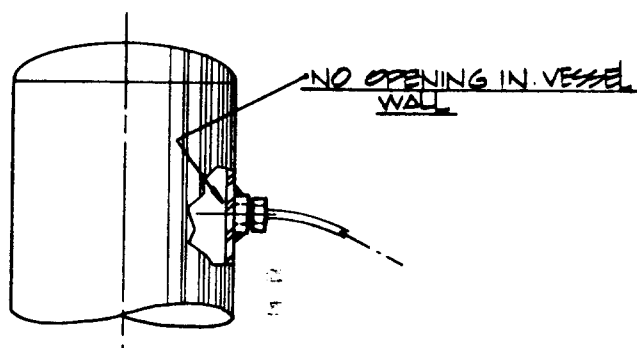
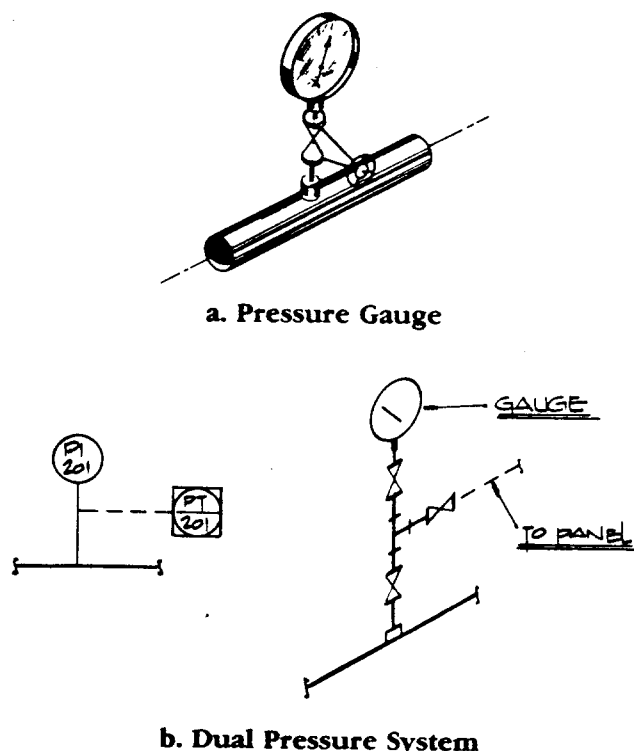


e. Side-Mounted
Handwheel

EXHIBIT 14-5
 Flow Instruments

a. Orifice Flanges

b. Venturi

c. Annubar
EXHIBIT 14-6 Transmitter


can be manufactured to suit most ratings and end connections (e.g., flanged, butt welded, socket welded, and screwed). The principal difference between the valves is that most control valves are furnished with a diaphragm actuator for automatic operation rather than a stem and handwheel for manual operation. When control valves are specified for both manual and automatic operation, they are equipped with a handwheel and a diaphragm actuator. Exhibit 14-4 shows examples of control valves and their accessories.

Flow instruments are installed in piping systems to indicate, record, and assist in the control of process and utility media. The most common component used is the orifice flange assembly, which consists of a pair of flanges tapped to receive the sensing connections, orifice plate, bolts, and gaskets. Other items (e.g., Annubars [Pitot averaging devices] and venturis) are also used as flow instruments. The sensing connections (usually $\frac{1}{2}$ in) are connected to a transmitter. The transmitter is located adjacent to the assembly before it is connected to the remote panel and controlling device (e.g., a control valve or vessel level controller). Exhibit 14-5 illustrates these components; Exhibit 14-6 shows a transmitter, which is located by the instrument engineer.

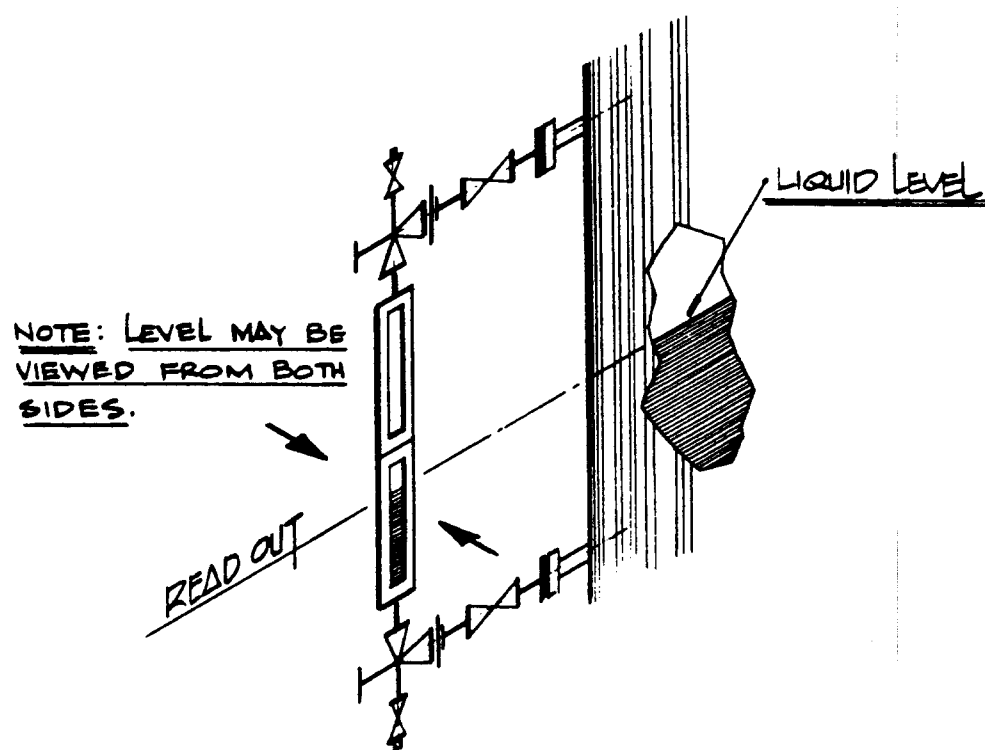
EXHIBIT 14-7
Temperature
Measurement
Instruments

EXHIBIT 14-8 Skin Temperature Attachment

EXHIBIT 14-9 Pressure Measurement Instruments


Temperature measurement for piping and vessel internal media is achieved either by the installation of local gauge indicators or by distributed control systems. The gauge indicator consists of a metallic probe for insertion into the pipe or vessel, with an attached gauge and indicator showing the required temperature range. The gauge is fixed or swivel-headed for specific visual readout angles. Thermocouples are used for distributed control systems or when the temperature must be read remotely. Like the gauge indicator, the thermocouple has a metallic probe, with a thermowell if required, but instead of a gauge indicator attached to the opposite end, it has a terminal head that houses the conduit connection used for interconnection to the remote panel. Both gauge indicators and thermocouples are generally flanged or screwed, and their pipe and vessel connection sizes range from $\frac{1}{2}$ in. to 2 in. Exhibit 14-7 illustrates both applications; Exhibit 14-8 shows a skin temperature attachment.

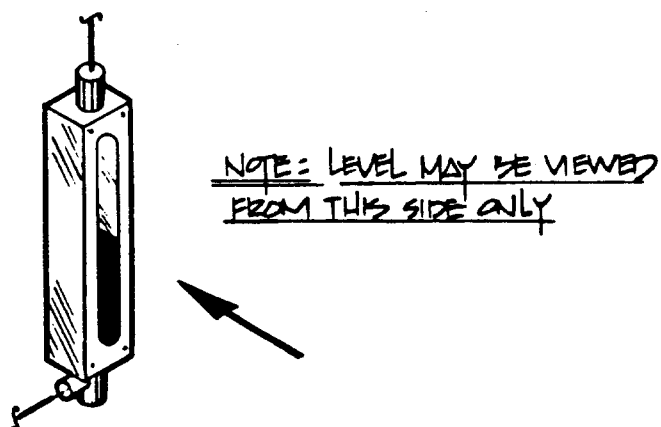
Pressure measurement for piping and vessels is achieved by the installation of dial indicators or by distributed control systems. The piping and vessels are tapped at the required location and furnished with a $\frac{3}{4}$ -in. threaded or flanged connection and a block valve. The dial indicator is screwed into the block valve; if a remote readout system is required, the valve becomes the sensing connection. Like the thermocouple, the dial can be either fixed or swivel-headed to facilitate readout. A dual local indicator and transmitter system needs only one tapping point. Exhibit 14-9 depicts a typical pressure gauge and a dual pressure system hookup.

Level gauges are installed at vessels to check the liquid level visually. They consist of metallic box segments with heavy-duty glass insertions and $\frac{1}{2}$ -in. threaded end connections. A $\frac{3}{4}$ -in.-by- $\frac{1}{2}$ -in. threaded angle valve is used for the connection between the gauge glass assembly and the vessel. Generally, a $\frac{3}{4}$ -in. block valve is required between the angle valve and the vessel; the vessel connection is threaded or

EXHIBIT 14-10
Level Gauge Assemblies



a. Typical Gauge Assembly



b. Reflective Glass

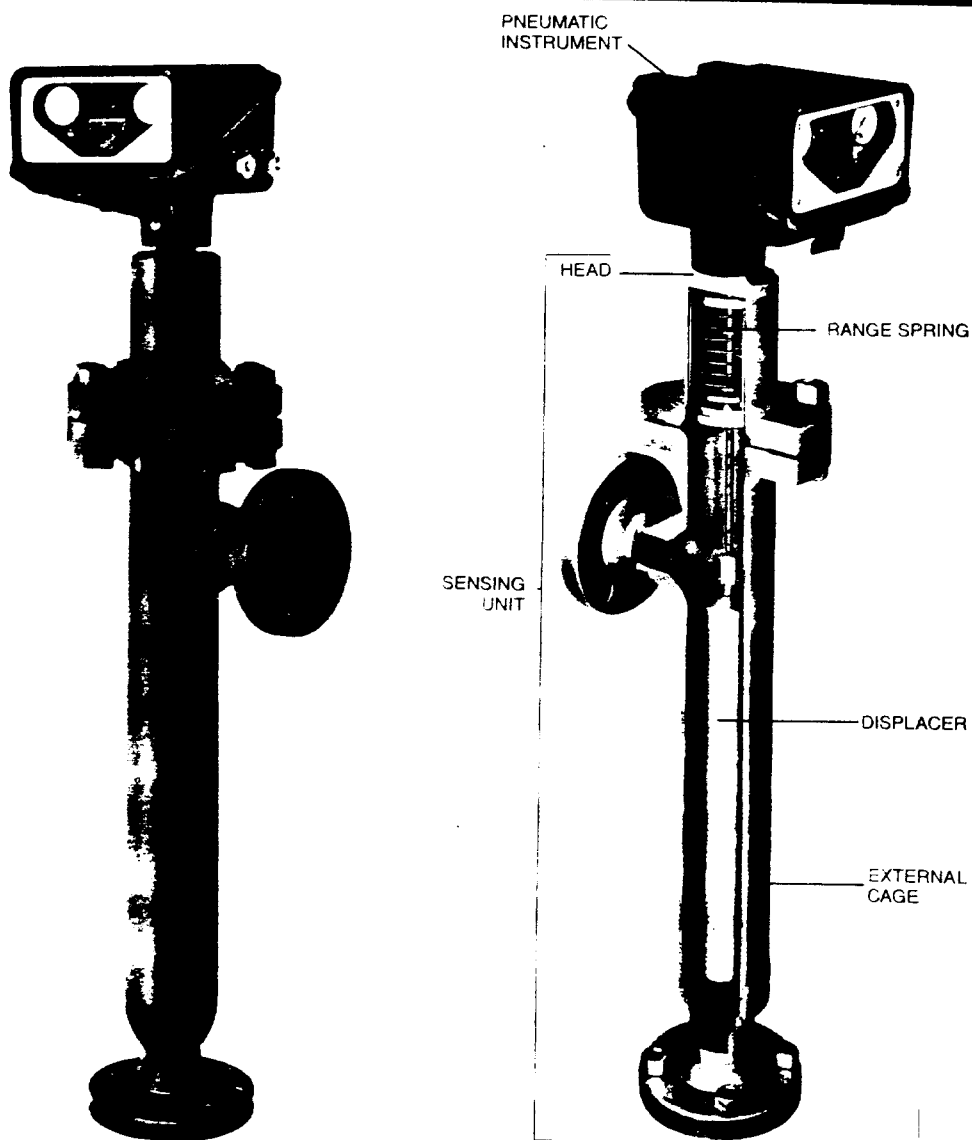


EXHIBIT 14-11
External-Cage Level
Controller and
Transmitter

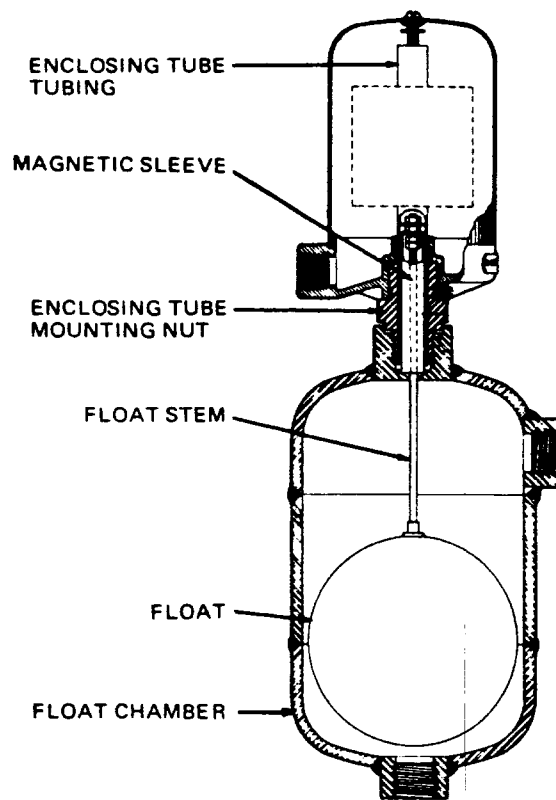
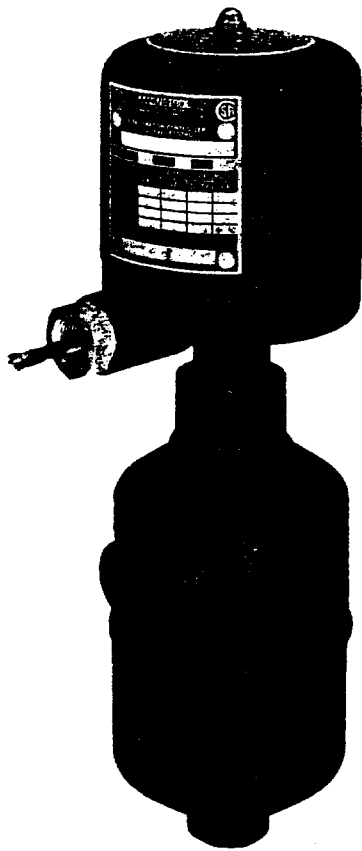


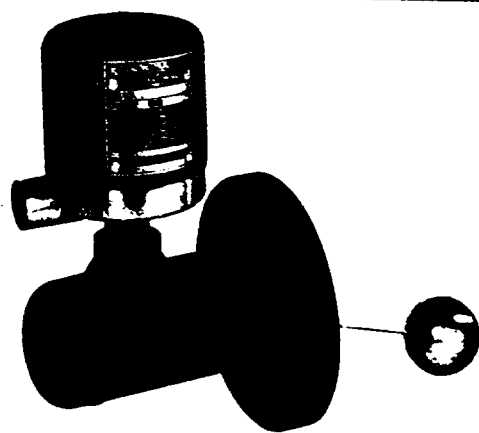
EXHIBIT 14-12
External-Cage Level
Switch

flanged. Exhibit 14-10a shows a typical level gauge assembly. It should be noted that if reflective glass is specified, it can only be viewed from one side, as shown in Exhibit 14-10b.

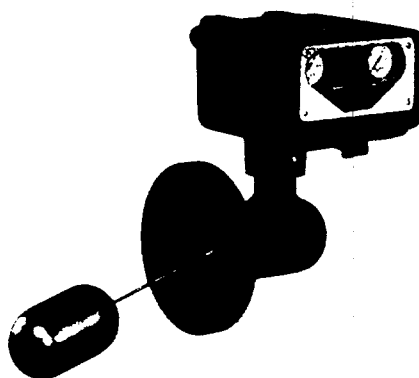
Aside from the level gauge, which is a local visual readout instrument, many devices are installed at vessels to control and record liquid levels. The displacer-type level controller or transmitter and switches are the most common. Basically, these operate by a float or displacer in a chamber that reacts to the changing levels of the liquid in the vessel and, in turn, operates

the sensing device. This device is connected to the control valve actuator directly for local control or to the control room for remote recording and control. The liquid flows through the chamber to the vessel by two flanged or screwed connections that are mounted on the vessel's side or on its top and bottom (or both). The size of the connections usually ranges from 1 in to 2 in; a block valve is installed between the vessel and the chamber to suit maintenance requirements.

Another type of level control instrument is based on an internal ball, which is generally used in vessels



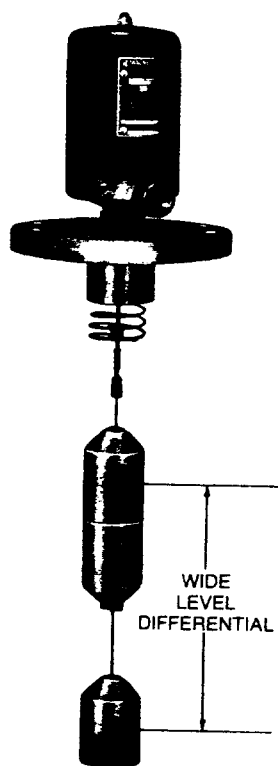
a. Switch



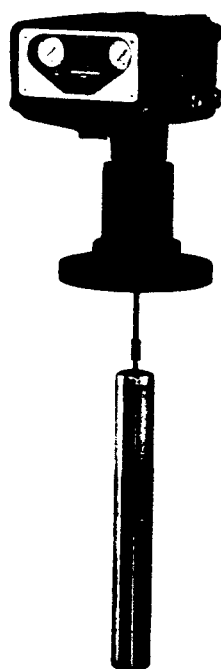
b. Transmitter

EXHIBIT 14-13
Side-Mounted Internal
Level Switch and
Transmitter

EXHIBIT 14-14 Top-Mounted Internal Level Switch
and Transmitter



a. Switch



b. Transmitter

containing viscous liquids. Unlike the housed displacer, the ball or float is immersed directly inside the vessel through a flanged connection, which is large enough for the assembly to be withdrawn for maintenance. These instruments have no block valves and are installed on the side or on the top of the vessel. Ex-

hibits 14-11 through 14-15 display typical examples of these applications.

Exhibit 14-16 illustrates the level control operating principle. A directly acting proportional controller is illustrated. A decrease in vessel outflow causes the liquid level to rise. Buoyant force on displacer C increases, unloading range spring E, which causes the displacer to rise. Attraction ball J rises inside the enclosing tube G. Magnet H follows and rotates cam L clockwise. Flapper M moves closer to pilot nozzle K, increasing pressure in chamber A of relay B. The pressure increase opens check valve S, increasing output pressure to the control valve, which throttles, decreasing flow into the vessel. Simultaneously, feedback bellows D senses the increased pressure and expands against proportional band spring N, ending pressure buildup in chamber A by driving pilot nozzle K away from flapper M. As a result, the liquid level is stabilized at a high point within the proportional band and vessel outflow again equals inflow. The reverse cycle takes place on a falling liquid level.

INSTRUMENT LOCATIONS

It is the responsibility of the plant layout designer to locate instrument components (e.g., control valves, orifice flanges, vessel level instruments, and temperature and pressure indicators) within piping systems and on vessels to accommodate process conditions and provide access for operation and maintenance. Such instrument components as individual transmitters, panels, and pneumatic piping are located by the instrument designer. The piping and instrumentation diagrams highlight the instrument requirements for each piping system and all equipment; the instrument engineer furnishes specific dimensional requirements

EXHIBIT 14-15
Level Transmitter
Control Diagram

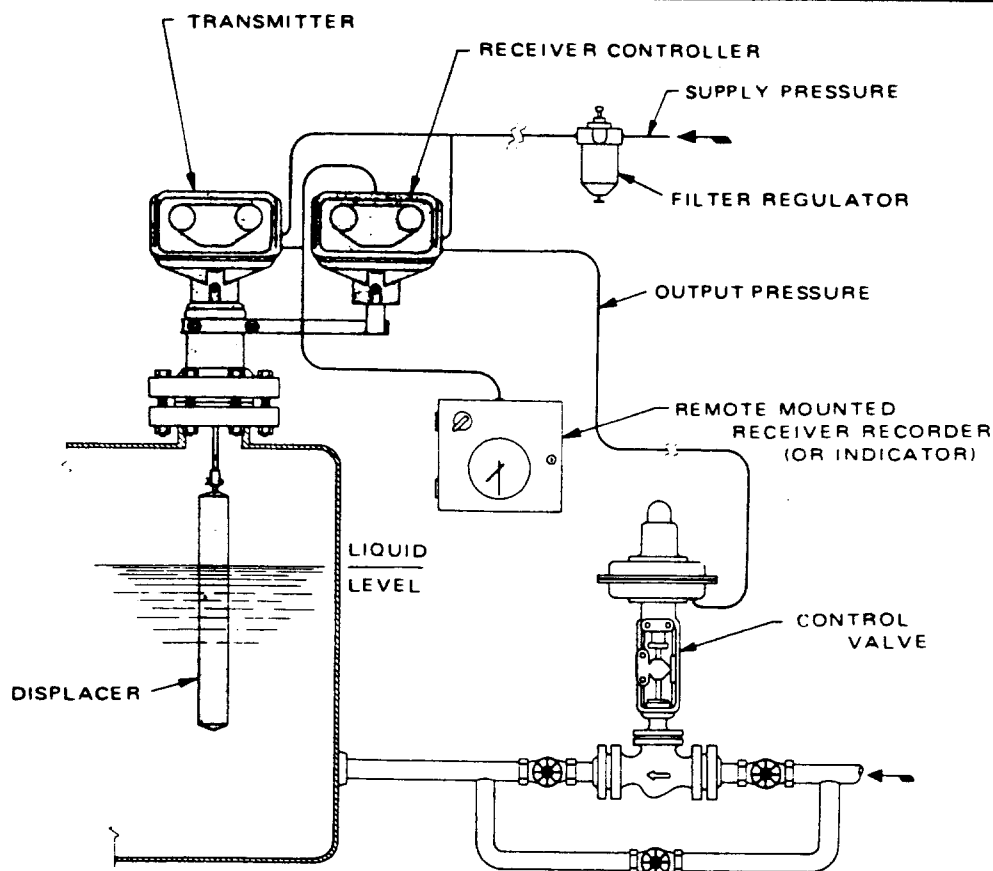
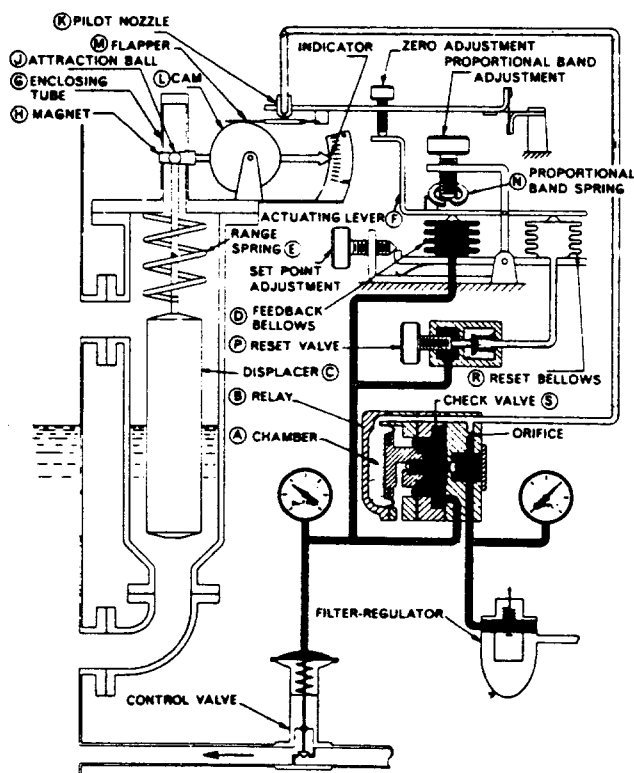


EXHIBIT 14-16 Level Control Operating Principle



(e.g., for level, pressure, and temperature instruments on vessels).

Control valves are located as single items in piping systems or are furnished with up- and downstream block valves and a bypass valve. These multivalve arrangements are called control valve stations. The blocks and bypass valves are used so that the system can continue to operate during maintenance work on the control valve. In the most common control valve station arrangements, the block valves are located in the vertical section of the assembly, with the control and bypass globe valve in the horizontal section. The globe valve can be used to regulate line flow manually while the control valve is out of service. For other arrangements (e.g., the steam control valve station), the upstream block valve is also located in the horizontal leg of the piping to accommodate adequate condensate removal. Low point drains and trunnion base supports are also furnished at control valve stations. Exhibits 14-17 through 14-20 show various control valve station configurations.

Control valve stations are preferably located at grade for the inline unit and at main operating levels for the vertical arrangement. It is not absolutely necessary to locate control valve stations in such a way that pneumatic or electrical interconnections are kept to a

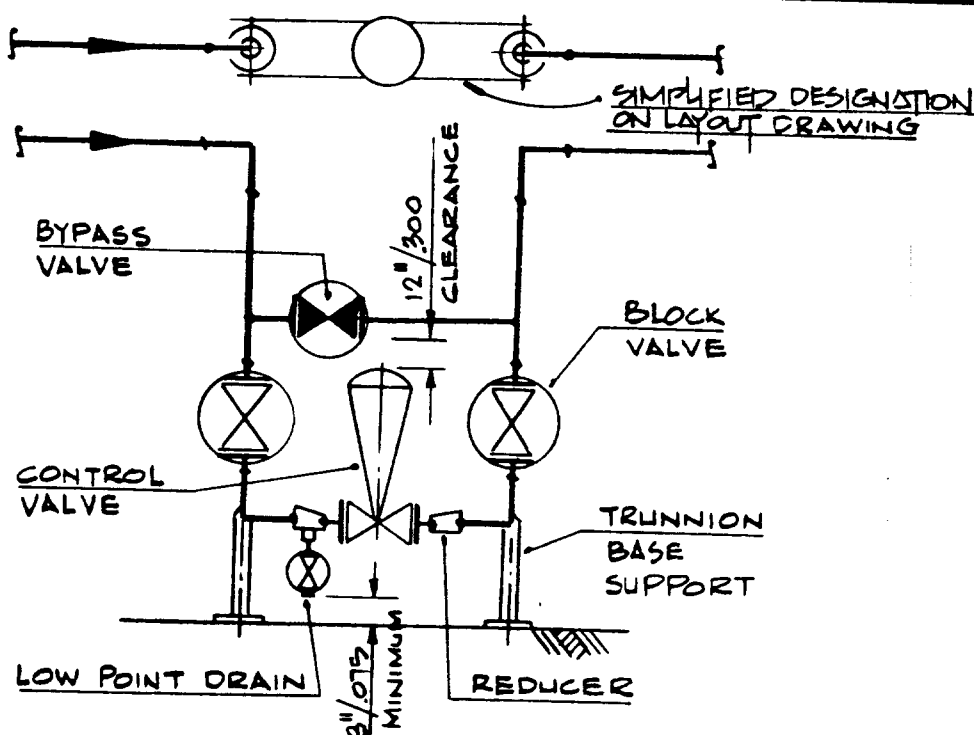
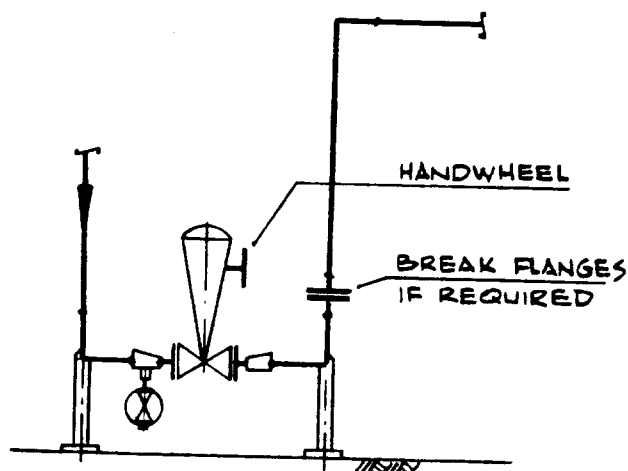


EXHIBIT 14-17
Standard Control Valve
Station

EXHIBIT 14-18 Single Control Valve Station



minimum; usually, however, the control valve is located in the same area as its source of control—for example, to facilitate the connection between the vessel level controller and its associated control valve. The prime considerations, however, are cost and, for the more expensive piping systems, accessibility. Control valve stations are located within process areas for ease of operation and maintenance, preferably on ei-

ther side of the access aisles, adjacent to equipment and structural columns. When locating control valves with valve positioners, the plant layout designer must allow adequate clearance between structural columns and vessels.

Orifice flanges need not be accessible from grade or a platform but should be positioned at a location and elevation that can be reached by a portable ladder. Care must be taken at horizontal banks of lines to allow for adequate space for side-oriented taps and, when required, close-coupled transmitters. Depending on service, orifice flanges can be mounted in the vertical and horizontal sections of piping, as shown in Exhibit 14-21, or with specific upstream and downstream dimensional requirements, as shown in Exhibit 14-22. For less common flow instruments (e.g., Pitot tubes and Annubars), advice from the instrument engineer is necessary for location and dimensional requirements.

Instruments at vessels (e.g., level control instruments and temperature, pressure, and level gauges) are positioned in conjunction with the instrument engineer's requirements for the project. Examples of these requirements and information relating to vessel internals and access and maintenance for vessel instrumentation are highlighted in Chapters 5 (Drums), 9 (Reactors), and 10 (Towers).

The location of pressure instruments on piping sys-

EXHIBIT 14-19 Steam Control Valve Station

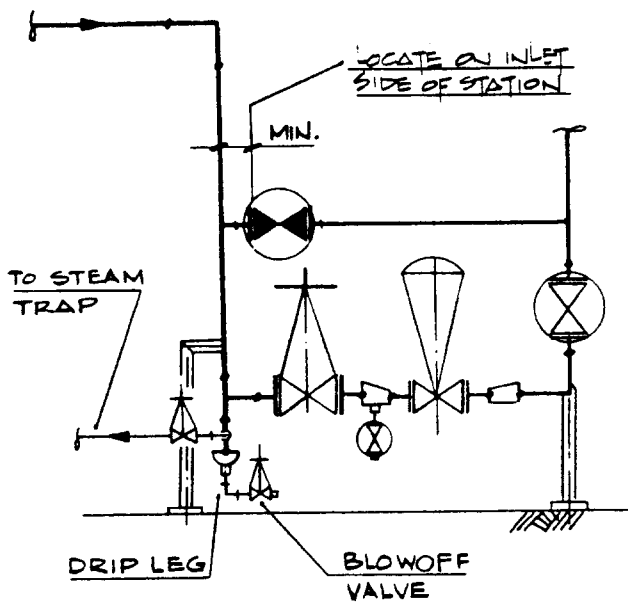


EXHIBIT 14-20 Elevated Control Valve Station

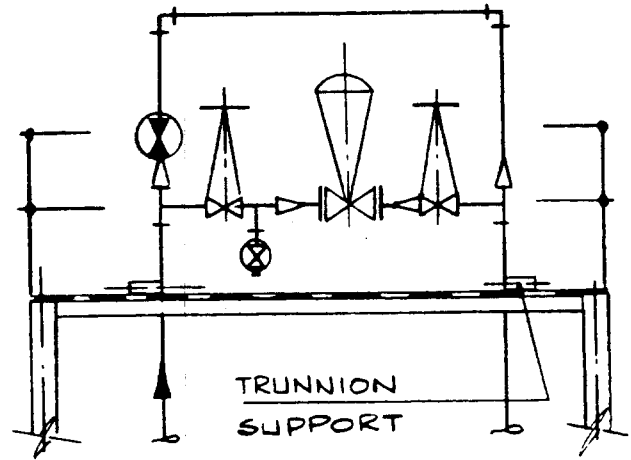
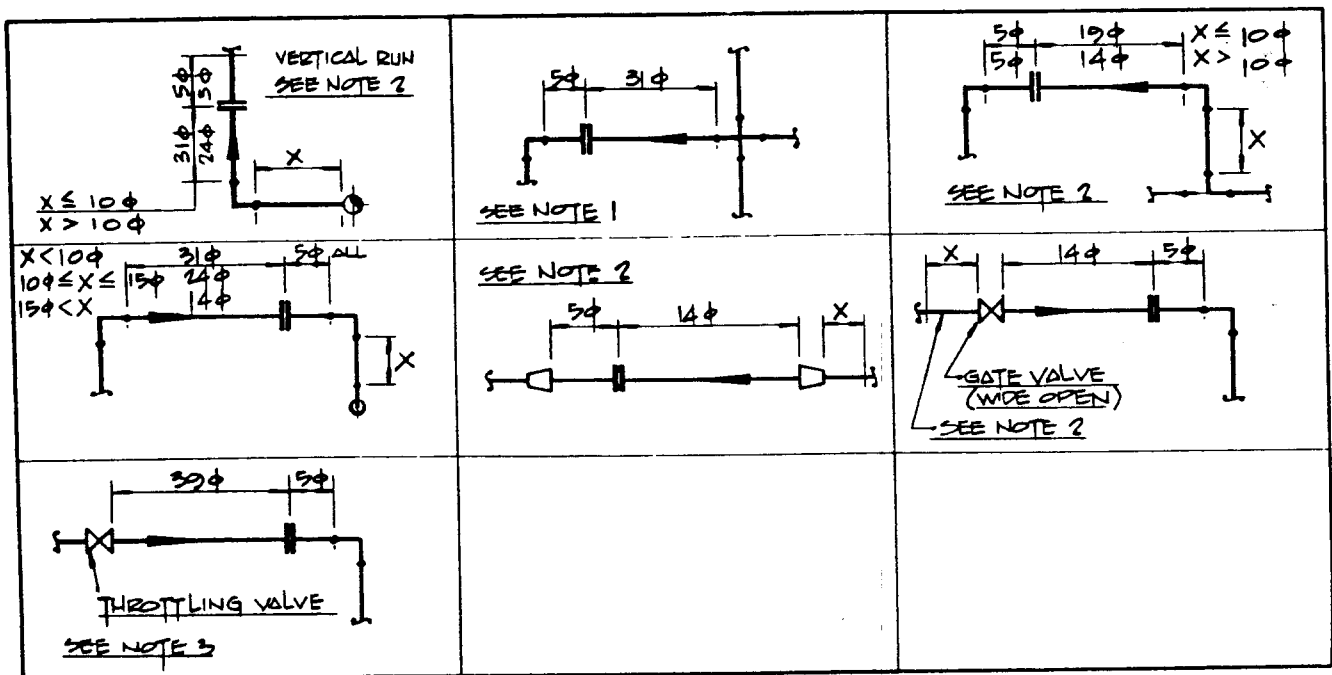


EXHIBIT 14-21 Straight Run Requirements



1. Multiple fittings may be considered as single bends when all but one line is usually blocked off.
2. The length of run upstream from the orifice must be equal to or greater than the number of diameters required by any fitting upstream from pipe segment x .
3. If a control or other throttling valve must be installed upstream from a flow measuring instrument, the minimum straight run requirement is as shown. If

there is an interference between the valve and the measuring device, the minimum distance between the intermediate interference and the measuring device is required by the applicable detail—that is, the measurement of material flowing inside a pipe should be made downstream from the interference. The remainder of the 39 diameters is between the valve and the intermediate interference.

Medium	Orifice Flanges	Venturi Tubes	Tap Location
Clean liquid	Horizontal or vertical ¹	Horizontal or vertical ³	Horizontal
Liquid with solids	Vertical ²	Horizontal or vertical ³	Horizontal
Steam	Horizontal or vertical ²	Horizontal or vertical ³	Horizontal
Dry gas or air	Horizontal or vertical ³	Horizontal or vertical ³	Vertical
Wet gas or air	Horizontal or vertical ²	Horizontal or vertical ³	Vertical

¹ Upward flow only² Downward flow only³ Upward or downward flow

EXHIBIT 14-22
Upstream and
Downstream Dimensional
Requirements

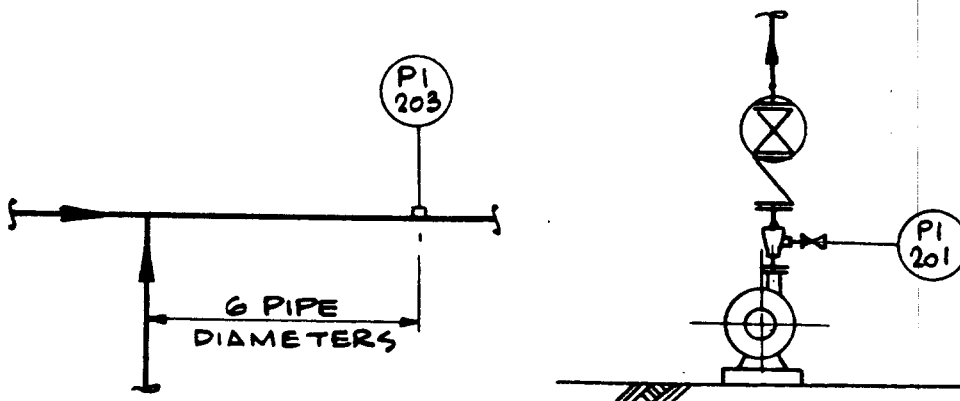


EXHIBIT 14-23
Pressure Tap Locations

EXHIBIT 14-24 Stream Intersection

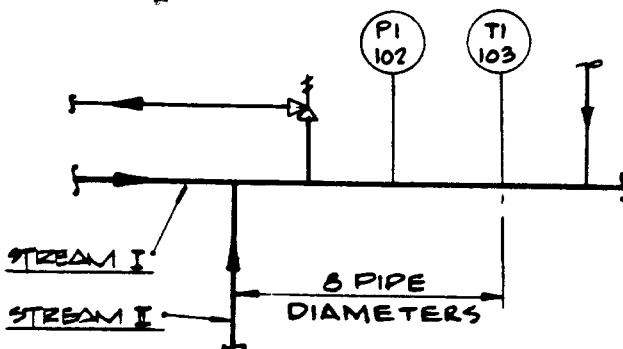


EXHIBIT 14-26 Alternative Instrument Details

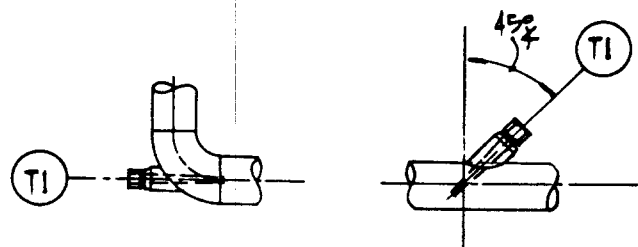
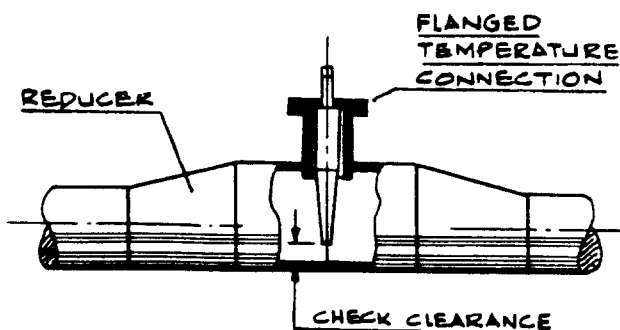


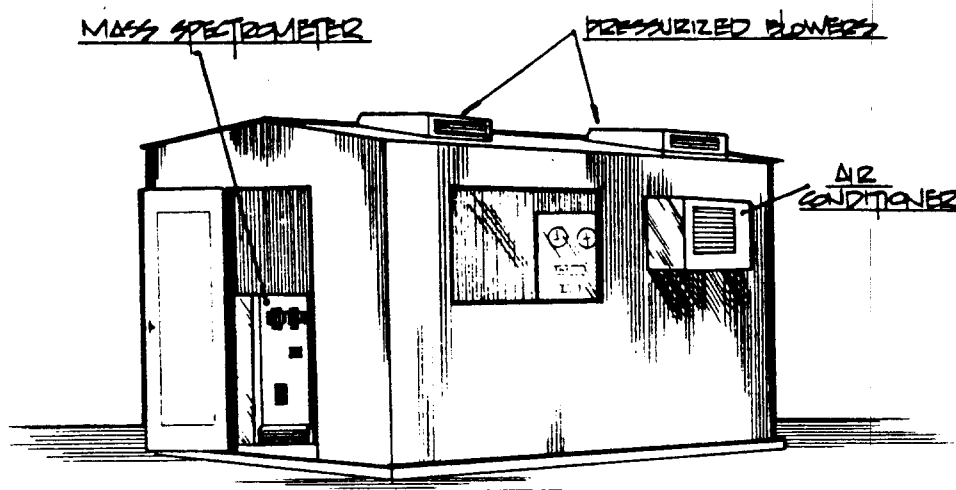
EXHIBIT 14-25 Internal Clearance



tems is not considered a major function during the plant layout phase of a project. Nevertheless, the plant layout designer must consider pressure requirements, especially between components or at junctions, to allow for sufficient space to include pressure taps. An allowance of at least six pipe diameters should be made for the inclusion of the pressure tap after a control valve or a pipe intersection. Generally, pressure gauges should be accessible from grade or a platform or at least from a portable ladder. In both cases, the gauge must be readable from the operating level without a portable ladder. Pressure gauges in piping systems at such equipment as pump discharge lines must be located as close to the equipment as possible. Exhibit 14-23 shows examples of these locations.

Like pressure instrument location, temperature in-

EXHIBIT 14-27
Analyzer House



strument location is not a major function of the plant layout phase of a project. The designer should give the same considerations to temperature instruments when locating between components, at equipment, and for accessibility. To secure maximum mixing of two or more incoming streams and to promote accurate readout, temperature connections are located a minimum of eight pipe diameters downstream from the stream intersection, as illustrated in Exhibit 14-24. Minor process connections (e.g., pressure taps or thermal relief valves) can be located within this section of pipe. Such additives as flushing oil are located downstream from the temperature connection.

The location of temperature instrument connections must provide adequate clearance for probe and dial or thermocouple head removal. On small piping systems (e.g., less than 4 in in diameter), it may be necessary to increase the size of the line near the insertion point of the probe or to locate the instrument in an elbow to maintain adequate clearance between the end of the probe or well and the inside of the pipe, as displayed in Exhibit 14-25. Alternative instrument configurations are shown in Exhibit 14-26.

MISCELLANEOUS

Another responsibility of the plant layout designer is to establish the location of the instrument cable trays and analyzer houses. Both items are coordinated with the instrument engineer during the early phase of the job. The main instrument cable runs are located either in elevated trays, generally in the pipe rack, or below ground in cable trenches. These requirements are discussed in Chapters 11 (Pipe Racks) and 13 (Underground Piping).

Analyzer houses in today's facilities contain a wide range of instrumentation, including portable sampling devices, washing facilities, and sophisticated mass spectrometers. These structures can be as large as 200 sq ft and are often located in a controlled environment containing blowers and air-conditioning units. A typical analyzer house is shown in Exhibit 14-27.

This chapter has covered the most common instrument requirements found on a conventional project. The plant layout designer should always discuss special instrument requirements with the project instrument engineer.

Process Liquid Storage Tanks

Steel containers are used for storing liquids in a process plant. Although many such vessels are found within the confines of a process unit, most vessels and tanks are located in areas commonly referred to as off sites or tank farms. The two most important factors governing these layouts are safety and economics. Any comprehensive design must consider local codes and regulations, client specifications, topography, adjacent process units, and neighboring commercial or residential property as well as maintenance, operation, and constructibility. This chapter discusses the most common types of storage vessels, plot plan arrangements, safety considerations, spill containment, pumping, and general piping layout.

CODES AND REGULATIONS

The plant layout designer should review codes and regulations of the National Fire Protection Association, the Occupational Safety and Health Act, and local jurisdictions.

National Fire Protection Association Codes

The latest issue of the following National Fire Protection Association (NFPA) codes should be reviewed before storage layout is begun:

- NFPA 11—Low-expansion foam and combined agent systems.
- NFPA 30—Flammable and combustible liquids code.
- NFPA 58—Storage and handling of liquefied petroleum gas.
- NFPA 59A—Production, storage, and handling of liquefied natural gas.
- NFPA 321—Basic classification of flammable and combustible liquids.

All NFPA codes are recommended as a basis for legal regulations. They are intended to reduce potential hazards to public safety, but compliance does not eliminate such hazards as those that occur when flammable and combustible liquids are stored in process facilities.

The Occupational Safety and Health Act

The main considerations in the layout of storage facilities that fall under Occupational Safety and Health Act (OSHA) regulations are personnel, access ladders, and stairways and catwalks.

Local Codes and Regulations

All documents concerning local codes and regulations should be reviewed before any off-site layout is begun.

TERMINOLOGY

The terminology used in text and illustrations is defined in the following sections.

Atmospheric tank This is a tank that operates at pressure levels ranging from atmospheric pressure to 0.5 psi.

Barrel A barrel is a standard unit of liquid volume in the petroleum industry that is 42 US gallons at 60° F.

Bullet This term describes a high-pressure horizontal storage vessel shaped like a bullet.

Cone-roof tank This is a low-pressure storage tank that has a fixed, cone-shaped roof.

Dike A dike is a barrier designed to contain liquid spills within a given area for safety reasons.

Distribution system This comprises equipment, piping mains, and services that carry and control gas supplies.

Diversion channel A diversion channel directs dangerous product spills away from primary diked areas to remote holding ponds.

Diversion dike This is a barrier designed to divert spills from other storage tanks; it uses natural terrain to direct liquids to a sump area.

Double-wall storage tank A double-wall storage tank has an inner wall to contain a liquid, an annulus space usually filled with insulation, and an outer wall for spill containment.

Fixed roof This is a low-pressure tank with a roof that is welded to the shell regardless of roof design or method of support.

Flame arrester In the event of lightning or another source of vapor ignition, a flame arrester in the vent line of a storage tank prevents flames from flashing to the vapor inside the tank.

Flame snuffer This is a device in a tank vent line that can be operated manually to snuff out a flame at the open end of the vent.

Floating-roof tank A floating-roof tank is designed to conserve vapor loss and minimize fire hazard.

Foam This is a solution with a density lower than that of oil and water. It is used to form a blanket over dangerous vapors and thereby reduce the risk of explosion.

Foot valve This valve is found at the bottom of a riser in a tank, where a submersible pump can be housed. During regular operation, the weight of the pump

keeps the foot valve open. When the pump is removed, the spring-operated foot valve closes the riser pipe.

Heaters These are heat exchangers used inside large storage tanks. They heat viscous materials using steam, hot water, or other heating fluids.

Hortonsphere This spherical vessel is used to store liquids and gases at high pressure.

Intermediate holding tank This tank is used for temporarily storing a liquid until it reaches a specified state, at which time it is pumped downstream in a process.

Remote impounding basin Used for temporary storage of potentially dangerous liquids, a remote impounding basin is a containment area located away from a process or off-site facility.

Sediment This sludge accumulates in tanks and piping. It consists of dirt, wax, and mill scale and must be disposed of periodically.

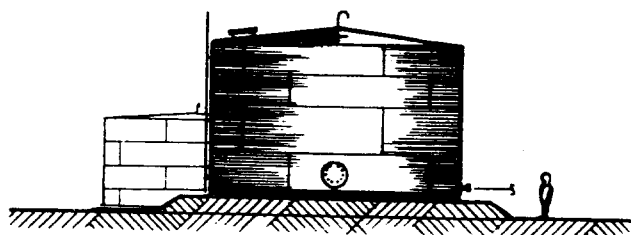
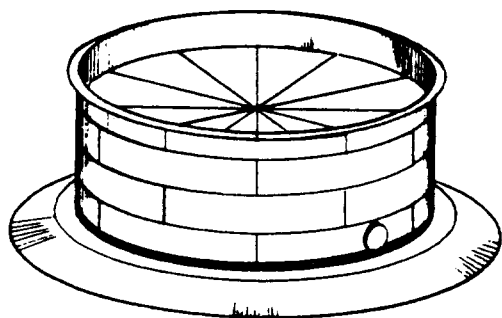
Sleeper Sleepers are steel or concrete supports usually located within 18 in (450 mm) of grade for piping systems commonly found in off sites.

Sump This is the low point within an area used to collect liquids for removal.

Tank farm A location with many storage tanks is often called a tank farm.

TYPES OF TANKS

Storage tanks come in many shapes and sizes, according to the type of product to be stored, its potential for fire, and the amount to be held. This section discusses

EXHIBIT 15-1 Cone-Roof Tank**EXHIBIT 15-2 Floating-Roof Tank**

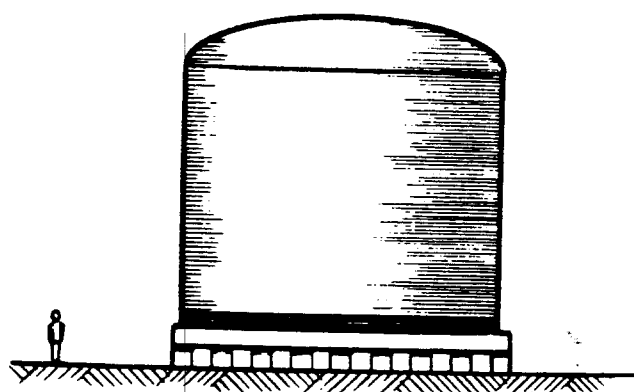
the most common types of vessels found in most process facilities.

Cone-Roof Tank

This low-pressure tank (see Exhibit 15-1) is used for countless products, including petroleum, chemicals, petrochemicals, food products, and water. Another low-pressure storage vessel is the flat-roof tank.

Floating-Roof Tank

The roof of this tank (see Exhibit 15-2) rises and lowers with the stored contents, thereby reducing va-

EXHIBIT 15-3 Low-Temperature Storage Tank**EXHIBIT 15-4 Horizontal Pressure Tank (Bullet)**

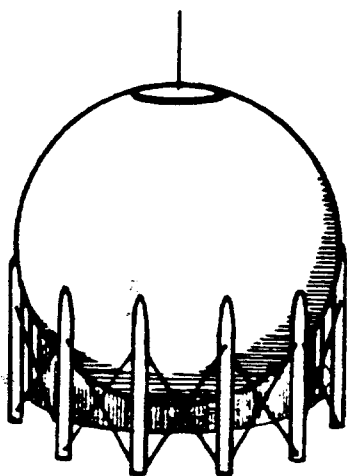
por loss and minimizing fire hazard. It is commonly found in oil refineries.

Low-Temperature Storage Tank

This tank (see Exhibit 15-3) stores liquefied gases at their boiling point. Products found in such tanks include ammonia (-28°F), propane (-43.7°F), and methane (-258°F).

Horizontal Pressure Tank (Bullet)

Bullet tanks (see Exhibit 15-4) are usually shop-fabricated vessels used to store products under high pres-

EXHIBIT 15-5 Hortonsphere Pressure Tank

sure. The heads of these vessels are either elliptical or hemispherical, the latter being used when higher pressures are required.

Hortonsphere Pressure Tank

This tank (see Exhibit 15-5) is used to store large quantities of liquids and gases under pressure. Limited road access to a plant site may make it more advantageous to erect a Hortonsphere in the field to store products under pressure.

SPILL CONTAINMENT

Because of the real risk of failure of storage tanks and primary piping systems, means must be provided to contain the resulting spills. Containment may be a second tank wall around the vessel holding the liquid or a continuous dike designed to hold all of the liquid stored in the largest tank. Dikes may be constructed of

earth, steel, concrete, or solid masonry. They may be square, rectangular, circular, or irregular in shape, conforming to the natural terrain around them. Dikes may hold one or many tanks. NFPA 30 should be consulted for matters that concern the diking of flammable and combustible liquids.

One common design is to make the dike out of earth, as shown in Exhibit 15-6. Dike heights typically range from 3 ft to 6 ft (0.900 m to 1.800 m) above interior grade. The width of the dike at the top should be a minimum of 2 ft (0.600 m) unless it is designed to accommodate vehicular traffic. The dike slope must be consistent with the angle of repose of the material; otherwise, industry dike slopes are usually 1.5 : 1 (i.e., for every foot of dike height, the toe of the dike is 1.5 ft from its top edge).

Another dike design commonly found in restricted or tight areas is the concrete wall, shown in Exhibit 15-7. The location of storage tanks often must be within the battery limits of a process unit, and earthen dikes are not practical for this application.

Should it be necessary to store liquefied gas close to a population center, double containment (see Exhibit 15-8) should be considered. This containment method uses a circular concrete wall surrounded by a conventional earthen dike. It provides for complete spill containment should the primary dike fail.

Another method of containment for use with tall concrete dikes is shown in Exhibit 15-9. Adding an earthen berm on either side of the concrete wall allows the thickness of the concrete wall to be reduced.

Tanks are often located in sloped or hilly areas, where square or rectangular dikes would be impractical. The designer should consider using the natural terrain for a group of tanks, as shown in Exhibit 15-10. In addition, roadways and pumping facilities must be located to suit the terrain.

Exhibit 15-11 shows how natural terrain is used to direct spills from spheres of highly volatile liquid to flow to a single sump. This is done by installing a diversion dike between the spheres to reduce the risk

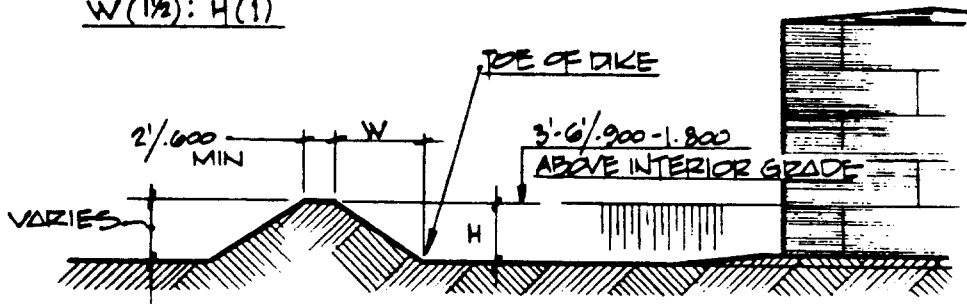
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EXHIBIT 15-6
Earthen Dike

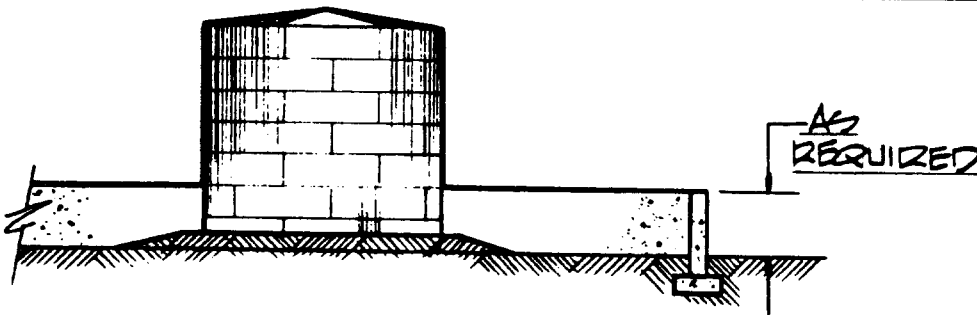


EXHIBIT 15-7
Concrete Dike

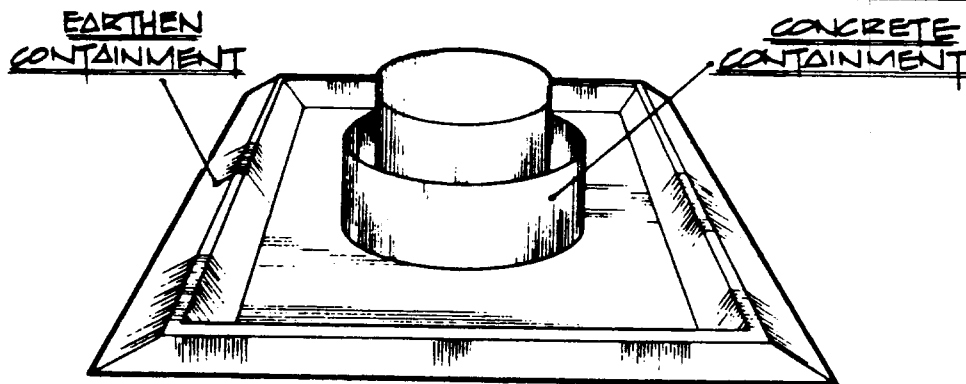


EXHIBIT 15-8
Double Containment
Diking Method

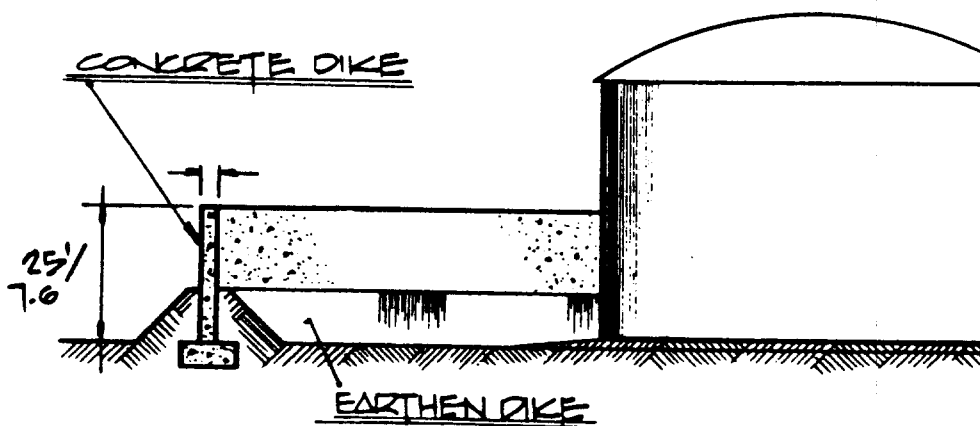


EXHIBIT 15-9
Earthen and Concrete
Combination Dike

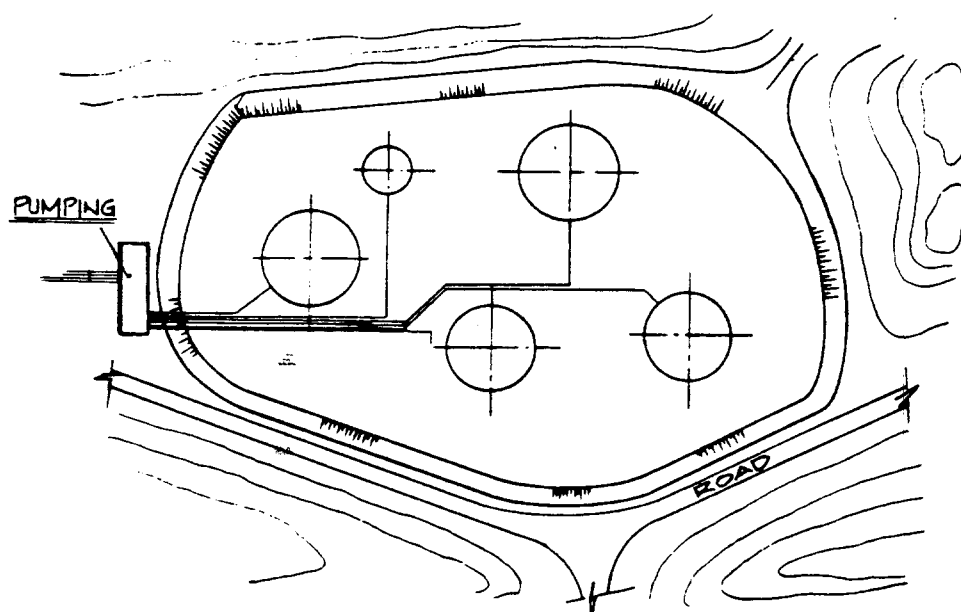
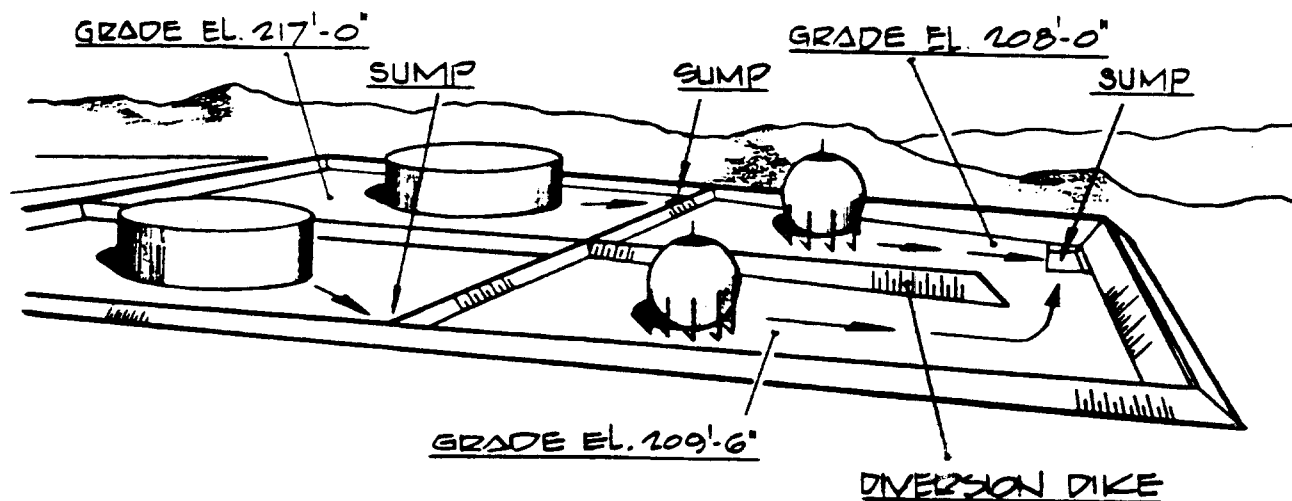


EXHIBIT 15-10
Natural Terrain Diking

EXHIBIT 15-11 Natural Terrain Diking with Tanks Containing Highly Volatile Liquids



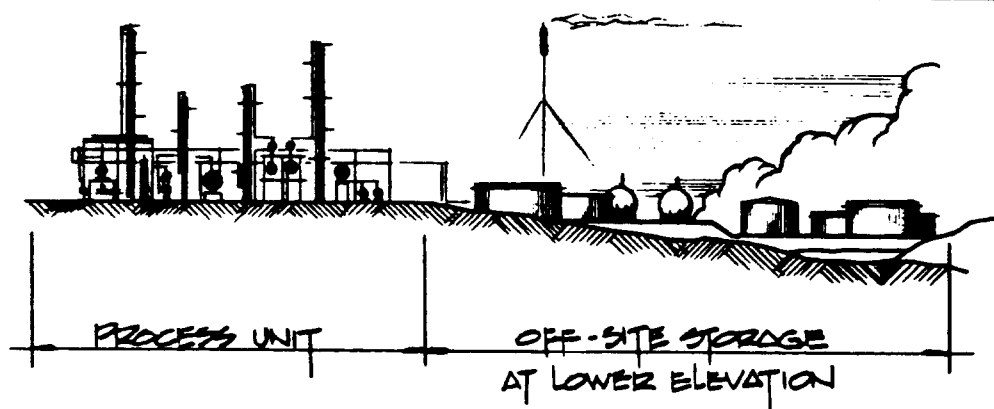


EXHIBIT 15-12
Plant Topography

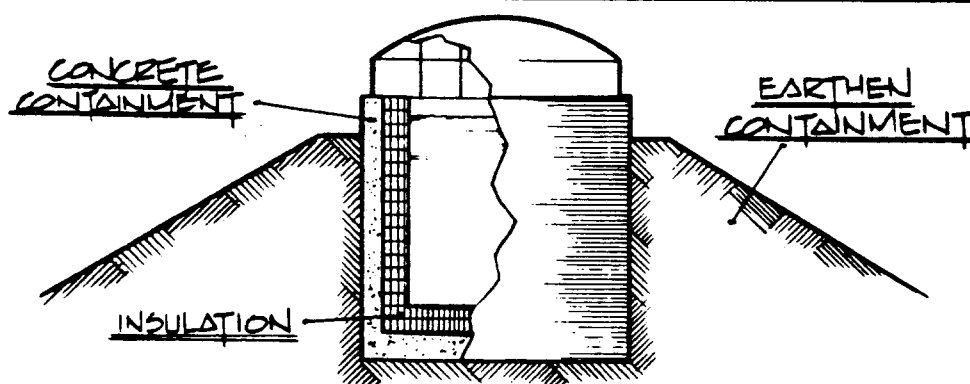


EXHIBIT 15-13
Earthen and Concrete
Containment for Buried
Low-Temperature Tank

of a fire spreading from one sphere to the other. As a result of the natural terrain, the spill is directed to its safest point within the dike.

When the overall plot plan for a process facility is developed, off-site storage should be set at a lower elevation than the process unit whenever possible. This approach (see Exhibit 15-12) provides an additional margin of safety in the event of a major rupture.

Containment of potentially dangerous liquefied natural gas spills is a significant concern to any operat-

ing facility. Therefore, extreme safety measures are employed, as shown in Exhibit 15-13. The inner tank is heavily insulated from the outer concrete containment and is buried in an earthen containment.

Developing a layout for buried storage tanks in an existing chemical plant often poses special problems. It may not be possible or practical to move existing underground obstructions in the area in which the tank must be located. One solution to this problem is to bury the tank above grade in a concrete contain-

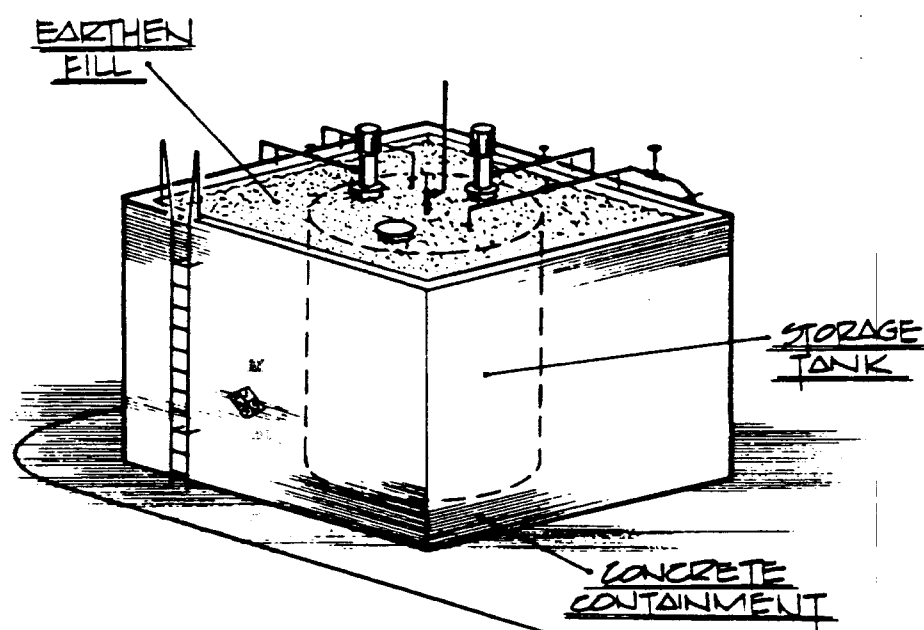


EXHIBIT 15-14
Tank Buried Above
Grade

ment, as shown in Exhibit 15-14. Pumps, maintenance access, and all appurtenances must be installed in the roof of the tank.

Spills that pose a high risk to adjacent facilities must be diverted to a remote holding area. One method would be to erect a concrete diversion canal (see Exhibit 15-15). Drain valves that are located outside the diked area usually would be closed but would be opened in the event of a critical spill. Sump drain lines discharge into the concrete diversion canal and flow downward to a holding basin.

DIKE ACCESS

Consideration must be given to providing vehicular and personnel access into diked areas. A typical arrangement is shown in Exhibit 15-16. The mainte-

nance vehicle ramp should have a maximum grade of 15%. It should be located on the side opposite the pump area. Personnel access should be by stairways designed according to OSHA standards. A single stairway located at the pump area provides access to a catwalk located on top of the dike. Two other stairways provide service access to the dikes, as shown in Exhibit 15-16.

When a layout of a tank farm must be developed at an existing facility, unmovable objects or structures may obstruct the dike area. Exhibit 15-17 shows how a dike may be designed to accommodate obstructions. Such designs are routine, but the spacing between the outside shell of the tank and the obstruction must meet NFPA or other governing regulations.

When initially trying to establish a tank farm layout, the designer should consult NFPA codes and local codes and regulations. Rules for spacing between

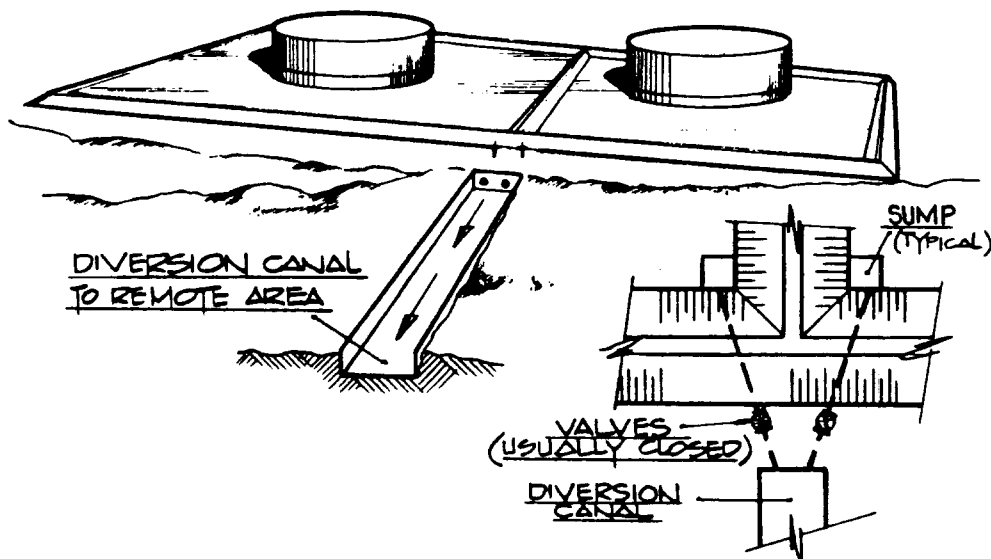


EXHIBIT 15-15
Concrete Diversion Canal

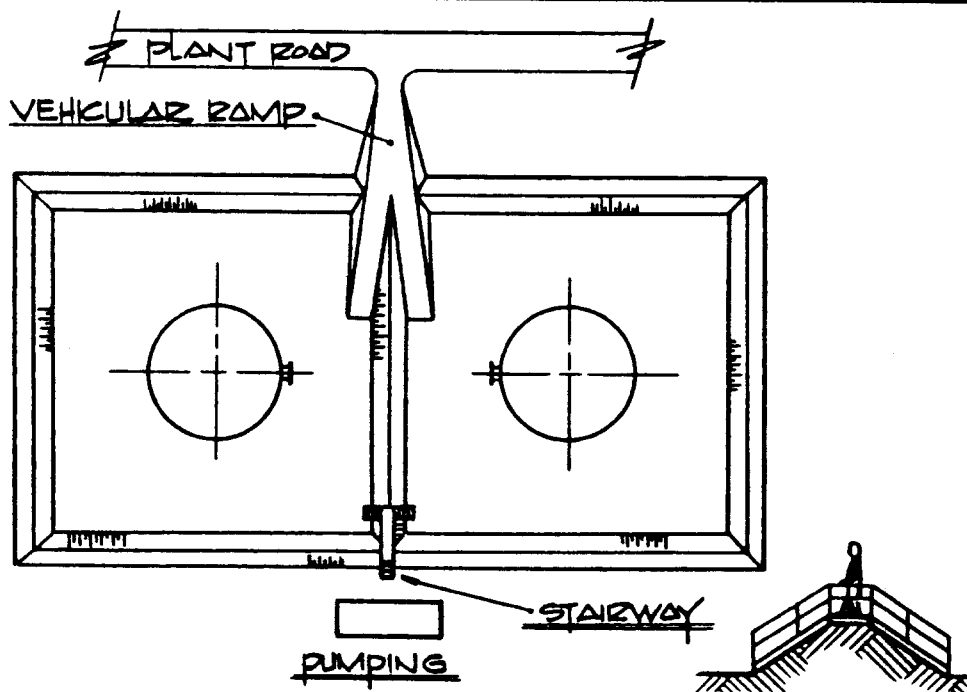
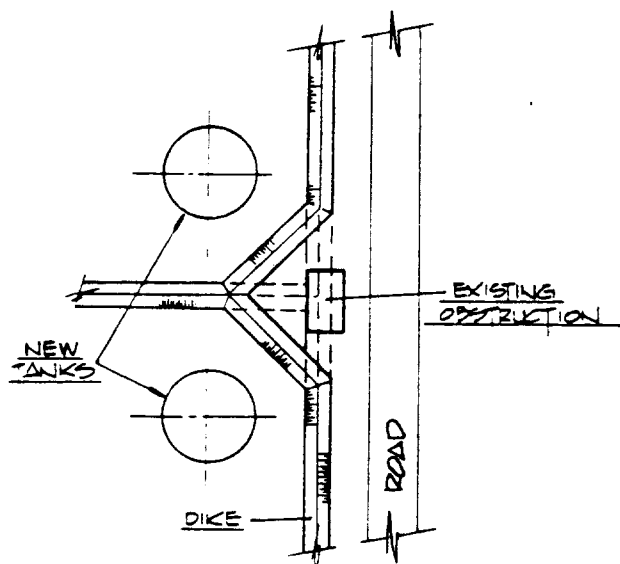


EXHIBIT 15-16
Vehicular and Personnel
Access

EXHIBIT 15-17 Building Dikes Around Obstructions



tanks and all adjacent facilities usually can be found in the latest issue of the Industrial Risk Insurers "General Recommendation for Spacing" pamphlet.

The NFPA will indicate what the designer should consider when grouping several tanks within a single dike or whether the tanks should be individually diked because of large capacities. There is no simple answer to this layout problem. Each plant site is unique, with different products, tank capacities, fire-prevention requirements, terrain, and adjacent commercial or residential property.

After the diking arrangement has been established, there are a few additional factors to plan for. The grade sloping away from the tanks to a sump must be determined; minor spills and rainwater may have to be pumped from the sump to a treating pond. Dike heights must also be established on the basis of inventories and available real estate.

SIZING TANKS AND DIKES

Development of optimum sizes for tanks and dikes comes through trial and error. Considerations include the availability of real estate, the possible use of standard-sized tanks for smaller capacities, and the nature of potential foundation design problems caused by early tank-size selections. The designer should refer to API 12F for standardized shop-fabricated tank sizes. Larger field-fabricated storage tanks must be sized to suit each site.

As an example of how to develop tank height and dike size, a 150,000-barrel (42 gallons per barrel), 150-foot-diameter tank is used. The first step is to convert the tank volume into cubic feet, as follows:

$$\frac{150,000 \times 42}{7.48} = 842,245 \text{ ft}^3 \text{ of liquid}$$

Tank height is calculated according to the following equation:

$$h = \frac{4V}{\pi D^2}$$

where:

h = height

D = diameter

V = volume (in cubic feet)

Therefore:

$$h = \frac{4 \times 842,245}{(3.1417)(150^2)} = 47.66 \text{ ft or } 48 \text{ ft high}$$

The volume of the tank berm is calculated as follows, using the data shown in Exhibit 15-18:

$$V = \frac{\pi b}{3} (r^2 + rR + R^2)$$

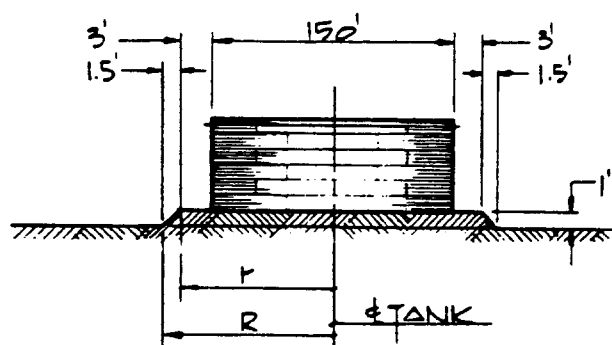
where:

r = top of berm radius (78 ft)

R = bottom of berm radius (79.5 ft)

b = berm height (1 foot)

EXHIBIT 15-18 Tank Berm Volume



Therefore:

$$\begin{aligned}
 V &= \frac{3.1417 \times 1}{3} (6.084 + 6.201 + 6.320) \\
 &= 1.047 \times 18.605 \\
 &= 19.479 \text{ ft}^3 \text{ of soil in the berm}
 \end{aligned}$$

Calculation of the volume required in the diked area is as follows:

$$\begin{array}{r}
 842,245 \text{ ft}^3 \text{ of stored liquid} \\
 + 19,479 \text{ ft}^3 \text{ of berm soil} \\
 \hline
 861,724 \text{ dike area required}
 \end{array}$$

The chart in Exhibit 15-19 is used to find the dimensions of a square dike. For example, for a dike height of 6 ft, the designer first finds the 6-foot dike data line that corresponds to 861,724 ft³ and then reads directly left to the vertical axis to find the dike dimensions. In this example, a 390-square-foot dike would contain the liquid. *K* is the volume of liquid held within a dike that is constructed to a 1.5:1 slope.

The exhibit may also be used to calculate the dimensions of a rectangular dike. First, the designer locates the point on the vertical axis for the known length of one side of the rectangle—for example, 425

ft. Next, the designer reads to the right until the desired capacity (861,724 ft³) is found and then reads down vertically until the 6-foot dike data line is reached. Finally, the designer reads left to the vertical axis of the chart to find the missing dimension of the rectangle, 350 ft in this example.

Dikes containing multiple tanks are sized to hold the capacity of the largest tank. For the dimensions of dikes containing more than one tank, it is necessary not only to subtract the volume of each tank from the dike's capacity but to subtract the volume of the soil in each berm.

TANK DETAILS

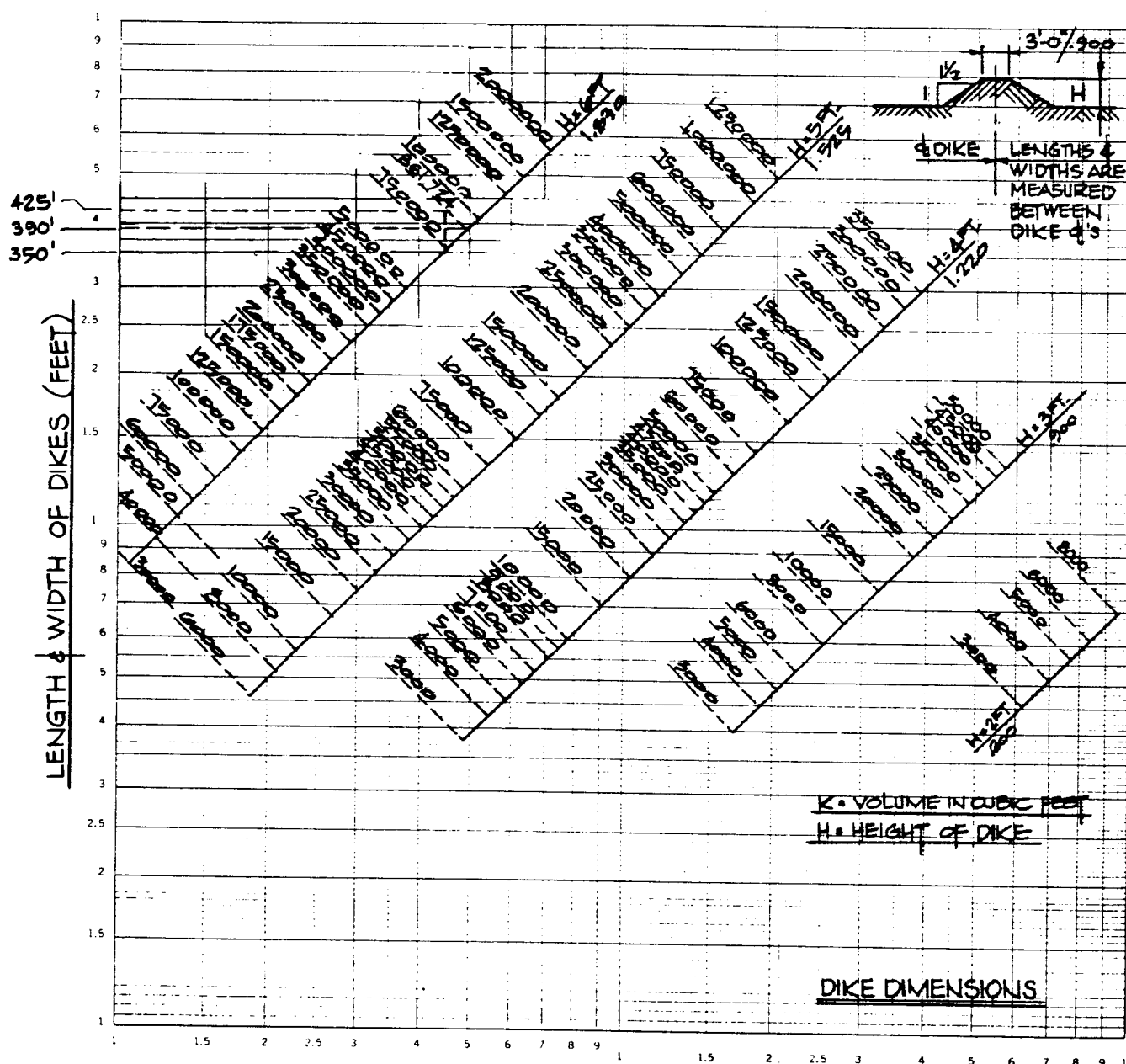
After primary liquid-transfer line connections have been located, roof access ladders (or stairways) and side shell and roof maintenance access connections should be located. Exhibit 15-20 addresses these issues.

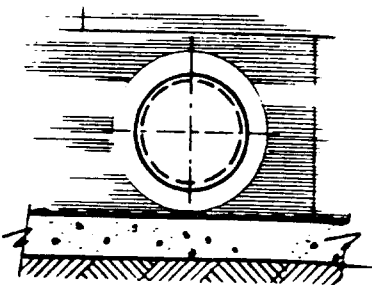
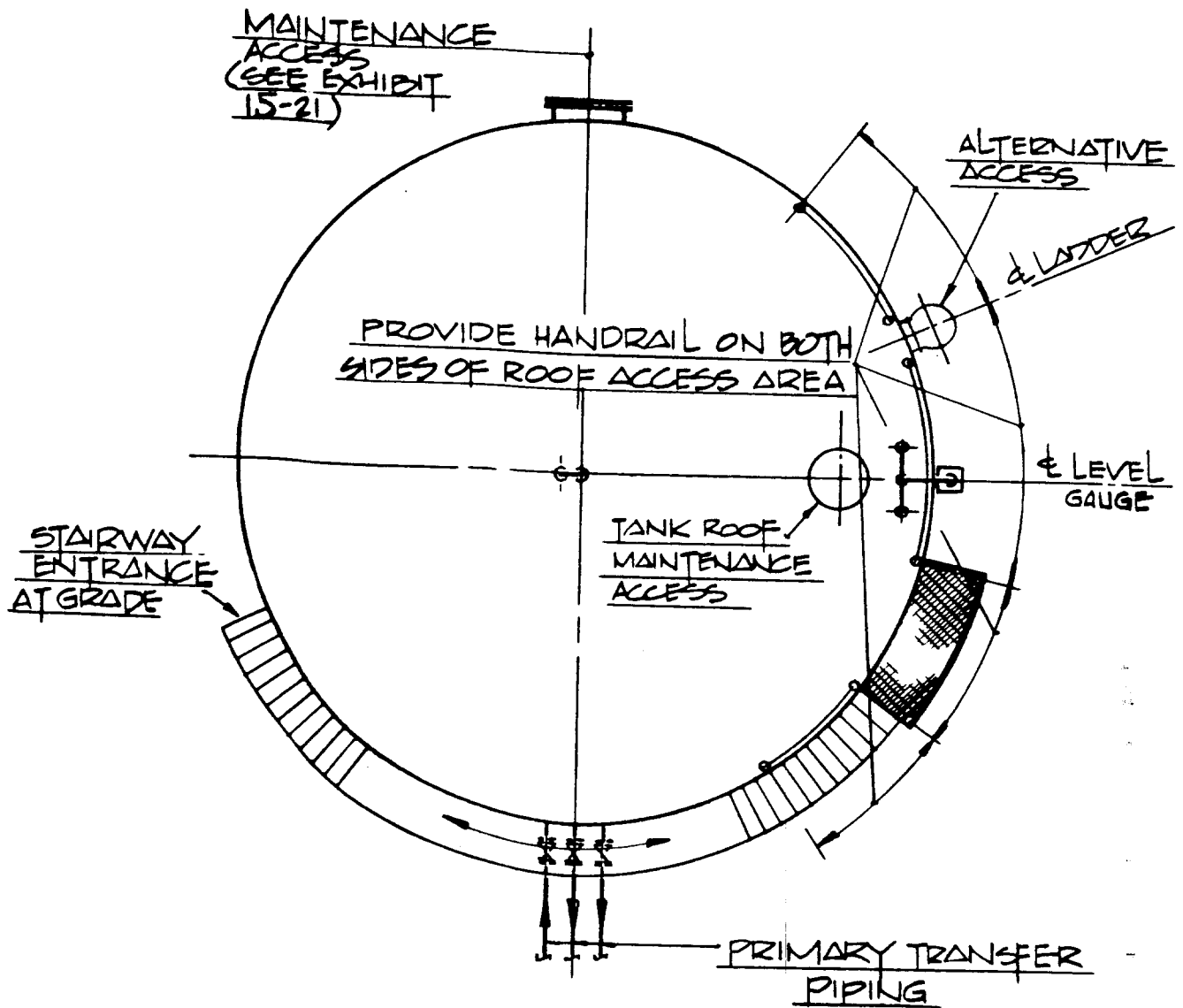
If tank heaters are employed, mobile maintenance equipment should be located in the most convenient area. Tank maintenance includes such activities as internal inspection, cleaning, and repairs to internals, roof supports, and level instruments. Setting entrances to stairway or ladder areas at grade is the most convenient choice for operations personnel. It should be noted that stairways are not recommended for tanks whose diameters are less than 15 ft 6 in (4.7 m).

For safety, handrails should be added along the tank roof edge on both sides of the ladder or stairway. Level instruments with internal floats are usually located in this area, as are roof maintenance access openings, which are convenient for inspections, repairs, and cleaning of instruments.

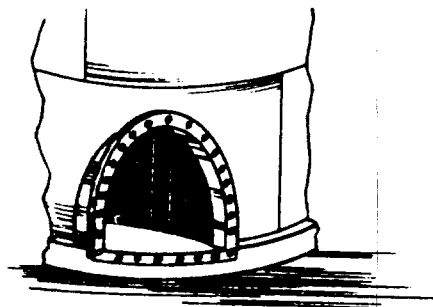
Two types of tank-shell maintenance access opening are shown in Exhibit 15-21. The standard, round opening is a minimum of 18 in (0.460 m) in diameter. The larger, oval-shaped, flat-bottom opening is more commonly used on large tanks or those that use inter-

EXHIBIT 15-19 Dike Volumes and Heights





a. Standard Maintenance Access



b. Large Tank Maintenance Access

EXHIBIT 15-21
Tank Maintenance
Accesses

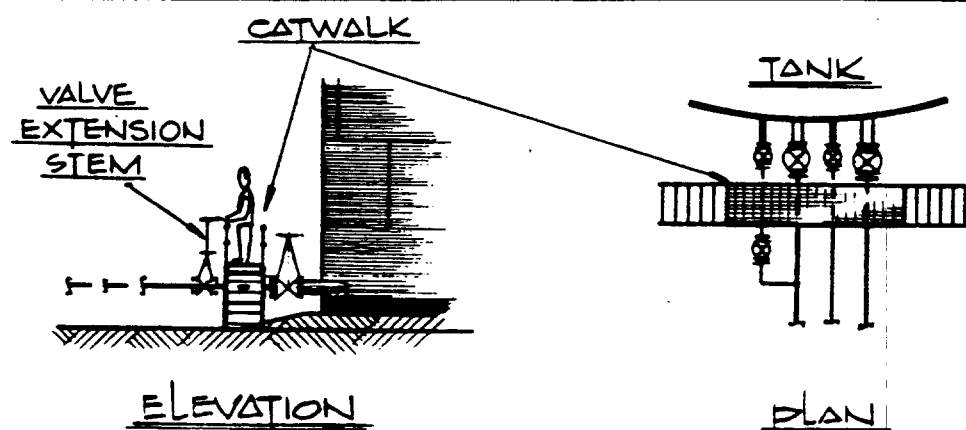


EXHIBIT 15-22
Valve Access Carwalks

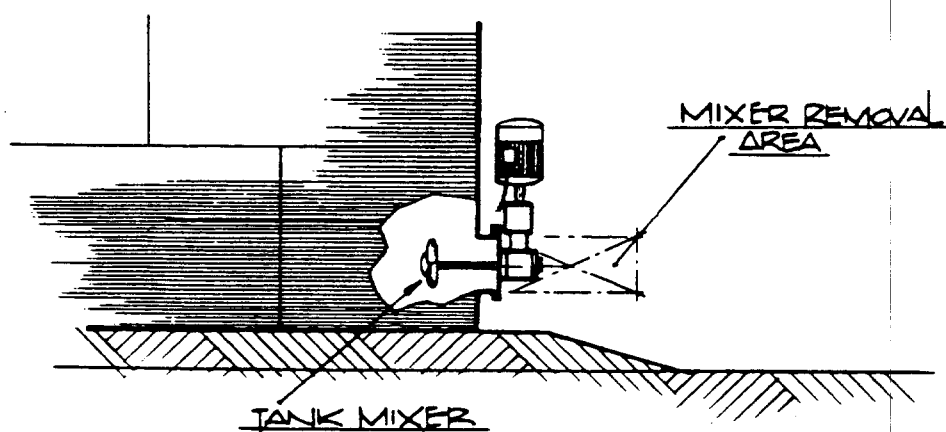


EXHIBIT 15-23
Tank Mixers

nal heaters. The layout designer must keep the area immediately around access openings free of such obstructions as large pipe supports, piping, and light poles.

Valve access carwalks can be seen in Exhibit 15-22. It is of utmost importance to give operations personnel adequate access to primary tank valves. Consider-

ation must be given to the elevation of all valve handwheels in relation to the catwalk. Adding extension stems to smaller valves will facilitate opening or closing such valves.

Tank mixers A tank mixer, shown in Exhibit 15-23, is another auxiliary piece of equipment found in tanks

EXHIBIT 15-24 Typical Tank Heaters

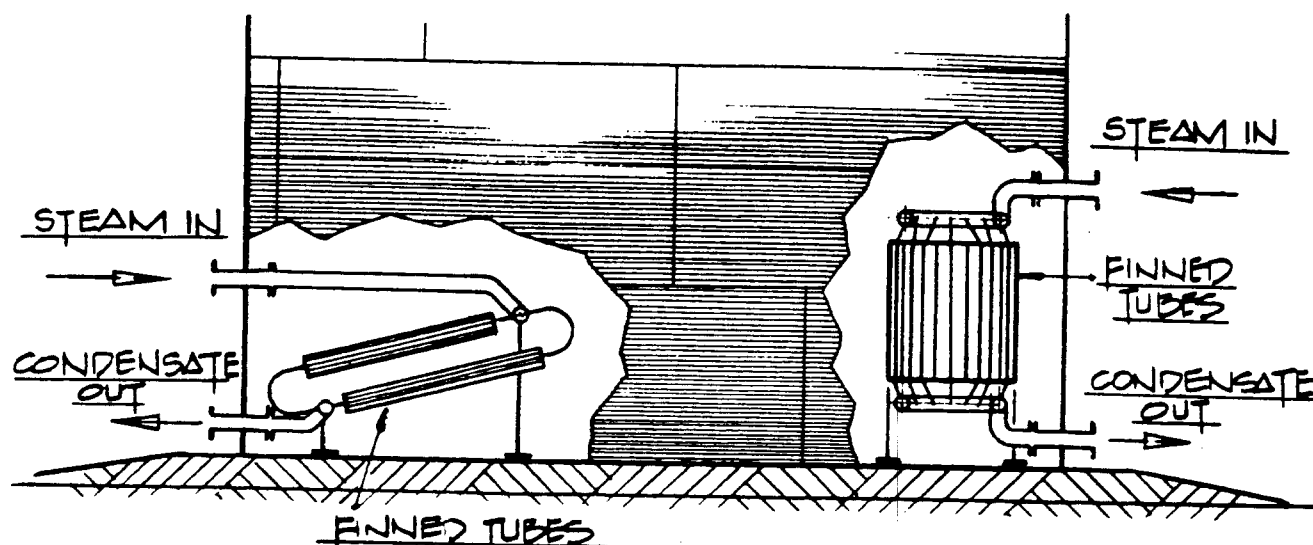
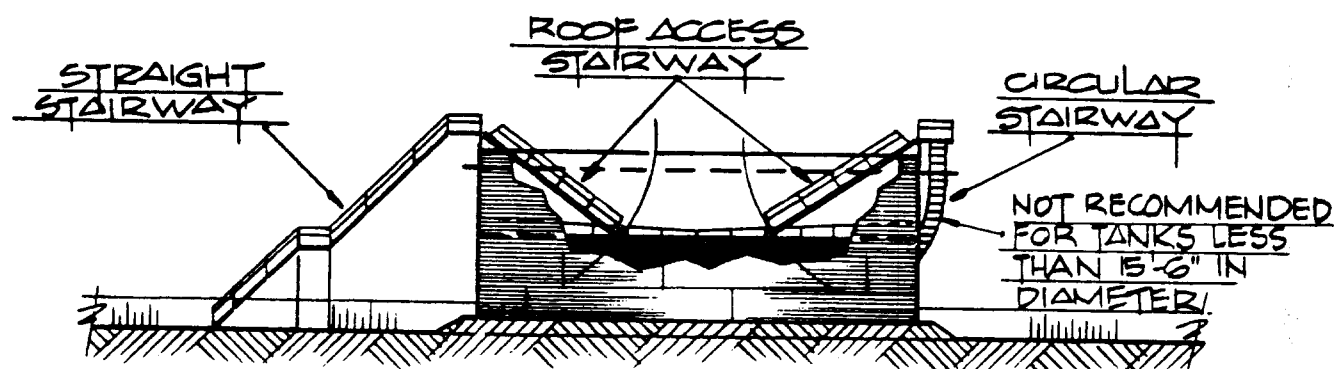


EXHIBIT 15-25 Floating-Roof Tank Access



with highly viscous fluids. Adequate area must be provided for removal of tank mixers.

Tank heaters Tank heaters come in various sizes and shapes, as shown in Exhibit 15-24. Sufficient unobstructed space must be provided outside access openings to permit removal of heaters.

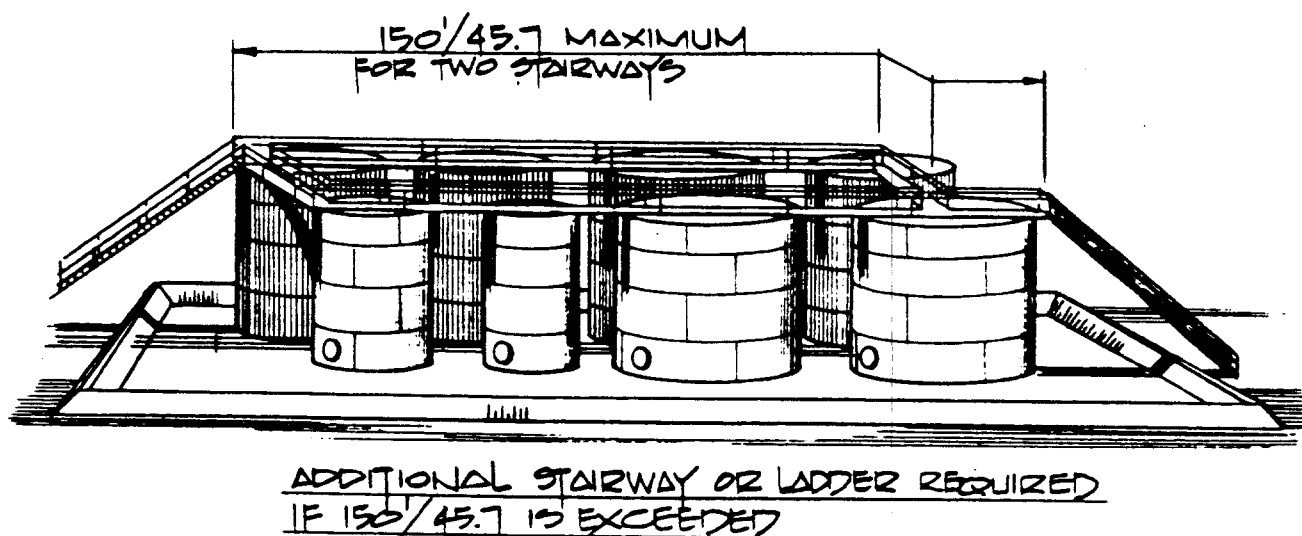
Floating-roof tank access Access to floating-roof tanks is shown in Exhibit 15-25. The straight stairway on the left of the diagram can be used for tanks of all diameters. Each stairway must have a landing outside the tank wall that allows adequate space for the stairway, provided by the tank vendor, down to the floating roof.

For storage areas with many small or medium-sized

tanks, consideration should be given to designing interconnecting catwalks for operator convenience. The limiting factor is catwalk length, as shown in Exhibit 15-26. Travel distance to exits in high-hazard industrial occupancies shall not exceed 75 ft (23 m). Additional length can be accommodated by adding ladders or stairways.

Because of the need to avoid imposing heavy loads on the external tank or containment walls of most low-temperature tanks, consideration should be given to using access towers (see Exhibit 15-27). The rectangular tower on the left of the diagram supports all piping and a conventional stairway; the circular tower on the right carries all piping inside with a spiral stairway on the outside. Both provide access to the operations platform at the top of the tank. Economics and client

EXHIBIT 15-26 Interconnecting Carwalks



preference usually dictate design selection.

Another approach to accessing tank roofs is shown in Exhibit 15-28. In this design, the interior dike elevation is lower than the outside grade, and all tank connections are on the roof. Therefore, consideration should be given to adding a carwalk over the dike parallel to the piping. Plant personnel use a stairway on the dike's outside wall to reach the carwalk, which connects to a ladder to the operations platform on top of the tank.

TANK SUPPORTS

Four common tank support designs are shown in Exhibits 15-29 through 15-32. The civil engineer is responsible for determining the most cost-effective design, on the basis of available data about soil condi-

tions. Layout designers should understand the fundamental nature of each design to optimize piping, stairway, and ladder locations without creating problems for construction or plant personnel.

A concrete ring wall is shown in Exhibit 15-29. The tank is supported by Class I compacted structural fill as well as a ring wall that is 12 in (0.300 m) thick.

Compacted granular fill support is shown in Exhibit 15-30. The top of the tank berm is 3 ft (0.900 m) wide, slightly sloped away from the tank wall, and coated with asphaltic concrete for weather protection.

A low-temperature tank foundation design is shown in Exhibit 15-31. This particular design employs a concrete slab supported by columns, providing an air space under the slab. This air space helps raise the temperature of the slab during a failure in the primary tank.

A more conventional low-temperature tank founda-

EXHIBIT 15-27
Piping and Personnel
Access Tower

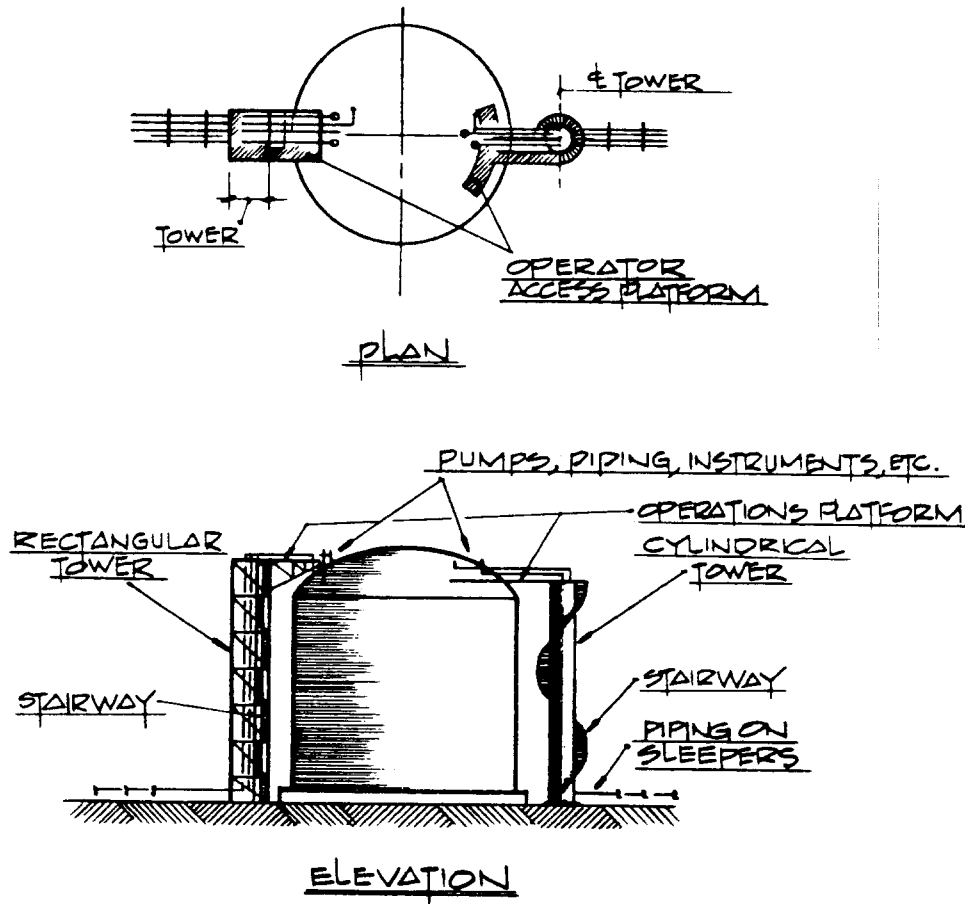


EXHIBIT 15-28
Elevated Pipe Way
and Catwalk

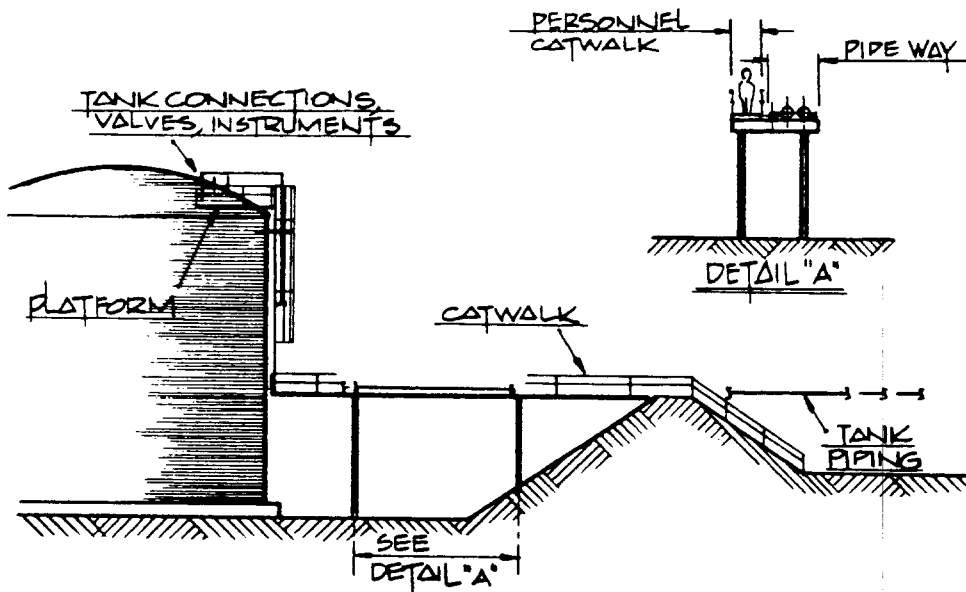


EXHIBIT 15-29
Ring Wall

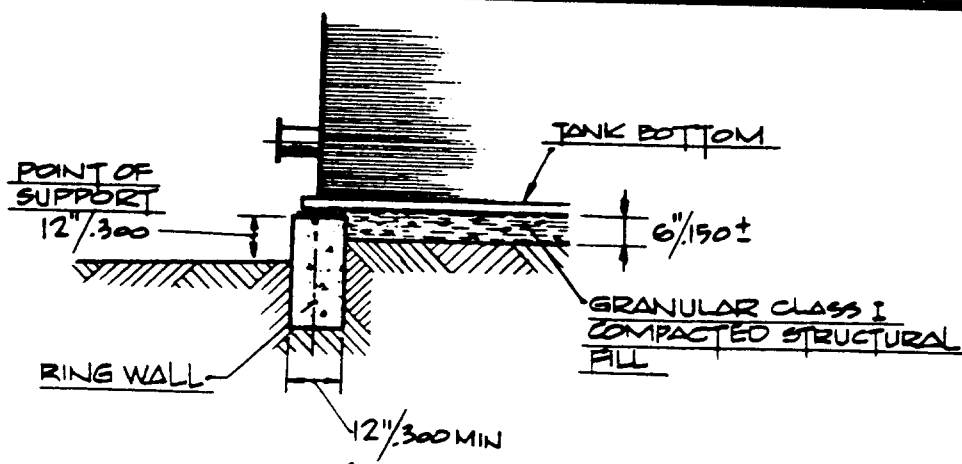


EXHIBIT 15-30
Compacted Fill Tank Pad

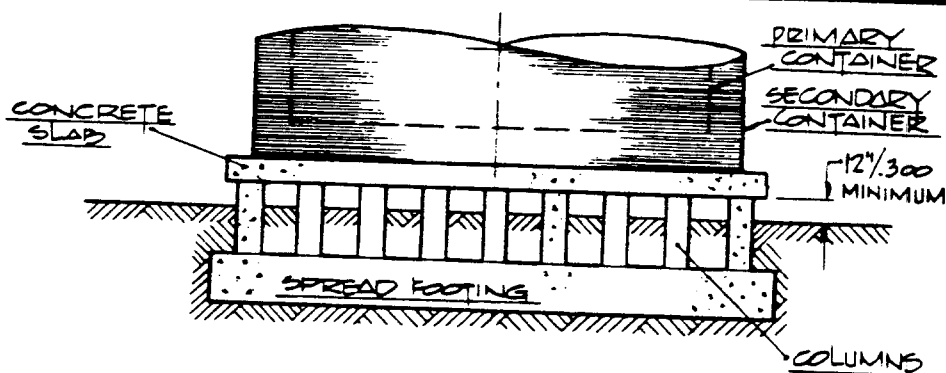
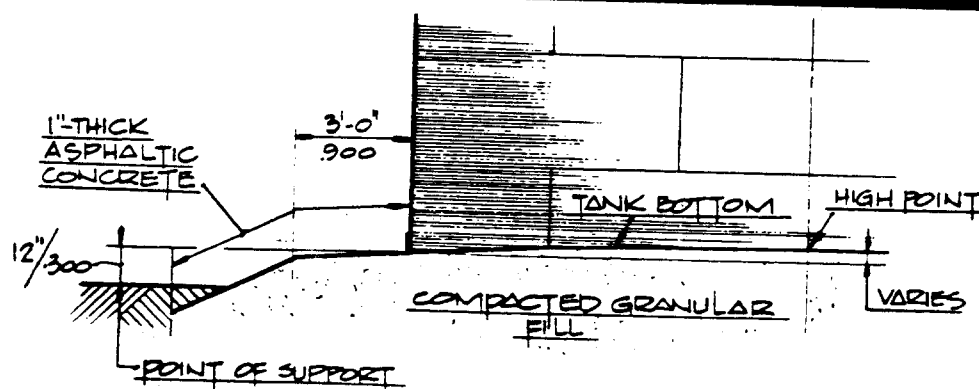


EXHIBIT 15-31
Low-Temperature
Tank Foundation with
Elevated Concrete Base

tion is shown in Exhibit 15-32. This design has an embedded heating element for use during possibly damaging spills. Consultation with civil engineers before any tank layout is undertaken is necessary to effectively use each design.

To establish the optimum location for pumps, consideration must be given to potential hazards and to

client preference. Exhibit 15-33 shows the pump located in the earthen diked area, surrounded by a curbed wall that is 15 to 18 in (0.380 to 0.460 m) high. This design protects the pump from minor spills within the dike and enables the discharge piping to exit the dike over the wall, thereby eliminating the need for dike-penetration seals. Piping outside the

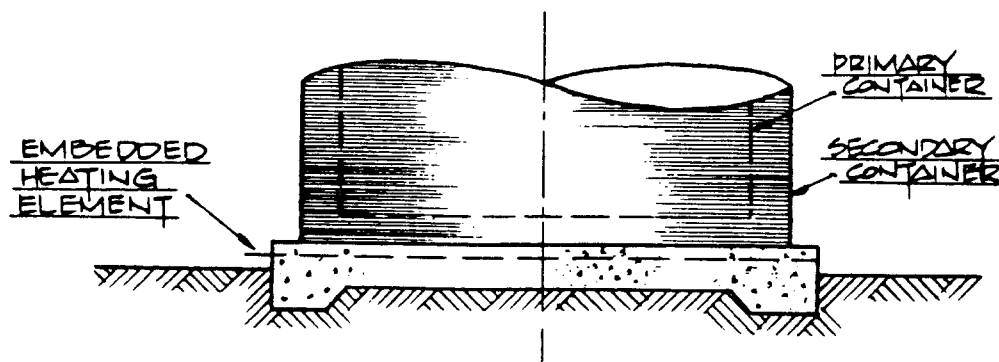


EXHIBIT 15-32
Low-Temperature
Tank Foundation with
Embedded Heating
Element

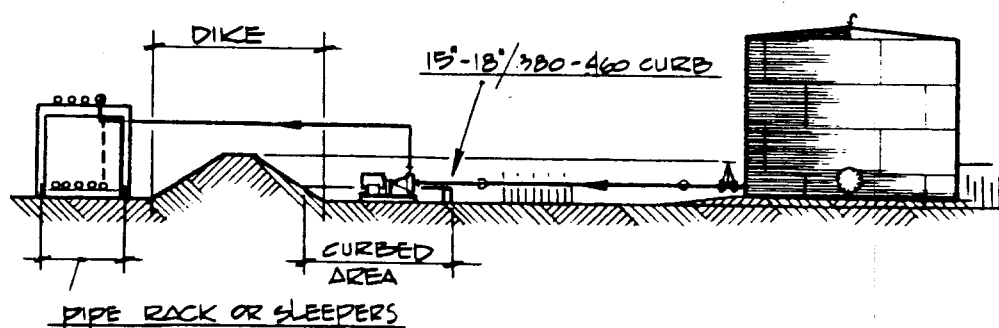


EXHIBIT 15-33
Pumps Inside Diked Area

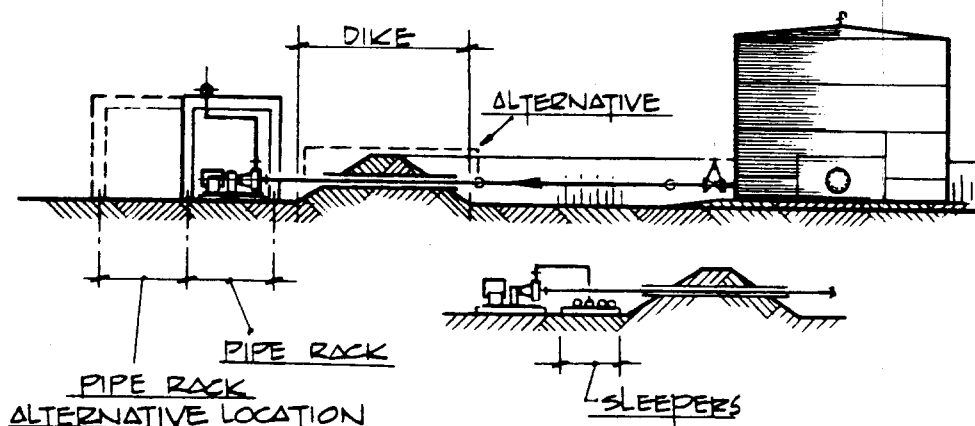


EXHIBIT 15-34
Pumps Outside Diked Area

dike may run on a pipe rack or sleepers.

Pumps located outside the dike are shown in Exhibit 15-34. Tank outlet piping can either penetrate the dike or pass over, as shown in this exhibit. The latter approach would usually be considered if the maximum dike height were 6 ft (1.83 m) and if the minimum liquid level in the tank would not cause damaging cavitation in the pump. The designer must carefully examine each layout before employing this design. The location of an elevated pipe rack or sleeper relative to the pumps should account for plant

maintenance philosophy. Sleepers permit unobstructed pump access when located between the pump and the dike wall. Pumps located under pipe racks support discharge piping but limit access to pumps during maintenance. Prime consideration should be given to providing an ample maintenance area around and above pumps.

Locating pumps inside a concrete diked wall is common in many process plants. The approach shown in Exhibit 15-35 shows the pump block set at the same elevation as the dike. With this configuration, the

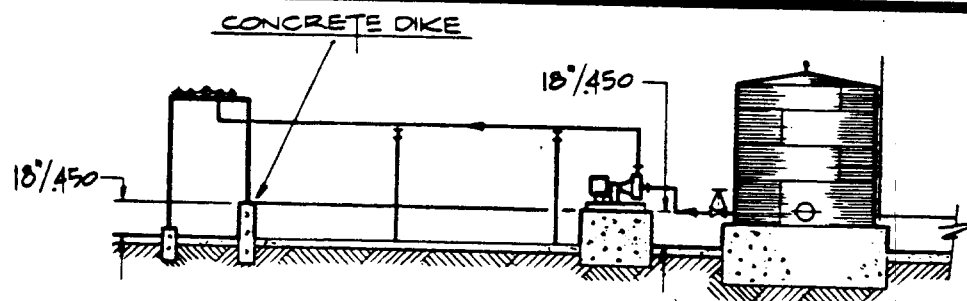


EXHIBIT 15-35
Pumps Inside Concrete
Diked Area

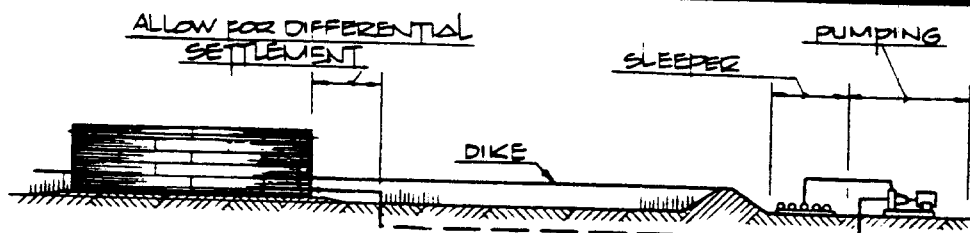
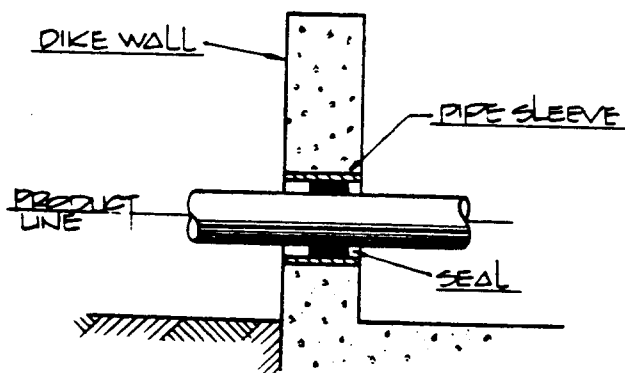


EXHIBIT 15-36
Buried Product-Transfer
Piping

EXHIBIT 15-37 Dike-Penetration Seal



pump would not be submersed during a spill inside the dike. This configuration enables a close-coupled piping arrangement. Providing for differential settlement allows the discharge line to be run to the pipe rack over the dike wall. This approach should be approved by the client.

An alternative arrangement in routing product lines to pumps from very large tanks is shown in Exhibit 15-36. With the pumps located outside the earthen dike, the transfer piping is routed underground after allowances are made for differential settlement. This approach reduces potential damage to suction lines when extremely large inventories are involved.

Lines penetrating concrete dike walls may be secured against leakage by using commonly available seals. The design shown in Exhibit 15-37 permits minor axial movement. The seal shown in Exhibit 15-38 is used when an insulated line runs through a larger

EXHIBIT 15-38
Flexible Dike Seal

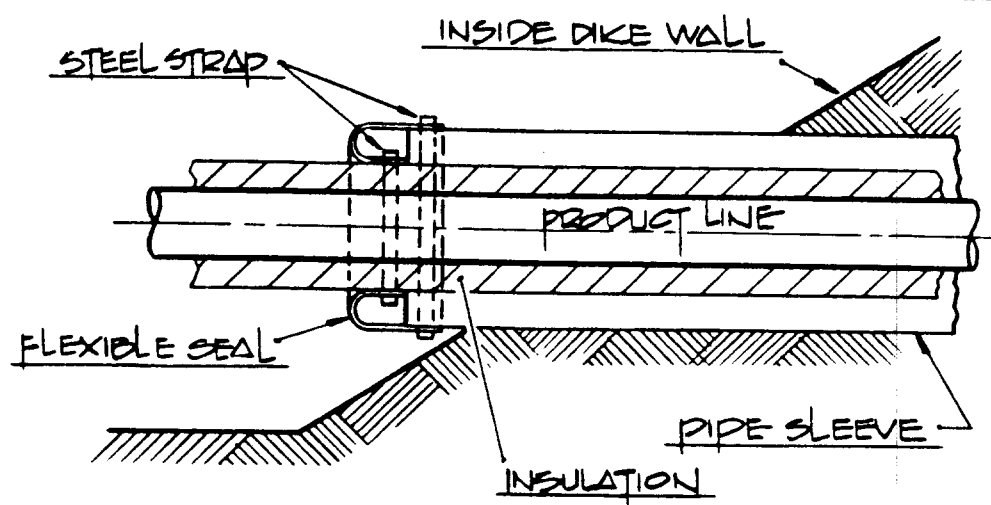
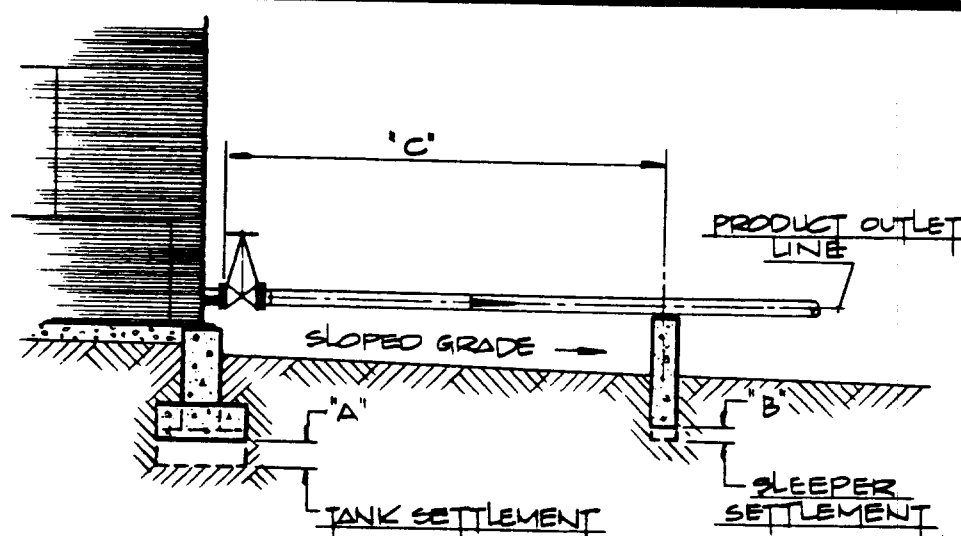


EXHIBIT 15-39
Differential Settlement



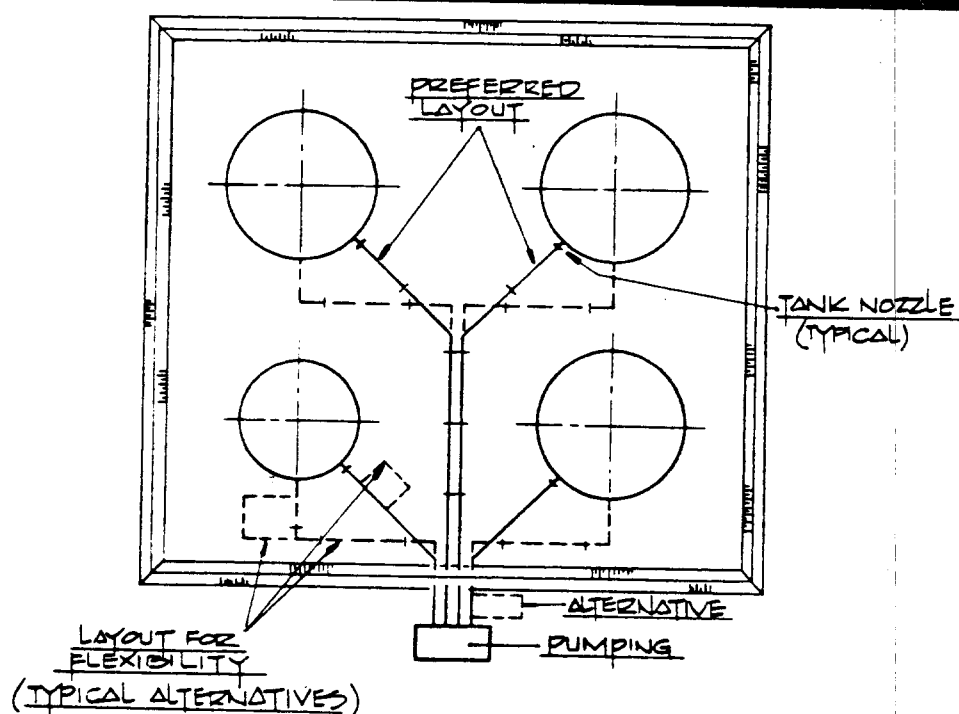
pipe sleeve that must be sealed on the inside of the dike. This design permits minor line movement. A stress or support engineer should be consulted when the designer is planning its application.

Differential settlement This concern must be addressed early in the layout of any process unit or tank farm. Exhibit 15-39 illustrates differential settlement. The foundation of any process facility will eventually settle or sink to some extent, depending on the weight it carries and the condition of the soil. To determine where pipes may be supported safely without imposing excessive stress on equipment nozzles, a civil engineer and soils experts must work together to determine how much the foundation is likely to settle. Subtracting sleeper settlement (distance B) from tank

settlement (distance A) yields the differential settlement between the two. By figuring line size, wall thickness, and allowable stresses, distance C can be established. Differential settlement can also be caused by tilting of the tank, by out-of-plane settlement, or by dishing of the tank bottom (which is a result of greater settlement at the center of the tank than at the edge).

The optimum piping arrangement in a tank farm, as elsewhere in a process facility, is the most direct route between two points, allowing for normal line expansion and stresses. Exhibit 15-40 illustrates piping between tanks and pumps. Anchor points, or places where piping movement is restricted, must be established. Tank nozzles are one such anchor point. The second anchor point may be the pump nozzle if line growth is permitted through the dike, or it may be

EXHIBIT 15-40
Alternative Piping
Layouts



anywhere along the piping within the dike or at the point of dike penetration. To minimize the potential for tank spills, expansion joints should not be used.

Exhibit 15-41 shows how to accommodate line expansion between tank nozzles and a manifold header. Expansion loops may be added at the sleeper level, as shown for lines A and B. Expansion may also be allowed for by running line C directly over the header, perpendicular to the portion of the line causing the expansion.

Exhibit 15-42 illustrates a cross section of piping, pumps, dikes, and a primary pipe way that is typical of what might be found in a tank farm. Because the primary pipe way is located to the left of the roadway, pump-discharge lines across the road must be routed to the headers in one of two ways: by burying them

under the road, making allowances for vehicular loads imposed on the pipe, or by placing them over the road on a pipe bridge. Client preference should be considered in this design. Adequate access to pumps on the side of the pipe way opposite the road must also be provided.

A bullet-tank piping layout is shown in Exhibit 15-43. Tanks are set at the lowest possible elevation to satisfy pump head requirements. A catwalk is located across all four tanks to provide sufficient access to operating valves and instruments. Liquid outlet piping to the pumps should allow for differential settlement and line flexibility. A fire water spray protection system for bullets is shown in Exhibit 13-36.

A typical piping arrangement for a high-pressure Hortonsphere is shown in Exhibit 15-44. Layout factors

EXHIBIT 15-41
Tank Piping Layout

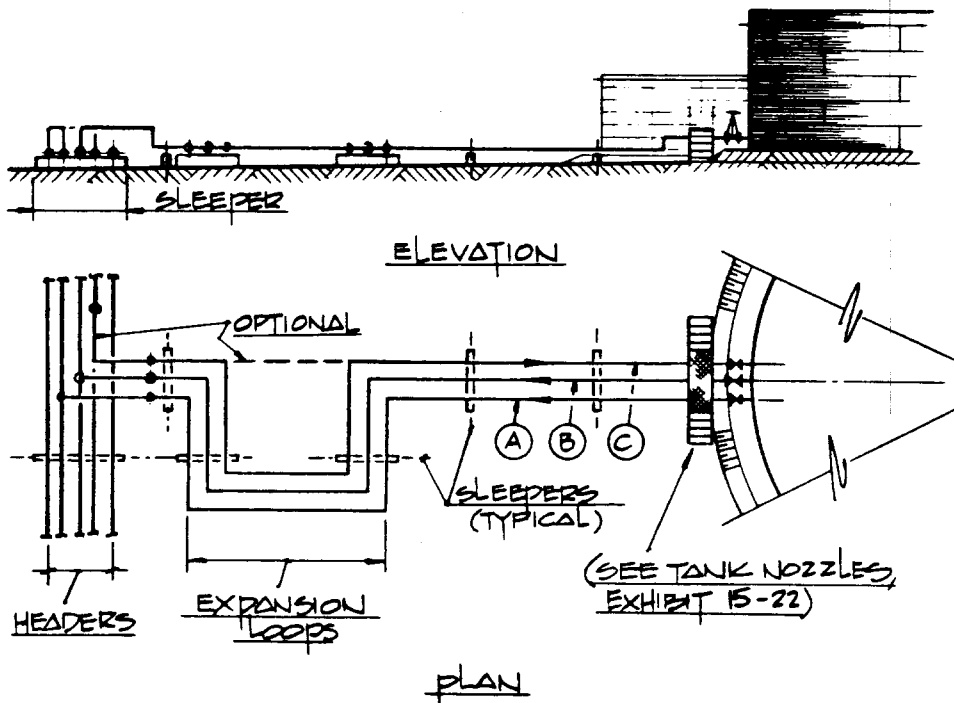
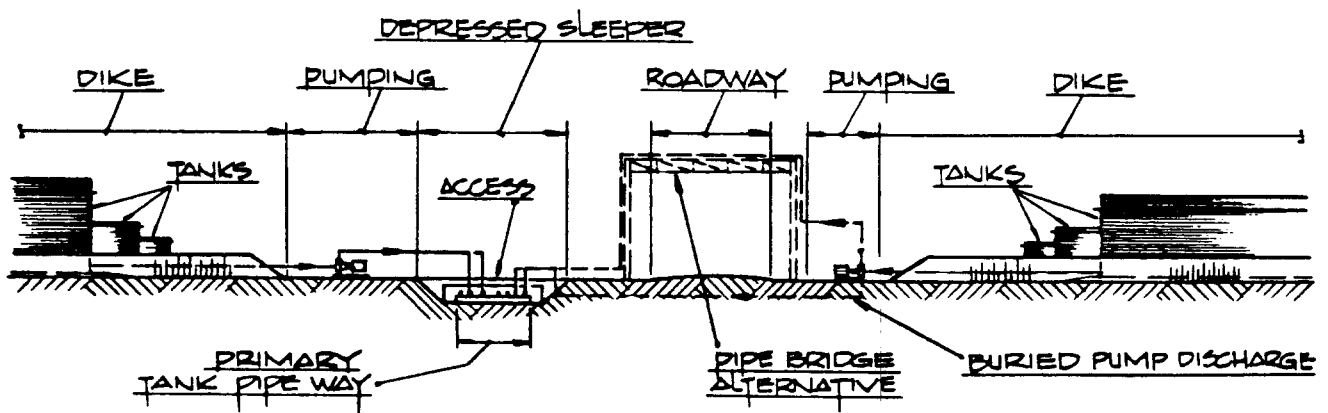


EXHIBIT 15-42 Cross Section of Pipe Way and Pumping



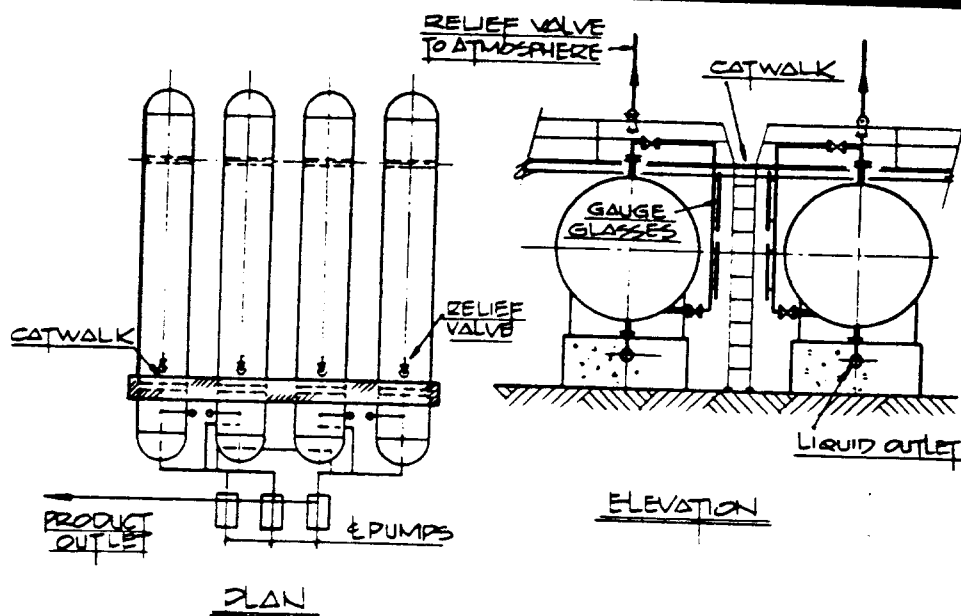


EXHIBIT 15-43
Bullet-Tank Piping
Layout

EXHIBIT 15-44 Hortonsphere Piping Layout

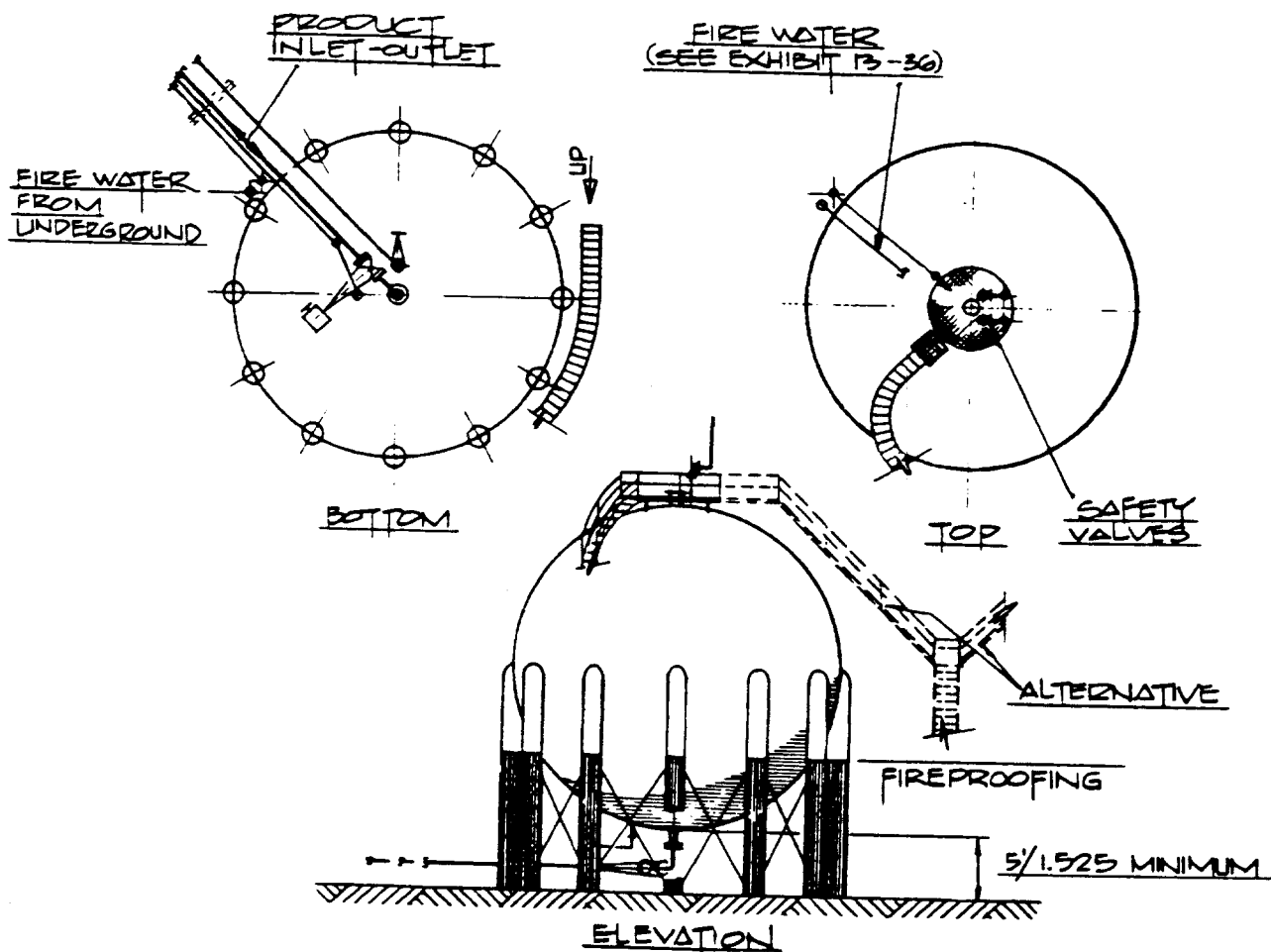
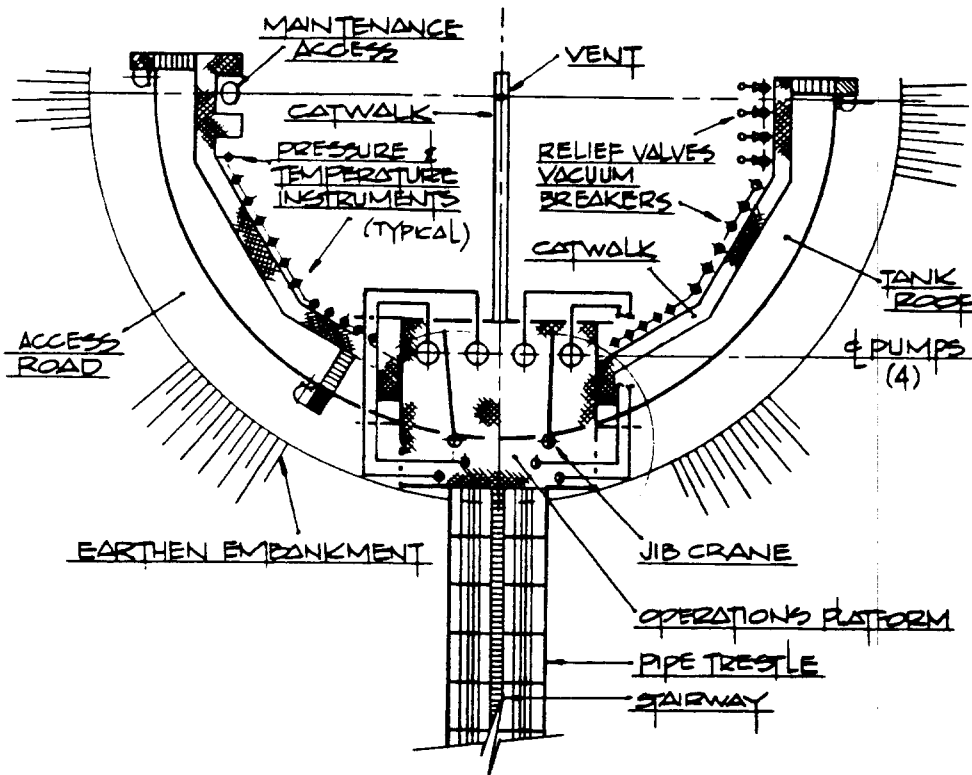


EXHIBIT 15-45
Liquefied Natural Gas
Tank Layout



for spheres include:

- Tank elevation should be kept low but not less than 5 ft (1.525 m) above grade.
- Ideally, each tank should have its own stairway—Exhibit 15-44 shows an acceptable alternative arrangement.
- Valves should be installed as close as possible to all nozzles.

Typical layouts of liquefied natural gas tanks in an earthen embankment are shown in Exhibits 15-45 and 15-46. Features of this arrangement include:

- The secondary containment is a steel-lined concrete structure.
- There is heavy cryogenic insulation between the primary and secondary containers.
- The earthen embankment provides an acceptable margin of safety in the event of tank failure.
- Submersible pumps are located at the bottom of the pump shaft.
- The roof is steel domed.
- The operations platform, piping, and jib crane are supported from the concrete containment wall.

The stairway on the pipe trestle provides access to

the operations platform and tank roof. Additional ladders are provided from the circular access road around the tank to the catwalk. This platform provides access to relief valves, vacuum breakers, maintenance access openings, and instruments.

If an above-grade, more conventional layout is preferred for liquefied natural gas tanks, a layout similar to that shown in Exhibit 15-47 may be used. NPSH requirements usually necessitate locating the pumps in a pit when the tank is above grade. A submersible pump and its motor are located within a containment vessel and supported on lugs. An adequate clear area directly over the pumps must be maintained to allow pump removal for maintenance. Motor-operated header valves are located at grade and made accessible by platforms. Individual suction and discharge valves are located near the nozzle connections in the pit. Safety requires that a water-deluge fire-fighting system be included in this layout as well as a sump and sump pump to remove unwanted water.

When high-pressure bullet tanks are located close to a process unit, a protection berm is often used (see Exhibit 15-48). Berm length is slightly longer than the width of the tank area, and the berm height is roughly equal to the height of the tanks. These berms offer some protection in the event of an explosion.

Although foam fire-fighting systems are often supplied by companies specializing in fire protection, a

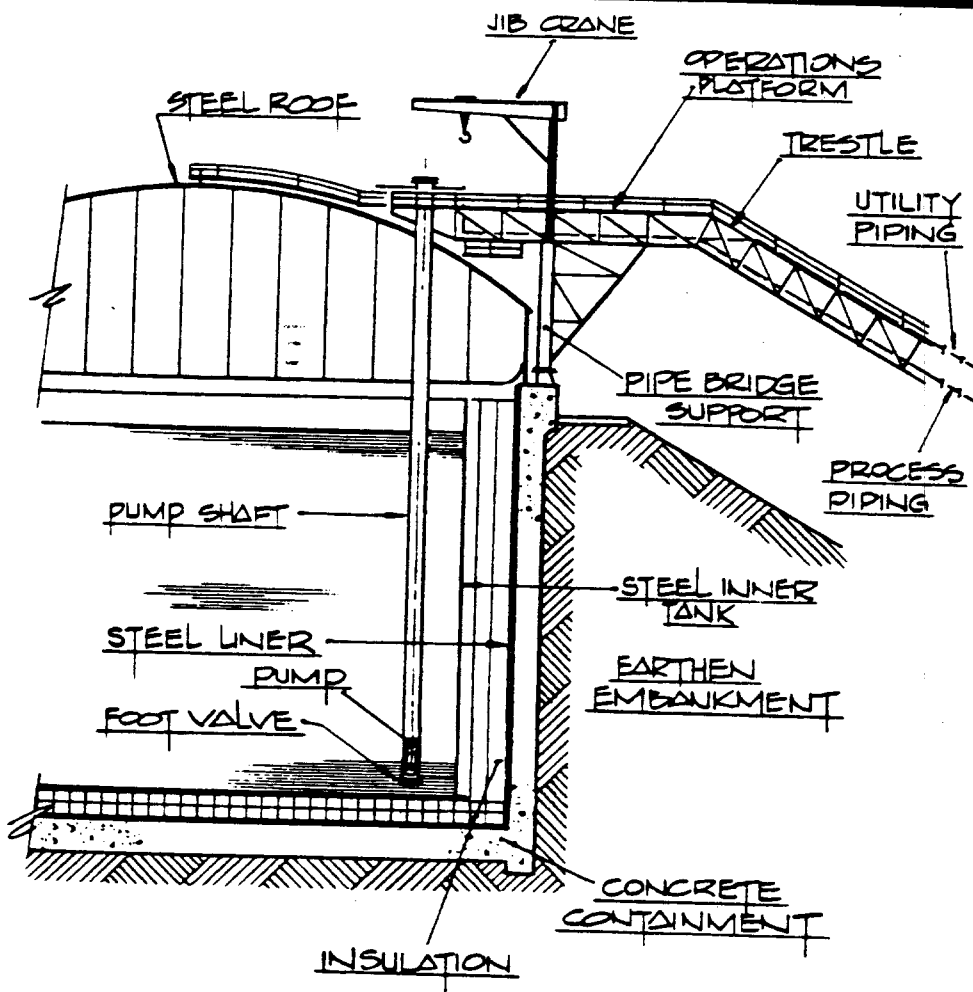


EXHIBIT 15-46
Liquefied Natural Gas
Tank

EXHIBIT 15-47
Above-Grade Liquefied
Natural Gas Tank Layout

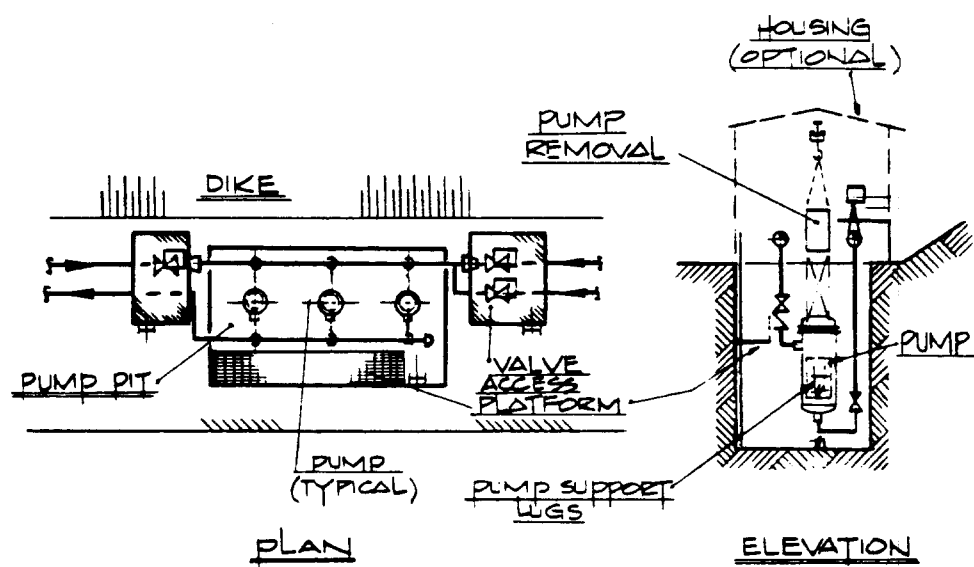
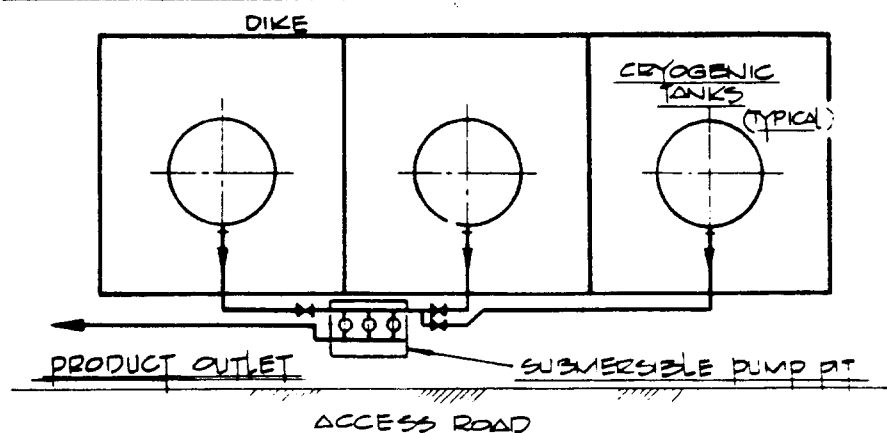


EXHIBIT 15-48
Protection Berm

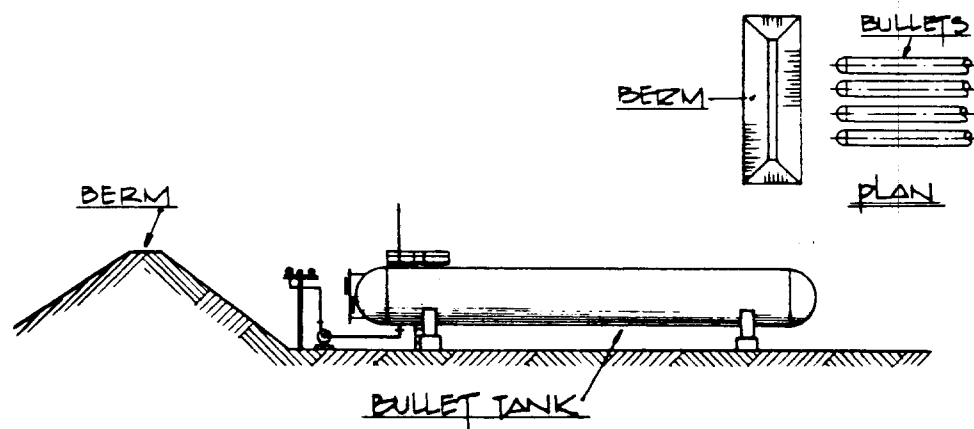
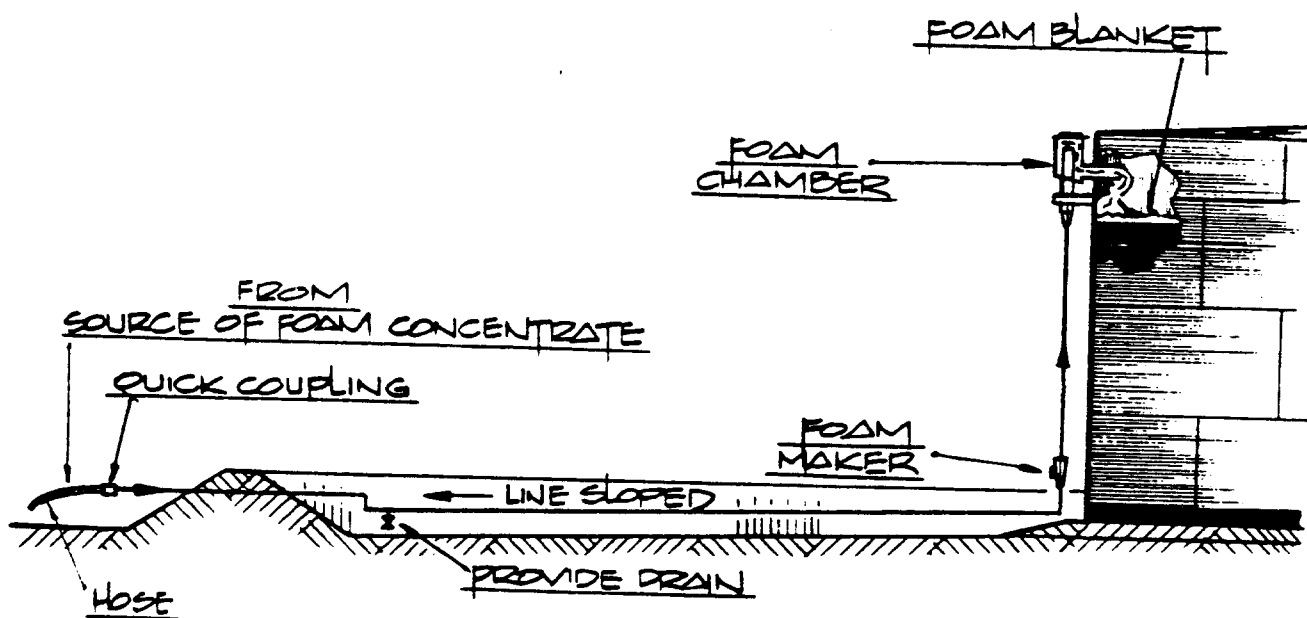


EXHIBIT 15-49 Foam Injection into Tanks



basic understanding of such systems is beneficial to a layout specialist. Exhibit 15-49 shows an arrangement in which foam concentrate is pumped with water from a truck to a storage tank. The piping usually has quick-connect coupling located outside the dike. The line is routed to the tank wall. A foam maker—which essentially consists of a pressure gauge, an air strainer, and a check valve—is located in the vertical riser. The foam solution enters a foam chamber located at the edge of the tank roof and then discharges across the top of the liquid in the tank.

Another way of injecting foam into a tank is shown in Exhibit 15-50. Foam concentrate from a truck or tank is supplied to a foam maker located outside the dike wall. The foam may be injected into the regular product transfer piping or routed directly to the stor-

age tank through a permanent line especially for that purpose.

An alternative to mobile fire-fighting equipment, permanent hydrants and monitors may be used for fighting fires in storage tank areas. Local codes and regulations as well as the latest issue of NFPA must be consulted to establish the appropriate coverage of water for a given layout. Exhibit 15-51 shows how fire hydrants and monitors may be arranged in a tank farm. The fire water piping around this area must come from two supply sources should any part of the system fail.

Exhibit 15-52 illustrates an effective overall layout of a process and off-site plot plan. The administration area is immediately inside the plant's main entrance, as are maintenance and fire-fighting equipment. Pro-

EXHIBIT 15-50
Semiportable Foam System

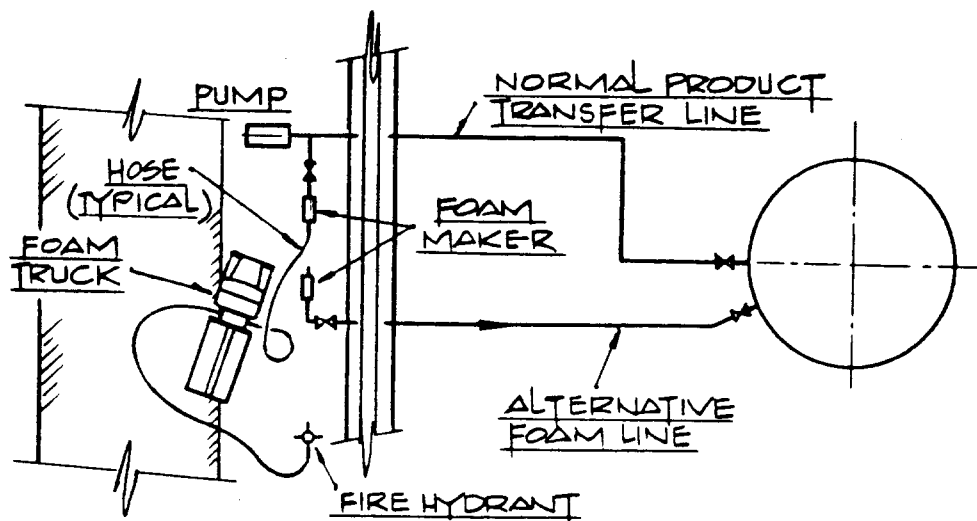


EXHIBIT 15-51
Tank Fire Water System

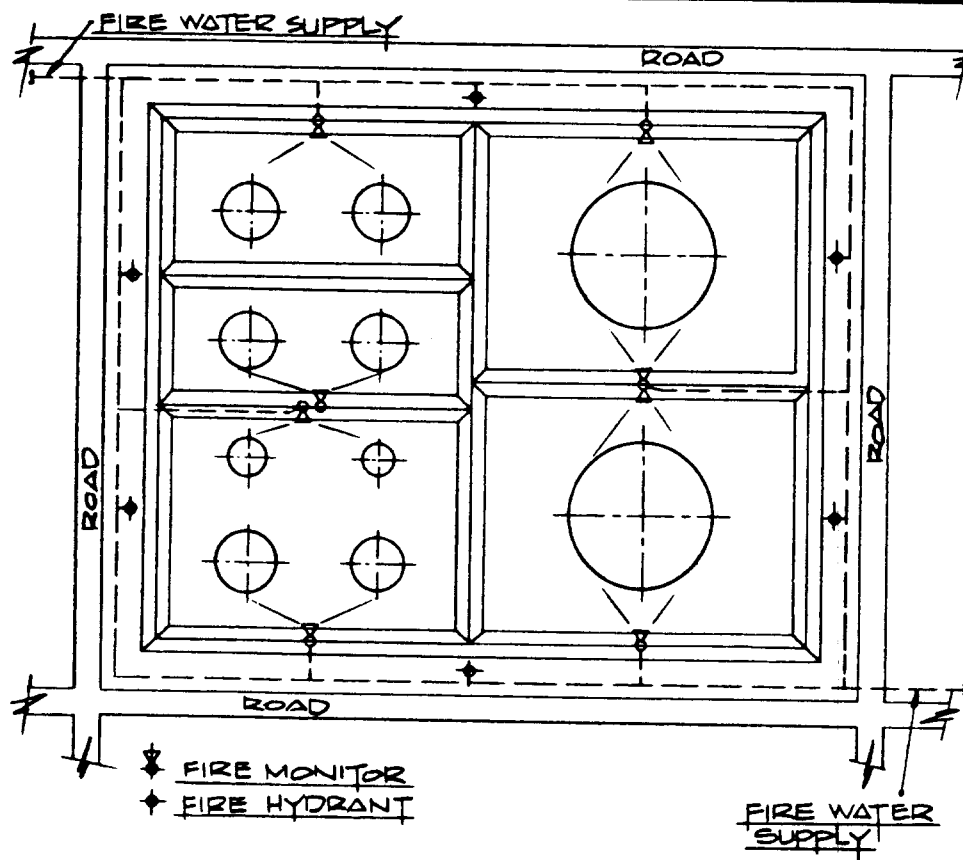
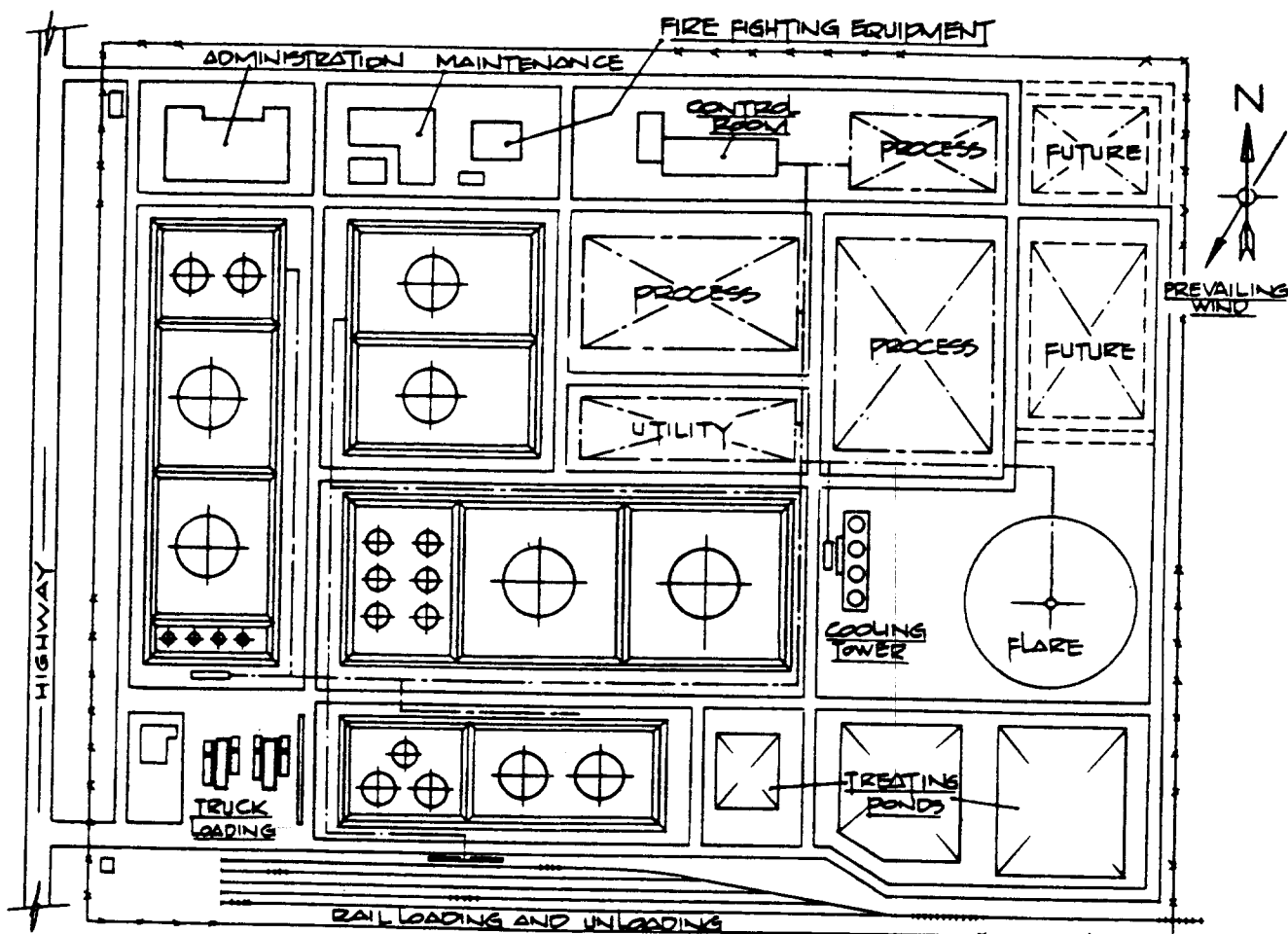


EXHIBIT 15-52 Overall Process and Off-Site Plot Plan



cess units and the utility plant are located in the central and eastern section of the plot, and allowances for future expansion are made. Storage tanks are located in the western and southern sections of the plot. Truck and rail loading and unloading areas are located together in the south and southwest corners of the plot. A flare stack, a cooling tower, and treating ponds are in the southeast corner.

Process units are located as far away as is practical from the storage tanks and product-loading areas. In cold climates, the wind will carry exhaust gases from

the cooling tower, across the storage tanks, and away from busy process units.

Tank farms can occupy vast areas of valuable real estate within a process facility. Development of the optimum design, considering all applicable codes and regulations, is achieved only through close attention to safety and economics. Although many solutions to layout problems are possible, a mixture of proven methods—along with the commonsense lessons of trial and error—will produce the optimum design.

Stress Analysis

INTRODUCTION TO PIPING STRESS

The impact of high piping stresses on operating piping systems can be dramatic and costly. Yet for many piping designers, piping stress analysis is the least-understood area of piping knowledge. A thoroughly analyzed plant will last longer and be more cost-effective. Neglecting the impact of the weight of pipe and the thermal expansion of hot pipe can cause significant maintenance problems. Some examples of typical maintenance problems due to high piping stress are the following:

- Pump bearings wearing out.
- Hairline cracks developing in vessel and nozzle junctions.
- Flanges leaking flammable liquids.
- Pipe permanently deforming.

The piping layout designer and the stress engineer must work together as a team during the design cycle. This team is critical to successful stress analysis. It is critical because the solution to many pipe stress problems is an adjustment of the pipe layout.

This chapter's purpose is to reduce the cycle time between the layout designer's proposed layout and the stress engineer's approved layout. This section will accomplish this goal by providing stress background and easily used stress analysis tools to the designer. Using these tools will assure the designer that his or her proposed layout will need little or no revision because of a stress engineer's comments.

We define *pipe stress* as the force per unit area applied to the cross-section of a piping component. Engineers typically express stress in pounds per square inch (psi). Many of the codes limit the design stress on carbon steel pipe to 20,000 psi or less. This limit is associated with stress due to pressure and weight. This allowable can change based on attached equipment, temperatures, load applications, and many other fac-

tors. Some allowable stresses expressed in this chapter are not addressed or defined by the code. Rather, we chose some of these lower limits to assure a high-quality, cost-effective, piping layout.

Before going further with stress analysis itself, let us first address the work process.

PIPE STRESS ANALYSIS WORK PROCESS

There are many steps in understanding how to lay out a plant with minimal piping stress revisions. The first step is to understand the work process on a project.

The steps the designer takes to assure quality stress analysis during the design of a petrochemical plant may vary. The steps vary with the size and complexity of the plant. Client requirements also can affect the work process. The process described in the following steps is a typical process for a plant design resulting in 3,000 isometrics. Other processes may work equally well.

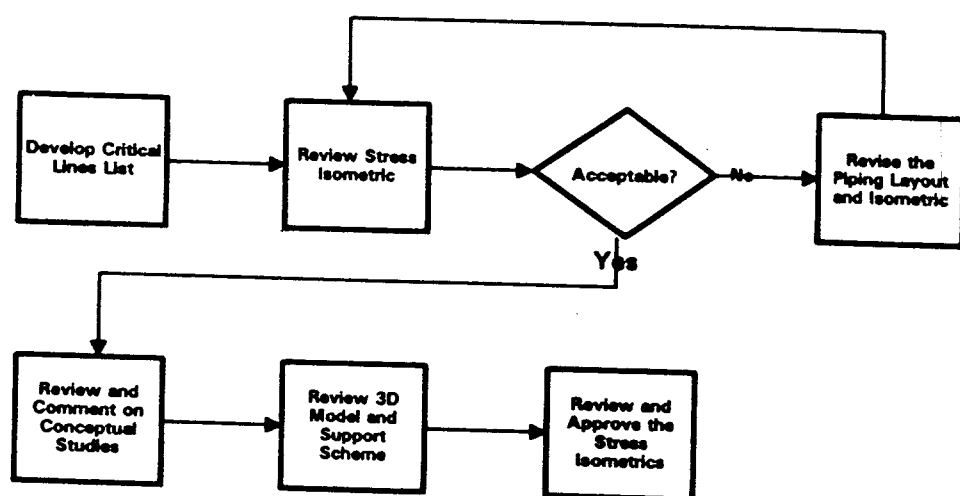
Critical Lines List

Exhibit 16-1 shows that the first step in the stress analysis work process is to identify the lines on the critical lines list. The critical lines list is a list of line numbers that are likely to receive formal calculations by the stress engineer. This list of lines is important to the designer. It identifies those lines that have the most potential for layout revision requests. The revision requests typically come from the stress engineer on the project. The designer will usually apply the techniques described later to the lines in the critical lines list.

The stress engineer normally supplies the critical lines list. At times the critical lines list is not available. The designer can then use the following tables as a guideline. There are two tables used for determining the critical lines. The designer uses the first table for lines attached to rotating equipment, such as pumps.

EXHIBIT 16-1 Pipe Stress Work Process Flow Diagram

Attachment A: Pipe Stress Work Process Flow Diagram



as shown in Exhibit 16-2. He uses the second table for all other lines as indicated in Exhibit 16-3. Because pumps are more sensitive to pipe loading than other equipment, pump lines are often more difficult to lay out. Many of the lines on a critical lines list will be pump suction and discharge lines.

To read the chart, the designer aligns the pipe size (not the nozzle size) and the upset line temperature. If the intersection of the two lines is not in the shaded area then the line is critical.

Stress Isometrics

The stress engineer uses the stress isometrics to serve as the basis for a formal calculation. The piping layout designer draws the preliminary isometrics as shown in exhibit 16.4.

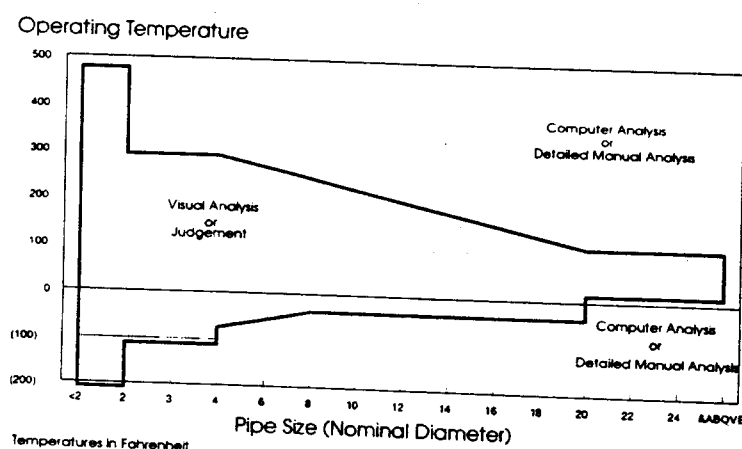
The creation of these isometrics is the step in the

work process that requires most of the designer's stress knowledge. A good layout at this stage reduces turnaround time between the stress group and the design group.

Analysis and Revision

The stress engineer will usually analyze critical lines with a computer. Over the last decade, the piping industry has made significant progress in computer-aided engineering (CAE) programs. The CAE programs have resulted in stress engineers analyzing increasing amounts of linear footage. Stress engineers are also performing more iterations of analysis on the same stress isometric. Lower costs in computer equipment and increasing hardware performance are the primary reasons for this increased level of analysis. What is the impact to the designer? The impact is more

EXHIBIT 16-2
Pipe Stress Review
Criteria Rotating
Equipment Piping



revisions to his or her original design as the stress engineer attempts to improve the computer results. This step in the work process requires close teamwork between the designer and the responsible area stress engineer.

Conceptual Studies

The piping layout designer will generate conceptual orthographic drawings (planning studies) based on good layout practice and the recommendations of the pipe stress engineer. The plant design supervisor circulates these documents to the other disciplines. The stress engineer will often write requests on this document for additional steel, additional nozzle reinforcement, critical pipe support locations, and other items. Refer to Exhibit 1-9 for an example of a "planning study." Feedback from the different engineering design groups concerning stress analysis requests may change the designer's piping layout.

Up to this point the stress engineer has reviewed

only the critical lines. The conceptual study contains layouts for noncritical as well as critical lines. Therefore, the layout designer may receive a stress engineer's feedback on the noncritical lines at this stage. The authors designed the tools given in this chapter to reduce this feedback to a minimum.

Three-Dimensional (3-D) Modeling

The 3-D designer builds the 3-D models based on the approved conceptual studies. The designer includes the pipe supports in the model. At this point, revisions to layout due to stress problems are unusual.

Isometric Extraction and Approval

Plant design extracts the isometrics from the 3-D electronic model automatically. The isometric checker reviews each isometric. The stress engineer then signs off on the isometric. The extracted isometric also includes pipe supports.

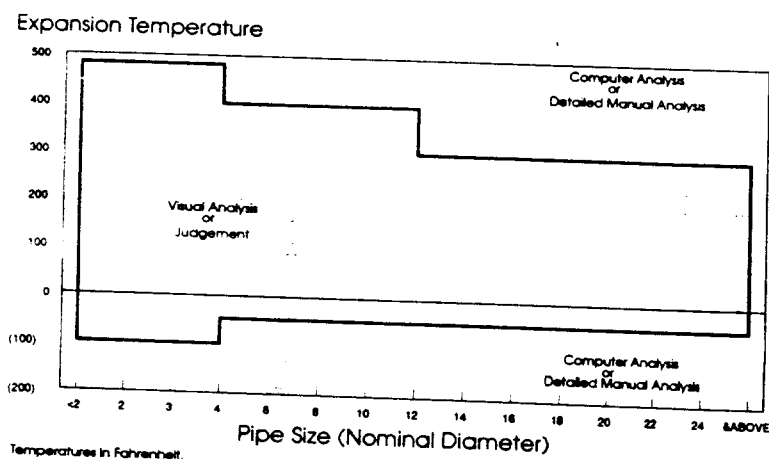


EXHIBIT 16-3
Pipe Stress Review
Criteria All Piping Except
Rotating Equipment
Piping

IMPACTS OF EXCESSIVE PIPE STRESS

We have discussed why stress analysis is important. We have also reviewed the work process steps the designer and the stress engineer take to accomplish a quality stress analysis. The next step is to address what the stress analyst specifically looks for when analyzing pipe. This section will provide the basis for understanding what stress analysis tools the layout designer should use when performing piping design.

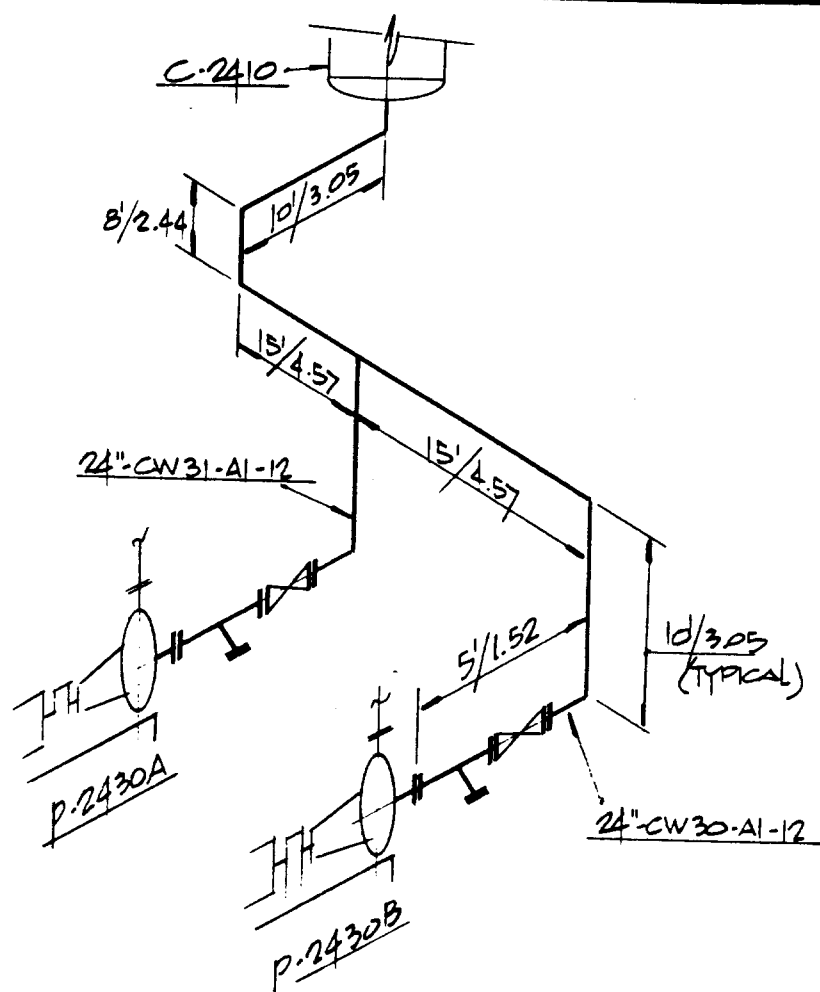
The following paragraphs discuss the three basic types of problems that the stress engineer faces. These three problems are overstressed piping components, overstressed vessel nozzles, and overloading the nozzles on mechanical equipment. There are a wide variety of other problems that the stress engineer addresses on a typical petrochemical project. However, these three types of problems are often the cause for piping layout revisions.

Overstressing Piping Components

The first item a stress engineer avoids is overstressing a piping component. Various forces act on a pipe from its own weight, thermal growth, wind, and other causes. As the forces are applied, the piping system begins to deflect or sag. The more forces, the more the pipe deflects. The greater the pipe deflection, the higher the stress becomes in the pipe material. Once the stress in the pipe reaches a maximum limit, the deflection becomes permanent. By "permanent deflection" we mean, when the cause of the deflection is removed, the pipe will not return to its original shape. The stress engineer calls this phenomenon yielding. This is what he seeks to avoid.

To avoid yielding a piping component during operation, the stress engineer manipulates the layout and the supporting scheme of the piping system. His goal is to keep the pipe stress below the limits described in the ANSI/ASME B31.3. Code. This is the code used for petrochemical projects in the United States.

EXHIBIT 16-4
Stress Isometrics



Overstressing Nozzles

The second type of problem the stress engineer seeks to avoid is overstressing vessel nozzles. The nozzle itself typically is not the problem. It is the junction between the nozzle and the vessel wall. As a pipe cycles

from cold to hot to cold again, it will push and pull on the nozzle. Many cycles of this force loading can cause cracking in the vessel wall. The reader can observe this type of failure when bending a paper clip. When the reader bends the paper clip the first time, the clip per-

manently deforms (yields) but does not break. Repeated bending of the paper clip will eventually crack and break it.

Impacting Mechanical Equipment

For this section, we will define mechanical equipment as equipment that rotates or reciprocates. The most common example of this type of equipment on petrochemical projects is a centrifugal pump. The stress engineer's goal is to limit the amount of force the pipe pushes on the mechanical equipment nozzle. When a piping system pushes a pump nozzle, the force deflects the linkage between the pump and the pump motor. Excessive deflection (misalignment) of this linkage causes rapid wear of the bearings and other parts of the pump. This extra wear results in extra maintenance effort on the pump.

Who defines what an excessive force on a mechanical equipment nozzle really is? Typically, the manufacturer lists allowable loads for his piece of equipment. In some cases, the vendors build the equipment to a standard specification. An example is the API610 specification for centrifugal pumps. In these cases, the standard specification defines the allowables.

These allowable forces on mechanical equipment nozzles often result in an equivalent pipe stress that is small. This equivalent pipe stress is typically a small portion of the allowable stress for the pipe. Therefore, it is sometimes difficult to achieve a piping layout that will satisfy the manufacturer's maximum allowable forces on a nozzle. The stress engineer on a typical Petrochemical project spends much of his time on solving this type of problem.

CAUSES OF PIPE STRESS

There are many causes of pipe stress in a piping system. The two most common causes are weight and

thermal causes. These two causes are also the most common reason for loads on equipment nozzles.

Weight

Weight causes the pipe to sag, which puts stress into the piping material and forces onto equipment nozzles. Proper spacing and design of supports, and careful attention to concentrated loads can take care of most weight problems.

Thermal

When a piece of pipe gets hot, it grows. The pipe itself physically becomes longer as the temperature of the pipe material gets hotter. As the pipe grows it pushes against the nozzles and supports that restrain it from moving. With an improperly stress-analyzed system, this "pushing" will cause pump bearings to wear out quicker, vessel nozzles to leak, and perhaps even the pipe or vessels themselves to rupture. Also, the restraint of this growth causes the pipe to deflect in directions different from an unrestrained pipe. This "unnatural" deflection causes additional stress in the pipe.

Other

The first two types of pipe stress problems cause most of the pipe stress effort. However, there are other causes. The following paragraphs list some of these.

Wind pushing on a pipe can exert large forces on a piping system. Exhibit 16-5 shows the approximate forces exerted on different pipe sizes 100 ft above ground during a hurricane force wind of 75 miles per hour (mph).

These loads increase with higher elevations of pipe and with insulated pipe. The Code requires that the designer considers the wind in the design of piping systems. Wind loading that reaches 70 mph is not un-

EXHIBIT 16-5 Wind Force on Pipe

NOMINAL DIAMETER WIND FORCE LB/LIN IN	2	3	4	6	8	10	12	14	16	18	20	24
	0.08	0.12	0.16	0.22	0.29	0.36	0.43	0.47	0.55	0.60	0.68	0.81

usual. Piping guides and anchors resist the wind loading on the piping system.

The petrochemical piping codes require that the designer considers the loads due to earthquakes. The Code allows a simplified version of seismic analysis for petrochemical plants, otherwise known as a static analysis. For areas of high earthquake activity, static analysis usually results in lateral loads that are about a third of the piping system weight. Pipe support engineers design pipe anchors and guides to resist these forces.

There are some dynamic loads that a petrochemical stress engineer encounters regularly. Pulsation loading due to reciprocating compressors is a common stress concern. The back-and-forth motion of the compressor pistons compresses the gas. The compressor pushes the gas into the piping system in pulses. The pulses usually happen around six times a second. This means that the pulsing frequency is six pulses per second. As a tuning fork has a natural vibrating frequency, every piping system has a natural vibrating frequency. If the piping system natural frequency is the same as the compressor pulsing frequency, large piping deflections occur. The stress engineer strives to make the piping system frequency different from the compressor pulsing frequency by adding and subtracting supports.

LAYOUT SOLUTIONS FOR WEIGHT STRESS

Pipe stress engineers can resolve most weight stress problems by the addition of pipe supports. For the piping layout designer, this solution may change the

routing of the piping system. Layout problems due to weight stress typically arise for piping systems that the designer has elevated. The pipe stress engineer can easily support systems that are close to the ground by using foundations or paving. When the piping layout is higher than 6 ft, the stress engineer usually supports from existing structures. Therefore, the layout designer must route the piping system close to these structures. Except piperacks, a designer will want to avoid a situation in which construction would have to build a structure to support one or two lines.

So, how often does a designer have to provide pipe support access to an existing structure? What is the allowable span for piping systems? The answers to these questions depend on the way the designer routes the system, the size of the pipe, the contents of the pipe, the pipe material, the temperature of the pipe, the insulation on the pipe, what the pipe connects to, and several other factors.

For our purposes here, we will make conservative assumptions about many of these variables. Let us focus on the different types of pipe routing and the impact different pipe sizes have on the span. The designer will use different piping spans for each size of pipe for three basic types of pipe routing. These three types of routing are piperack spans, branch spans, and unsupported overhang spans.

Piperack Pipe Allowable Spans

The first type of pipe routing typically encountered is pipe that is "continuously supported." This is the type of routing associated with pipes in a piperack. By con-

tinuously supported, we mean there are at least two identically supported spans on either side of the span in question as shown in Exhibit 16-6.

This type of routing provides a balance in loading on either side of the support point. This allows a greater span than what the designer will observe with "free-to-rotate" end conditions. Exhibit 16-7 gives the allowable spans for the continuously supported pipe routing situation. We should note here that although we have used the piperack routing as a typical example, the designer usually spaces piperacks at 20 ft or 25 ft between bents. This is partly to accommodate the

smallest diameter of piping typically allowed in a rack, which is 2 inches.

For example, for a 6-inch diameter pipe that fits within the parameters defined in notes 1 and 2 in Exhibit 16-7, the allowable span is 44 ft.

Branch Pipe Allowable Spans

The second type of pipe routing that affects the allowable span is pipe that is "simply supported." This is the type of routing associated with branch lines coming out of a piperack. What this means is that either end of the span in question is free enough to rotate slightly about the support point. There is no span on the other side of the support to hold the end of the span from rotating.

This situation makes the end conditions of the span "free." Therefore, it makes the allowable span for branches smaller than the allowable span for piperacks. In Exhibit 16-8, you can see that the simple span does not have completely free ends. The span has an elbow for each end. The vertical piece of pipe at each end acts as a support. However, an elbow has much more flexibility than a straight piece of pipe. Therefore, the designer can consider the elbow as a hinge. This makes this span simply supported.

Exhibit 16-9 gives the allowable span for branches.

For example, for a 10-in diameter pipe that fits within the parameters defined in notes 1 through 4 in Exhibit 16-9, the allowable span is 40 ft.

Unsupported Overhang Allowable Spans

The third type of routing that impacts the allowable spans is "unsupported overhangs." This is the type of routing a designer sees at turning points of piperacks. The supported piping has different lengths of pipe hanging over the last support beam. The pipe then turns up or down and then travels at a right angle to the next support as shown in Exhibit 16-10.

In this case, one end of two connected straight spans of pipe is not supported. Where the line turns up or down, there is no support. Note that the end of

EXHIBIT 16-6 Continuously Supported Spans

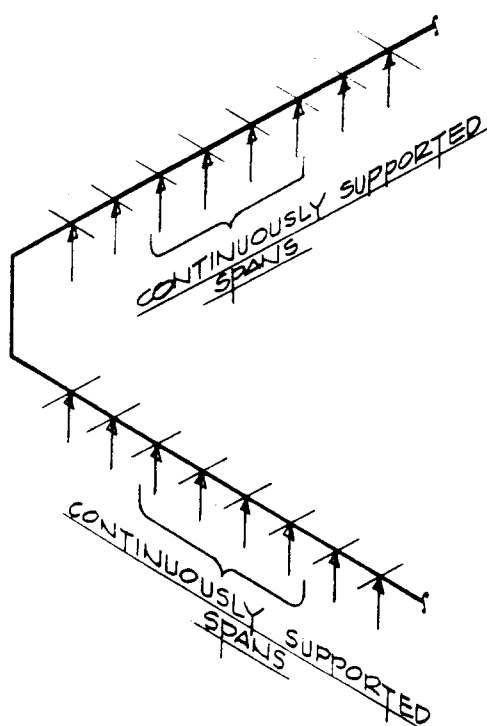


EXHIBIT 16-7 Allowable Spans for Continuously Supported Pipe Routing

MAXIMUM ALLOWABLE SPAN IN A PIPEWAY*

PIPE SIZE	2	3	4	6	8	10	12	14	16	18	20	24
SPAN (FT)	25	30	36	44	48	55	56	57	59	61	66	70

1. Calculations of pipe spans are based on the following:
2" through 6" pipes, Wall Thickness Schedule 40
8" through 12" pipes, Wall Thickness Schedule 30
14" through 24" pipes, Wall Thickness Schedule 20
2. The table assumes that pipes are filled with water and insulated for 450° F.
3. The spans in the table above are limited by longitudinal bending stress of $\leq 9,000$ psi and by acceptable pipe deflection between supports determined from past experience.
4. Supporting of the end span of a continuous run of pipe in the main pipeway shall be given special consideration.

* NOTE: Normal spans for general pipeway design shall be within 20' to 25'.

the overhang is free to rotate *and* deflect. This type of routing is acceptable, but the allowable span for each overhang is smaller than both the simply and continuously supported spans described earlier.

The designer will use a graph to determine the allowable span for unsupported overhangs. This is because the allowable span for one overhang changes with the span of the attached overhang. The two overhangs impact each other.

For example, for a 6-in diameter pipe that fits within the parameters defined in the notes in Exhibit 16-11, the allowable A span is 18 ft when the allowable B span is 13 ft. A "B" span greater than 13' would require additional support.

Breaking Up a System into Its Spans

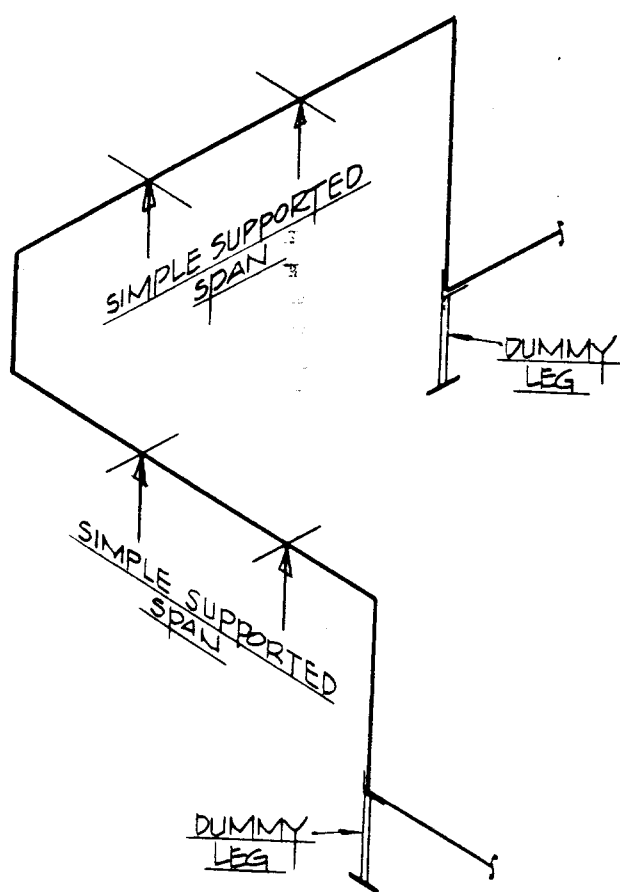
The designer can break up most piping systems into one of the three different span types. Exhibit 16-12 gives an example of this.

Once the designer has identified the system as a collection of one or more of these three types of routing, then it is a simple matter for him or her to apply the correct table and determine the location of the support points. Once the designer has the support points determined, he or she has the responsibility to make sure that there is a structure available for the support to use.

Other Weight Stress Problems

So far when determining the span, we have only considered the pipe stress due to the pipe weight. There are two other points a designer also should consider: first, the significant effect concentrated weights such as valves and pipe risers can have on auxiliary steel locations; and, second, the impact of large weight loads on equipment nozzles.

Solving concentrated weight problems A common problem facing a stress analyst is how to support con-

EXHIBIT 16-8**Simple Supported Span**

concentrated weights. We can define concentrated weights as a portion of the piping system that weighs significantly more per linear foot than the pipe itself. The most common example is a valve. Another example is a pipe riser. Stress analysts consider risers to be point loads. The designer should try to picture the piping system in a plan view. From the plan view, a pipe riser is a point load equal to the pounds per foot of pipe times the total length of the riser.

The usual support solution for concentrated loads is to provide a support as near to the concentrated load as possible. Therefore, the designer should try to provide "pups" or support access to the pipe near the location of concentrated loads as shown in Exhibit 16-13.

Weight on nozzles The allowable load on a nozzle varies with the type of equipment. Centrifugal pump nozzles are more sensitive to loads than vessel nozzles. Good general practice for a pipe designer is to provide a layout that will allow a stress analyst to reduce the load on a nozzle. On pumps this usually means an adjustable support within a few feet of the nozzle. Therefore, the designer must provide some room on the pipe free of fittings, drains, and instrumentation. The support designer will use this space to attach a support near the pump nozzle. The pipe support engineer does not typically provide maintenance supports during the pipe support design. However, there is an exception to this rule. Support designers normally provide an adjustable support next to the centrifugal pump nozzles. As described earlier, the piping layout should provide for a pipe support attachment near the nozzle. Exhibit 16-14 shows a recommended routing for a vertical discharge pump.

LAYOUT SOLUTIONS FOR THERMAL LOADS

There are many challenges a designer faces when laying out a piping system. One of the biggest challenges is to develop a layout that will satisfy the requirements for acceptable thermal loads on equipment nozzles. The following section will try to give the designer the tools and skills necessary to accept this challenge. This section first shows the designer how to calculate the amount of axial thermal growth on any straight piece of pipe. To satisfy the equipment nozzle allowables, the designer can then go to nomographs. The nomo-

EXHIBIT 16-9 Allowable Spans for Branch Lines

MAXIMUM ALLOWABLE SPANS FOR BRANCH LINES

PIPE SIZE	¾	1	1½	2	3	4	6	8	10	12	14	16	18	20	24
SPAN (FT)	10	13	17	20	25	30	35	35	40	40	45	45	45	50	50

1. Calculations of pipe spans are based on the following:
2" through 6" pipes, Wall Thickness Schedule 40
8" through 12" pipes, Wall Thickness Schedule 30
14" through 24" pipes, Wall Thickness Schedule 20
2. The table assumes that pipes are filled with water and insulated for 450° F.
3. The spans in the table above are limited by longitudinal bending stress of $\leq 9,000$ psi and by acceptable pipe deflection between supports determined from past experience.
4. Supporting of the end span of a continuous run of pipe in the main pipeway shall be given special consideration.

graphs will determine how long the other pieces of pipe in the system need to be.

Determining the Thermal Growth of a Pipe

The first step is to determine the amount of pipe growth in a given direction for a piping system. This calculation is in two parts. First, determine the temperature to use. Second, determine the overall growth between the anchors for each global direction (north-south, east-west, and up-down).

Temperatures to use Choosing the correct temperature is critical to successful stress analysis. For preliminary layout purposes, the designer should use the operating temperature for piping attached to rotating equipment nozzles. For other piping systems, the designer should use the maximum upset temperature.

Unfortunately, the documentation of all temperature cases is not always available at the preliminary piping layout stage. If this is the case, use the temperature shown on the process flow diagrams. Typically, the design temperatures shown on pieces of equipment are too conservative for this effort.

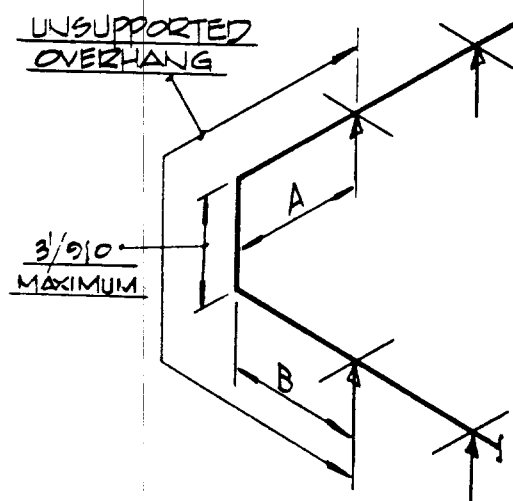
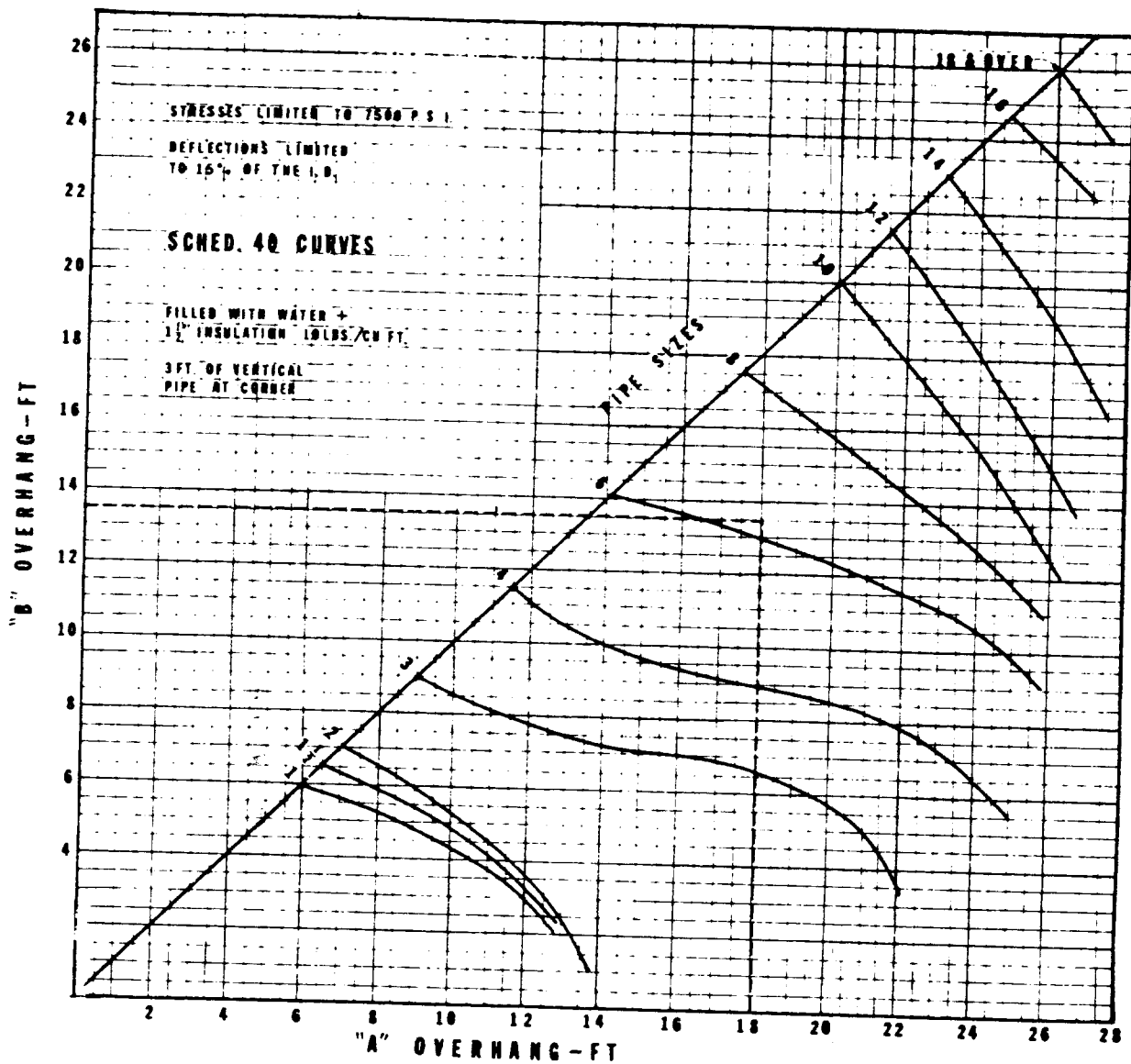
EXHIBIT 16-10 Unsupported Overhang

EXHIBIT 16-11

Unsupported Overhang Allowable Span



EFFECTIVE WT. - INCL. WATER & INSUL.

PIPE	LBS/FT	PIPE	LBS/FT	PIPE	LBS/FT
1"	2.97	6"	34.13	16"	165.0
1 1/2"	4.71	8"	53.51	18"	207.0
2"	6.37	10"	78.61	20"	250.3
3"	12.41	12"	106.6	24"	353.4
4"	18.26	14"	127.1		

NOTE

CURVES GIVE THE MAXIMUM ALLOWABLE OVERHANG OF AN UNSUPPORTED PIPE BEND FILLED WITH WATER & WITH 1 1/2" OF INSULATION.

IF GREATER OVERHANG IS UNAVOIDABLE, ADDITIONAL SUPPORT MUST BE ADDED.

OVERHANGS SHALL BE INVESTIGATED SEPARATELY FOR LINES SUBJECT TO VIBRATION FROM DYNAMIC LOADING.

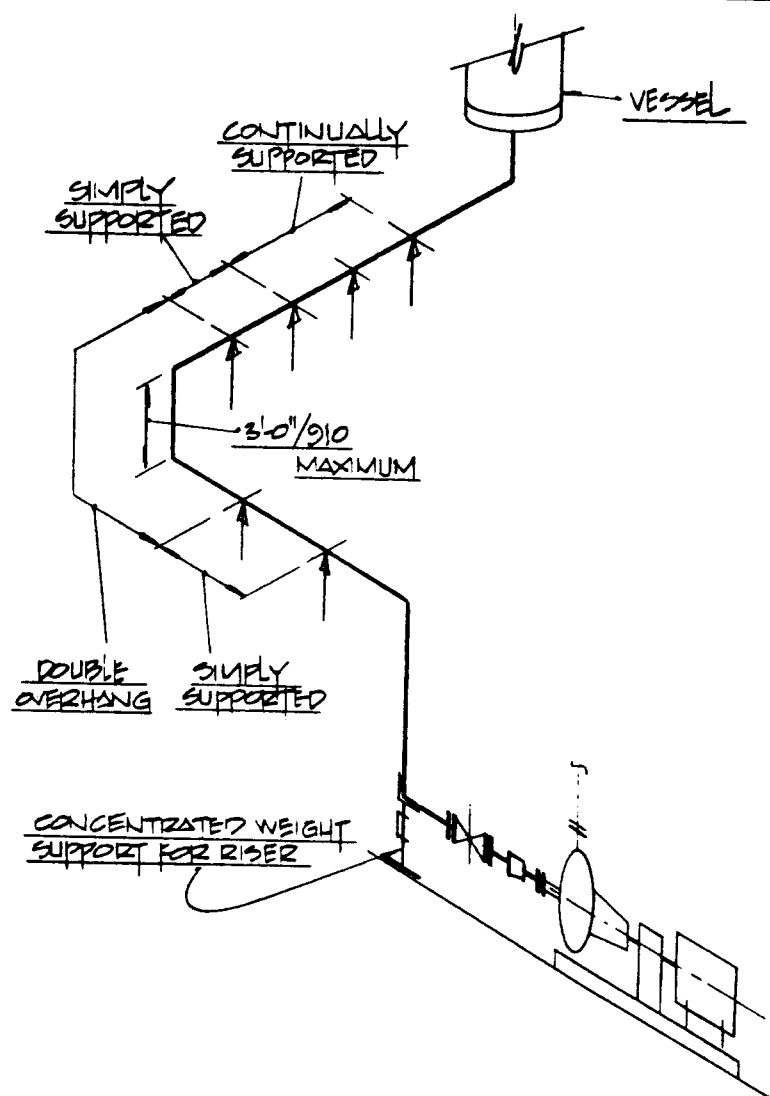
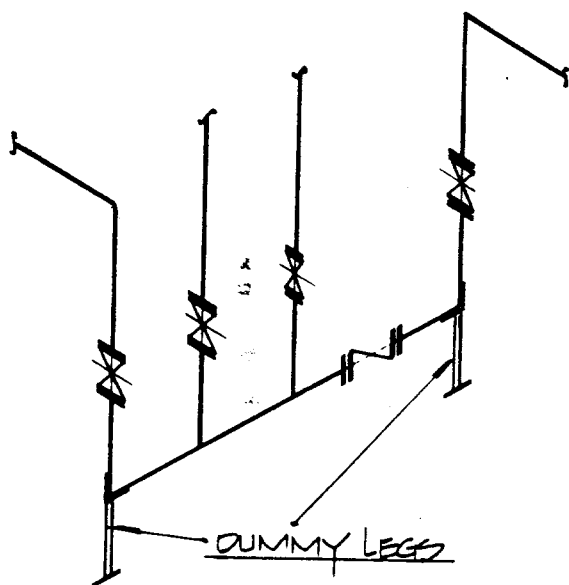


EXHIBIT 16-12
Piping System Showing
Three Different Span
Types

Growth charts Once the designer determines the temperature, he or she goes to the growth charts. The designer must know the temperature and the material of the pipe. With the temperature and the material the designer looks up the growth per 100 linear ft of pipe (reference Exhibit 16-15).

Checking the Piping Layout on Rotating Equipment

To determine the amount of leg needed to satisfy the pump nozzle allowables, the designer must first know

EXHIBIT 16-13 Supporting Concentrated Loads

the nozzle allowable loads. Once the designer knows the rotating equipment allowable loads, he can enter a nomograph and determine the amount of leg needed to satisfy the loads.

Rotating Equipment Nozzle Allowable Loads As discussed earlier, the designer should use the equipment manufacturer's published allowable loads. However, these loads may not be available at the "planning" stage of piping layout. For this example, we will make the following assumption. The maximum allowable force on steel rotating equipment nozzles is $(200 \text{ lb}) \times (\text{the nominal nozzle size})$. The maximum limit for the allowable load is 2,000 lb.

Example of Allowables Calculation

2-in, 300# RF, CS nozzle $200 \times 2 = 400 \text{ lb}$
 18-in, 150# RF, CS nozzle $200 \times 18 = 3,600 \text{ lb}$,
 exceeds the allowable limit. Use 2,000 lb.

The maximum allowable force on cast iron equipment nozzle is $(50 \text{ lb}) \times (\text{nominal nozzle size})$. The limit is 500 lb.

Example of Allowables Calculation

4-in, 125# FF, CI nozzle $50 \times 4 = 200 \text{ lb}$
 12 in, 250# FF, CI nozzle $50 \times 12 = 600 \text{ lb}$,
 exceeds the allowable limit. Use 500 lb.

Rotating Equipment Nozzle Example Calculation

This section describes how to determine the pipe length required for achieving a flexible pump layout. (Reference Exhibit 16-16 for example diagram.)

Step 1.0

Calculate the allowable force on the pump.

$(10\text{-in pump nozzle}) \times (200) = 2,000 \text{ lb maximum force allowed}$

Step 2.0

Calculate the expansion in the north-south direction. The 15 ft 6 in leg is the only run in the north-south direction. (Reference Exhibit 16-15 for thermal growth table.)

$(15 \text{ ft } 6 \text{ in}) \times (0.046) = 0.713 \text{ in expansion}$

Step 3.0

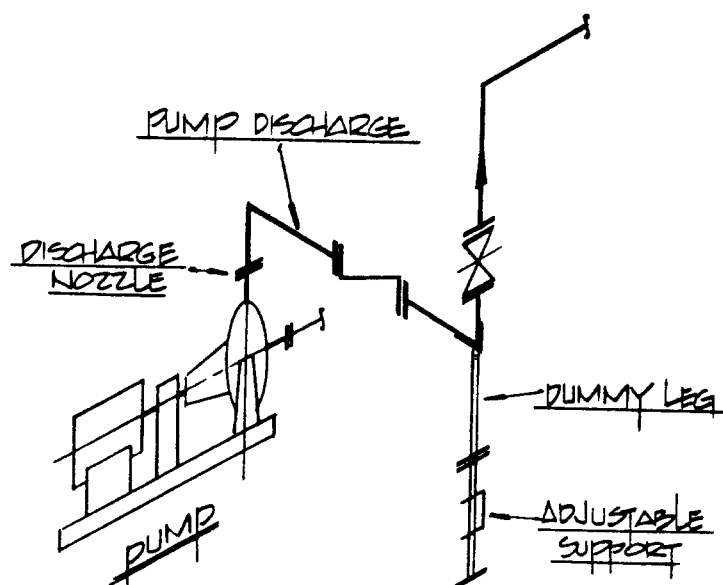
Calculate the total absorbing legs that are 90° to the 15 ft 6 in leg. These legs are the east-west leg (11 ft) plus the vertical leg (7 ft 3 in). Due to the rigid valves and nozzles in the system, neglect the 6'-8" vertical leg.

$\text{total available absorbing legs} = (11 \text{ ft}) + (7 \text{ ft } 3 \text{ in})$
 $= 18 \text{ ft } 3 \text{ in}$

Step 4.0

Apply the chart shown in exhibit 16-17 to determine if the absorbing leg required is less than the total available absorbing legs determined earlier. Refer to the circled numbers on the chart.

EXHIBIT 16-14
Pump Piping



Step 4.1

On the Force scale locate the maximum allowed force on pump nozzle: 2,000 lb. (point 4.1)

Step 4.2

On the Total Thermal Expansion scale locate expansion in inches: 0.713 in. (point 4.2)

Step 4.3

Draw a line from point 4.1 to point 4.2. Where this line crosses the Pivot Line, locate point 4.3.

Step 4.4

On the Nominal Pipe Diameter scale, locate the line size 12 in. When the schedule of the pipe is other than the standard weight, use the Pipe Moment of Inertia scale.

Step 4.5

Draw a line from Point 4.3 on the Pivot Line to point 4.4 on the Nominal Pipe Diameter scale. This locates point 4.5 on the Pipe Length scale. Read 23 ft on the Pipe Length scale as the *minimum required* absorbing pipe length.

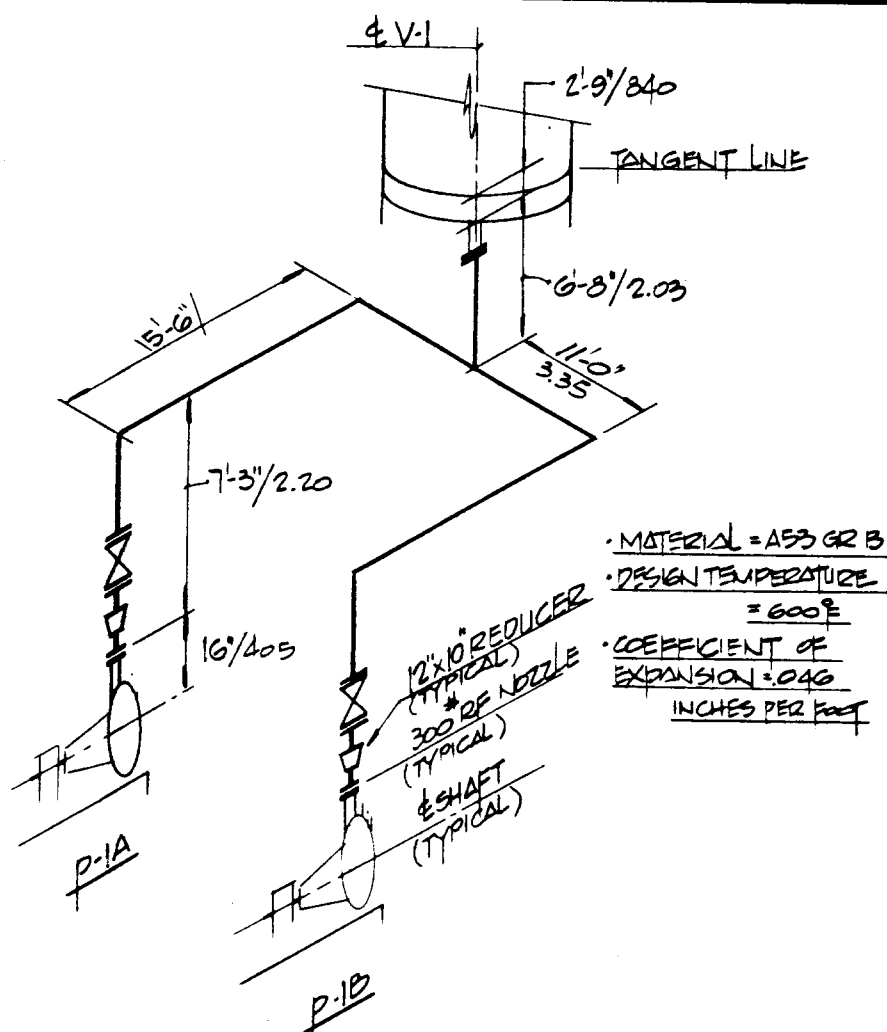
EXHIBIT 16-15 Thermal Growth Chart Table

Notes:

1. Carbon steel (C.S.) = Carbon-moly steels (through 3% Cr.)
2. Low chrome (L.Cr.) = Intermediate alloy steels (5% Cr. Mo. through 9% Cr. Mo.)
3. High chrome (H.Cr.) = Straight chromium stainless steels; 12% Cr., 17% Cr., and 27% Cr.

°F	C.S.	L.Cr.	H.Cr.	°F	C.S.	L.Cr.	H.Cr.
100	0.003	0.003	0.003	800	0.067	0.061	0.056
200	0.010	0.009	0.009	900	0.078	0.071	0.065
300	0.018	0.017	0.016	1,000	0.089	0.081	0.074
400	0.027	0.025	0.023	1,100	0.100	0.091	0.083
500	0.036	0.034	0.031	1,200	0.111	0.100	0.092
600	0.046	0.042	0.039	1,300	0.122	0.111	0.101
700	0.056	0.051	0.047	1,400	0.133	0.121	0.110

Inches of growth per linear foot.



Step 4.6

The available absorbing leg 18 ft 3 in (see step 3.0) is less than 23 ft. Therefore, the designer must add a minimum of 5 ft to the vertical or east-west direction. By adding this extra leg the designer will be within the maximum allowable force on the pump nozzle. The 6'-8' vertical leg previously neglected may be sufficient flexibility, despite the presence of rigid valves and nozzles.

Step 5.0

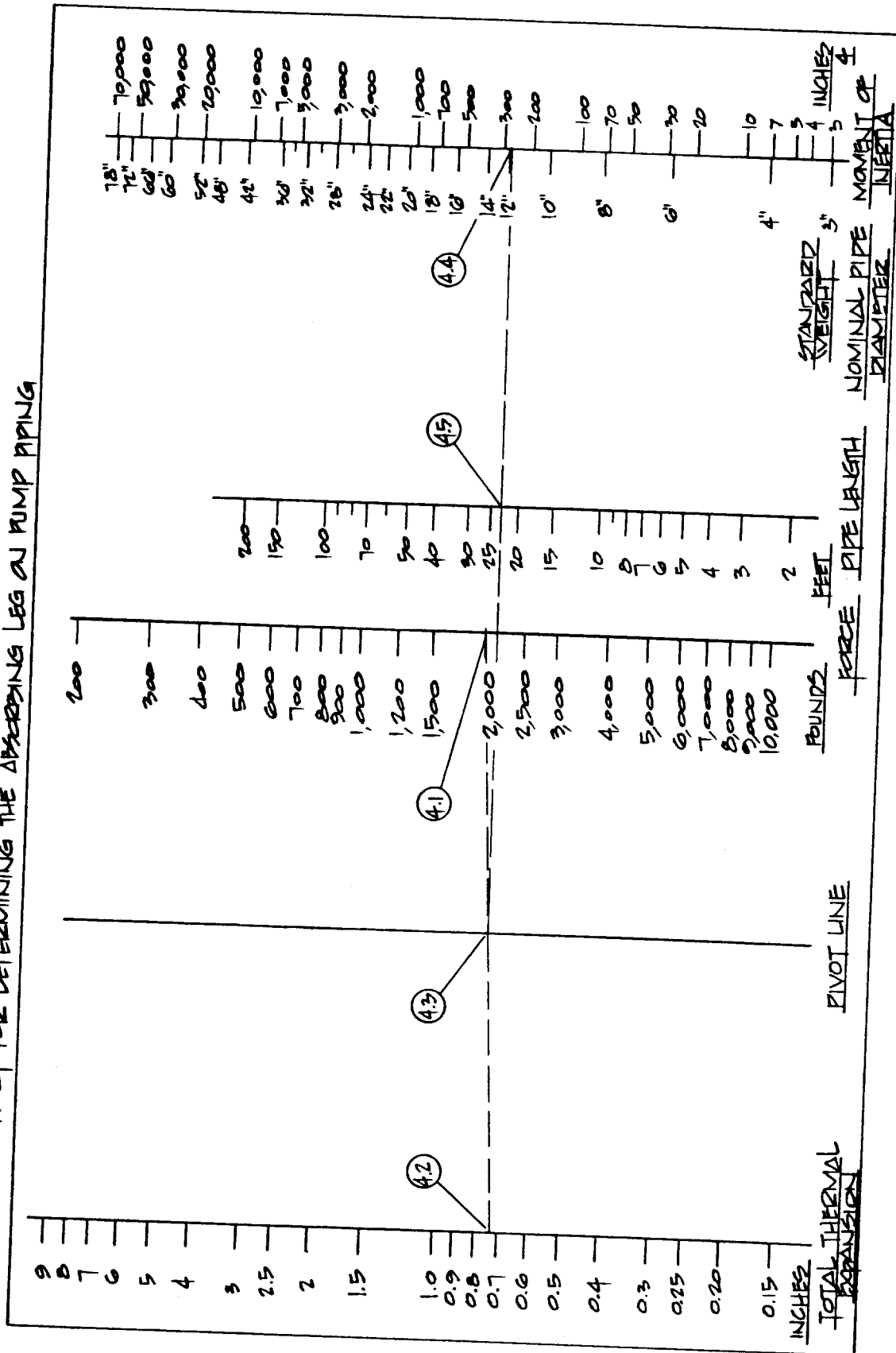
Calculate the absorbing leg required for the expansion leg in the east-west direction.

The 11 ft leg is the only run in the east-west direction: $(11 \text{ ft}) \times (0.046) = 0.506$ in expansion. Follow the procedure described in steps 3.0 and 4.0 to find the minimum required absorbing pipe length (21 ft).

EXHIBIT 16-17

Nomograph for Absorbing Leg on Pump Piping

CHART FOR DETERMINING THE ABSORBING LEG ON PUMP PIPING



Step 6.0

Calculate the absorbing leg required for the expansion leg in the vertical direction.

$$(2 \text{ ft } 9 \text{ in}) + (6 \text{ ft } 8 \text{ in}) + (7 \text{ ft } 3 \text{ in}) + (1 \text{ ft } 4 \text{ in}) \\ \times (0.046) = 0.828 \text{ ft}$$

Follow the procedure described in steps 3.0 and 4.0 to find the minimum required absorbing pipe length (25.0 ft).

Checking the Piping Layout on Other Equipment

To determine the amount of leg needed to satisfy the vessel nozzle allowables, the designer must first know the allowable vessel nozzle loads. Once the designer knows the allowable loads, he or she can enter a nomograph and determine the amount of leg needed to satisfy the loads.

Vessel equipment nozzle allowable loads The maximum allowable load on a nozzle of a vessel is expressed in stress. Earlier, we expressed the rotating equipment allowables in pounds. However, for this section it is useful to express vessel nozzle allowable in pounds per square inch or stress.

The maximum allowable stress on a steel equipment nozzle is 14,000 psi.

Vessel equipment nozzle example calculation This section describes how to determine the pipe length required for achieving a flexible piping layout that will have a minimum impact on the attached vessels. Reference Exhibit 16-18 for the example diagram.

Step 1.0

Determine the amount of expansion in the north-south direction. The distance to consider is from the anchored side of the exchanger to the centerline of the vertical vessel. Reference Exhibit 16-15 for the thermal growth table.

$$(10 \text{ ft}) \times (0.0065) + (20 \text{ ft} + 5 \text{ ft}) \times (0.003) + \\ (6 \text{ ft}) \times (0.0065) = 0.1790 \text{ in}$$

Step 2.0

Next, determine the length of the absorbing legs. The two legs 90° to the north-south expansion are the east-west leg (25 ft) plus the vertical legs (80 ft + 4 ft).

$$\text{total available absorbing legs} = (25 \text{ ft}) + (80 \text{ ft} + 4 \text{ ft}) = 109 \text{ ft}$$

Step 3.0

Given these numbers and the known allowable of 14,000 psi for vessel nozzles, we can now enter the nomograph shown in Exhibit 16-19 and determine if the available absorbing legs we summed earlier is sufficient.

Step 3.1

On the pipe stress scale locate the maximum allowable stress on the steel equipment: 14,000 psi (point 3.1).

Step 3.2

On the Total Thermal Expansion scale locate the expansion in inches: 0.179 in (point 3.2).

Step 3.3

Draw a line from point 3.1 to point 3.2. Where this line crosses the Pivot Line locate point 3.3.

Step 3.4

On the Nominal Pipe Diameter scale locate the line size: 30 in (point 3.4).

Step 3.5

Draw a line from point 3.3 on the Pivot Line to point 3.4 on the Nominal Pipe Diameter scale. This locates point 3.5 on the Pipe Length scale. Read 18 ft on the Pipe Length scale as the minimum required absorbing pipe length.

Step 4.0

Now we determine the amount of expansion in the east-west direction. The 18 ft leg is the only run in the east-west direction.

$$(25 \text{ ft}) \times (0.003) = 0.075 \text{ expansion. Say } - 0.1 \text{ in.}$$

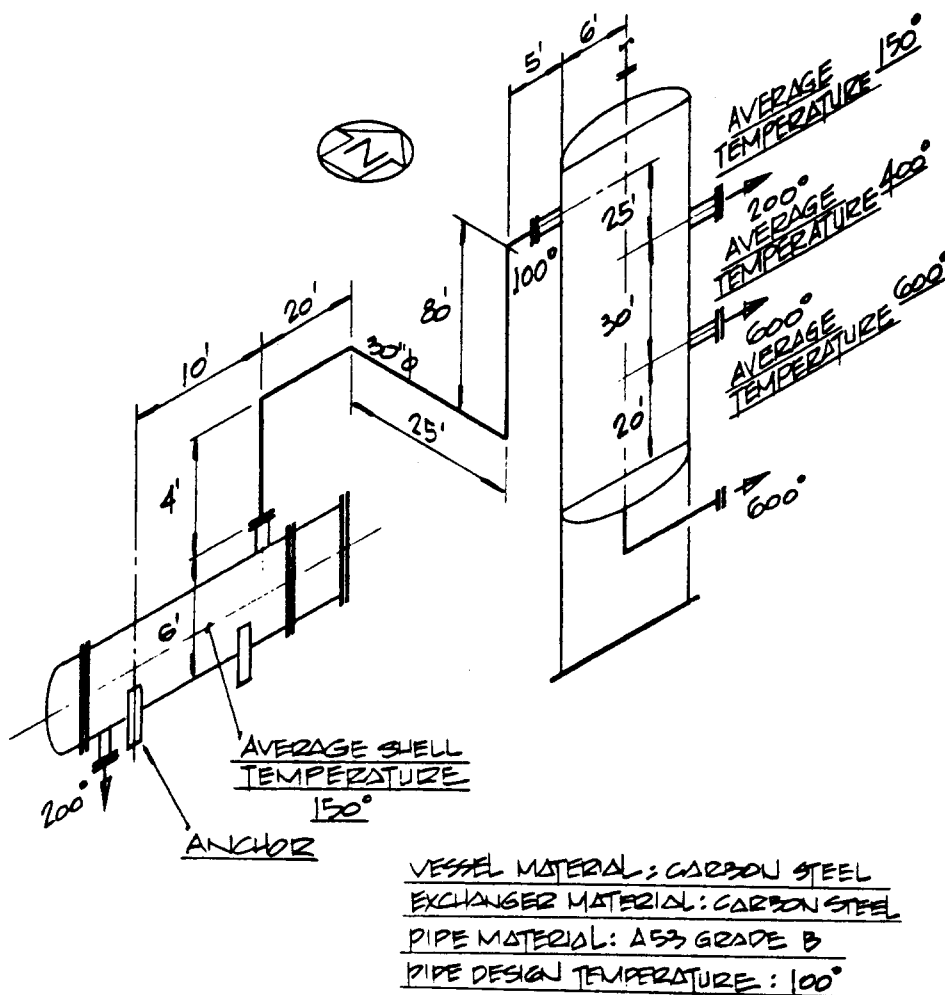


EXHIBIT 16-18
Example Thermal
Calculation for Vessel
Piping

Step 5.0

Follow the procedure describe in step 3.0 to determine that the minimum required absorbing pipe length is 13 ft.

Step 6.0

The last step is to determine the vertical expansion and its impact on the vessel nozzles.

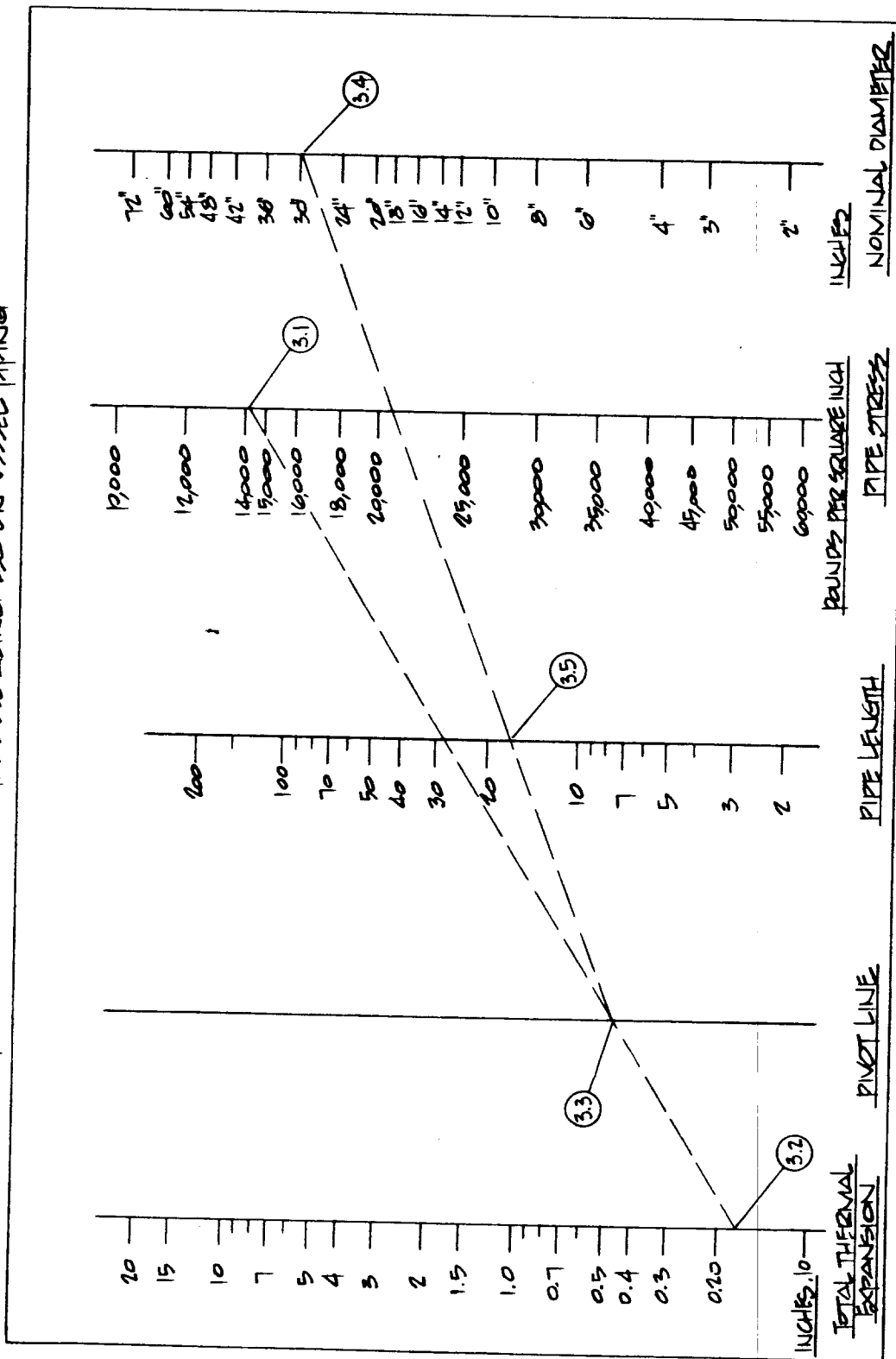
$$(20 \text{ ft}) \times (0.046) + (30 \text{ ft}) \times (0.027) + (25 \text{ ft}) \times (0.0065) - (80 \text{ ft} + 4 \text{ ft}) \times (0.003) - (6 \text{ ft}) \times (0.0065) = 1.6015\text{-in expansion}$$

Follow the procedure described in step 3.0. The minimum required absorbing pipe length is 52 ft. The available absorbing leg is $(20 \text{ ft}) + (25 \text{ ft}) + 5 \text{ ft} = 50 \text{ ft}$. These absorbing legs are smaller than the minimum

EXHIBIT 16-19

Nomograph for Absorbing Leg on Vessel Piping

CHART FOR DETERMINING THE ABSORBING LEG ON VESSEL PIPING



required pipe length. Therefore, add at least 2 ft in the north-south or east-west direction to be within the maximum allowable stress on steel equipment nozzles.

Checking the Piping Layout in Piperacks

This section will describe how to size a piperack loop. The first step is to determine the location of the anchors and loops in the line. Once the designer locates the anchors, he or she will design preliminary loop sizes and locations. Once he places the loops, the designer can check the stress in the pipe.

Piperack allowable loads There are different types of allowables for each phase of the piperack design. For the location of the anchors, the allowable movement is 6-in maximum pipe movement at the loops and 5-in maximum movement at changes of direction.

For the sizing of the pipe loops in a rack, the designer uses a maximum pipe stress allowable. The maximum primary stress in a loop is 20,000 psi for most temperatures encountered (reference ANSI B31.3, Appendix A for more detailed information).

Piperack loop example calculation The following example describes how to size a piping loop in a piperack. Reference Exhibit 16-20 for a diagram of the example.

Step 1.0

Determine the location of the anchors and loops for this 500° F carbon steel line.

Step 1.1

Calculate the total expansion in the east-west direction.

$$(500 \text{ ft}) \times (0.0362) = 18.1 \text{ in}$$

Step 1.2

Locate a preliminary location for the loops and anchors based on inspection.

The designer should locate anchors such that the expansion going into the loop does not exceed 12 in. Also, the total unbalanced forces at the anchors will be within the limiting criteria. Locate anchors at 125 ft from points A and B.

Step 1.3

Calculate the expansion going into the loop. Reference Exhibit 16-15 for the thermal growth chart.

$$\{(500 \text{ ft}) - (2 \times (125 \text{ ft}))\} \times (0.036) = 9.00 \text{ in}$$

Step 2.0

Determine the minimum size of the loop based on the allowable stress.

Step 2.1

Determine the amount of expansion in each leg of the loop perpendicular to the direction of pipe expansion:

$$\Delta = \frac{\text{Total expansion into the loop}}{2}$$

$$\Delta = 9 / 2 = 4.5 \text{ in}$$

Step 2.2

Enter the table "DETERMINING LENGTH OF LEG IN A PIPERACK LOOP" listed as Exhibit 16.21. Locate the expansion of 4.5" on the X-Axis.

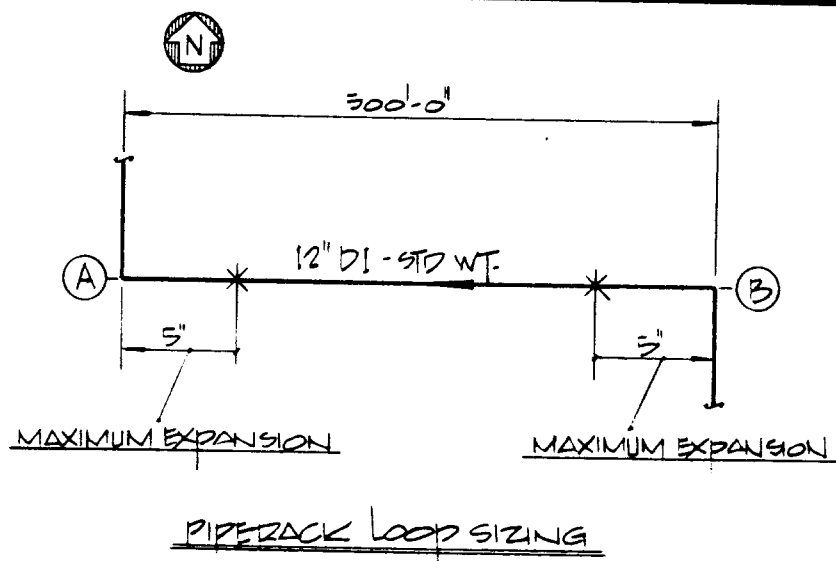
Step 2.3

Draw an imaginary line vertically from the 4.5" mark to the line labelled "12" nominal diameter. Next draw a horizontal imaginary line from this intersection point to the vertical axis. Read the loop leg length as 24 ft.

Step 2.4

Try to make the width of the loop approximately 20 feet wide for pipe sizes between 3 in. and 20 in. For pipe sizes above 20 in. make the loop 30 ft wide. Note that the leg length is dependent on the assumption that the pipe is standard wall and the al-

EXHIBIT 16-20
Piperack Loop Sizing



allowable stress is 20000 psi. Consult the Stress Engineer for exceptions.

Cold Springing the Piping System to Reduce the Loads on Equipment Nozzles

Cold springing a pipe is the act of cutting short a section of a piping system and then "pulling" the two ends together to make the final weld. This places a prestress in the piping system that is opposite to the stress imposed on the system when it is hot. Per the B31 Code, the stress engineer can take no credit for cold spring when he considers the maximum stress in the system. However, the piping code does allow the stress engineer to apply two-thirds of the calculated reduction in nozzle loads to the impacted nozzles. Therefore, the benefit to cold spring is some reduction in nozzle loads on critical equipment.

Why does the code only allow the stress engineer to consider two-thirds of the calculated benefit of cold spring? The reason is it is very difficult to install prop-

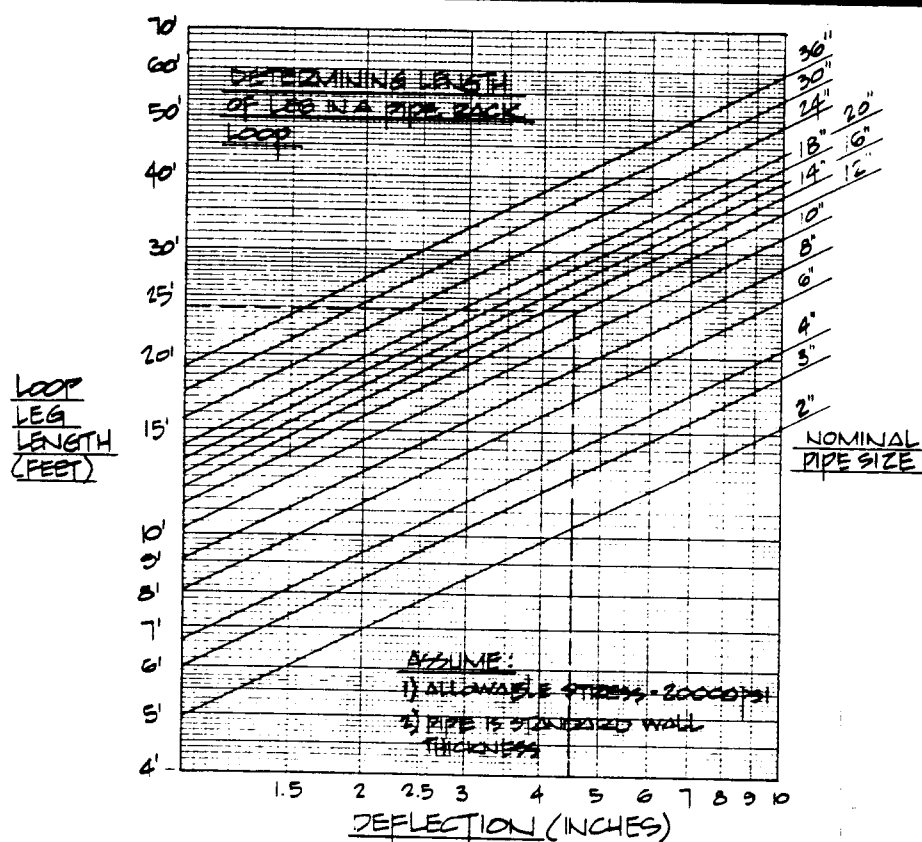
erly a cold-sprung system. This is also why we do not recommend cold springing as a piping layout solution for thermal loads. Another reason is the difficulty of maintaining accurate cold-spring records over the operating life of the plant. Future maintenance efforts may not consider the original cold spring when disconnecting the piping system.

On petrochemical projects, cold springing is very rare. However, if the piping designer is considering this option, we recommend the client approves the procedure before proceeding with the final piping layout design.

LAYOUT SOLUTIONS FOR OTHER STRESS

Layout solutions for stress problems due to reciprocating equipment, wind, or earthquake are similar in nature to the solutions provided for weight stress problems. Thus, most solutions revolve around rout-

EXHIBIT 16-21



ing a piping system such that there is existing steel or concrete within reach of the support scheme. This section primarily addresses the spacing of anchors and guides so that these other types of stress do not adversely impact the piping system.

Checking the Piping Layout for Reciprocating Equipment

As described earlier, routing pipe to satisfy thermal criteria usually involves adding more absorbing legs and reducing the number of guides and anchors. This

makes the system looser, and therefore lowers the system stress. However, on reciprocating systems there is an additional problem. The pipe can vibrate with the compressor pulsations. To resist this vibration, stress engineers often ask for stiffer systems with more guides and anchors. These opposite types of solutions for different problems provide the challenge for a stress engineer. The resolution to this routing challenge is first to route to satisfy the thermal problem (using the methods described earlier) and then solve the vibration problems. Normally, the stress engineer will go through a series of iterations working the two types of stress concerns.

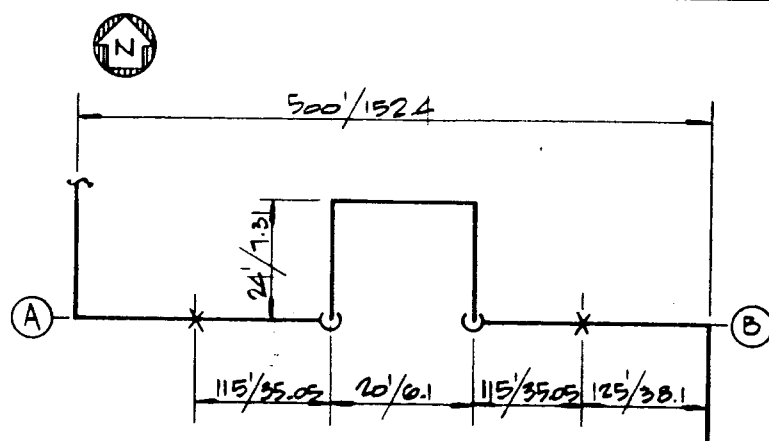


EXHIBIT 16-22
Piperack Loop Sizing

Once a line is routed for access and thermal considerations, the piping layout designer considers the vibration problem. The designer will determine the forcing frequency of the compressor. With the forcing frequency known, the designer will use a nomograph that will show the allowable spacing for the vibration restraints. He can then route the piping to assure that the needed restraints will be accessible to structural steel and concrete.

Allowable natural frequencies in a reciprocating compressor piping system For initial routing on a typical multistage reciprocating compressor, the designer can use the following formula for an allowable natural frequency of the piping system.

$$\text{allowable natural frequency} = 4 \times (\text{motor rpm} / 60)$$

Reciprocating equipment piping example calculation
The following example will calculate the appropriate

span for a typical reciprocating compressor piping system.

Step 1.0

Determine the reciprocating compressor forcing frequency. Often, the motor speed is around 360 rpm. If we use this value in our example, then we get the following:

$$4 \times (360 \text{ rpm} / 60) = 24 \text{ cycles per second}$$

Step 2.0

Determine the allowable span for a "clamped" end condition using exhibit 16-23.

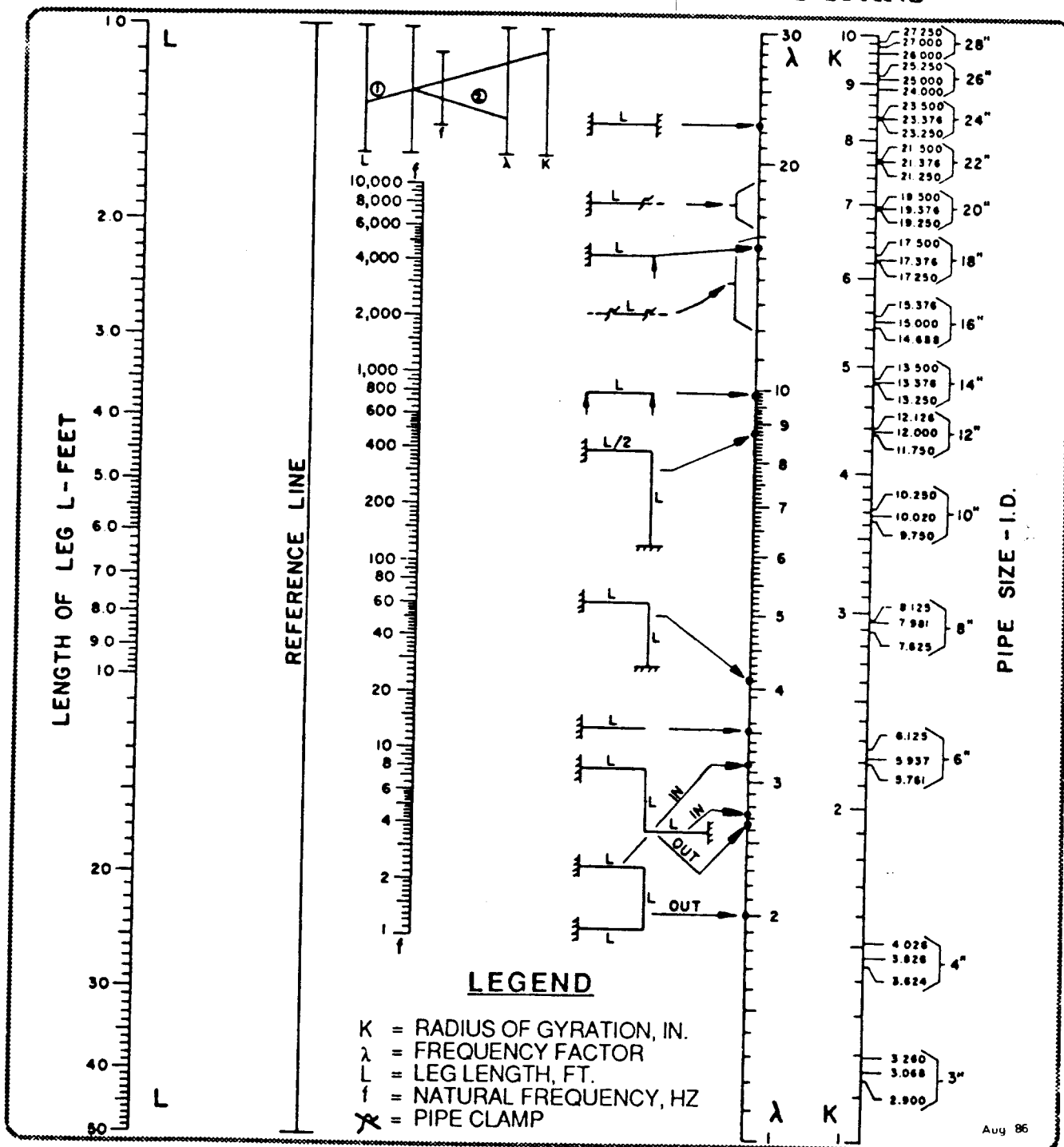
Step 2.1

Draw a line from the λ frequency factor (equal to approximately 14 for clamped end conditions) to the allowable frequency of 24 cps. Extend this line through the Reference Line.

EXHIBIT 16-23

Nomograph for Determining the Allowable Span for a
Reciprocating Compressor Piping System.

LOWEST MECHANICAL NATURAL FREQUENCY OF GAS-FILLED, UNIFORM STEEL PIPING SPANS



Aug 86

EXHIBIT 16-24.**Guide Spacing for Vertical and Horizontal Pipe**

PIPE SIZE	¾	1	1½	2	3	4	6	8	10	12	14	16	18	20	24 & up
VERTICAL SPACING	10	15	20	25	25	30	30	35	35	40	40	40	40	40	45
HORIZONTAL SPACING	20	30	35	45	50	60	80	120	200	200	200	200	200	200	200

Step 2.2

Draw a line from the pipe size (assume 6-in pipe) on the Radius of Gyration (K) line through the intersection on the Reference Line. Extend this line through the Length of Leg (L) line. Read the L dimension of 16 ft. This is the allowable span for a steel pipe with no concentrated weights.

Step 2.3

Similarly, check each of the portions of the pipe routing for the correct span.

Checking the Piping Layout for Wind Stress

Depending on the location of the plant, the designer can design piping systems to withstand more than 100-mph winds. The designer must place guides on the pipe at regular intervals to help brace the piping system. Piping systems that travel down vertical columns are particularly susceptible to vibrations because of high winds. To prevent this vibration, the designer

must place guides on the pipe at intervals smaller than the guide spacing for horizontal pipe.

Layout suggestions for reducing wind stress Although most wind guides placed in a system have little impact on proposed piping routing, vertical pipe on columns requires some special consideration. Guides on vertical pipe are physically larger than guides on horizontal pipe. Also, the guide spacing is smaller on vertical pipe than on horizontal pipe. Therefore, the piping layout designer must carefully consider where the support designer will place the guides. Some column piping such as overhead vapor lines are large, therefore generating large lateral loads. These loads can result in very large structural guides that may impede access on column platforms.

Exhibit 16-24 is a suggested spacing chart for guides on vertical column piping. Also provided for comparison is the spacing chart for horizontal lines. The piping layout designer should consult with the pipe support designer to confirm the guide locations. This should happen during the preliminary layout phase of the piping design.

Computer-Aided Design

Today's rapid changes in computer technology demand that industry adopt formal means of educating future designers. Many engineering contractors as well as operating companies are now committed to establishing a position in this rapidly developing technology. Computer-aided design (CAD) supports the entire engineering work flow from process simulation to mechanical design. This chapter provides an overview of the tools used and how they benefit the engineering and construction contractor.

Applications range from the basic use of standard symbols and details to sophisticated 3-D graphics modeling with associated data bases, extracted reports, and drawing generation. The use of these tools results in a higher-quality engineering design at lower overall cost. The enhanced quality results from improved accuracy, greater consistency, improved constructibility, and enhanced operability and maintainability; lower costs are a result of fewer engineering staff hours, less field rework, lower material surpluses, and shorter schedules.

BASIC CAD APPLICATIONS

Graphics Symbols

Each engineering technology group has designed exhaustive libraries of standard graphics symbols. These range from simple arrowheads to entire mechanical assemblies, from schematic equipment symbols to drawing title blocks and borders.

The most significant immediate benefit of using standard symbols is the lower engineering costs as a result of reduced designer time and better overall efficiency. The other major benefit is consistency. Symbols appear exactly the same every time, as shown in Exhibit 17-1. Overall drawing presentation is dramatically improved. An indirect advantage is the ability to customize these symbols easily for particular project

needs. Even existing drawings may be easily regenerated with revised symbols.

Standard Drawings

Extensive libraries of standard drawings and details have also been developed. These range from electrical lighting fixtures and pipe support details to commonly used process flow diagrams or contractor proprietary vessel assemblies. Each represents the cumulative experience of many contractors over decades of engineering design. They conform to major industry codes as well as the contractor's own design practices. Exhibit 17-2 shows an example of a CAD-generated drawing.

The most important benefit of standard drawings is quality. Each detail for each project initially reflects the latest engineering design technology and is customized to meet particular client needs as well as special code or material requirements. Drawings are laid out well, and because CAD is used, lines and text are clear and uniform. Standard symbols are also used.

Layering

Computerization also takes practical advantage of graphics layering (the placement of different elements of a drawing on different layers) and overlays in a single drawing file as well as overlays, or referencing, of entirely separate files. For example, piping layout drawings are referred to by various downstream functions that develop pipe support location plans, electrical and instrument cable and conduit routing plans, steam tracing plans, and others, as Exhibit 17-3 demonstrates. Reproducible copies of piping drawings were often used in the past. If equipment was moved, new drawings were made and overlay drafting redone, or each downstream function revised its drawing. With CAD, these groups may begin work much earlier. When changes are made, they need only reference the latest revisions.

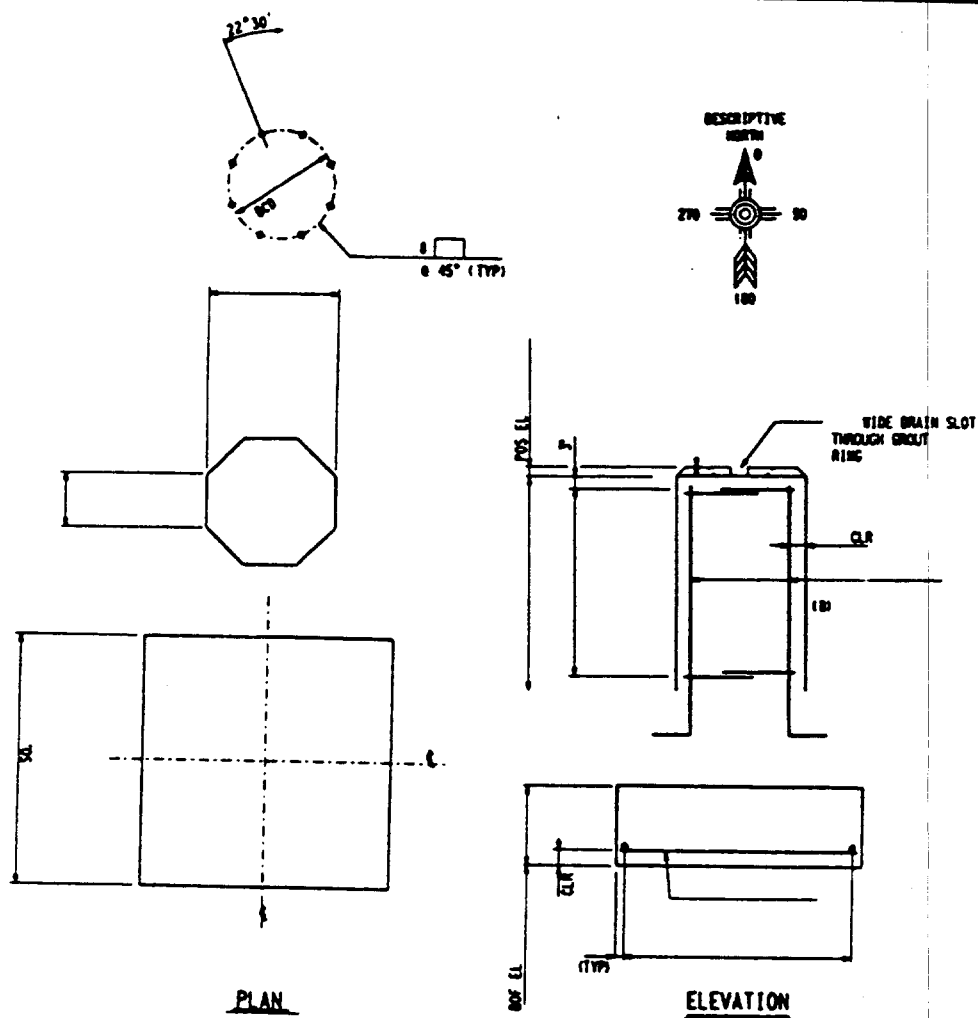


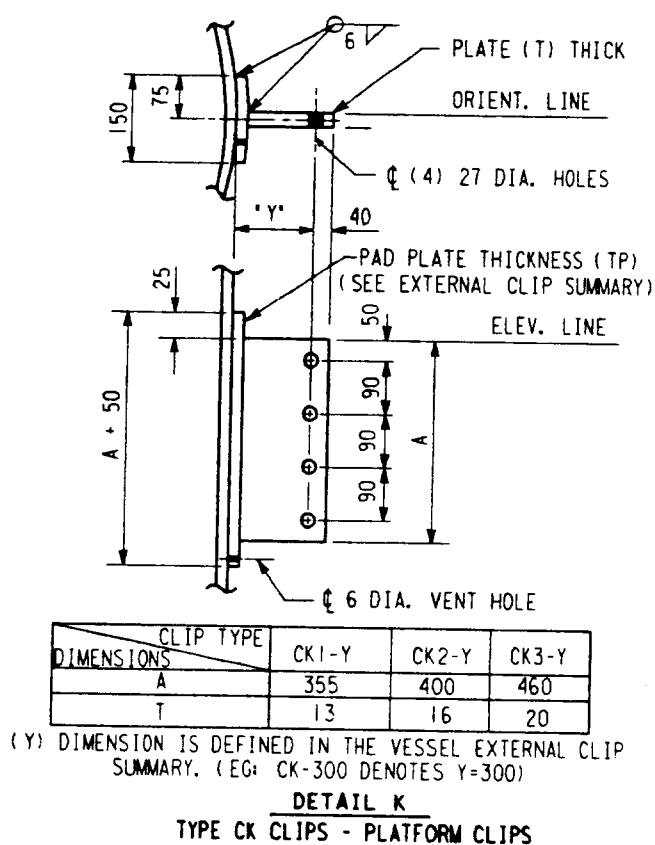
EXHIBIT 17-1
Standard Symbols for
Foundations Detail
Drawings

Scanning and Translation

With graphics scanning, manually drafted documents may be converted to an electronic CAD file. Typical applications include the modification of existing client piping and instrumentation diagrams or piping draw-

ings for plant enhancements. Generally, blue-line prints are actually scanned, although microfilm aperture cards may be scanned as well. The edited image is converted to a CAD system for actual design work, as Exhibit 17-4 shows. This method may be preferred by clients who have adopted CAD systems of their own

EXHIBIT 17-2 Standard Vessel Clip Details



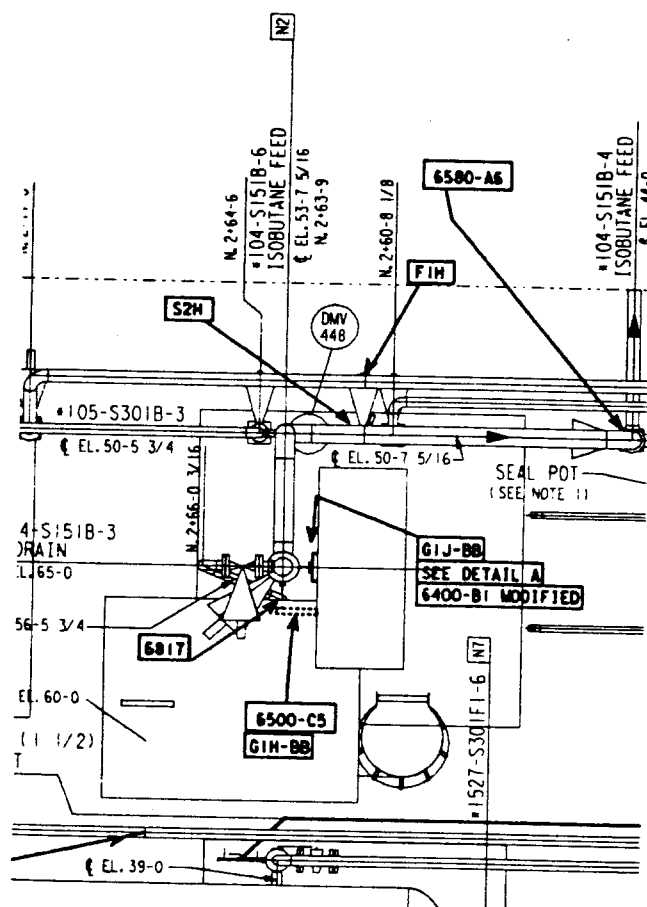
and desire their drawings in that format.

Although a contractor may select a particular CAD system, the client may use another. Therefore, it may be necessary to translate files between the two CAD systems for direct communication.

Automated Drawings

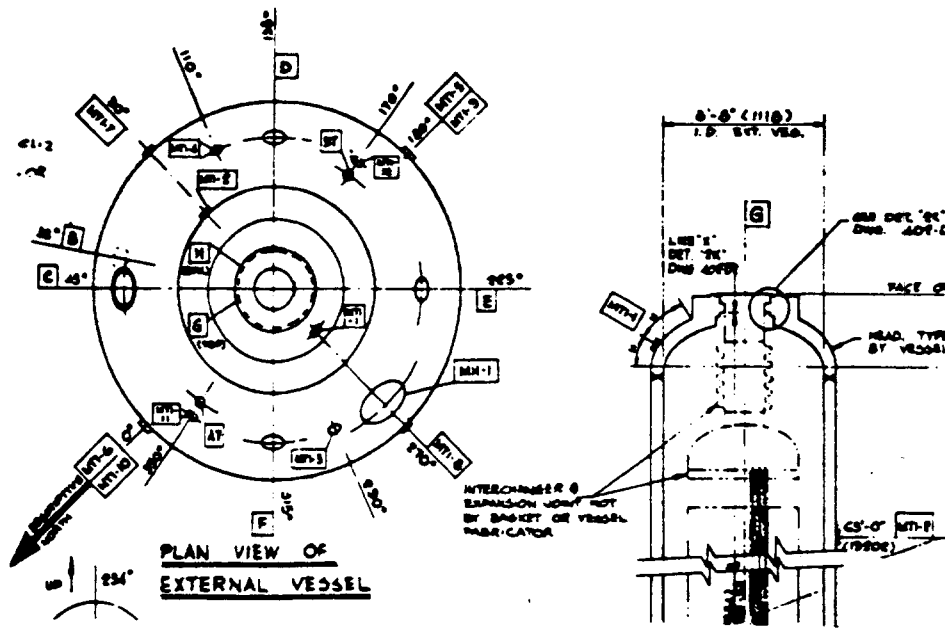
For years, contractors have used computer programs to create certain engineering designs. Many generate most of the data needed to produce the drawing. In

EXHIBIT 17-3 Portion of Pipe Support Location Plan Using a Referenced Piping Layout Drawing

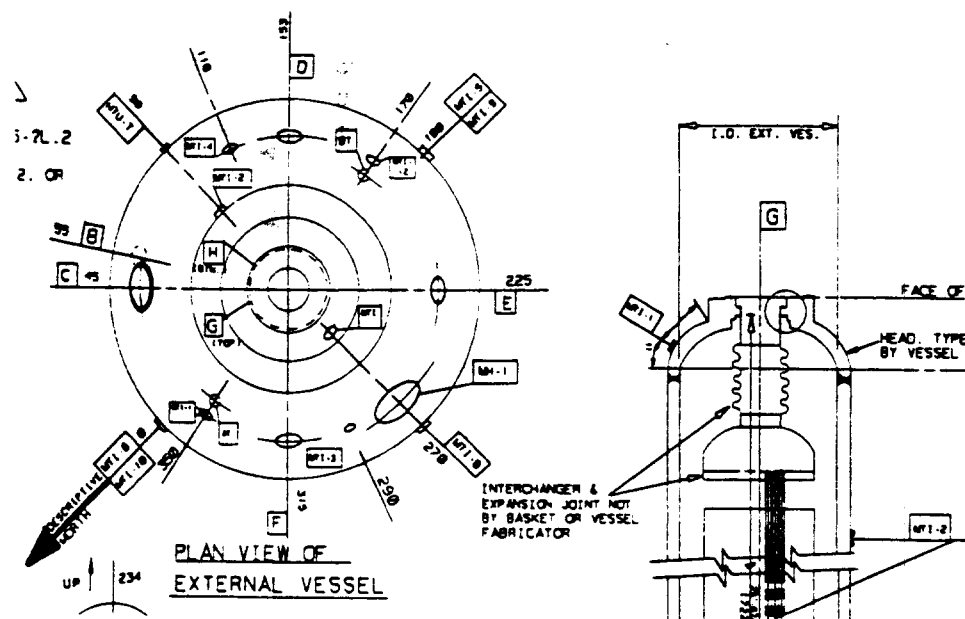


the past, the engineer made a sketch based on design results and passed it to a draftsman. With the advent of CAD, graphics symbols libraries and standardized drawing formats were developed to expedite the design effort.

Special programs have been developed to aid in interfacing the contractor's design programs with the graphics system. Programs were enhanced to generate



a. Manually Drafted



b. After Scanning into CAD System

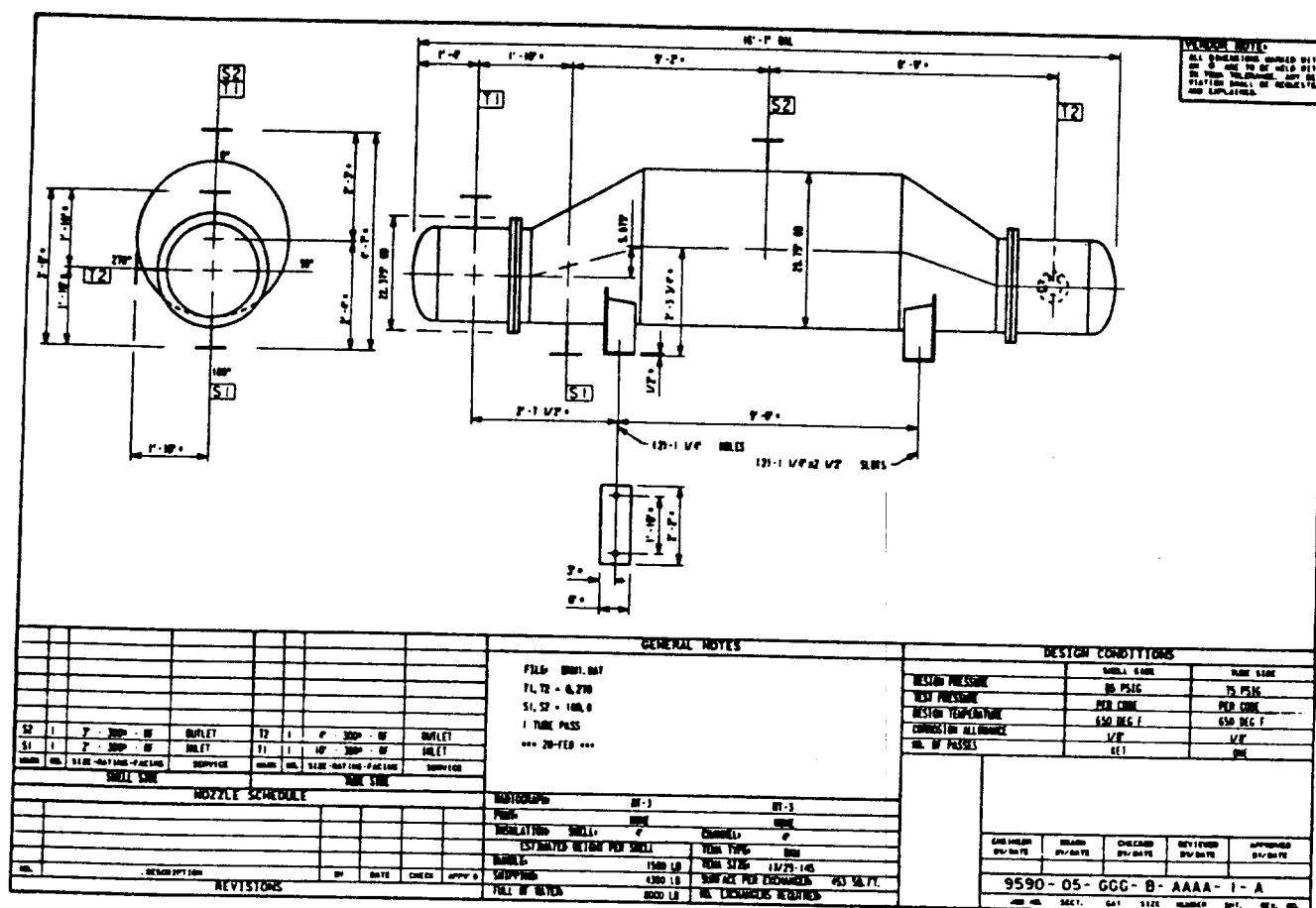
special graphics data files, and applications were written to format these drawings. They also select and place appropriate graphics symbols, add dimensions and text, perform material scheduling and take-off calculations, and execute plots.

Automated programs are now available for many heat exchanger setting plans and tube layout sketches, electrical one-line and control wiring diagrams, fur-

nace mechanical drawings, foundation detail drawings, and structural pipe support schedule drawings. Exhibit 17-5 shows an example of such a plan.

The advantages of automated drawing systems are significant. The drafting effort is radically reduced or entirely eliminated in terms of design staff hours and graphics terminal time. Engineering cost reductions are substantial, and valuable schedule time is saved.

EXHIBIT 17-5 Automatically Generated Heat Exchanger Setting Plan



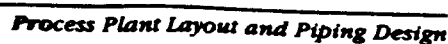


EXHIBIT 17-7
Equipment Plot Model
Using Plot Modeling
Software

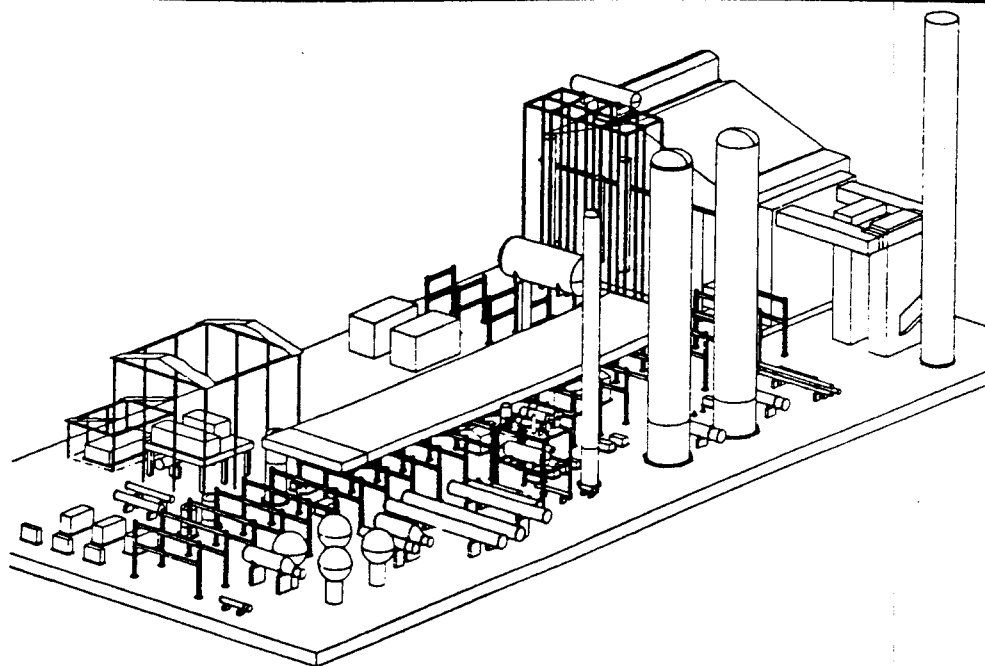
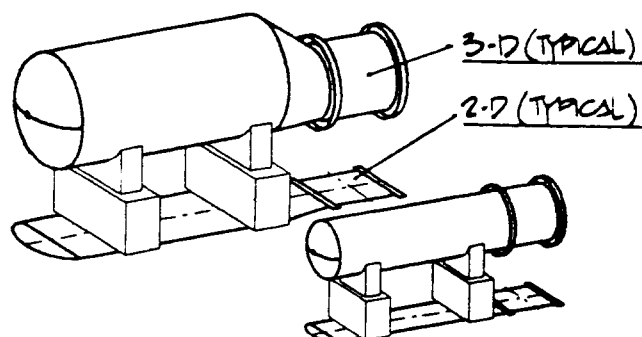


EXHIBIT 17-8 3-D Equipment Plot Model with 2-D and 3-D Layers



ciated piping is automatically rerouted with the same basic configurations. Complex piping assemblies (e.g., piping control stations) that are used more than once are easily duplicated as a unit through macros. The piping model geometry is interfaced with a pipe stress analysis program to ensure adequate piping flexibility.

The major advantages of this system include:

- The simplicity of pipe routing.
- Automated rerouting with equipment changes.
- The ability to extract preliminary piping material quantities to support defined estimates and early orders.
- The ability to extract the detailed layout drawings directly from the model.

Detailed Engineering

During the detailed engineering phase, exhaustive analysis and designs are performed. The resulting documents are those actually used to requisition, fabricate, and construct the plant.

Equipment is modeled in more detail, followed by the piping layout. This process is expedited in the plant design system by the fact that routing information may be transferred directly from the planning model. Piping parameters are downloaded from the system data base, which also ensures that all piping specified in the piping and instrumentation diagrams is accurately accounted for; even small bore lines are run.

At this point, an exhaustive piping component catalog and specification data base are used. Only components approved for the project may be entered. The software automatically checks for compatibility between adjacent components—for example, to ensure that a flange piece is not placed against a nonflanged component. Parts are placed to dimensional tolerances of less than a millimeter on the basis of catalog values. Materials (e.g., piping, flanges, gaskets, nuts, bolts, washers, and insulation) are tracked per specification.

Steel structures are modeled initially by centerline representation, then with preliminary member sizes. An electronic interface to finite element structural analysis programs allows the project to proceed to detailed design.

Structural component catalogs of steel shapes are

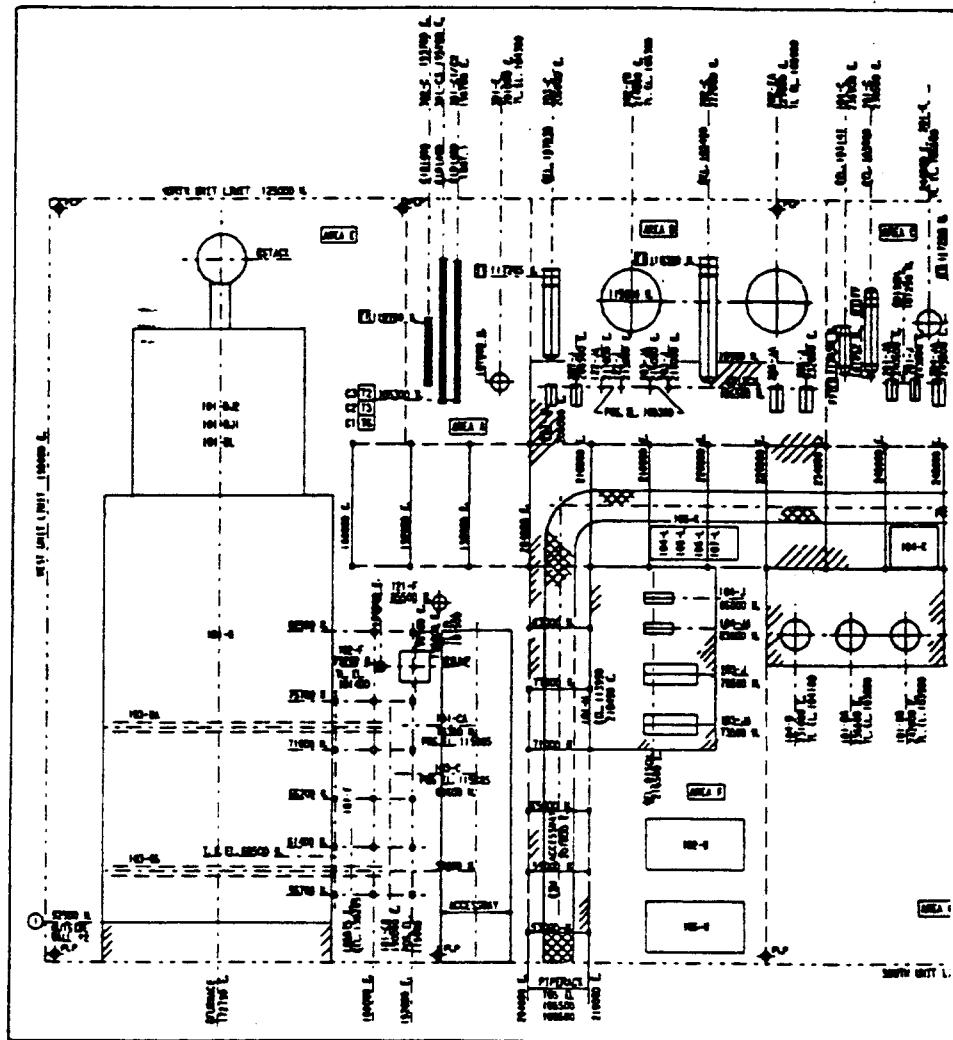
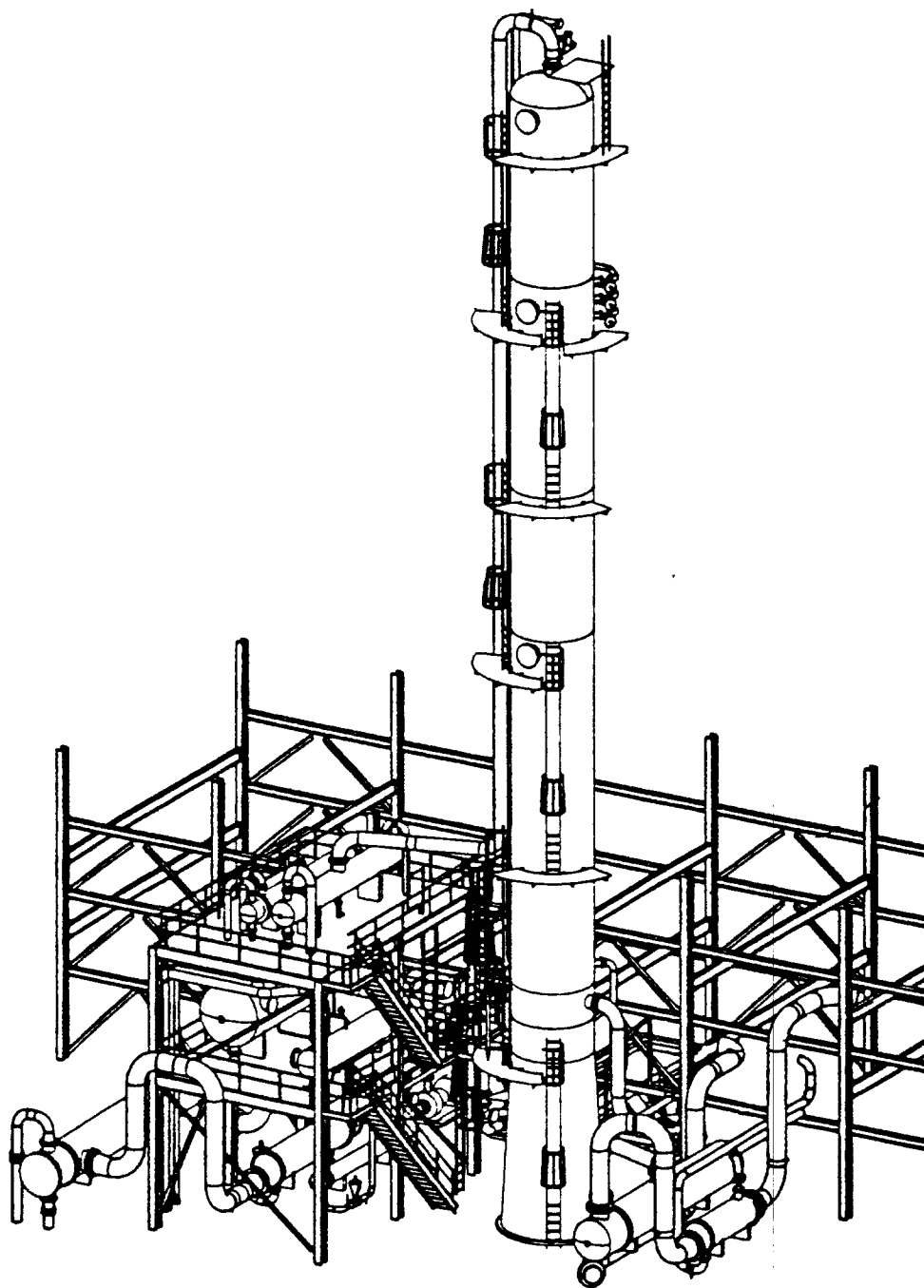


EXHIBIT 17-9
Partial Conceptual Plot
Plan (Extracted from Plot
Model)

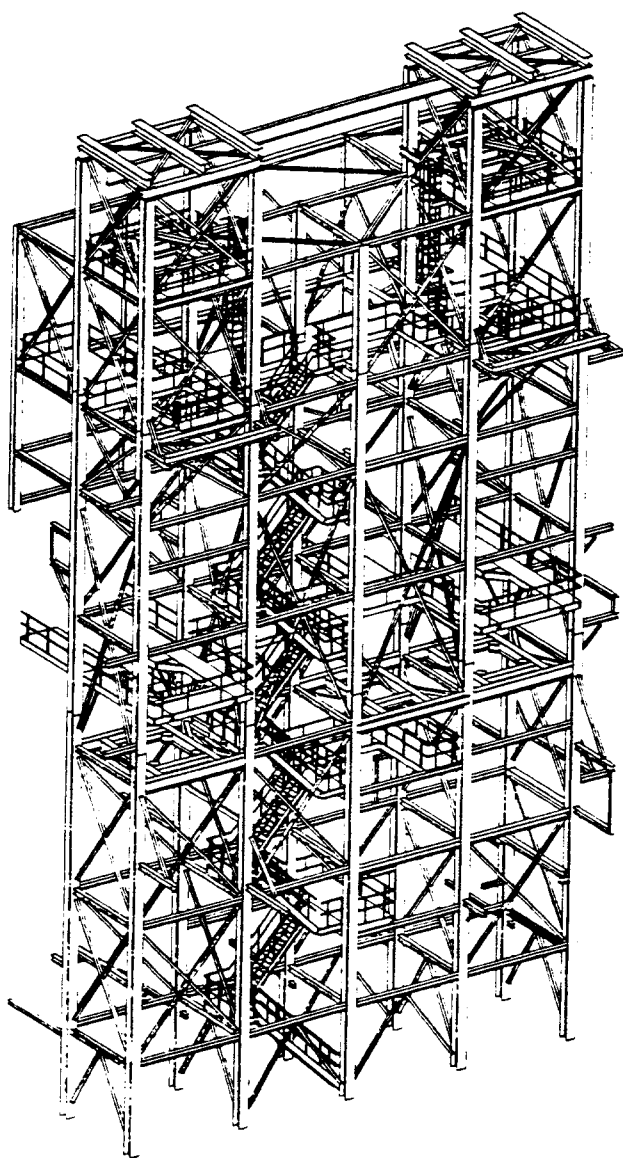
EXHIBIT 17-10
Partial Planning Model



referenced for final member sizing in compliance with engineering specifications and design codes. A return interface is then made to upgrade the graphics layout model to that of the final design, as shown in Exhibit 17-11. Foundations and concrete structures can be added as designs are completed through the use of a foundation modeling system. Piles are placed in a 2-D model at grade for subsequent drawing extraction. The entire underground can be modeled, including electrical and instrument conduits as well as

pipng. In addition, the automated system is a much more valuable tool for plant maintenance and future expansion because, unlike the above-ground structures, the actual installation cannot be seen except by computer once it is in place.

Each engineering function (e.g., civil, structural, and piping design) builds its portion of the model with the ability to view but not change the other functions' work. An example of this detailed engineering model is depicted in Exhibit 17-12.

EXHIBIT 17-11 Structural Steel Model

Model Review

The capability of reviewing the CAD 3-D model has been greatly enhanced by the ability to download the model files at various stages of a project to a specially configured high-performance workstation. The intent of the system is to provide an alternative to the use of plastic models for reviewing integrated models that can be easily used by project team members and client personnel. There are no special computer skills required to complete the short training session on learning to operate the system.

The composition of the model can be controlled using various features, such as level-control and display-set manipulations. Highlighting and color rendering can also be used to separate specific files from the remainder of the model. With the use of these features, clutter and confusion can be kept to a minimum.

The system allows for a view from any point of the model to be quickly generated. Various techniques can be used to set the eyepoint to any position within the model area and view any direction that is desired. Also the package allows a "step through" of the model in any direction and increments.

Any problem areas detected while reviewing the model can be tagged with a number and description of the problem. Saved views of these tags can be generated and brought back at a later time for resolution by the area designer.

Interference Checking

Once completed, a batch process is run to identify all component interferences for the entire model, as shown in Exhibit 17-13. It also checks for such interferences as pipes that cross a designated clear space (e.g., a walkway or equipment maintenance area). Because these problems can be resolved before documents are extracted, an extremely small number of interference reports during construction are now gen-

EXHIBIT 17-12
Detailed Engineering
Model Using a Plant
Design System

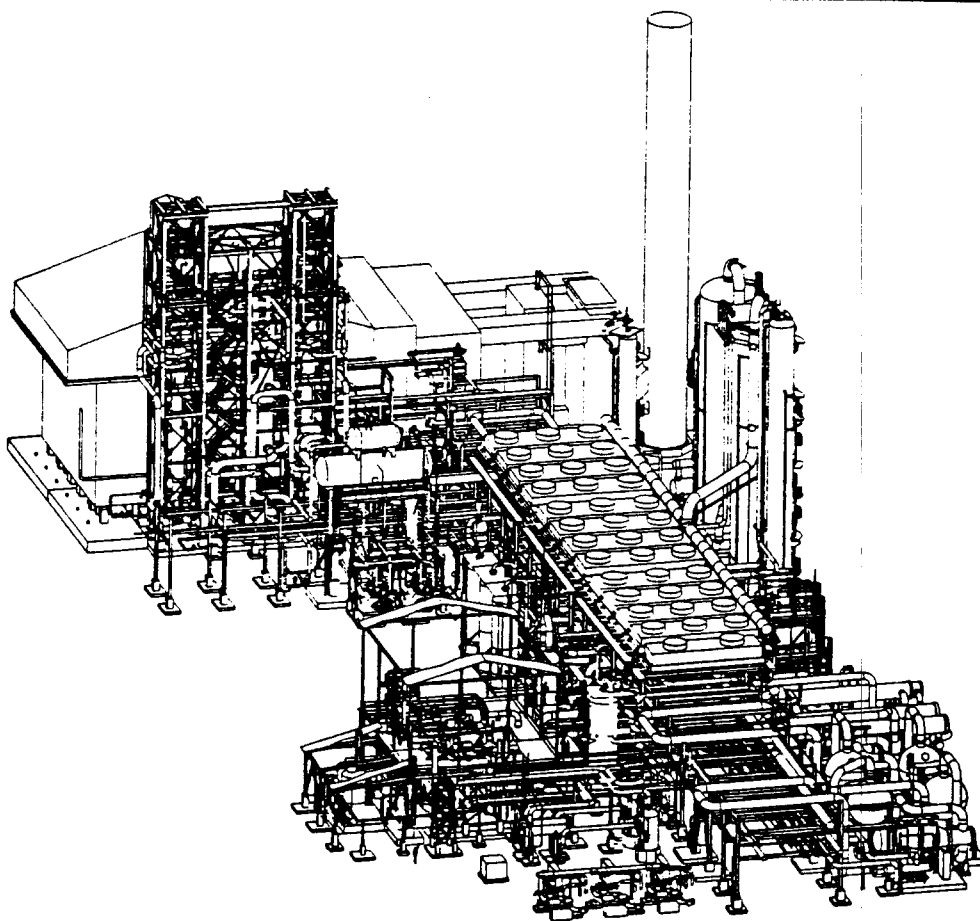


EXHIBIT 17-13 Example of a Component Interference Problem

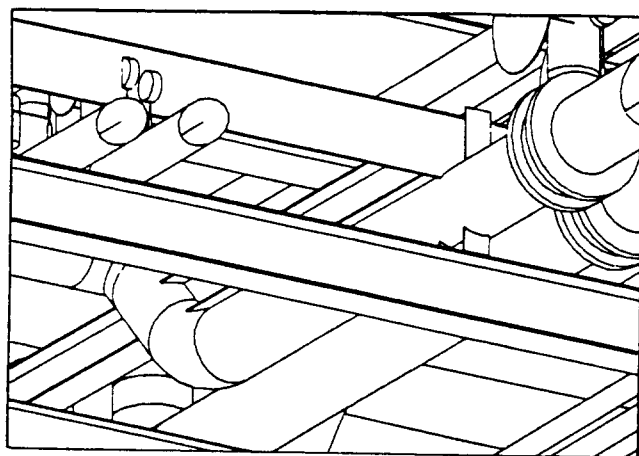


EXHIBIT 17-14 Isometric View

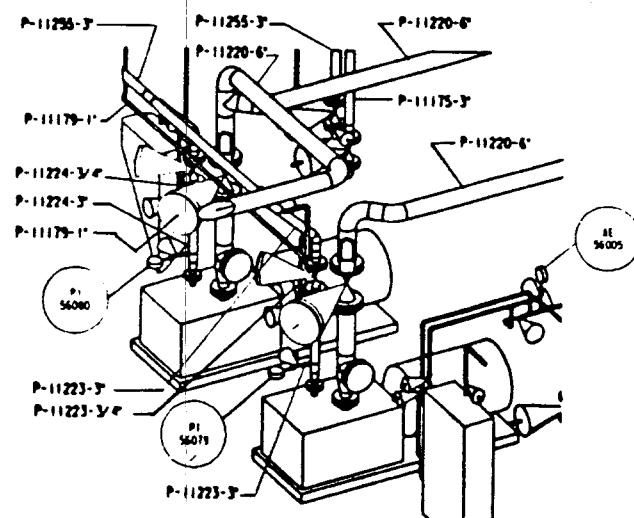
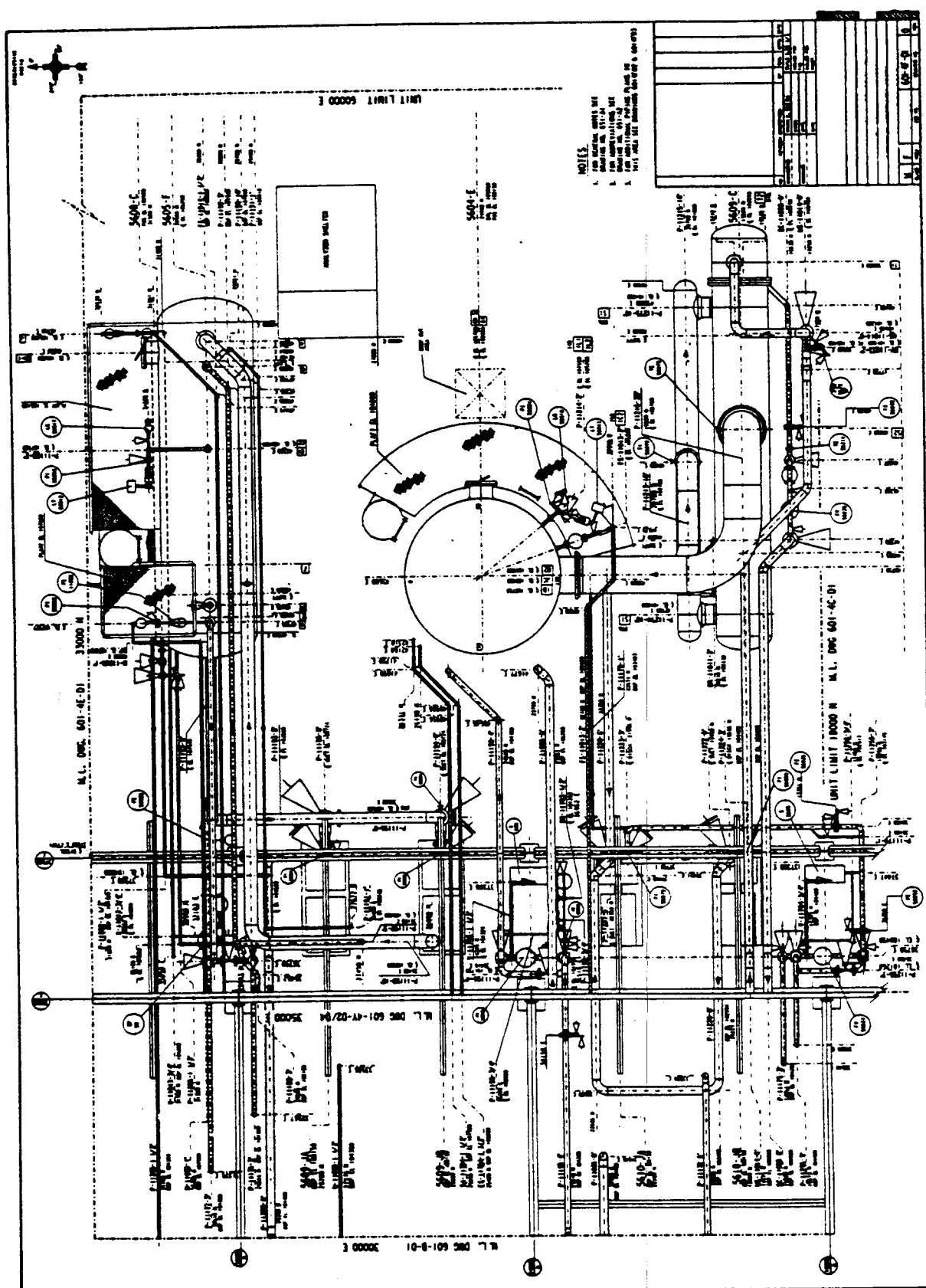


EXHIBIT 17-15 Partial Piping Layout Drawing



erated, significantly lowering fixed field and refabrication costs and enhancing the ability to adhere to critical schedules.

Issue Documents

The real return on investing resources to construct an electronic model is the ability to generate issue documents quickly and accurately. Plot plans and piping layout drawings are taken directly from the model by specifying plan and vertical boundaries, as shown in Exhibit 17-15. Elevation views are produced in the same way. These are often augmented with isometric views of especially complex piping configurations to aid in visualization and construction, as illustrated in Exhibit 17-14. Such downstream disciplines as electrical, instrument, and piping engineering then reference these drawings to generate their own data and reports.

The largest benefit of the system is the ability to automatically generate piping isometrics complete with detailed bills of materials, as Exhibit 17-16 shows. The designer merely indicates breakpoints for each sheet. Process plans require thousands of isometric drawings, and the system cross checks the model to ensure that sections of pipe are neither omitted nor duplicated. Structural steel erection drawings, plans, and elevations are extracted and annotated, and material summaries are automatically produced. Foundation and pile location plans are extracted in much the same way the equipment plot plans are. Pile counts by type are automatically created, and foundation and pile data sheets are generated for internal checking.

Automating take-off material quantities offers a great productivity gain. The material quantities are completely specification driven, which ensures conformance with project requirements and precise assembly breakdowns. Because quantities are computed directly from the model data base, accuracy has improved; this has allowed some standard surplus order rates to be reduced.

Graphics modeling also allows the schedule se-

quence to better reflect a project's critical path. Material quantities may be extracted at any stage for estimates or early orders. As soon as the model is completed, piping isometrics and other fabrication drawings are extracted, followed by orthographic views for construction. (Manual drafting methods require the reverse order.)

Finally, materials reports may be directly interfaced with the contractor's materials control system, which automates much of the requisitioning, tracking, field inventory control, and cost reporting.

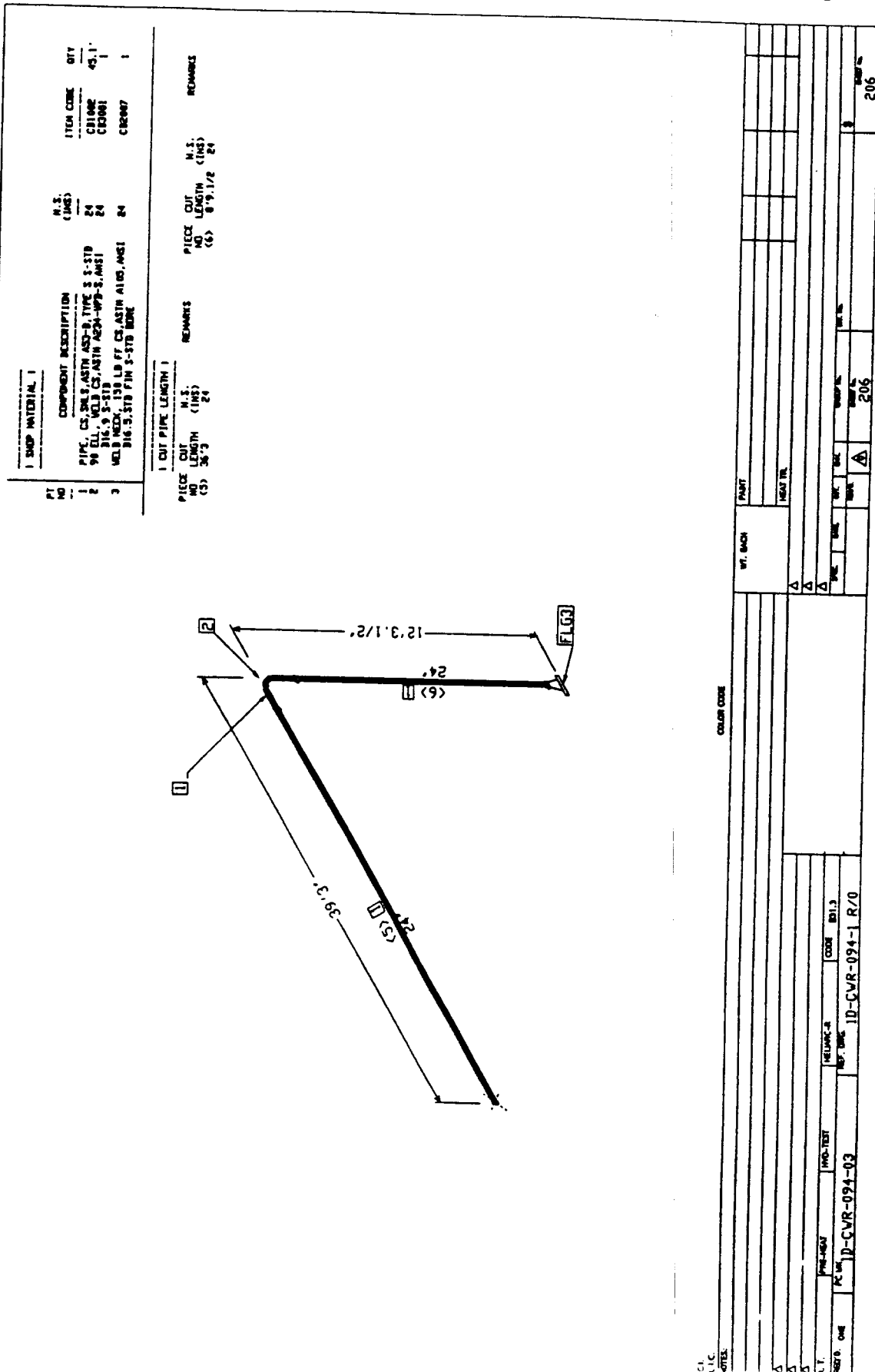
ELECTRONIC SPOOL SHEETS

Electronic spooling is the term used for automatically generating spool sheets, complete with bills of material (BOM), for pipe spool fabrication. Pipe fabrication shops have traditionally hand drafted these sheets using isometrics as a reference, but are now developing computer programs to interface with contractors isometric data files directly.

The programs used for this system are capable of reading input data generated from a CAD 3-D model using interface software provided with the 3-D model. The first step in generating a spool sheet is to convert the input data into a standard format for processing. The 3-D model is then restored with all of the branches and connectivity established. The model is then transversed and broken into sheets to suit prelocated field welds or natural material breaks. Finally, the material requirements for each sheet are matched with the pipe fabricators computerized warehouse or material information.

The geometry of the sheet is then evaluated, and a best view is determined. Scaling and drawing composition requirements are automatically considered and appropriately set. Using the necessary software, the spool-sheet design file is then created with components, piece mark numbers, dimensions, title block, and a BOM. The spool sheet can then be automatically plotted, checked, and issued to the shop floor for fabrication, illustrated in Exhibit 17-17.

Figure 17-17.



CAD BENEFITS SUMMARY

CAD users generally believe that the benefits of a properly executed computer-aided design program result in higher quality at lower installed cost. Higher quality is a result of the following:

- Improved accuracy—Because of automated tasks and electronic data exchange between design, modeling, and drawing systems.
- Consistency—In standard drawings and symbols, well-designed document formats, and automated error checking.
- Flexibility—In project specification customizations.
- Improved constructibility—As a result of standards that reflect contractors' cumulative expertise and fewer errors to construction.
- Improved operability and maintainability—Because of readily available engineering information (model, drawing, and data base files).
Lower installation costs are a result of the following:
 - Fewer engineering staff hours—Because of automated task and electronic data exchange.
 - Less graphics terminal time—As a result of using alphanumeric terminals for most data entry and automated drawing generation.
 - Less field rework—Because of reduced engineering error rates.
 - Lower material surpluses—As a result of more accurate take-offs.
 - Shorter schedules—As a result of all of these factors.

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[Italic numbers indicate illustrations]

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