50 Years in Teaching Process Plant Design

with special focus on:

Process Plant Layout

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v5

Outline

1. Purpose statement
2. Timeline of knowledge creation
3. Example: layout as one of process plant design topics
4. Main layout considerations
5. Concluding remarks

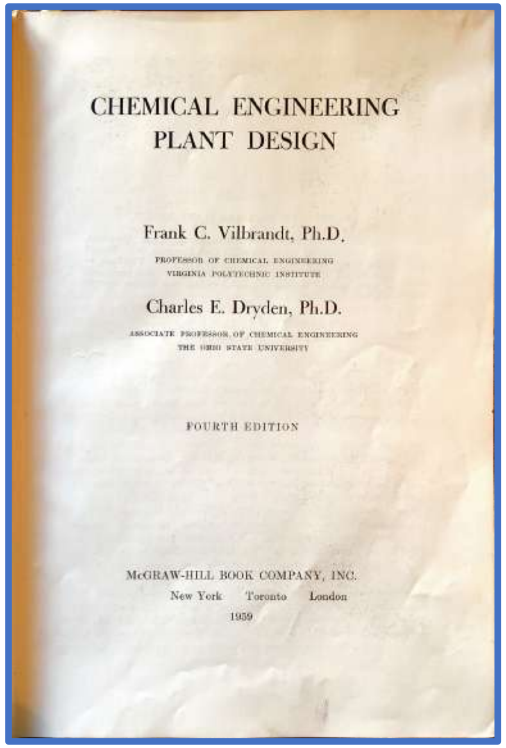
1. Purpose Statement

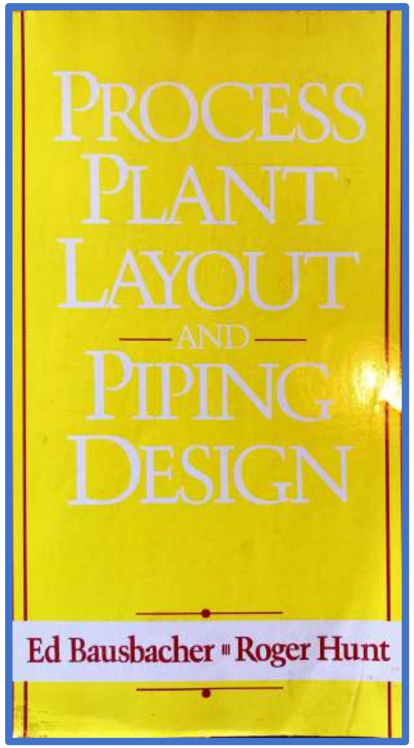
- The purpose of this lecture is to present and discuss the timeline of knowledge creation related to process plant design
- Process plant layout was selected to demonstrate the state of the art of process plant design
- The lecture emphasizes the importance to integrate academic experience and practical experience and introduces the work of IChemE on the rules of thumb
- The lecture calls engineers to access and utilize the wealth of knowledge available on the subject matter

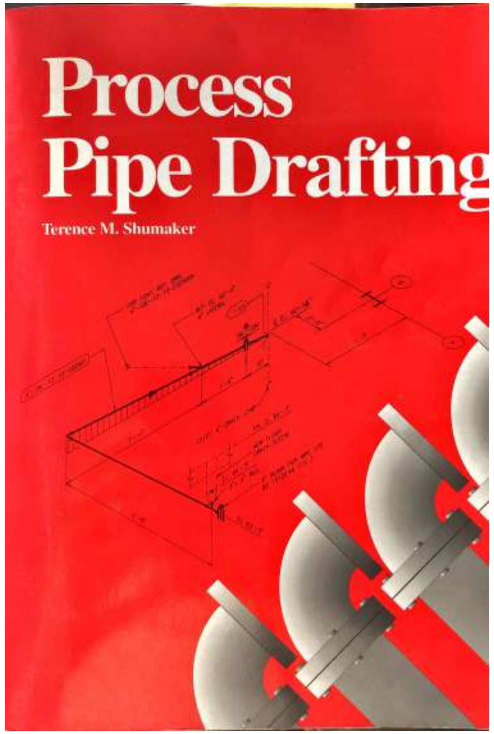
2. Timeline of Knowledge Creation

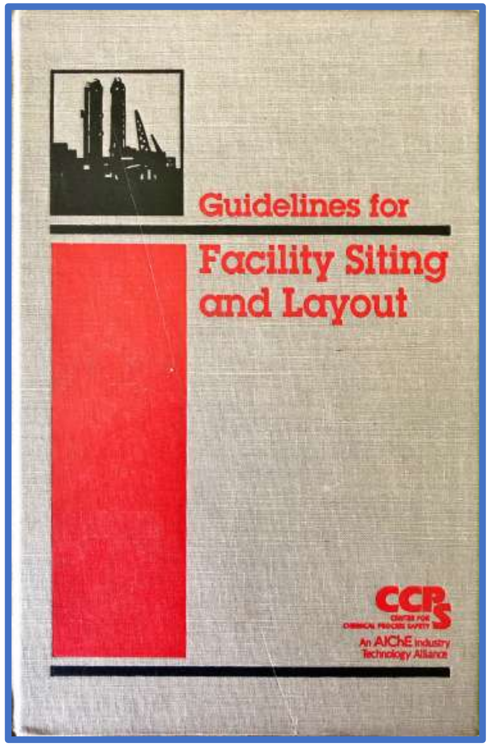
- Over the last 50+ years many books have been published in the field of process plant design, much less in number than process design
- Follows is a presentation of the timeline for what is believed to be the most important 12 books published in the field of plant design (1959-2018)
- The contribution of the Institution of Chemical Engineers (IChemE) is highlighted.

Vilbrandt	Bausbacher	Shumaker	CCPS
1959	1993	1995	2003









Chemical Engineering Plant Design

Vilbrandt — 1959

1. Development of the project
2. Process design
3. Selection of process equipment and materials
4. Economic evaluation
5. Plant layout
6. Locating the chemical plant
7. Site preparation and structures
8. Process auxiliaries

Process Plant Layout and Piping Design

Bausbacher — 1993

1. Basics of plant layout design
2. Plant layout specs
3. Plot plans
4. Compressors
5. Drums
6. Exchangers
7. Furnaces
8. Pumps
9. Reactors
10. Towers
11. Pipe racks
12. Structures
13. Underground piping …

Process Pipe Drafting

Shumaker — 1995

1. Overview of pipe drafting
2. Pipe and fittings
3. Valves and instrumentation
4. Pumps, tanks, vessels and equipment
5. Flow diagrams
6. Piping plans and elevations
7. Piping isometrics
8. Piping spools

Facility Siting and Layout

CCPS — 2002

1. Management overview
2. Preparing for site selection process
3. Site survey and selection
4. Site and plant layout
5. Equipment layout and spacing
6. Optimize the layout

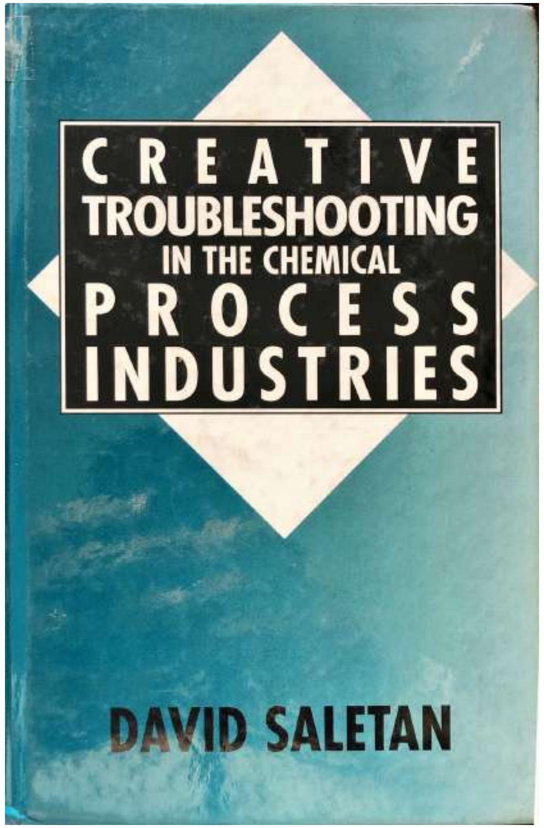
CCPS: center for chemical process safety for the AIChE

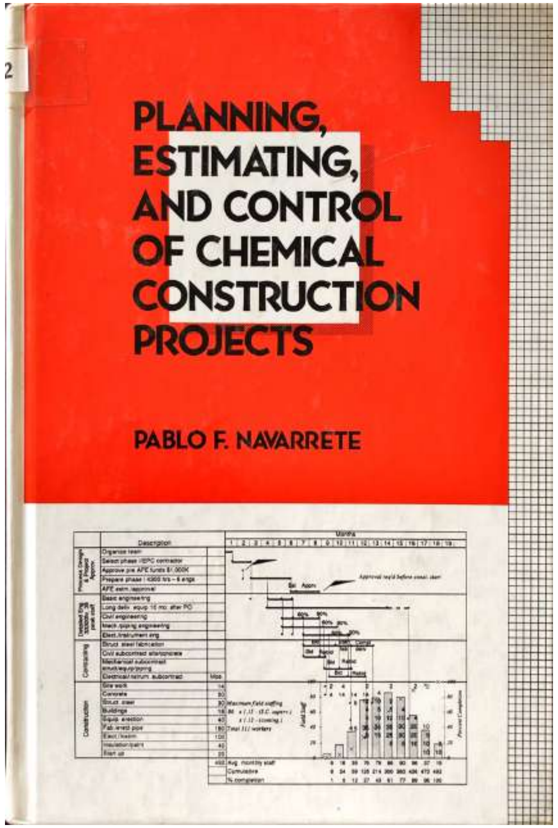
Saletan — **1994**

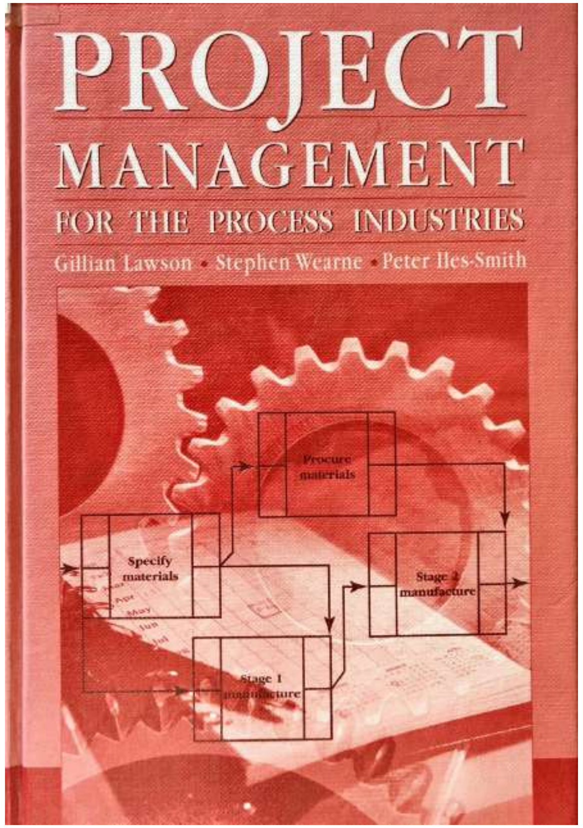
Navarrete — **1995**

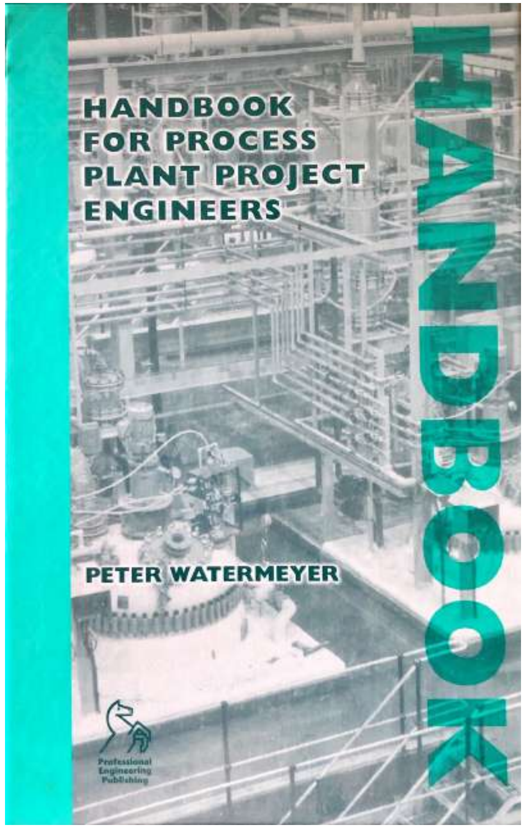
Lawson — **1999**

Watermeyer — **2002**









Creative troubleshooting in the chemical process industries

Saletan

1994

1. Troubleshooting as a skill
2. Mature operating process
3. Classic problem elements: fluid mechanics, distillation, control, reaction systems,..
4. Diagnostic aids
5. Safety and health

Planning, estimating and control of chemical construction projects

Navarrete

1995

1. Project execution overview
2. Plan of action
3. Process design: process design package, conceptual plant layout guidelines
4. Project execution plan/mater schedule
5. Estimating
6. Contracting
7. Construction management …

Project management for the process industries

Lawson

1999

1. Project principals
2. Project initiation
3. Project strategy and organization
4. Process specification
5. Detail design
6. Procurement
7. Construction
8. Commissioning
9. Project closure
10. Health, safety and environment
11. Quality assurance
12. Hazard studies ….

Handbook for process plant engineers

Watermeyer

2002

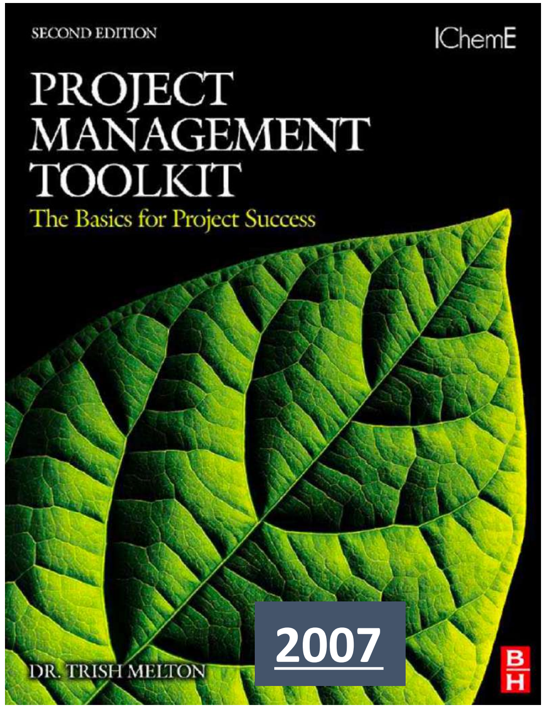
1. A process plant
2. A project and its management
3. The engineering work
4. The project’s industrial environment
5. The contracting environment
6. Conceptual development
7. Engineering development and details

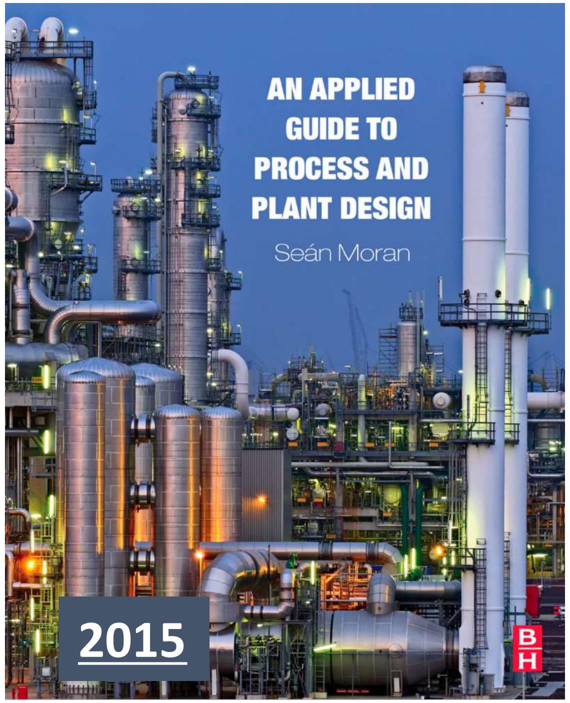
Melton — **2007**

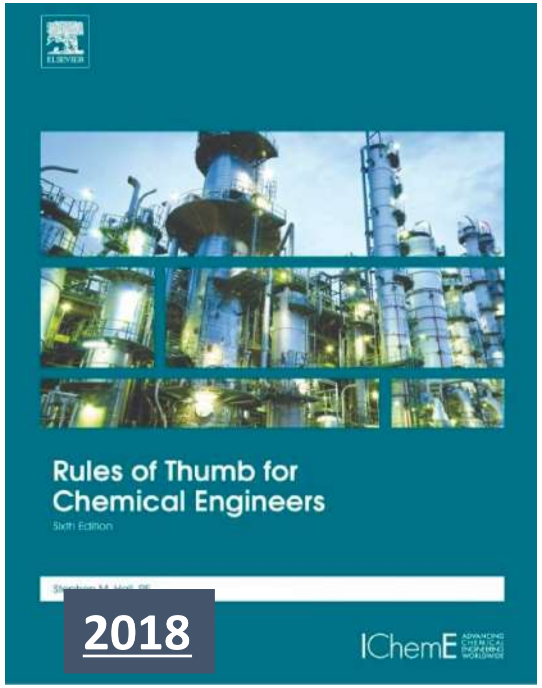
Moran — **2015**

Moran — **2017**

Hall — **2018**







2007 — Melton — Rules of thumb for chemical engineers

1. The project life-cycle
2. Stage one: why?
3. Stage two: how?
4. Stage three: in control
5. Stage four: benefits realized?
6. Case study one: the pharma facility project
7. Case study two: the business change project

2015 — Moran — An applied guide to process and plant design

1. Process plant design
2. Stages of process plant design
3. Process plant design deliverables
4. 21st century plant design tools
5. The future of process plant design
6. System level design
7. Professional design methodology …

2017 — Moran — Process plant layout

1. The discipline of layout in context
2. Site layout principals
3. Plot layout principals
4. Planning of layout activities
5. Methods for layout development
6. Hazard assessment
7. Detailed site and plot layout
8. Detailed layout and equipment

2018 — Hall — Rules of thumb for chemical engineers

1. Safety
2. Project evaluation
3. Process modelling
4. Fluid flow
5. Vessels
6. Blending and agitation
7. Pumps
8. Fans, blowers and compressors
9. Vacuum systems
10. Pneumatic conveying
11. Filtration
12. Heat exchangers …

Rules of thumb for chemical engineers

According to the author of 2018 edition: "This new edition of Rules of Thumb for Chemical Engineers is much more than a concise "manual of quick, accurate solutions to everyday process and plant engineering problems," I strive to provide process and project engineers the information needed to address each of the various topics. This includes lists of proven results (the "rules of thumb") and equations (sometimes replacing nomograms from the early editions).

Rules of thumb for chemical engineers: example 1

TABLE 7.1 Safety Considerations for Pumps

Sizing and Specifications	Provide motor that is nonoverloading under foreseeable operating conditions. Engineers often specify that motors for centrifugal pumps be nonoverloading at runout Specify all pump components, such as seals, for the design pressure and temperature of the system (e.g., the same as connected piping and valves) Provide pressure relief and evaluate potential overpressure scenarios Consider abnormal operations such as dead-heading Ensure that if shaft seals require seal fluid that the fluid is always available when the pump is running Consider providing a means to measure pressure rise through the pump and flow rate For pumps that give a pulsating flow, ensure that the connected piping system is designed for the maximum pressure (not just the average discharge pressure) and for the pressure pulsations. Consider using a pulsation dampener
Installation	Follow all precautions and procedures provided by the pump manufacturer Provide drip pans, curbs, or drainage to contain leaks that may occur during operation or maintenance Provide adequate space around pumps for maintenance Guard against potential injuries to personnel with covers and screens that prevent people from touching rotating parts or having rotating parts snag clothing Use temporary strainers on the suction side of pumps during initial start-up to trap materials that may be in the newly installed piping system (such as welding slag)
Operation	Maintain operating logs that track the pump performance (such as discharge pressure). Logs should be reviewed periodically to identify trends that may indicate performance degradation Ensure operators are trained in the start-up, normal operation, and shut down of pumped systems. This includes alarms and emergency response Before starting any pump, check that all valves are in the correct position. Valves in the intended flow path should be open and vents and drains should be closed. When pumps are operated for an extended period while closed in they can explode. This is because all of the pumping energy is converted to heat. The heat expands the fluid in the pump, which can break the seal or casing [1]
Maintenance	Enforce the use of Lock Out/Tag Out procedures whenever pumps are being maintained Perform routine preventative maintenance according to established schedules and following prescribed procedures Maintain equipment history files that document the pump's life cycle. This typically includes the original specifications, changes (such as components that might be replaced whether or not the new component is "like for like" to the original), maintenance, and failures

Rules of thumb for chemical engineers: example 2

TABLE 12.4 Shell-and-Tube Exchanger Selection Guide (Cost Increases from Left to Right) [11]

Type of Design	"U" Tube	Fixed Tubesheet	Floating Head Outside Packed	Floating Head Split Backing Ring	Floating Head Pull-Through Bundle
Provision for differential expansion	Individual tubes free to expand	Expansion joint in shell	Floating head	Floating head	Floating head
Removable bundle	Yes	No	Yes	Yes	Yes
Replacement bundle possible	Yes	Not practical	Yes	Yes	Yes
Individual tubes replaceable	Only those in outside row	Yes	Yes	Yes	Yes
Tube interiors cleanable	Difficult to do mechanically, can do chemically	Yes, mechanically or chemically	Yes, mechanically or chemically	Yes, mechanically or chemically	Yes, mechanically or chemically
Tube exteriors with triangular pitch cleanable	Chemically only	Chemically only	Chemically only	Chemically only	Chemically only
Tube exteriors with square pitch cleanable	Yes, mechanically or chemically	Chemically only	Yes, mechanically or chemically	Yes, mechanically or chemically	Yes, mechanically or chemically
Number of tube passes	Any practical even number possible	Normally no limitations	Normally no limitations	Normally no limitations	Normally no limitations
Internal gaskets eliminated	Yes	Yes	Yes	No	No

Rules of thumb for chemical engineers: example 3

INSTALLATION RECOMMENDATIONS

Shell-and-tube heat exchangers

Here are installation tips for typical shell-and-tube heat exchangers [1,19].

- Provide sufficient clearance for removing the tube bundle at the head end of the exchanger. For exchangers with fixed tubesheets, allow room to remove the heads and clean the tubes (consider the possibility of using brushes that would be at least as long as the tubes).
- Provide valves and bypasses in the piping system for both the shell and tube sides. Ball valves with locking handles are recommended if available for the pipe sizes.
- Provide thermowells and pressure gauge connections in the piping at each inlet and outlet, located as close to the unit as practicable. Some exchangers are designed with these features, in which case they can be omitted from the piping.
- Provide valves to allow venting of gas vapor from the exchanger, and vacuum breakers for exchangers in steam service. The normal locations are close to the steam inlet or on the top portion of the shell.
- Ensure that foundations are adequately sized. In concrete footings, foundation bolts set in pipe sleeves of larger size than the bolt size will allow for adjustment after the foundation has set.
- Loosen foundation bolts at one end of the unit to allow free expansion and contraction of the heat exchanger shell.
- Exchangers in condensing steam duty should be installed at a 3° to 4° slope, toward the shell outlet, to facilitate the drainage of the condensate. Heat exchangers should be installed to promote gravity drainage with no vertical lift before or after steam traps. Condensate accumulating in the exchanger results in water hammer and poor temperature control; corrosion problems may also occur.

Rules of thumb for chemical engineers: example 4

TABLE 14.13 Global Manufacturers and Suppliers of Trays and Packings

Company	Brands	Products
Artisan Industries http://artisanind.com	Dualflo	Trays for solids-containing and fouling solutions (metallic)
Compagnie de Saint-Gobain Saint-Gobain NorPro http://www.norpro.saint-gobain.com	Norton WavePak	Saddles (ceramic) Super saddles (ceramic) Raschig rings (carbon) Cross-partition rings (ceramic) WavePak packing for sulfuric acid towers
FinePac Structures Pvt, Ltd. http://www.finepacindia.in	Finepac	Structured packing (metal) Trays (conventional) Pall rings and saddles (metal)
HAT International http://www.hatltd.com	Alpha	Structured packing (metal, plastic) Trays (conventional) Standard and high-performance random packings (metal, ceramic, plastic, glass)
Jaeger Products, Inc. http://www.jaeger.com	Super-Ring Tri-Packs Max-Pack	Structured packing (metal) Trays (conventional) (metal) Rings (plastic) Saddles (plastic, ceramic) Tri-Pack (plastic) Raschig Super-Ring (plastic, metal)

3. Example: Layout as One of Process Plant Design Topics

3.1 Importance of the topic
3.2 The discipline of layout design

3.1 Importance of layout design

- Good layout practice plays a vital part in the ongoing commercial success of a project. It does this by making the plant safe and efficient to construct, operate, and maintain, while making effective use of the land available.
- A well-thought-out layout also contributes to successful planning of the design and construction stages of a project.
- Good layout will not compensate for bad process design, but a bad layout can easily lead to an unsuccessful or unsafe plant. Changes to the layout during or after construction are very costly in both money and time.

Layout relation to accidents in chemical process plants

Journal of Loss Prevention in the Process Industries 25 (2012) 655–666

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Design as a contributor to chemical process accidents

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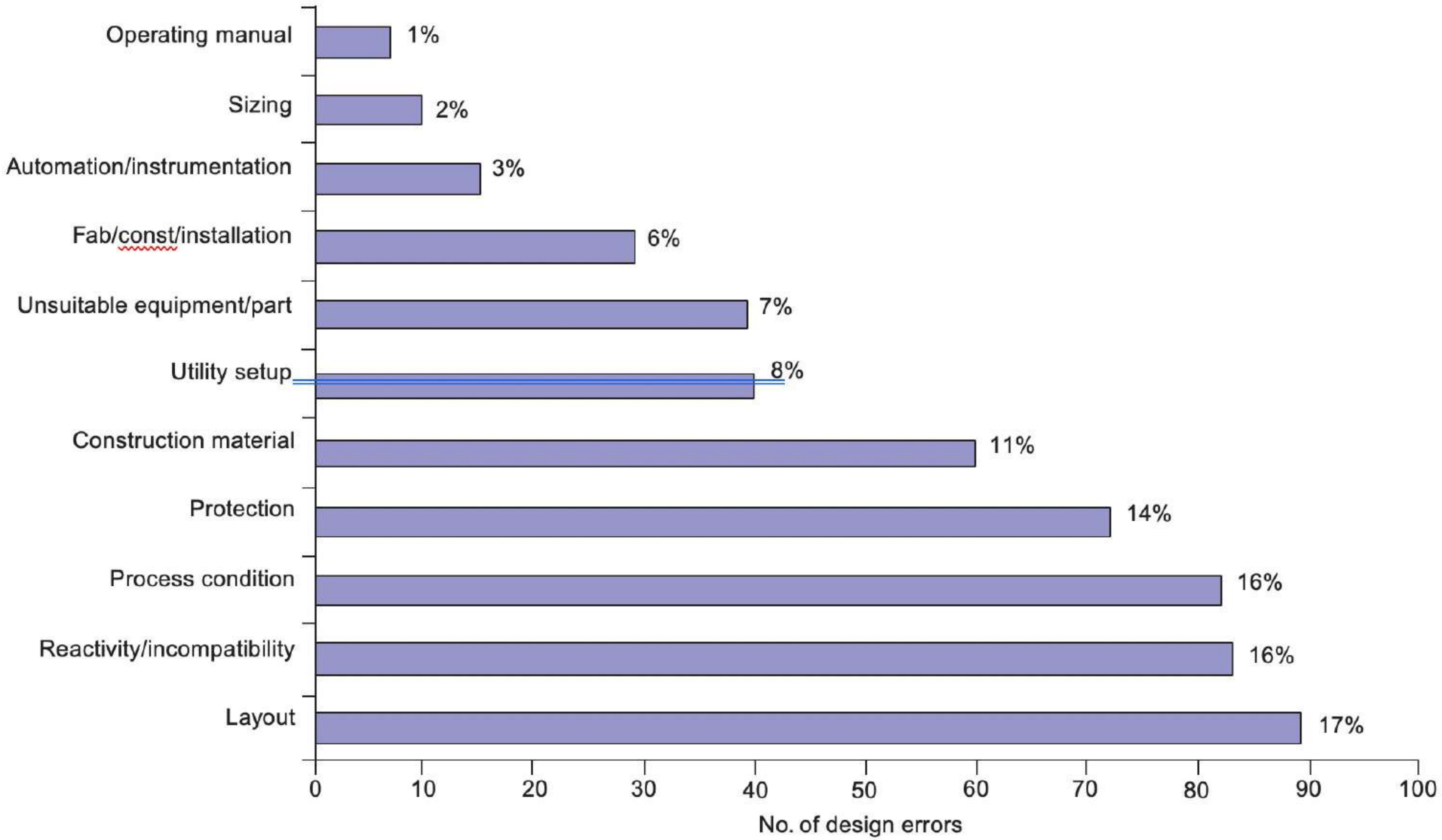
A B S T R A C T

The paper discusses the design errors in chemical process industry (CPI) by analyzing major equipment related accident cases from Failure Knowledge Database (FKD). The aim is to recognize the contribution of design to chemical process accidents and to evaluate the time of occurrence of the errors in a plant design project. The analysis of accident cases found out that the contribution of design to accidents is very significant: 79% of accident cases analyzed were contributed by design errors. The most critical design errors were poor layout (17%), insufficient consideration of chemical reactivity and incompatibility (16%) and incorrectly chosen process conditions (16%). The design errors were initiated at basic (32%), detailed (32%) and preliminary (22%) design phases of the project. Errors in fundamental aspects of chemical processes e.g. route selections are more severe (as compared to others errors class) and might creates many similar errors in later phases of design project. Based on the accident information gathered, a straightforward point-to-look list for error detection and elimination was suggested for process lifecycle stages.

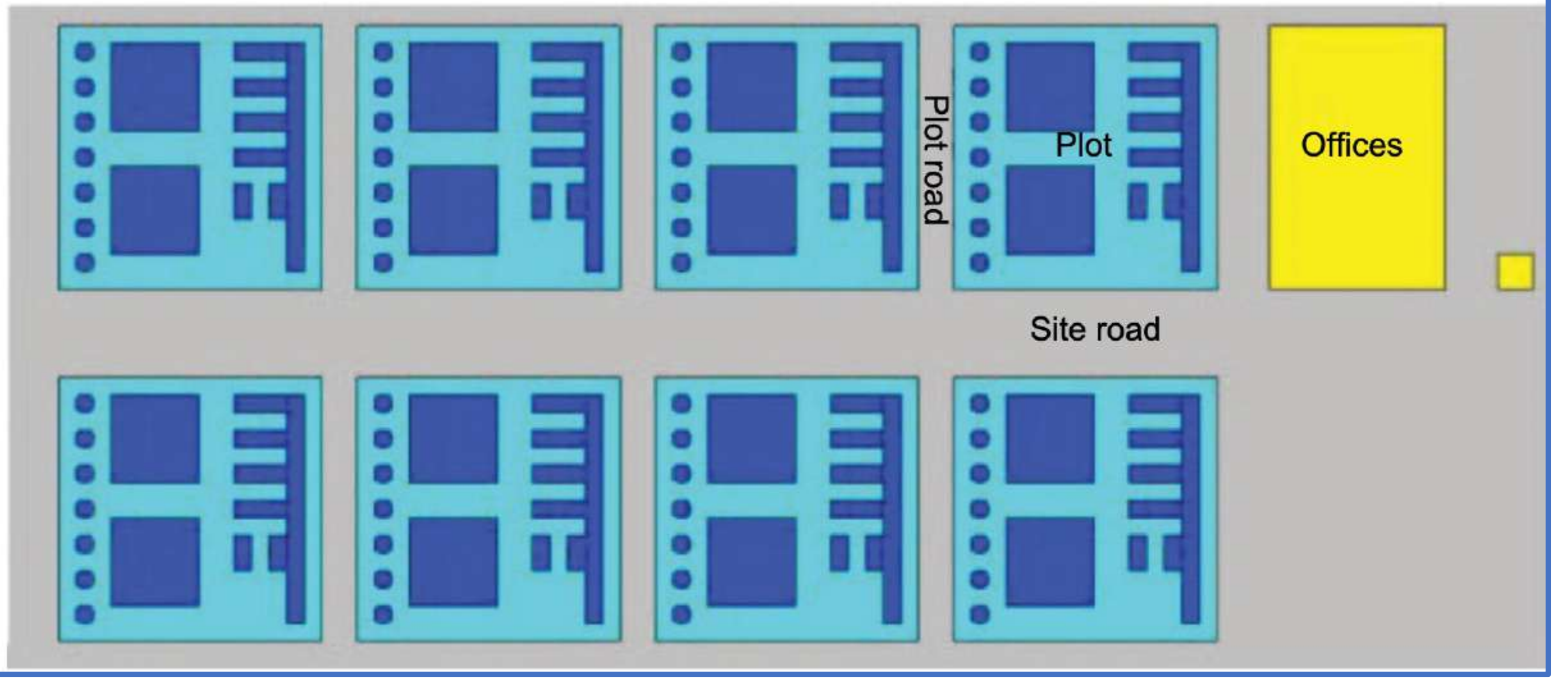


Distribution of design errors, Kidam, K., & Hurme, M. (2012). Design as a contributor to chemical process accidents, Journal of Loss Prevention in the Process Industries, 25(4), 655-666

3.2 The discipline of layout design

- The discipline of layout design is concerned with the spatial arrangement of process equipment and its interconnections, such as piping.
- Good layout practice achieves a balance between the requirements of safety, economics, the protection of the public and the environment, construction, maintenance, operation, space for future expansion, and process needs. It will also take into account weather conditions, country-specific legislation and regulations, as well as esthetics and public perception.

- A process production facility or “Site” (defined as “Bounded land within which a process plant sits”). A Site may contain a number of process plants, as well as non-process plant and buildings. In the shown figure, the site is in gray.
- A “Process Plant” (or more simply “Plant”) has been defined as “a complete set of process units and direct supporting infrastructure required to provide a total operational function to produce a product or products.”



Within the discipline of layout design, a distinction is commonly made between piping layout (defined as “the layout of piping and associated support systems”) and equipment layout (“layout at the level of a single process unit and associated ancillaries”).

4. Main Layout Considerations

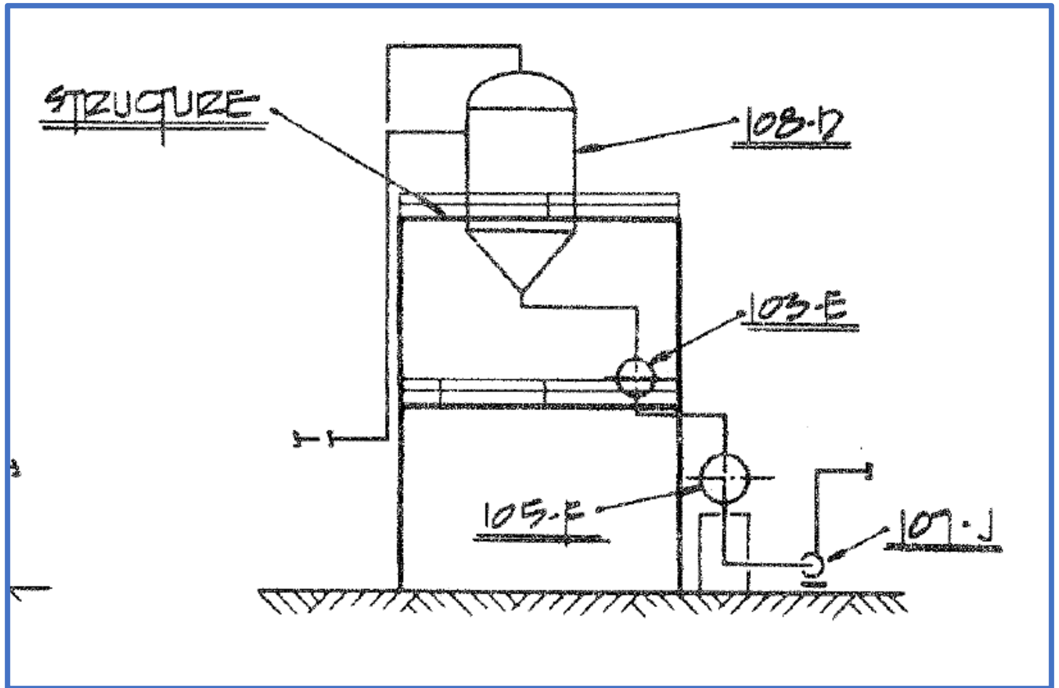
4.1 Process Requirements
4.2 Economical Considerations
4.3 Construction Considerations
4.4 Commissioning Considerations
4.5 Operational Considerations
4.6 Maintenance Considerations
4.7 Future expansion Considerations
4.8 Safety and emergency considerations

4.1 Process Requirements

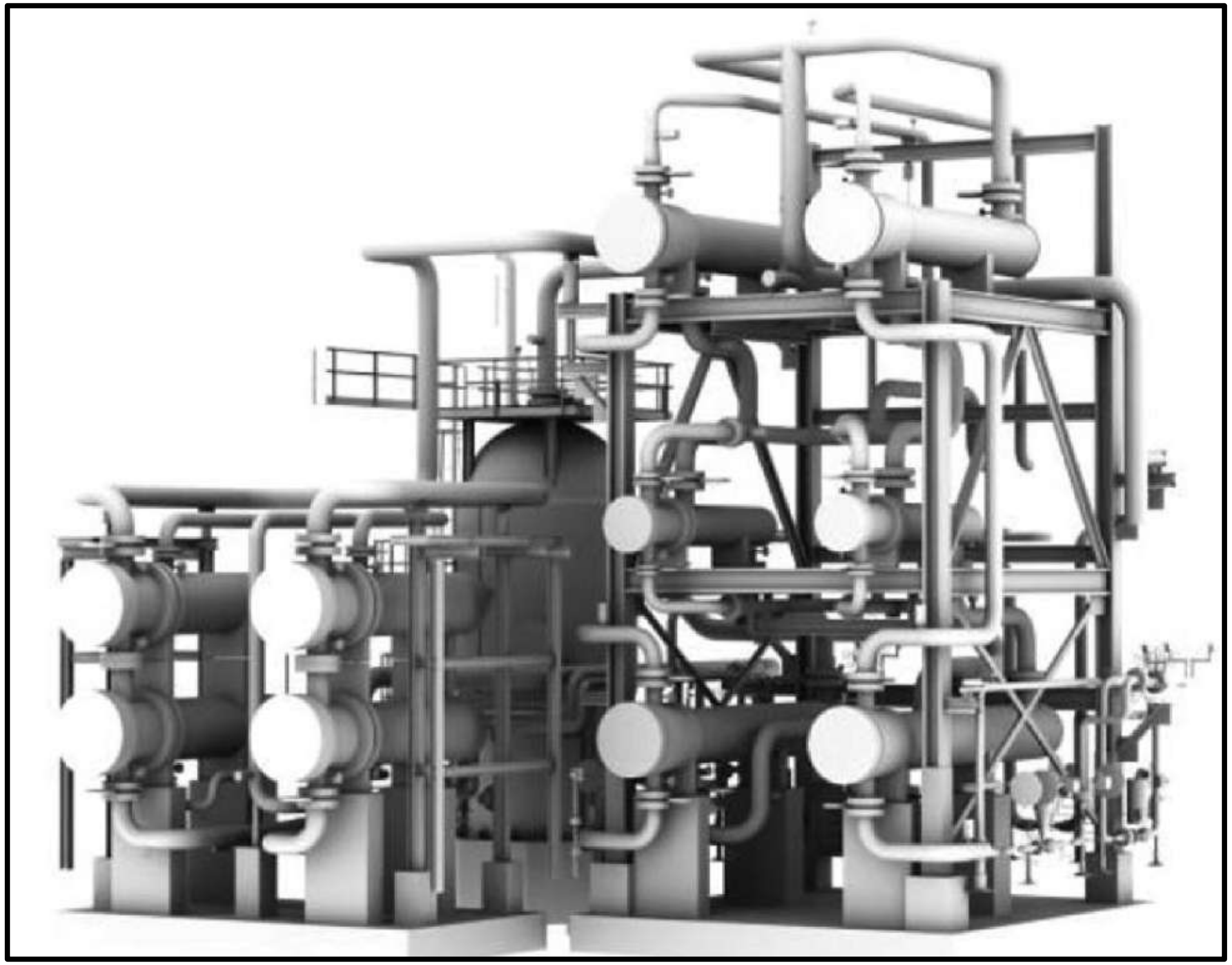
Process considerations include:

1. The desirability of gravity flow
2. Limitations of pressure or temperature drop in transfer lines and heat exchangers
3. Sufficiency of head for orifices, reflux returns, control valves, and pump suctions, particularly for liquids near their boiling points
4. Positioning of flow meters
5. Length of instrument transmission lines
6. Requirements for operation particularly for manual materials handling operations

Process requirements example:
one vessel may need to be placed above another to provide gravity flow.



Gravity flow design



Spacing

Moran's book presents a guide to good practice and, although the contents set out recommended spacings and arrangements, it must be remembered that these are only typical and not mandatory. They may have to be altered to suit local conditions, the specific requirements of plant owners and established safe practices.

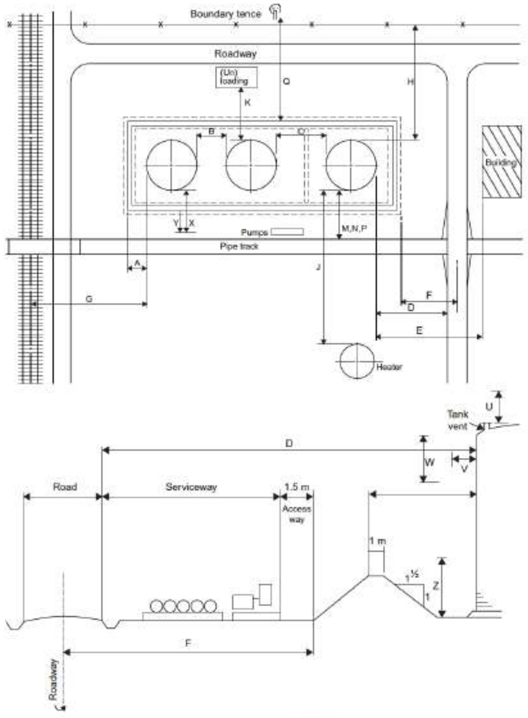
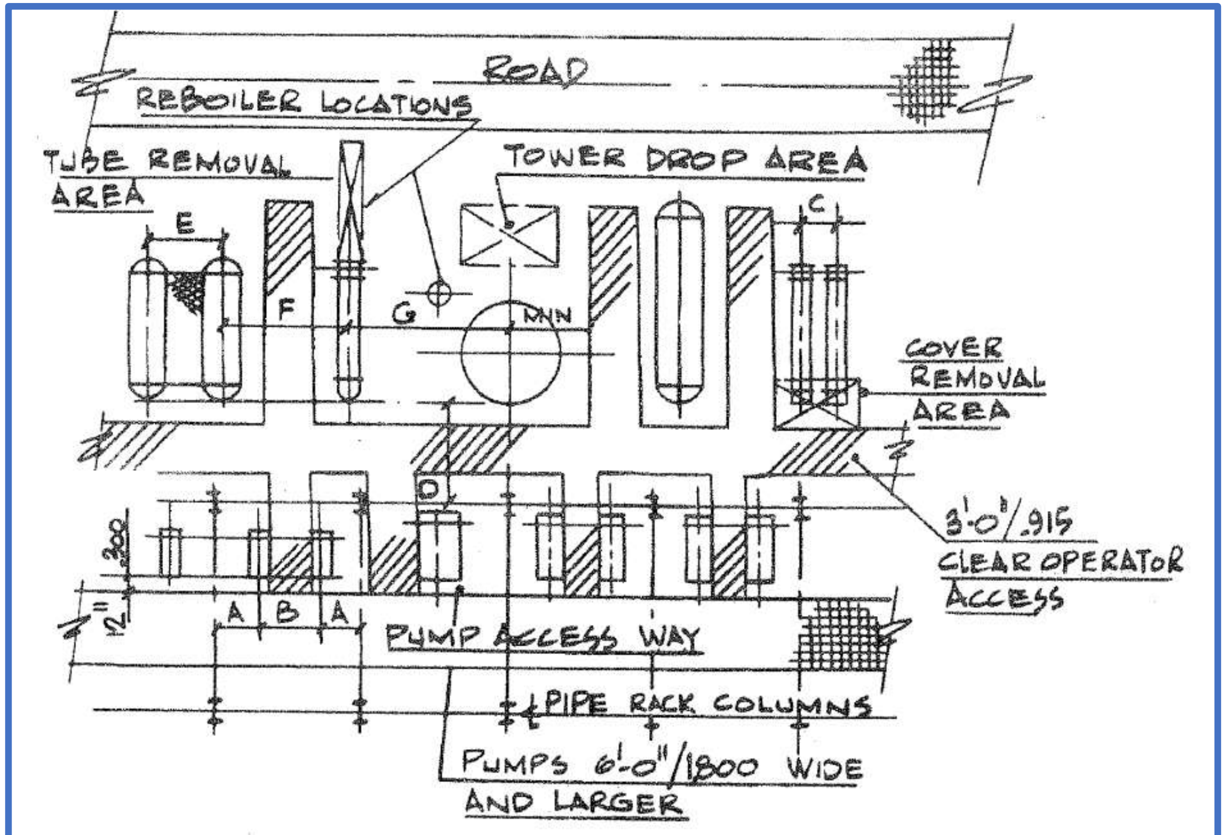


FIGURE C.1 Preliminary tank farm layout: (A) plan view and (B) elevation. (See Table C.8 for key and full data)

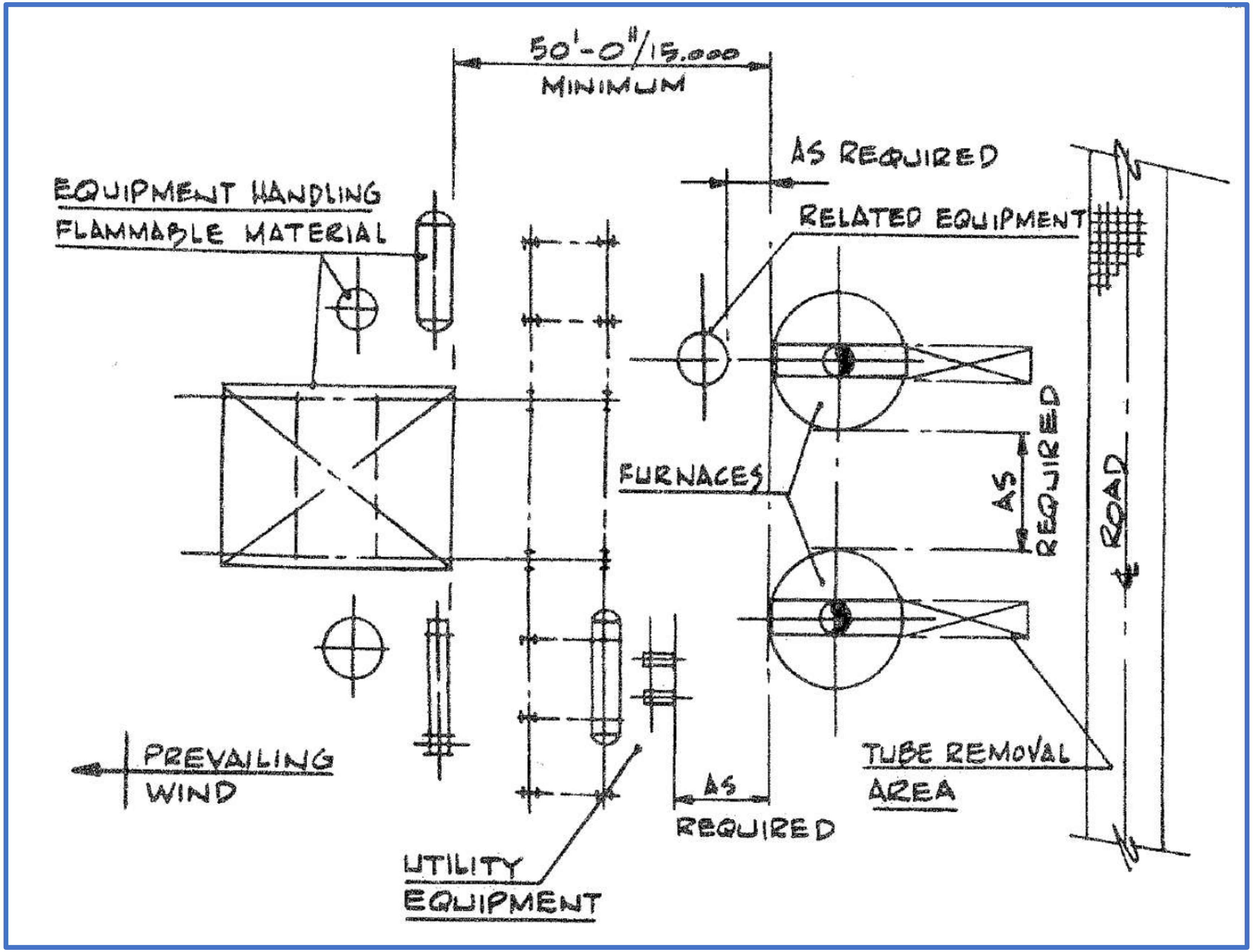
TABLE C.8 Liquids Stored at Ambient Temperature and Pressure (see Fig. C.1)

		Preliminary Minimum Clearance			
Dimension (Fig. C.1)	Diameter of Tank	Water and Nonflammable Liquids	Class A and B Products	Class A and B Products (Flash Point < 32°C)	Class C Products
			Fixed Roof	Floating Roof	
A: from outside of tank to outside of bund at top	Up to 6 m	–	3 m		3 m
	6–30 m		Half tank diameter		Half tank diameter
	Over 30 m		15 m	6 m	Half tank diameter
B: between any 2 tanks in one tank bund	All	1.5 m	Least of: Half diameter of largest tank, diameter of smallest tank, 15 m (minimum 6 m)	Least of: Half diameter of largest tank, 6 m	Half diameter of smallest tank, minimum 3 m
C: between any two tanks in adjacent bunds	All	–	Diameter of largest tank, minimum 10 m	Diameter of largest tank, minimum 6 m	Diameter of largest tank, minimum 6 m
D: from tanks to main plant roads	All	6 m	15 m	6 m	6 m

Typical tower area spacing



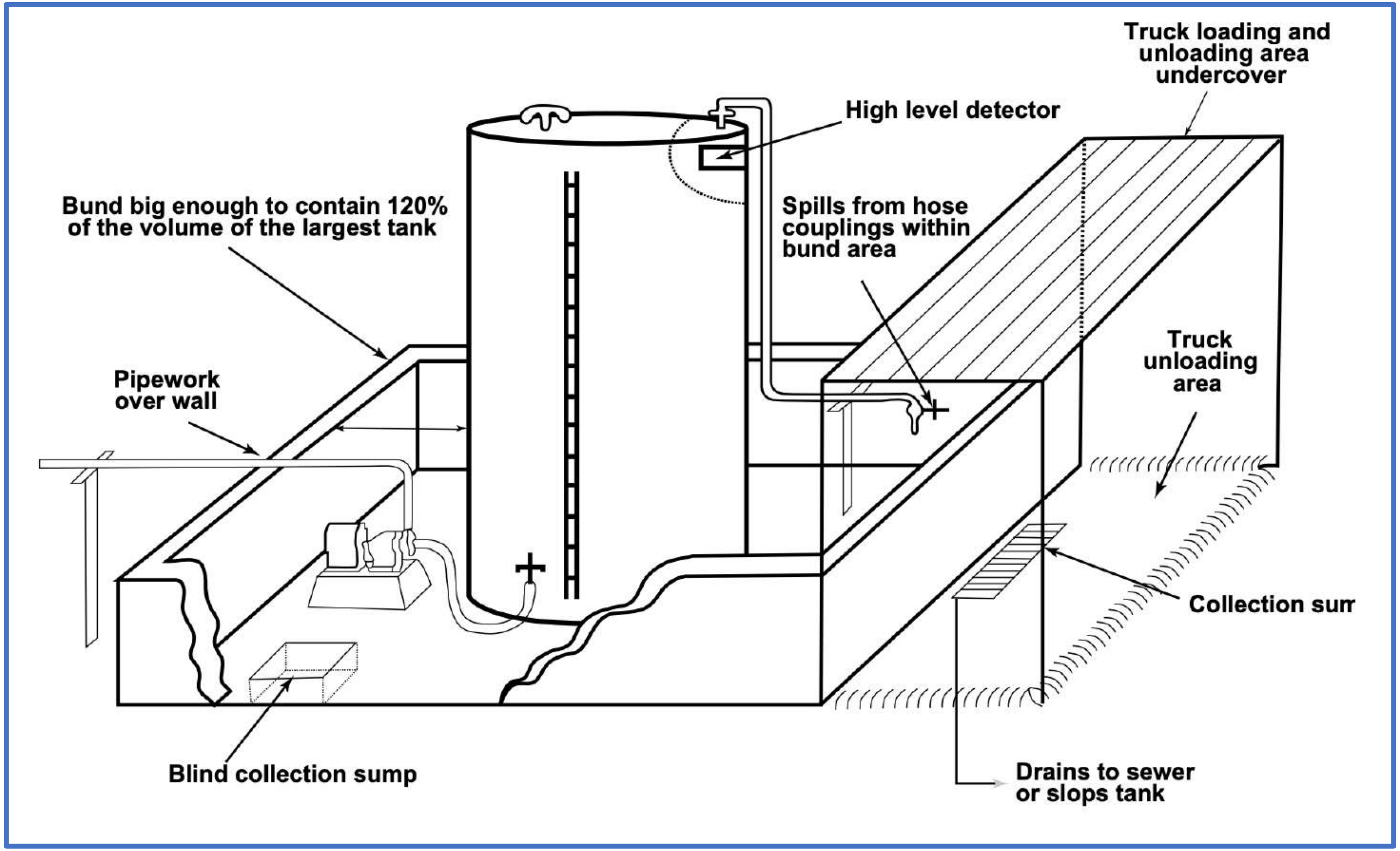
A =	5'-0" 1.500
B =	10'-0" 3.000
C =	1/2 DIAMETER EXCHANGER FLANGES + 18"/.450
D =	8'-0"/ 2.400 TO 10'-0" 3000
E =	1/2 DRUM DIAMETERS + 4'-0"/1.200
F =	1/2 DRUM DIAMETER + 1/2 EXCHANGER DIAMETER + 3'-0"/.915 OPERATOR ACCESS + 3'-0"/.915 FOR PIPING AND CONTROLS
G =	MINIMUM FOR FLEXIBILITY



Typical furnace area spacing

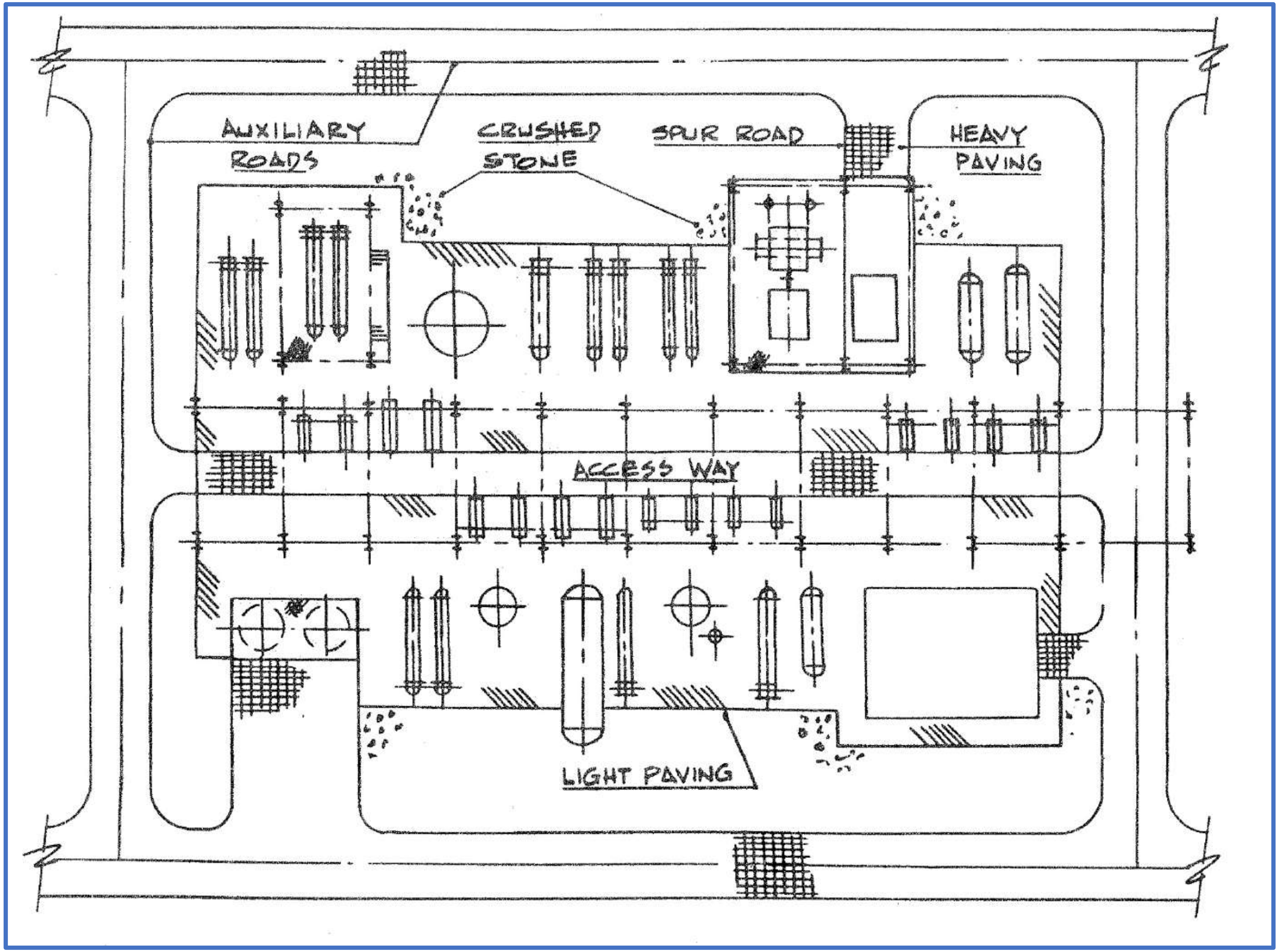
Segregation

- The main reasons for segregation of plots are safety and loss prevention (to prevent a major accident or fire in one plant from spreading to another plant), housekeeping, prevention of cross-contamination, and access for construction and maintenance.
- Segregation may be achieved by several methods:
  - Distance-based segregation: in open plant, considerations of weather-related impact need close consideration
  - Bunding: this must be sufficient to provide containment of a hazard
  - Physical object or enclosure based: this may be via the introduction of a wall or floor, or as a part of a total containment system or building envelope.



Example of bunding for bulk liquid storage tanks

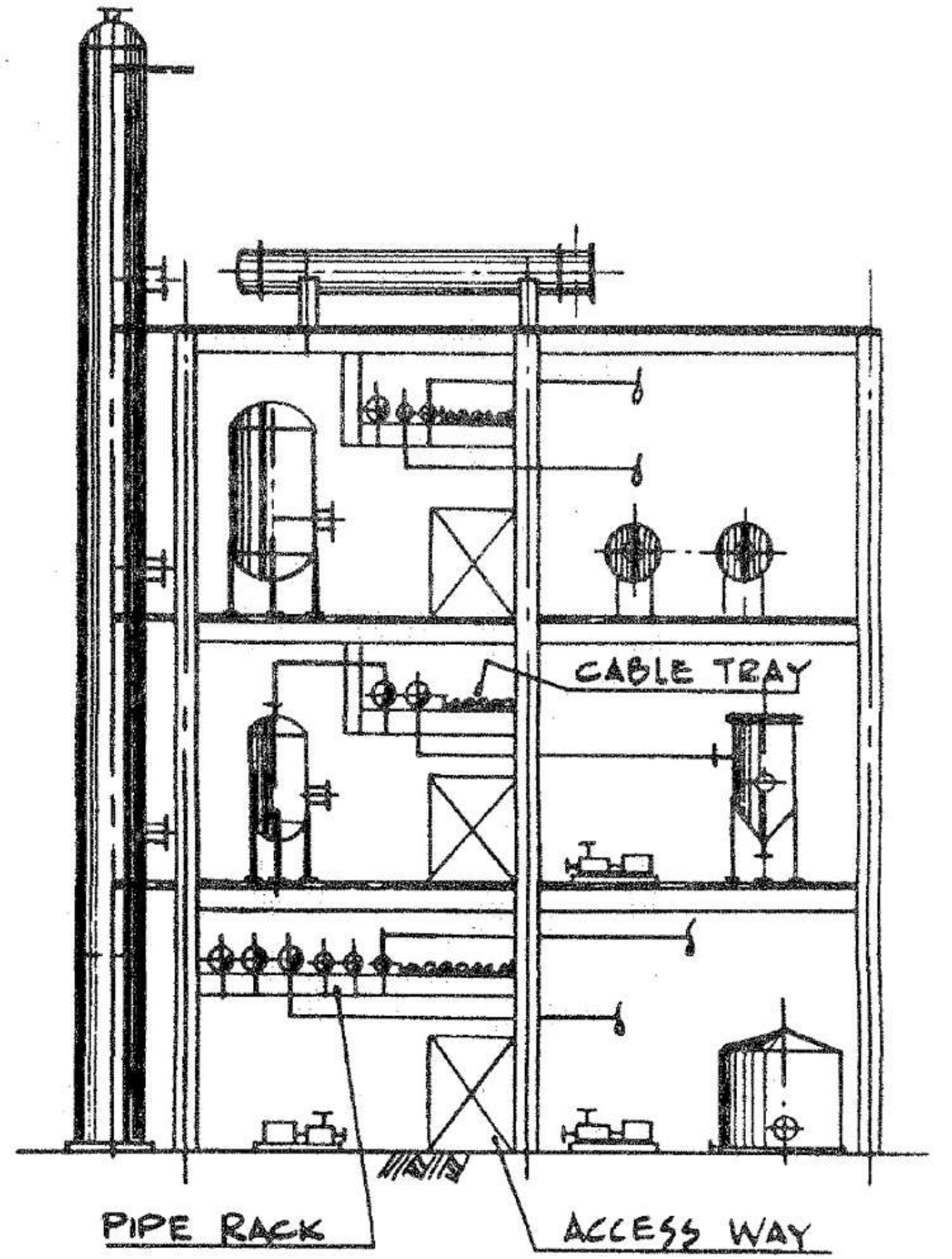
Typical process unit road and paving arrangement



4. 2 Economical Considerations

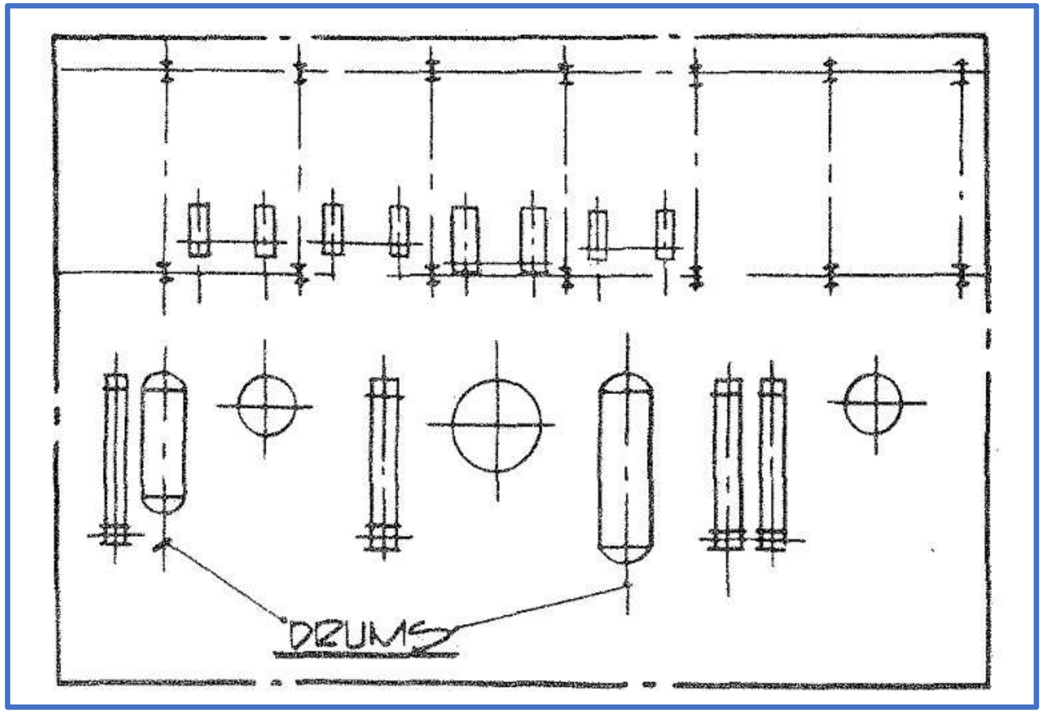
- Economical plant layout is concerned mainly with minimizing the costs of steelwork, concrete, piping, and electric cables.
- Tall structures with their deep foundations can be greatly reduced by placing most equipment on the ground. Where structures are needed, they should support more than one item. To minimize piling costs, the heaviest equipment should ideally be located over the best load-bearing soil.
- Equipment should be located to avoid excessive pipe and cable runs. Long runs increase the amount of traywork and ductwork, conduit and insulation, bracketry and fittings. They also have greater energy losses, and consequently increased running costs.
- Computer programs intended to support the economic optimization of layouts are available. It should be emphasized, however, that economic considerations must never cause the constraints of safety and operability be overlooked

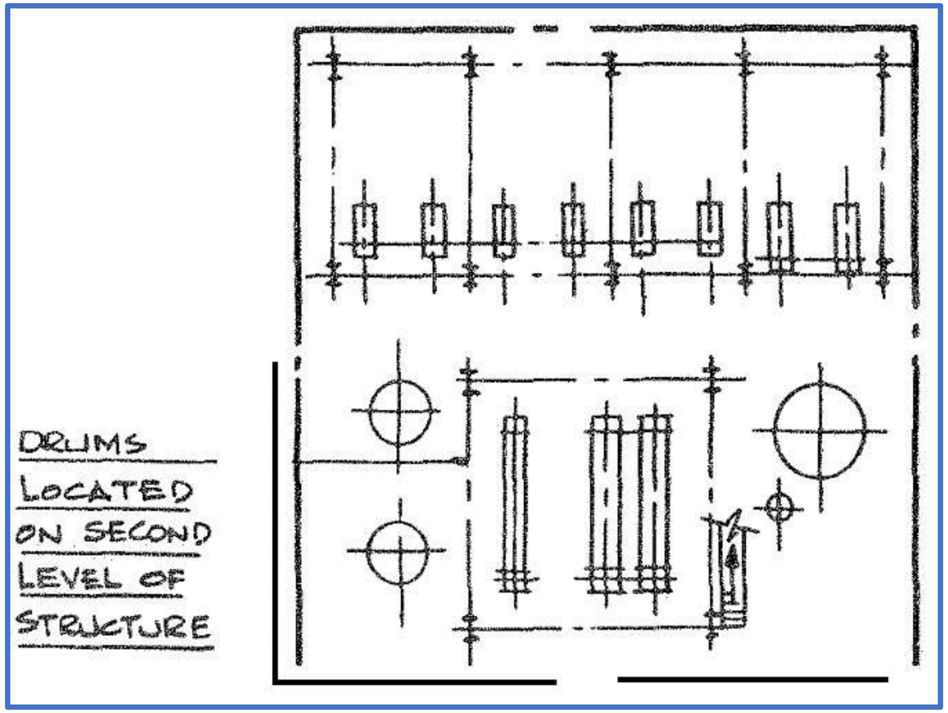
Economics example:
having two items sharing the same supports minimizes structural work, and placing heavy equipment on good load-bearing ground reduces the need for expensive piling.



Structure housing several pieces of equipment, pipe racks, cable trays.
Note relation with vertical column.

Economizing floor space





Before minimum space adjustment

After minimum space adjustment

4.3 Construction Considerations

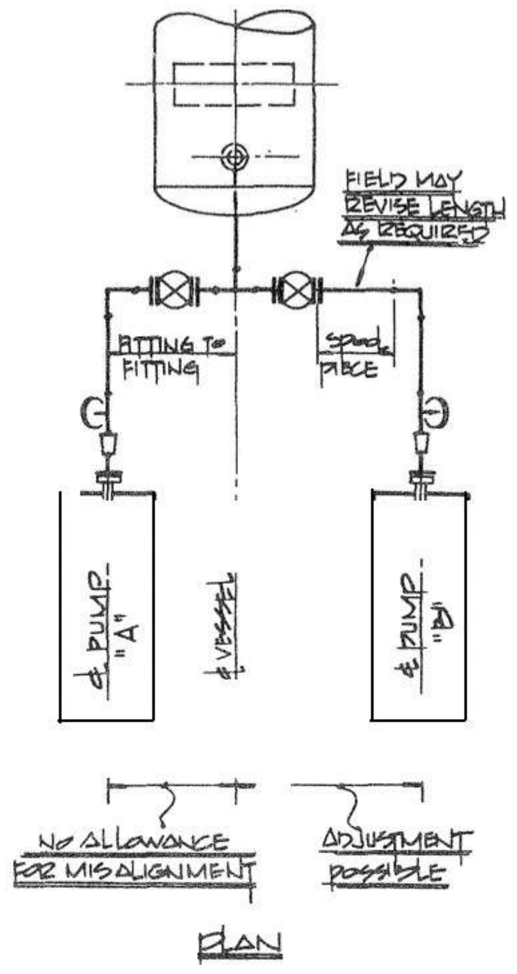
The locations of any item of process equipment likely to be delivered late in the construction program should be accessible without having to remove equipment already erected.

Delivery of a rotary dryer

Installation of a column

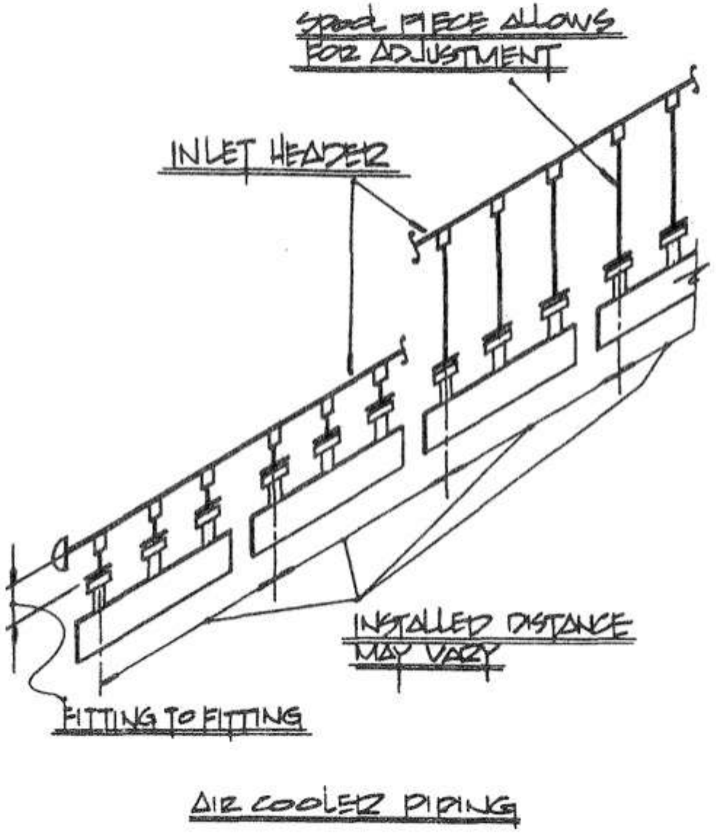
Constructability planning-example 1

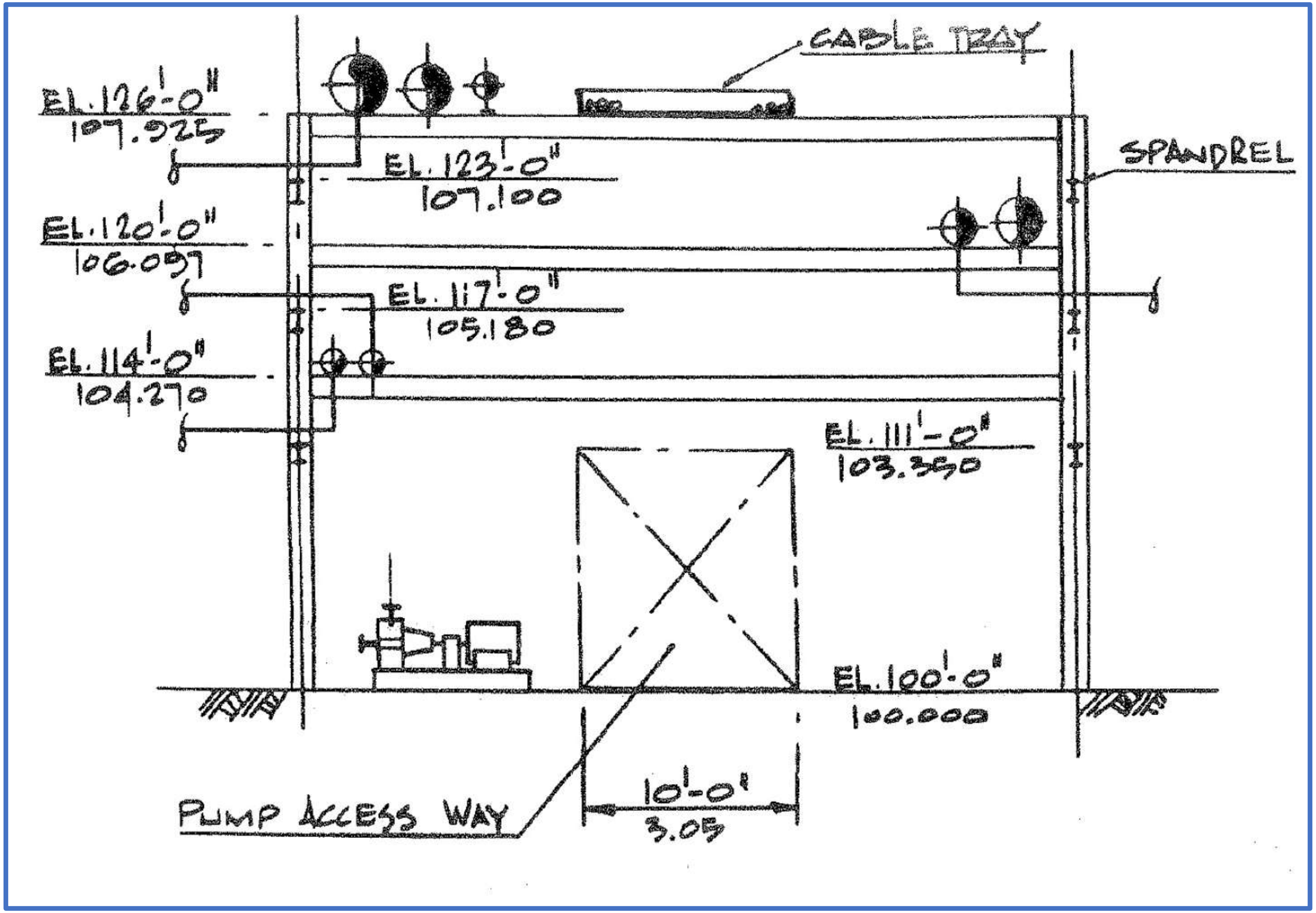
The suction piping of pump A is arranged fitting to fitting and does not allow the construction contractor any way to make an adjustment to a mis alignment between the centerline of the vessel and the pump. Although the piping configuration is basically correct, it ignores the constructability of the overall layout. Adding a spool piece to pump B permits any adjustment that construction may require.



Constructability planning-example 2

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 pre fabricated 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 re-centered on the nozzles. The fitting-to-fitting configuration does not permit this flexibility to the constructor.



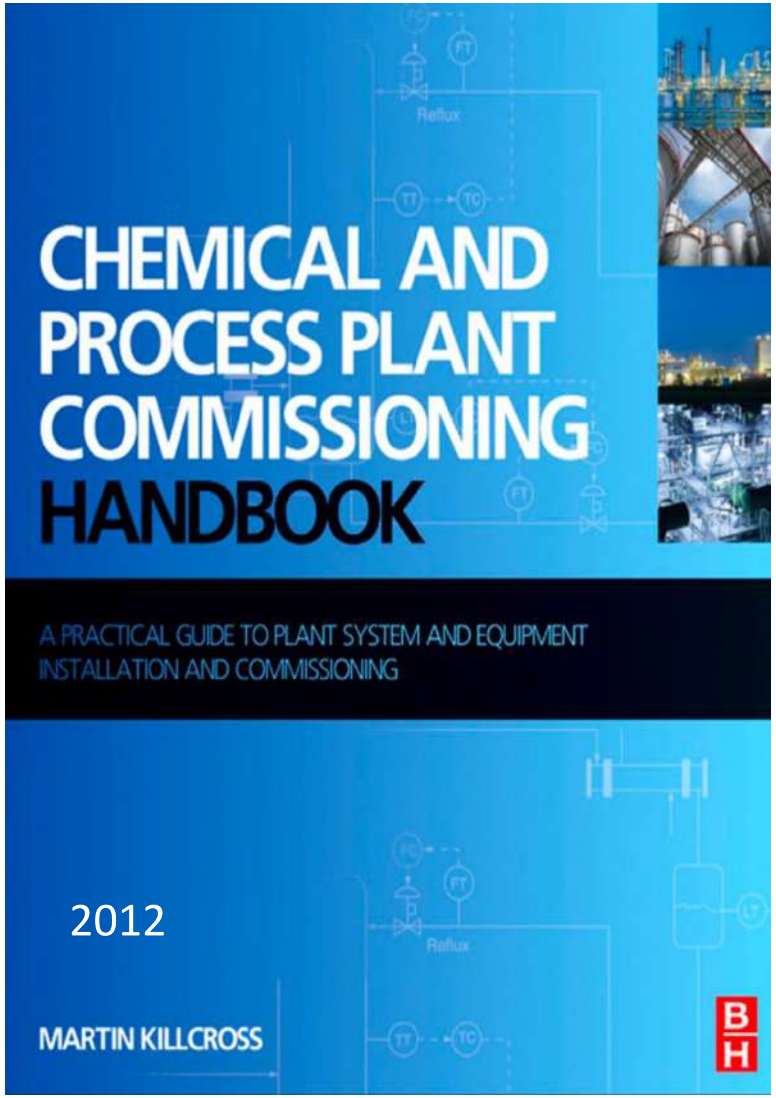


Pipe rack elevation

4.4 Commissioning Considerations

Ease of commissioning example: layout should allow easy commissioning of each piece of equipment.

- **Pre-commissioning**
- **Commissioning**
- **Start-up**



2012

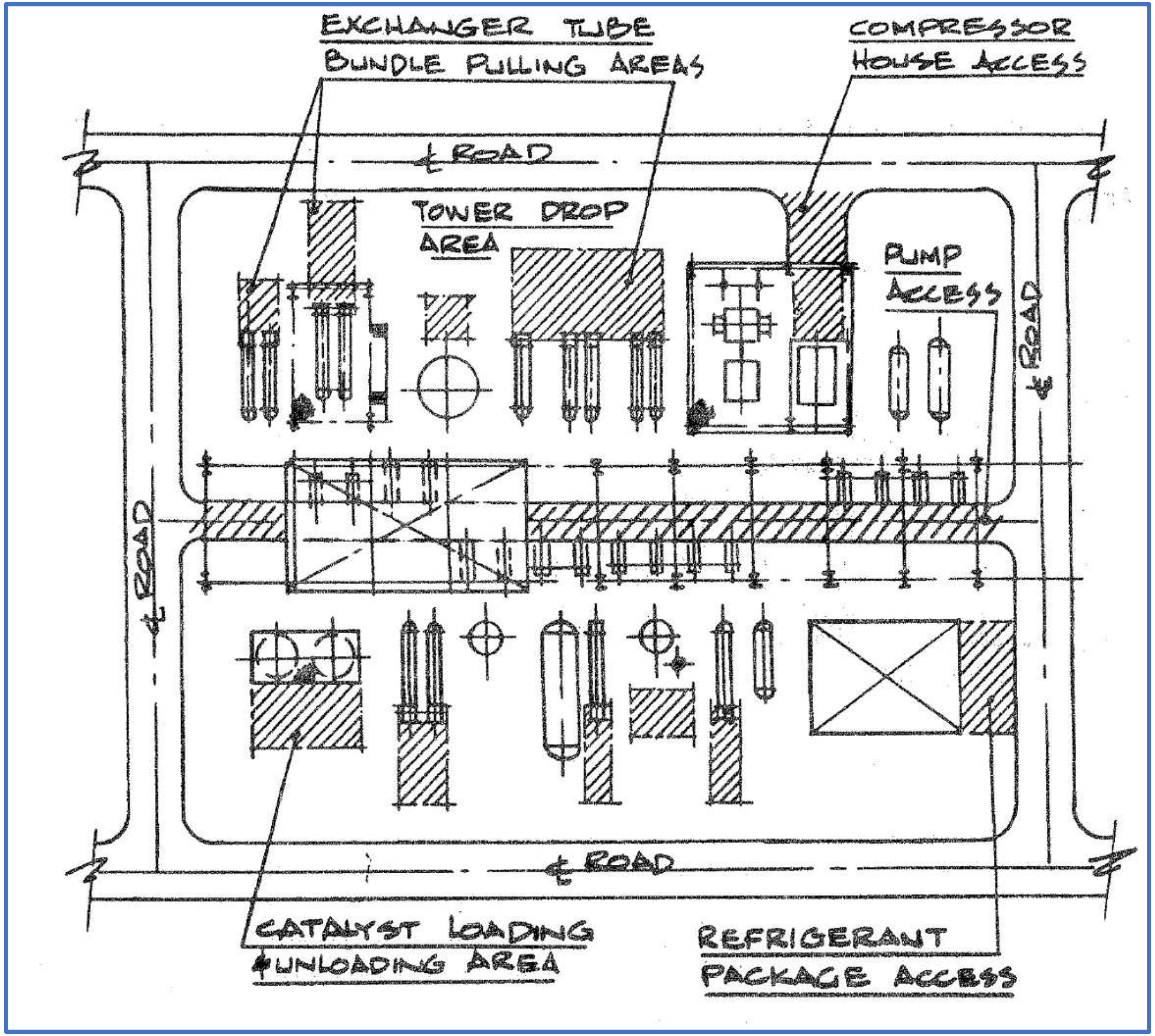
Layout Reviews by the Commissioning Team:

- Layout reviews access the overall plot plan of the asset for optimal placement of major items of equipment, vessels, pipe runs and escape routes.
- During a layout review, the commissioning team should be ensure that proper consideration has been made to the location of:
  - Utility stations
  - Safety equipment, showers, fire extinguishers
  - Ingress and egress; ensure there are no restrictions, support steel, stairways, pipes that
  - obstruct the ability to get in and out of the unit
  - Stairways and access ladders; ensure reverse “stepping off” from access ladder support pads does not create a tripping or stumble hazard
  - Major isolation valves
  - Instrument stands and motor start/stop buttons.

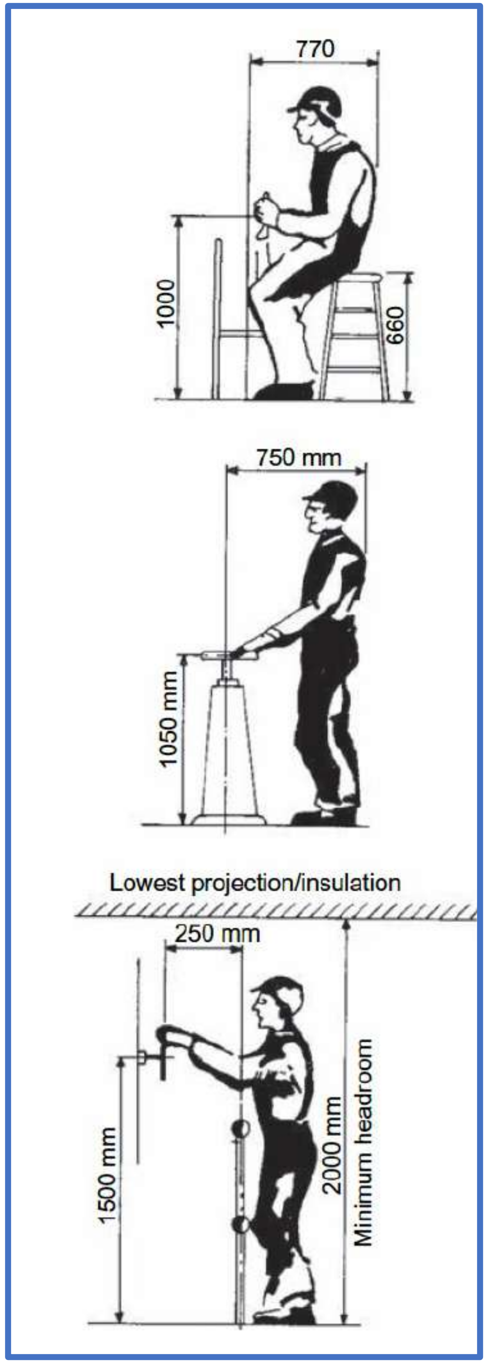
4.5 Operation Considerations

- Operational convenience is very important to achieving safe and reliable operation, by reducing the chances of making mistakes and increasing the probability of a malfunction being detected early.
- Equipment requiring frequent attendance should be reached by the shortest and most direct routes from the control room, which must itself be in a safe location. Valves and instrument dials should be at a suitable height so that they can be easily used or read.
- Batch processes require more attention by the operator than continuous ones and so greater consideration is be given to the ergonomics of the layout.
- All plots may require emergency escape routes and firefighting measures
- These considerations may be reviewed during design by virtual operation of a "walkthrough" 3D computer model of the plant.

Typical access requirements in an inline arrangement

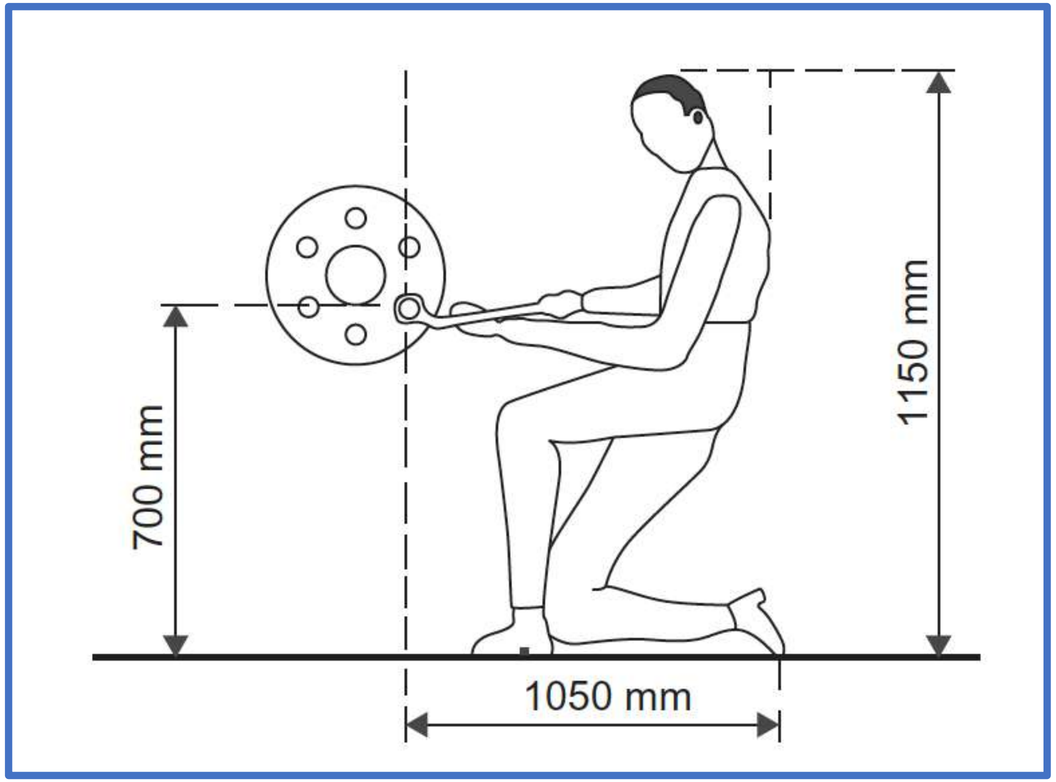


Main Layout Considerations



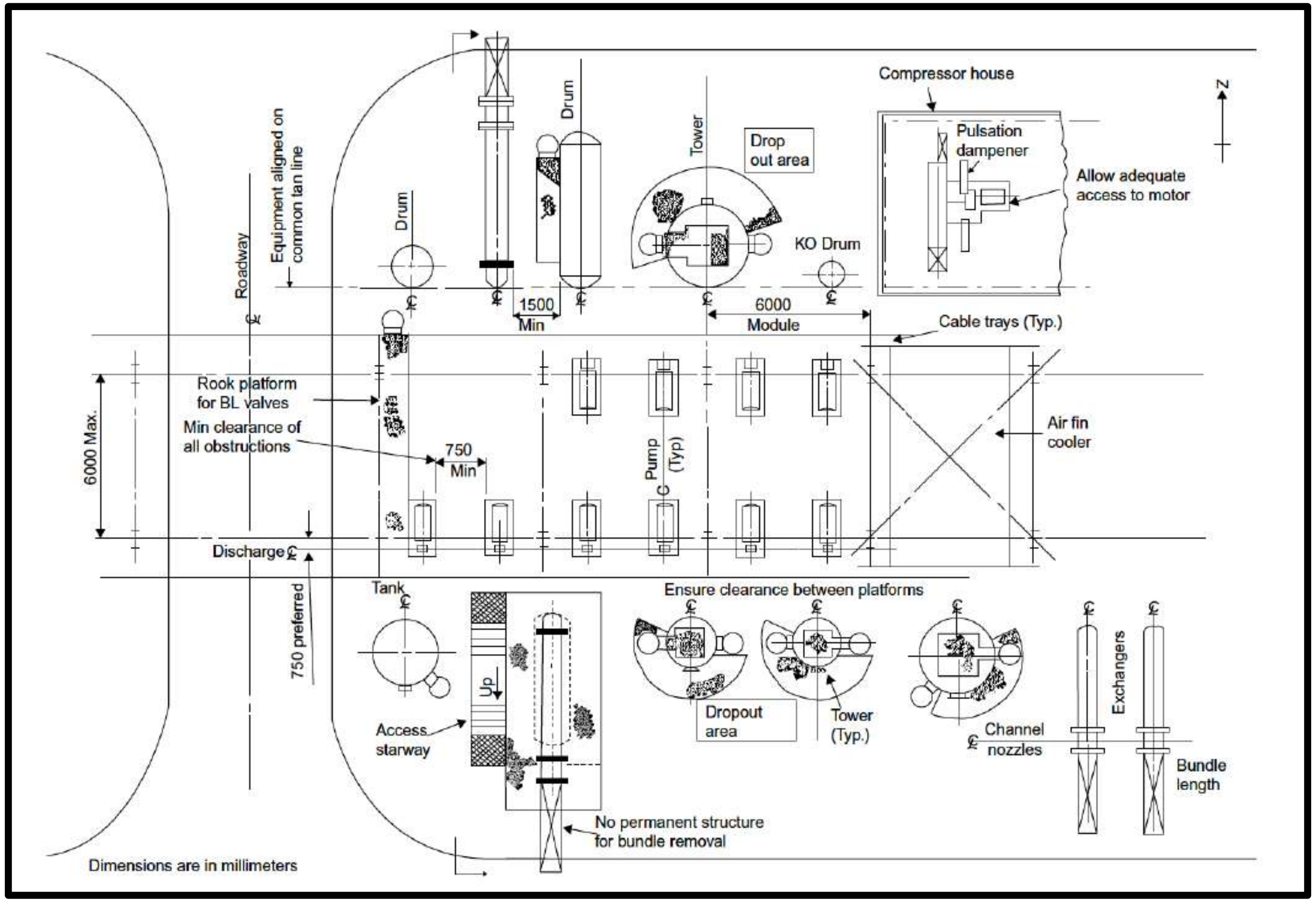
Valve heights

Operability example:
valves and instruments should be easily accessible to the operator, and operators should be able to move efficiently between areas of the plant.

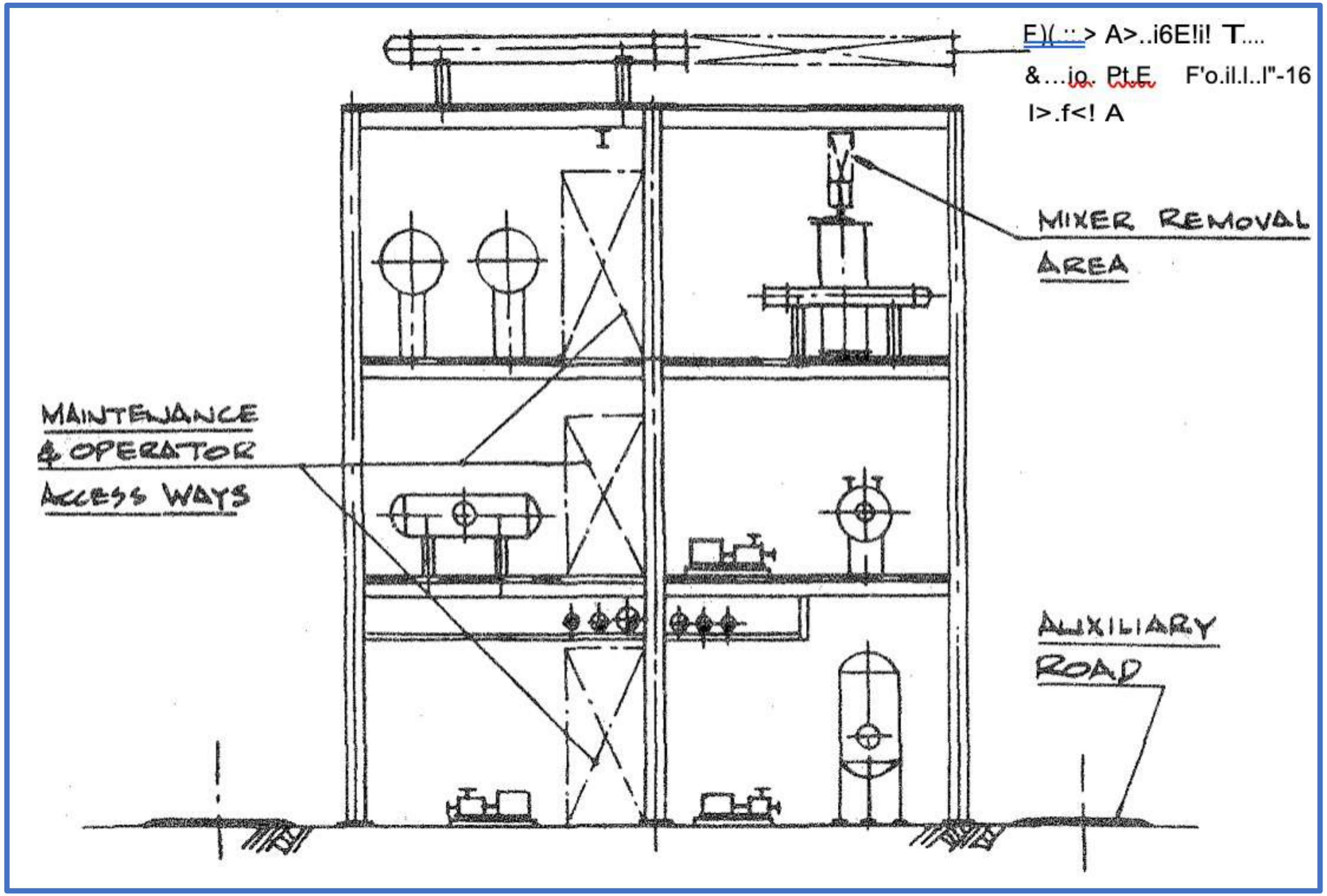


4.6 Maintenance Considerations

Ease of maintenance example:
a process unit should be capable of being dismantled and, if necessary, removed for repair and/or routine calibration.

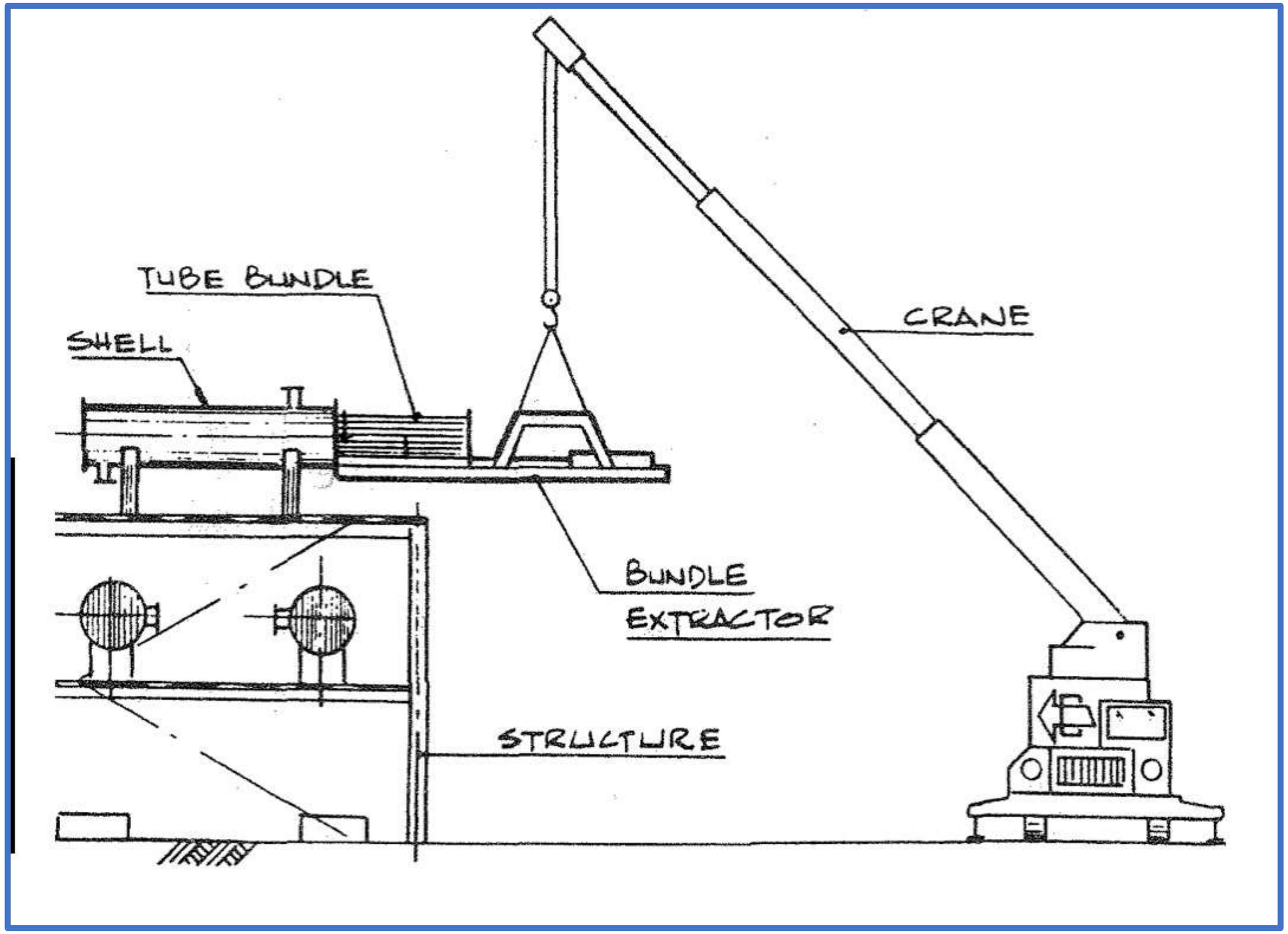


Typical access for maintenance



Typical access requirements in vertical arrangement

Main Layout Considerations



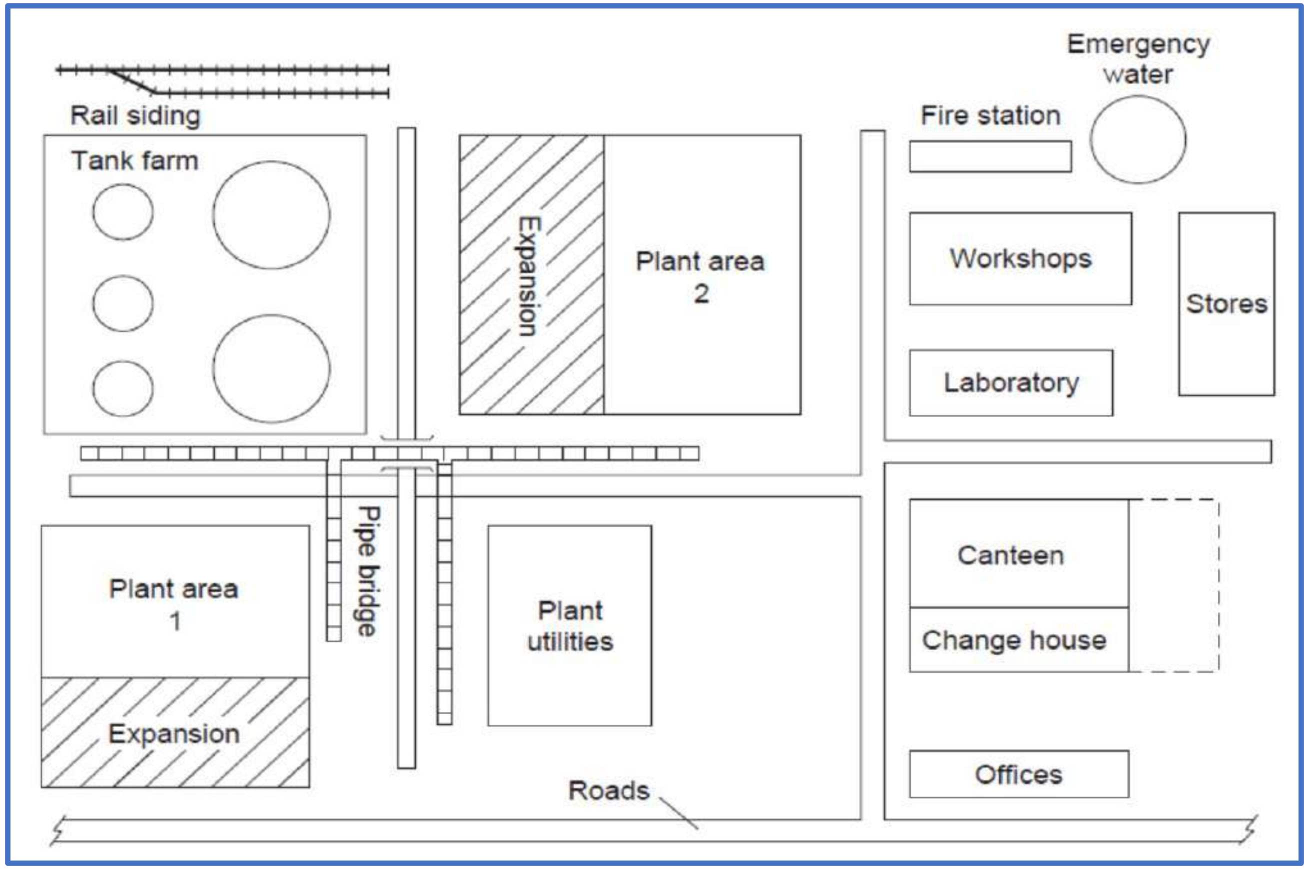
Removal of heat exchanger bundle using an extractor and a mobile crane

4.7 Ease of future expansion and extension

Moran: "Thought should be given to likely future expansion of structures, equipment, and pipework, so that any additions can be erected and tested with the minimum interference to plant operation.
On the other hand, the positioning of potential extensions should not involve excessive runs of pipework to link up
with the existing plant. The distance is fixed by balancing the cost of extra piping against the cost of taking precautions during erection, including the possibility of shutting down and then draining and purging pipework.
One approach to considering future expansion is to draft the likely working conditions on a permit to work and then see if the layout can be altered so that the conditions will be less restrictive on both operators and the construction team.
On the main pipe runs, it is desirable to leave room for future extensions. For oil and gas projects, 20% of the piperack width is a common allowance for future piping."

Ease of future expansion and extension

Foreseeable expansion should be possible with minimum interruption of production.



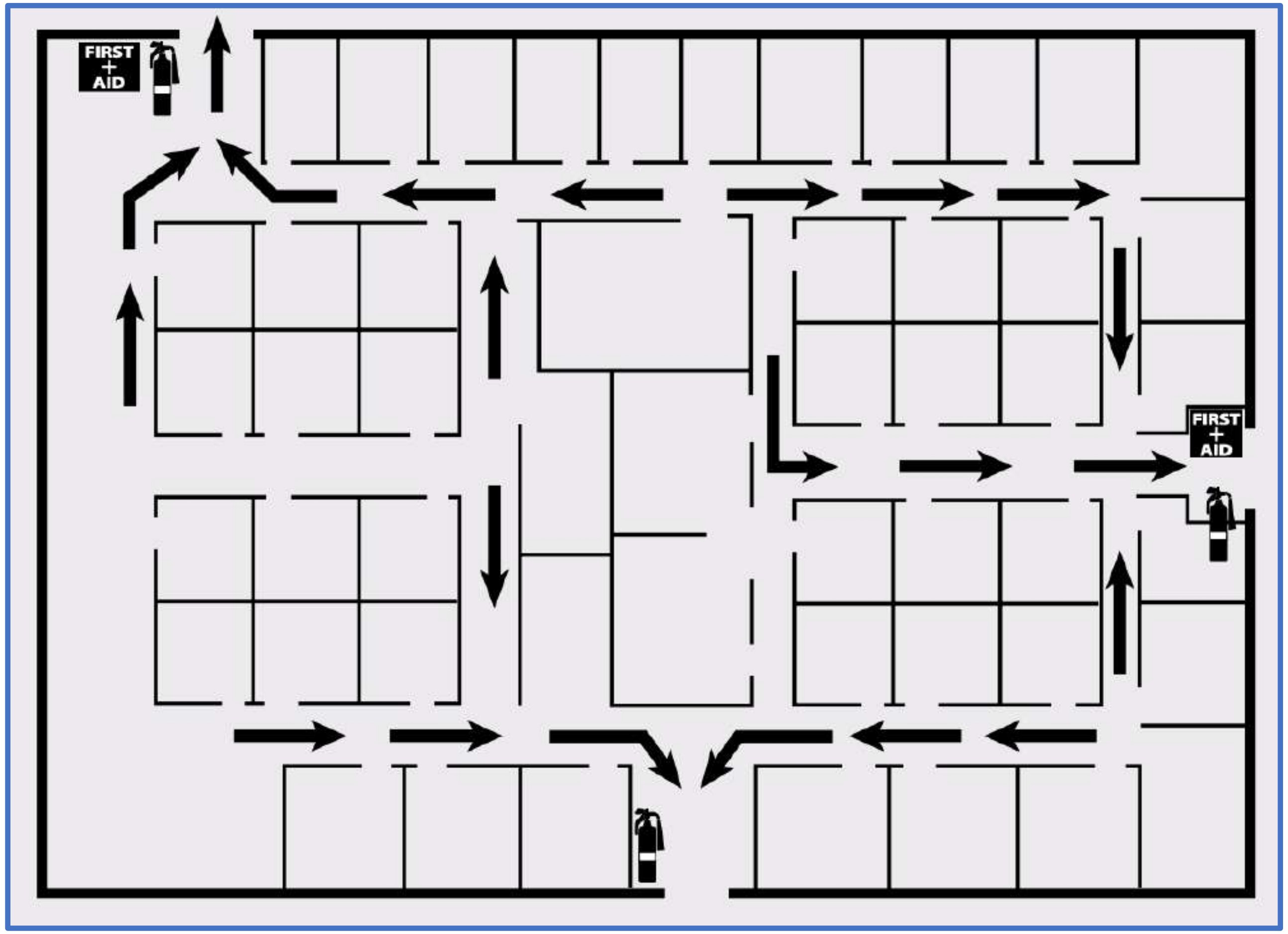
Vilbrandt,1959

4.8 Safety and Emergency Considerations

The layout of a plot can have a number of important impacts on plant safety. Layout designers need to make provision for:

1. Protecting operators from such hazards as tripping, bumping their heads or coming into contact with hot surfaces
2. Containing and channeling liquid spillages to safe recovery points, directing vents to safe locations, and installing adequate ventilation
3. Allowing vessels and pipework to be completely and safely drained
4. Reducing pipe and vessel fractures due to vibration, heat stress, and impact
5. Separating flammable materials from ignition sources and adopting electrical classification schemes
6. Protecting plot equipment and adjacent plots from the spread of fire by means of separation, insulation, and water screens
7. Planning appropriate firefighting and emergency escape procedures

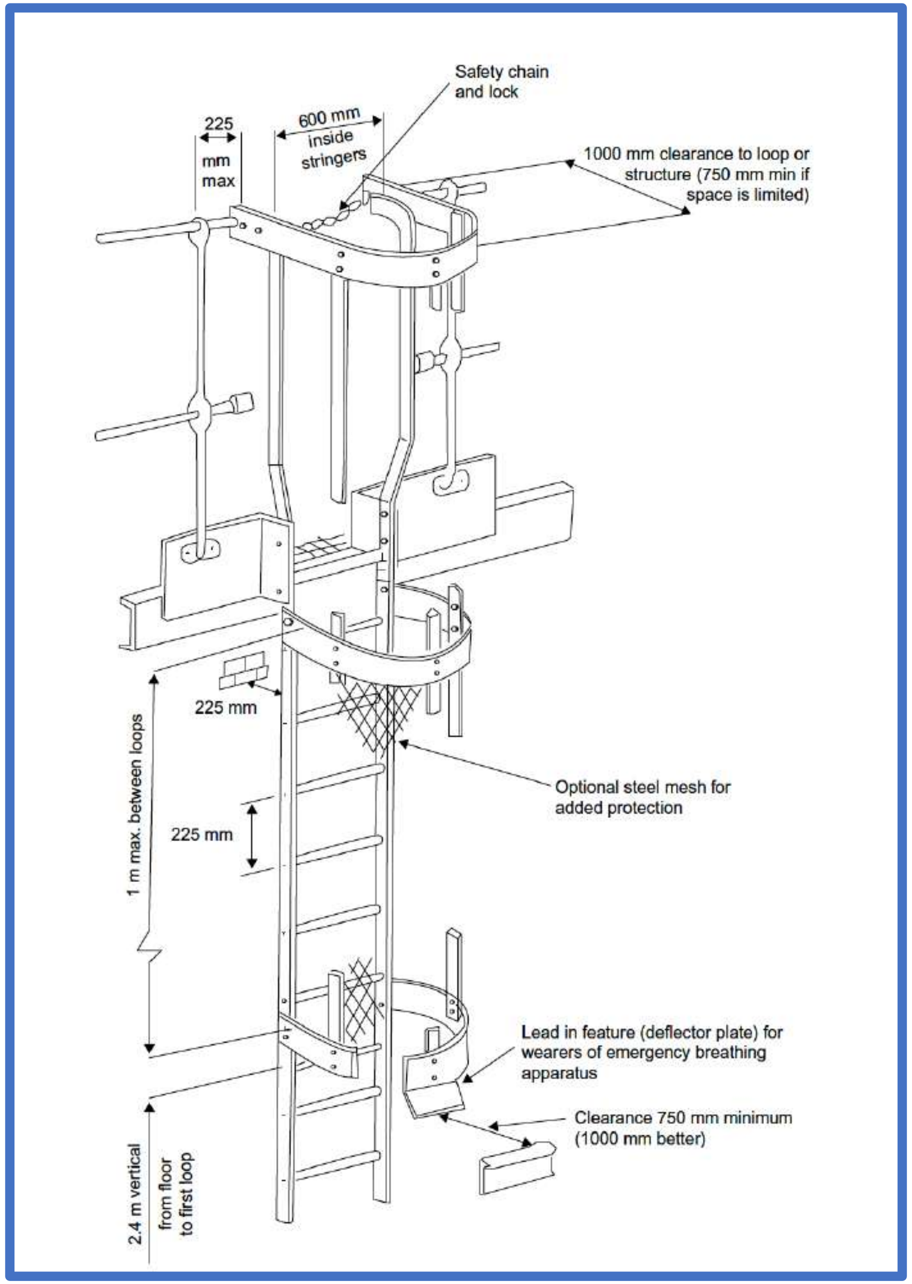
Ease of escape and firefighting: in an emergency, operators must be able to leave quickly and fire tenders must be able to approach close to the plant by more than one route.



Main Layout Considerations

Operator safety example: the operator must be protected from injury by (for example) protrusions, moving machinery, hot/cold surfaces, or escaping chemicals.

Safety ladder and safety bar

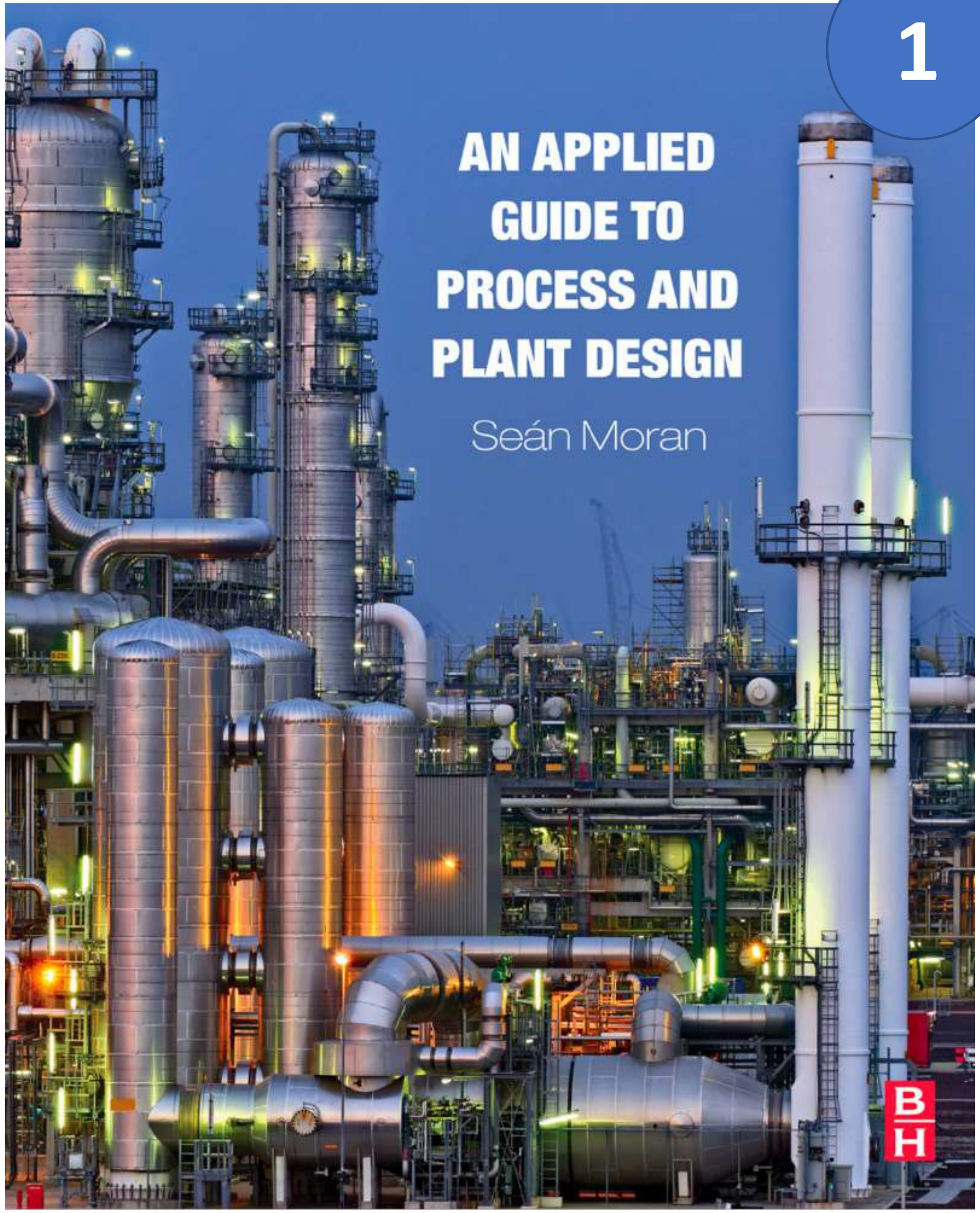


5. Concluding Remarks

I am proposing a program composed of six workshops to be sponsored by the Egyptian Society of Chemical Engineers.

Each workshop shall focus on one of the following references (all IChem E) . The material should be shared in advance with participating chemical engineers who can prepare case studies to be presented in the workshop.

1


AN APPLIED GUIDE TO PROCESS AND PLANT DESIGN
Seán Moran
B H

2


IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE
Second Editi
Process Plant Layout
Seán Moran
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3
ELSEVIER
Rules of Thumb for
Chemical Engineers
Sixth Edition
Stephen M. Hall, PE
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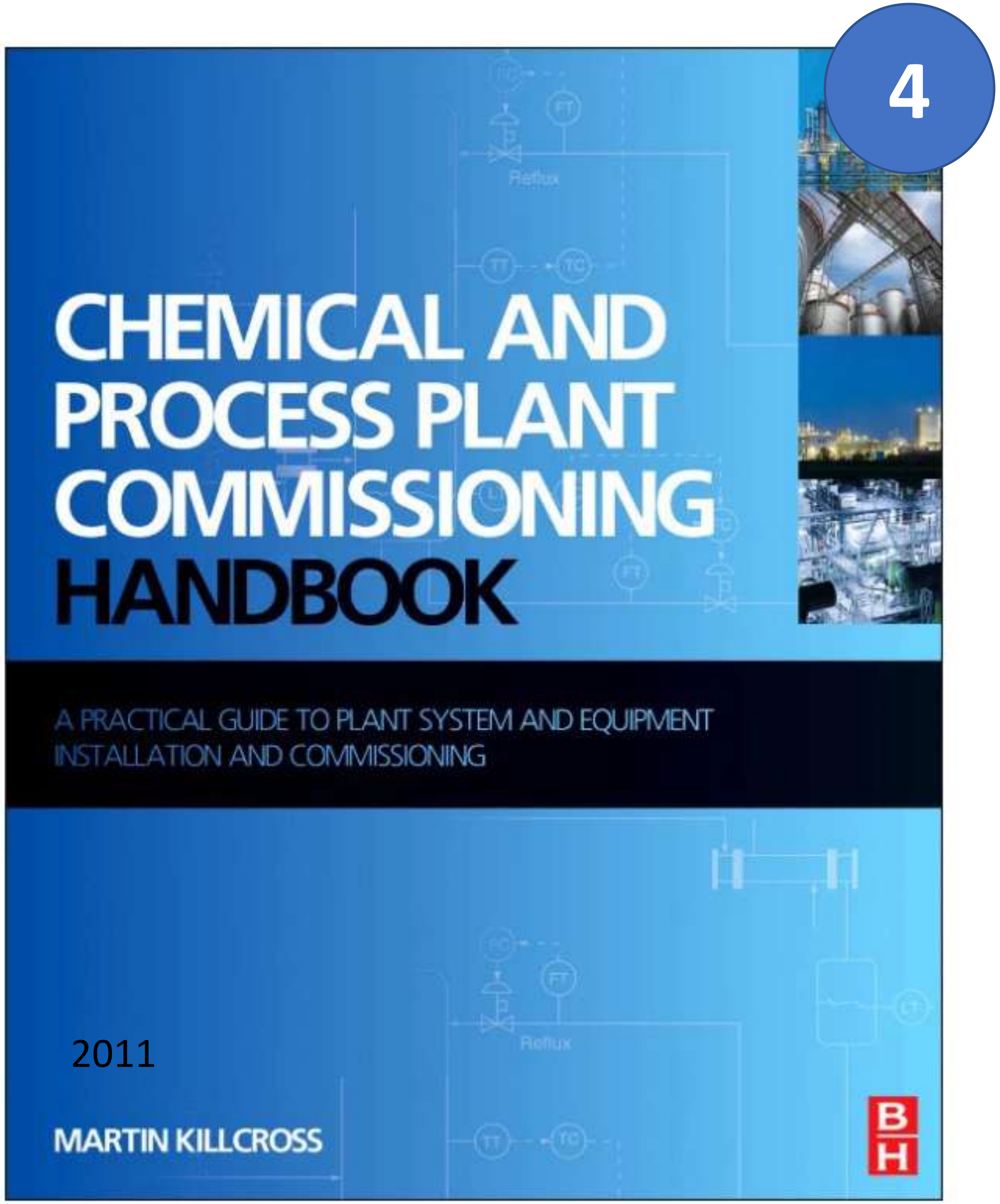
4
CHEMICAL AND
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A PRACTICAL GUIDE TO PLANT SYSTEM AND EQUIPMENT
INSTALLATION AND COMMISSIONING
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MARTIN KILLCROSS
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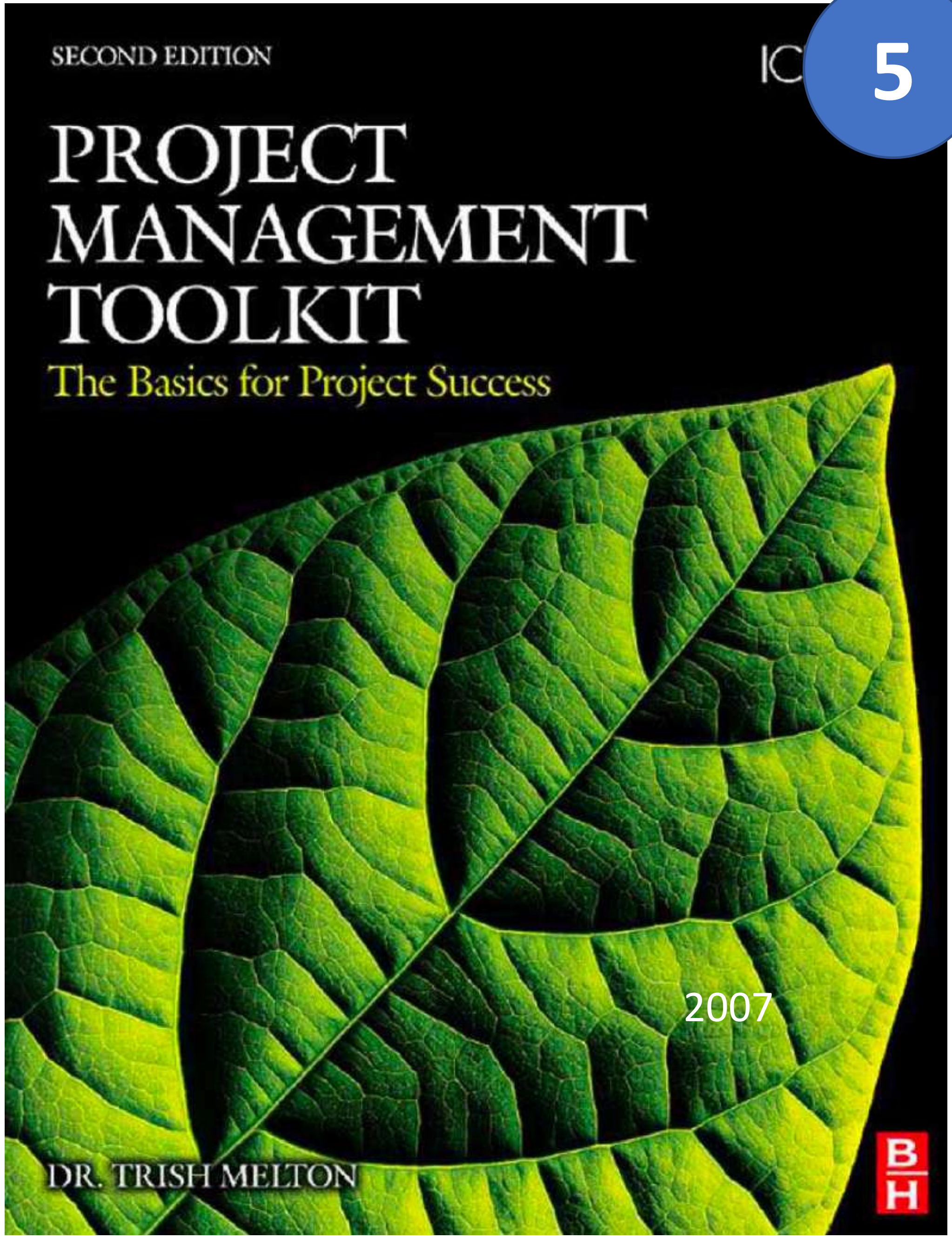
SECOND EDITION
PROJECT MANAGEMENT TOOLKIT
The Basics for Project Success
2007
DR. TRISH MELTON
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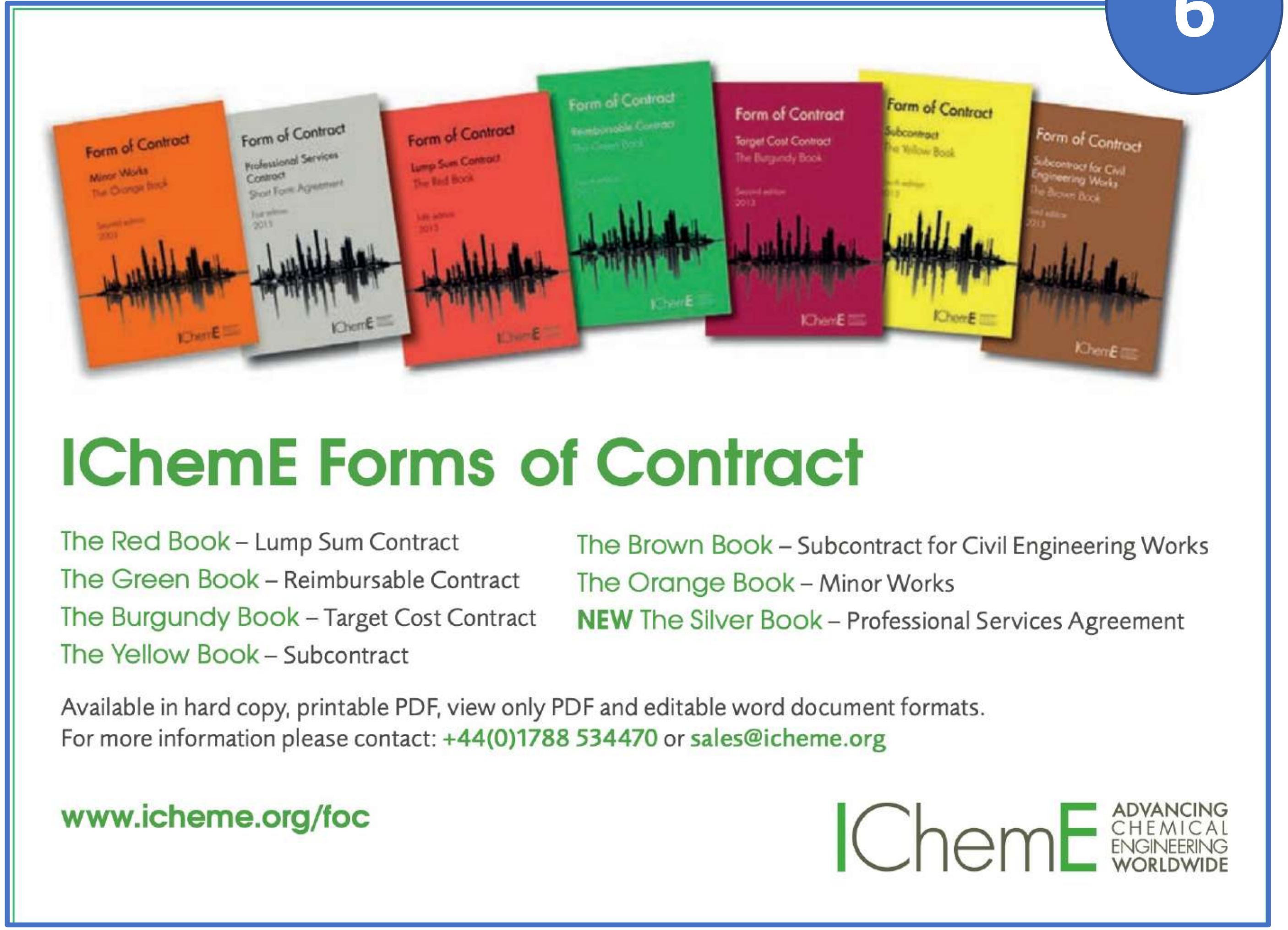
6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