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Distr.
LIMITED

ID/WG.60/12 SUMMARY
4 May 1970

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

UNIDO/DECHEMA Seminar on Operation,
Maintenance, Design and Manufacturing of
Chemical Plants and Equipment in
Developing Countries

Königstein (Taunus) near Frankfurt/Main
Federal Republic of Germany
2[illegible] - 26 June 1970

SUMMARY

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(DESIGN, CONSTRUCTION, OPERATION AND MAINTENANCE OF THE PETROCHEMICAL COMPLEX OF NATIONAL ORGANIC CHEMICAL INDUSTRIES (N.O.C.I.L.) BOMBAY, INDIA)

by

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Construction Manager
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Bombay, India

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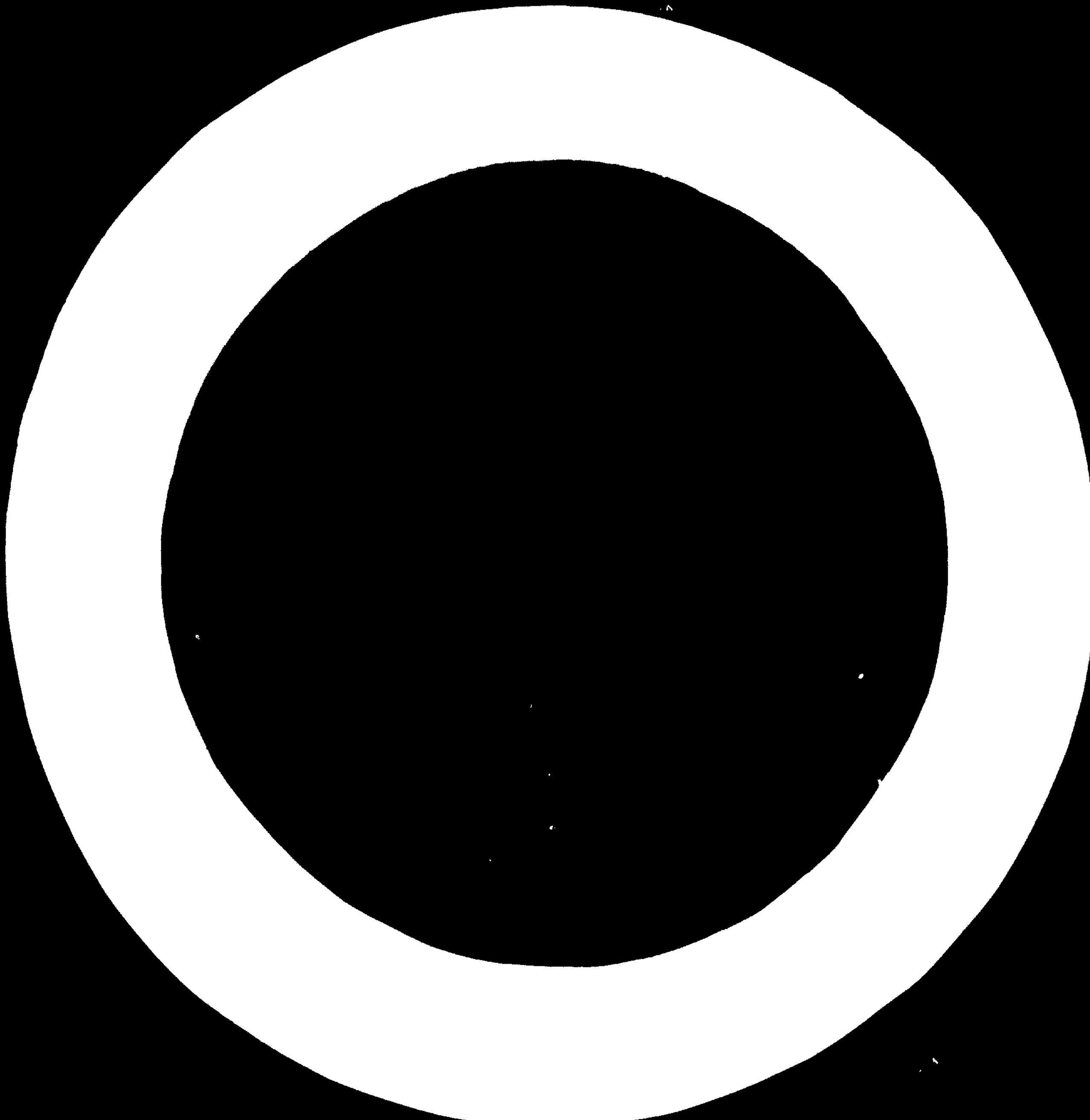

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3 June 1970

ORIGINAL: ENGLISH

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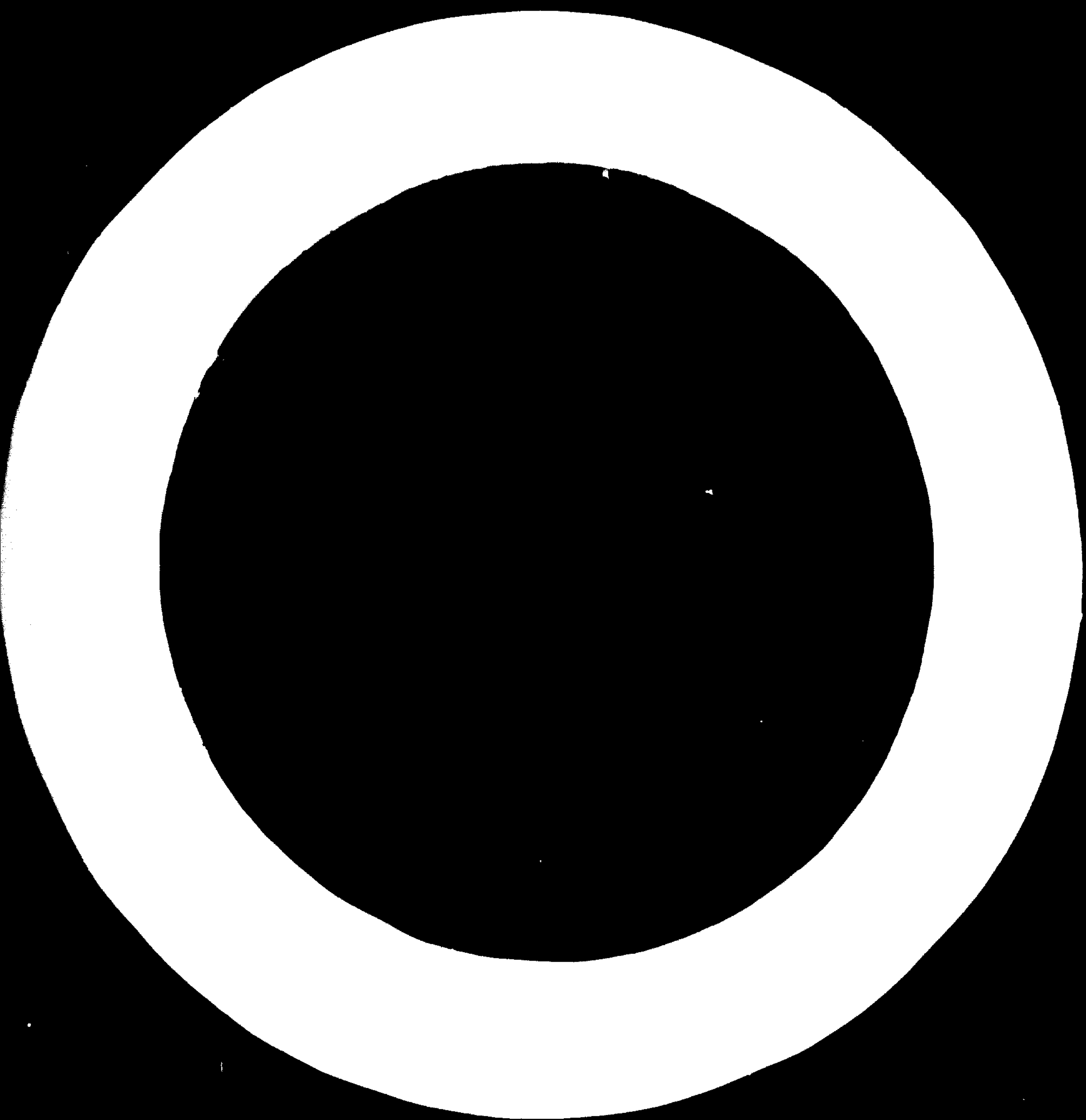

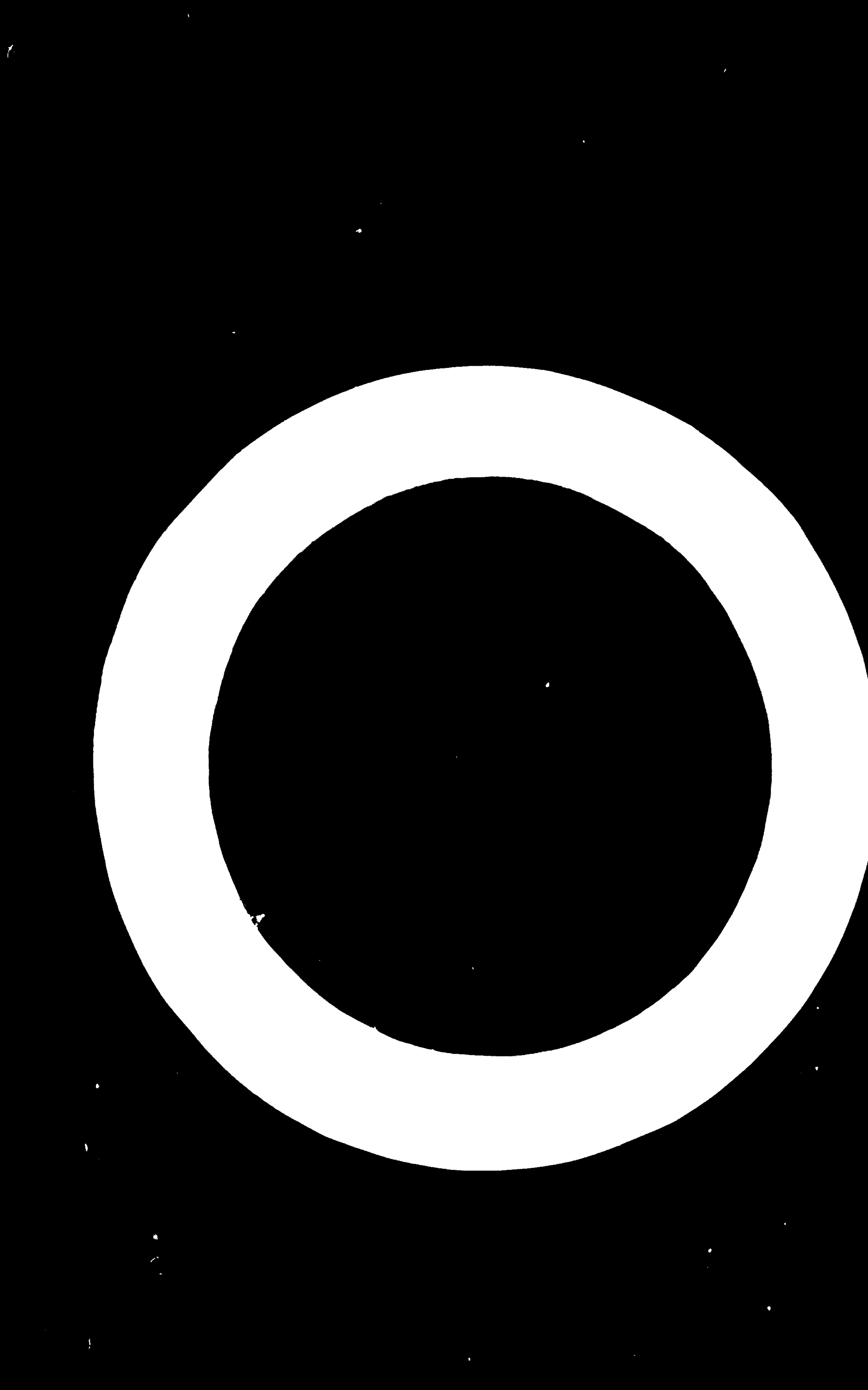

1. **Brief History of N.O.C.I.L.**:

Ground work on the first ever major petrochemical complex in India viz. N.O.C.I.L., Bombay, in collaboration with Shell and the reputed Indian business house of Mafatlals was started in January 1965. The design, engineering and procurement services for all the plants in the complex were obtained from/or through Shell. An American contractor was employed for construction for the major portion of the complex.

The heart of the complex is a naphtha cracker with a capacity of 60,000 M. tons per year of ethylene and with corresponding yields of propylene, butadiene and benzene containing fractions. Ethylene, as well as other products such as propylene are not only for captive use in the complex to manufacture ethylene oxide and glycols, DCE/VC/PVC, solvents, alcohols etc. but also for sale to other organic chemical industries in India, for manufacturing high density polyethylene, terrylene fibre, synthetic rubber etc.

The capital cost of the complex is about 30 mill. £ and all the plants of the complex have been commissioned progressively commencing in January 1968 and are in continuous commercial operation for about 2 years.

Further in this article, all the mechanical aspects of the problems associated with the design, engineering, construction operation and maintenance of such a large chemical complex for the first time in a developing country like India will be dealt with. Specific examples will not be mentioned, but it is needless to say that the information contained herein is factual, based on actual experience.
It is believed that these problems are similar to all developing countries, which are dependent on foreign know-how and capital for rapid and sustained industrial growth.

2. Design and engineering:

a. General

The processing know-hows, being proprietory and patented, obviously have to be licensed out from the collaborators. The basic mechanical information on sizes and specifications of various pieces of equipment such as columns, reactors, compressors, turbines, pumps, furnaces, etc. as well as sizes of pipes, materials of construction have also to be provided by the collaborators, as these processes are licensed under performance guarantees. For these reasons, in such plants, the complete chemical engineering design and construction drawings by and large are also provided by the collaborators and there is not much scope for carrying out even part of such work locally. Moreover, there is a lack of established contractor design and drafting services for such jobs to the different specifications of the different collaborators and the usual hurry to go into production as soon as the governmental, administrative and financial hurdless are cleared limits any adventure in trying to educate and make use of the existing limited facilities.

However, Hocil reviewed the design and engineering information, drawings and bills of materials not only in the beginning but also from time to time to ensure maximization of local procurement and fabrication, taking into account the Governments' stringent requirements of justification before an import license (also called "capital goods license") was granted. The information received was also reviewed in the light of special requirements as dictated by the climatic conditions and the physical location of the site. The effect of these factors on design and engineering is dealt with in detail below.

b. The Capital Goods License (C.G.L.):

The Indian Government has been and is always keen on maximizing the use, both of local materials and manufacturing facilities to minimize foreign exchange expenditure. There is no doubt that this is true of all developing countries. All items which are necessary to be imported either for setting up a new industry or for its operation and maintenance should be approved and licensed for import. This license to import is called the Capital Goods License or in short CGL. A complete, exhaustive list of all items required to be imported, with reasons, why they should be imported and the necessary back-up information based on actual local surveys clearly establishing the impossibility of their local availability or manufacture should be submitted to the Government while requesting for a license to import. In most of the cases, the Government insists upon a letter of regret from the possible local manufacturers in that particular field. The Government keeps an up-to-date list of all local facilities available and checks whether all the local manufacturers have been approached and whether items banned for import have been included. Therefore obtaining a Capital Goods License is time consuming as it is subject to close scrutiny. The description and quantities of items to be imported, the

the total value of foreign exchange required and the period of validity of the license are all to be as exact as possible not only because approvals to any additions/alterations are time consuming but also for speedy clearance through customs. It is therefore imperative that all the effort is put in before submitting the applications and therefore N.O.C.I.L. obtained complete specifications, bills of materials etc. for all items, the approximate values and delivery times and the time these were required at site as dictated by the construction schedule and embarked on an exhaustive survey to determine what could be definitely procured locally and was possible to manufacture locally.
The findings of this survey and how this was utilized in practice have been fully dealt with subsequently under the heading "Local procurement and fabrication". As a result of the efforts put in by N.O.C.I.L. before submitting the application the license was obtained in a much shorter time than normal (which is about [illegible] months) and N.O.C.I.L. was able to confirm orders on overseas suppliers much earlier. Based on the definite findings of the survey, letters of intent to place orders had already been developed with the overseas suppliers - as definite orders cannot be placed before the license to import is issued - and orders could be confirmed for all major long delivery items within a week of receiving the approved license.

c. <u>Local conditions</u>:

In the salt and dust laden atmospheres of a tropical place like Bombay, with high humidity and high intensities of rainfall, it is necessary to specify all electrical equipment as tropicalized and to provide a more liberal than normal corrosion allowance in the design of all equipment such as columns, vessels etc. It may not be out of place to mention here that the overseas materials should be packed and protected to withstand these conditions during shipment and storage.

N.O.C.I.L. site is located inland at a distance of about 8 km to a creek which is about 40 km from the Bombay harbour. There is no railroad to the site and the road route to the site is circuitous, passes through densely populated areas and the road bridges and clearances do not allow easy transportation of equipment of large dimensions and/or heavy loads.
Over 2,000 items of equipment had to be imported for the complex and N.O.C.I.L. scrutinized the overall dimensions and approximate weights of major pieces of equipment and found that about 150 items could not be transported to the site by road unless they were received in a dismantled state. For information, it may be mentioned here that the

heaviest weight required to be unloaded and transported was 110 M. tons and the tallest equipment 4.5 meters diameter and 45 meters long. So it was decided to build unloading facilities at the creek 8 km from the site and to bring the heavy packages from the Bombay Harbour in towed barges. This helped us to obtain all major equipment in one piece and/or in fully assembled condition thus enabling us to develop a realistic construction schedule.

3. <u>Local procurement and fabrication:</u> General:

Only after the first few oil refineries pioneered by Shell and other foreign oil companies were completed in 1954, there has been significant development in the manufacturing and fabrication facilities in India.
These first few refineries have practically no locally fabricated or manufactured equipment and almost everything had been imported. However, after commencement of operations, the companies not only started training their technical personnel in all aspects of design, standards, techniques of frabrication and acceptance inspection but also began to make use of existing fabrication shops to get simple pressure vessels, tanks, andexchangers etc. for their minor expansion or debottlenecking although complicated items were continued to be imported. This was the start of organized growth of the local fabrication industry.

By mid 1960's, when N.O.C.I.L. petrochemical complex took concrete shape, the import licensing policy of the Government of India had become very stringent and every item of import had to be critically and thoroughly justified. This was not only because the available foreign exchange for the country as a whole was to be utilized to import only the most essential items but also because the Government was progressively more committed to establishing a self sustaining and self regenerating economy as quickly as possible.

N.O.C.I.L., therefore obtained, a complete list of all items required for the complex along with bills of materials to investigate and determine what was locally possible. Almost every known fabrication shop in the length and breadth of the country was visited and reports were made as to their individual capabilities and limitations. Simiarly information was gathered on materials available locally. It was found from the investigations that the fabricators were loaded with routine work such as for water tanks, steel structures, cement and sugar mill machinery, etc. which gave them good and quick return on investment and effort. This made them generally not eager to take up such work, which called for compliance with international standards, use of tested materials and methods of fabrication and rigorous, time consuming stage and acceptance inspection both by the customer and an independent inspecting agency like Lloyds. N.O.C.I.L. also realized that all tested materials for fabrication as well as complete designs and fabrication details had to be supplied to the fabricator and setting up of a good and competent expediting and inspecting team was necessary to obtain deliveries on promised dates.

Although there was quite an element of risk involved, vis àvis the construction requirements, N.O.C.I.L. decided to maximize local fabrication and put their best efforts in that direction. I am glad to say, that the fabricators to whom N.O.C.I.L. work had been entrusted realized later that fabrication to international codes and standards and rigorous inspection was not only commercially attractive but also brought recognition to them as an established concern who could get such works from similar industries without hesitation and can take advantage the Government of India export incentive schemes.

I shall now list below in categories of chemical plant equipment, what our findings were and how maximum use was made of what was locally possible.

Pressure vessels:

At the time, the survey was conducted, it was found that in the whole of India, there was only one fabrication shop which was duly certified by Lloyds Register of shipping, as being capable of performing fabrication work confirming to their class I requirements.
This facility was located far away from Bombay and the deliveries expected were very long. Even this factory expected the customer to supply the materials. It was therefore the obvious conclusion, that we could attempt to fabricate ordinary carbon steel vessels which did not require stress relieving, did not have internal cladding or lining, provided complete engineering drawings, typical fabrication details and tested materials of construction were supplied. The fact that materials had to be supplied and close inspection and expediting had to be maintained dictated that orders be placed with firms closer to Bombay. Dished heads required for these pressure vessels were being made by all sorts of methods including manual hot forging and the sizes available were largely governed by the dies, the fabricator had. This information was used to our best advantage, slightly modifying design requirements where possible. Wherever the ASME code allowed, API pipes of larger diameters with forged caps were used to fabricate small and simple vessels like knock-out or settling pots. Plates to ASTM standards are not rolled in the country and we persuaded the Government owned steel mills to specially manufacture for us all the firebox quality plates required for local fabrication work, thus saving considerable foreign exchange.

Local fabricators could fabricate simple internals for pressure vessels, such as jet trays, sieve trays, anti-vortex baffles etc.

c. Heat exchangers:

Most of the fabricators were not capable of making heat exchangers to TEMA Standards even if all the materials were supplied. None of the fabricators could design heat exchangers based on process data and offer performance guarantees. The few fabricators, we came across, had experience in fabricating say simple small air after coolers, therefore almost all process heat exchangers had to be imported and only a few non-critical ones were fabricated locally and these with great difficulty. Instead of seamless tubes specified, which had to be imported, E.R.W. tubes were used as they were locally available.

d. Storage tanks:

All atmospheric storage tanks can be fabricated and erected locally. There are quite a few competent firms, always busy in this sphere. However, all tested materials are to be supplied and basic drawings giving thickness of shell courses have to be supplied.
N.O.C.I.L. made a complete take off all plates required and obtained them from the local steel mills. Lloyds inspection was arranged at the steel mills to stamp the plates.

The local fabricators do not have experience in fabricating the plates for spheres. Also the material for the spheres had to be imported. In view of this prefabricated sections were imported and the field erection, welding and stress relieving were carried out with a local experienced contractor in this type of job.

e. Furnaces:

No equipment suitable for use in a chemical industry like N.O.C.I.L. is made. Hence all furnaces had to be imported.

f. Boilers:

Investigations revealed that package boilers not exceeding 20,000 lbs/hour could be obtained locally. N.O.C.I.L. requirements being of the order of over 200 tons/hour the steam generating equipment was imported. There are stringent Government regulations applicable to the manufacture, testing and operation of boilers and the manufacturers were completely appraised of the requirements at the time of placing the order.

g. Cooling towers

Manufacturing facilities established with know how from reputed firms in this field are available. N.O.C.I.L. had this entire work executed by a local firm with performance guarantees.

h. Water treatment plant:

There are firms designing and supplying these plants in collaboration with foreign companies for know how. N.O.C.I.L. had their water treatment plant supplied and installed by a local contractor.

i. Flares:

Except for the last alloy steel section of the flare and the burner assembly, the flare stack can be manufactured locally.

j. Pumps:

Manufacturing facilities exist for making pumps with cast iron casings and impellers and with gland packings. Process pumps are usually specified in cast steel casings and the majority of these have special materials for internals and mechanical seals. In order to minimise import, locally available pumps were used with modifications which were possible, for non-critical services outside battery limits and for water and condensate services inside the battery limits.

k. Compressors and blowers:

Process compressors are not made. Small capacity - say of the order of 400 SCFM - air compressors are made for use with pneumatic tools. Also these air compressors are not oil free. All the compressors were therefore imported.

l. Turbines:

All turbine drives had to be imported.

m. Extruders/mixers:

Limited manufacturing facilities as are existing were used to best advantage.

n. Conveying equipment:

Provided design and construction drawings are given, there are firms who can fabricate and supply satisfactory conveying systems, which are not very sophisticated. Almost all N.O.C.I.L. conveying equipment was bought locally.

o. Piping:

Seamless pipes to ASTM spec. in sizes 3", 4" and 6" are made in India. ERW pipes to API 5 L specs. are also made in sizes 1½" through 20". ERW tubes 2" and less in sizes are also made in India. All these items were procured in India. As is the case with all materials, bulk ordering has to be done as early as possible as deliveries are long up to 1 year.

p. Pipe flanges and fittings:

There are only 2 or 3 small firms who forge carbon steel flanges to ASA standards in a few sizes. Even these firms do not have thorough inspection facilities from materials to finished product stage and therefore these flanges cannot be used in process piping without jeopardizing safety. Hence almost all the requirements were imported.

q. Valves:

Only cast iron sluice valves were made in the country and a few firms were attempting to manufacture cast steel gate valves, plug valves and ball valves in a few sizes. All our requirements of various types of valves were imported. Use of cast iron valves was made in such services as on tank farm drain pipes, etc. substituting carbon steel valves specified.

r. Fire fighting equipment:

Except for mobile fire fighting equipment which had special design requirements, all items were procured locally.

s. Structural steel:

Structural steel fabrication is the major effort in almost every fabrication shop in the country. Quite a few leading fabricators carry considerable stocks of structural sections and the job is contracted normally on the basis of supply, fabricate and erect to drawings. As the sections available in the country are rolled to Indian Standard specifications design has to be based on these.

t. Insulation and painting:

Both materials and services are available. As cork for cold insulation was not available styrofoam insulation was employed to eliminate import.

u. <u>Electrical</u>:

All distribution switch gear and transformers, both indoor and outdoor type are manufactured. Power cables are available only in aluminium conductors as copper has to be imported. Control cables are however made from copper and are available as specified.

Sparkproof motors are not made. Explosionproof motors up to 40 HP were being planned for production. No explosion-proof switch gear is made in the country.

v. <u>Instrumentation</u>:

Apart from Dial thermometers and Dial pressure gages, all process instrumentation had to be imported. Negotiations by an Indian firm with a well-known overseas firm in this field to eventually produce all items required for process instrumentation were in an advance stage.
All hardware, such as instrument panels, junction boxes, instrument trays were locally fabricated. Very good contracting services are available for instrumentation erection.

The most important factor to be borne in mind when procuring materials or services in India is that there is an enormous gap between demand and supply and the delivery/completion times are very long, as long as 12 to 1[illegible] months. Hence advance planning is necessary right at the beginning of construction to acquire the services or materials and thereafter to continuously expedite and inspect till completion. Construction tools and tackle of very good quality are in short supply as also mechanised equipment such as lifting cranes.

4. <u>Construction</u>:

Government approval is required for the lay-out of the plant, the buildings, the electrical systems, the effluent disposal system etc. and designs should be firmed up only thereafter. Otherwise there could be hold up in construction. The Explosives department of the Government of India has more stringent regulations than what is practised in the West in respect of location and spacing of tankage containing flammable products such as petroleum. N.O.C.I.L. lay-out had to be altered considerably in the beginning to meet the requirements of this department.

In so far as labour for construction is concerned, it is needless to say that there is abundant supply of unskilled labour. Semi-skilled labour of almost all categories is generally available and skilled labour in certain categories have to built up with semiskilled labour by on the job training. However after drawing up a realistic time schedule

based on such factors as equipment deliveries at site, it is necessary to compute the total manhours required for the job and the manhours required for each phase of activity such as civil, structural, piping etc.
These manhours should be computed based on the possible methods of construction adoptable in the country - to quote an example, civil work is largely carried out by manual labour and not mechanised - and the efficiency of the local labour as compared with his European or American counterpart.
For the entire construction job of N.O.C.I.L., it was estimated that 3 million manhours were required spread over a period of about 30 months. The physical effort required for each phase of activity as a percentage of the total effort of 100% was estimated for each phase of work as follows:

Civil	- 8%
Structural steel	- 4%
Mechanical Equipment	- 16%
Piping	- 40%
Electrical	- 9%
Instrumentation	- 10%
Insulation	- 2%
Painting	- 1%
Tankfarm, etc.	- 10%

Adverse weather conditions prevailing in Bombay for a period of about 3/4 months due to heavy rainfall, affecting the tempo of construction as well as the limited availability of good construction tools, tackle and equipment were also taken into account not only while determining the overall time schedule, but also in manpower planning per quarter year per craft.

In a modern chemical complex like N.O.C.I.L., where the processes are carried out at temperature as low as - 100°C to as high as 800°C and pressures ranging from vacuum to say 100 kg/sq.cm and handling corrosive fluids and chemicals, special materials of construction, not normally employed in a refinery have to be used. Materials of construction ranged from carbon steel, stainless steels, inconel, monel, titanium, copper, aluminum, polypropylene, polyethylene, PVC and equipment lined with glass, epoxy resins, rubber, acid proof brick not to mention cladding and lining with special steels.
N.O.C.I.L. was keen right from the beginning to associate as many local contractors in all types of work during construction with a view to developing such contractor services for use during commissioning and maintenance and shut down work. Almost all types of work were therefore contracted out. More than one contractor was utilized for the same type of work to introduce an element of competition

and close supervision and guidance was provided by the overseas contractor. Quite a substantial amount of work was also carried out with direct labour and N.O.C.I.L. laid down a liberal wage policy in respect of this labour to avoid any strikes during construction.

As already stated elsewhere, close follow-up was maintained for materials ordered locally and a competent inspecting and expediting team was set up to progress local fabrication work. The problems of the local fabricator were treated as our own problems and timely solutions were found by us in co-operation with the fabricator.
A good cost accounting and reporting system is a must to control costs and to execute the job within the budget. Bank borrowings every month should be accurately forecast in order to minimise interest charges.
In the case of imported materials, it is the author's experience that a very liberal allowance should be made in the bulk take off in respect of small bore piping and flanges and fittings of all sizes as shortages were experienced in these items in the final stages of construction and had to be airfreighted.
25% extra of the bulk take off appeared to be a realistic figure.

5. <u>Operation and Maintenance:</u>

a. <u>Spare parts:</u>

In view of the difficulties to be overcome to obtain spare parts for imported equipment, it is desirable not to exceed and/or vary radically the design operating conditions of the equipment. Moreover, the import licenses issued by the Government for operational items is always far below in money value than that which is asked for and is in most cases tied up for buying in specific countries from which aid/loan has been available to the Government. This is essentially due to the [illegible] countries which limits the foreign exchange at the disposal of the Government. From the time action for obtaining a license is initiated it takes about 2 years to have the materials at site. In view of this while setting up a new industry, spare parts for 2 years operation should be procured and at the same time an import substitution group should be set up.

During the design and specification stage itself, it is preferable to make use of "good enough" items available locally instead of asking for "the best" which will have to be imported. In case of items, which have to be definitely imported it is always better to go in for a robust, well proven design with the least possible materials rather than for those with latest refinements and sophistications.

For key items of plant equipment such as process compressors or turbines, the breakdown of which could shut down the plant, it is advisable to have complete rotors as spares as facilities for their repair and balancing is inadequate and experience available is limited. When several pumps are to be bought, it is better to negotiate and buy from one manufacturer and to standardize on as few types and sizes possible. Mechanical seals on equipment should be standardized on a few types from one manufacturer and spare impellers should always be bought in maximum sizes.

The overseas supplier of manufactured equipment has also a role to play in easing the spare parts problems of the industries. Firstly he should ensure that his local agents are not sellers only but should keep where possible adequate stocks of spares, commonly required for such equipment supplied by him in the country. Lists of similar equipment requiring similar spares should be kept up-to-date for each country by the overseas manufacturer so that he could advise the new industry to go in for the type or size already in use in his country and which can meet his specifications. This provides a possibility of borrowing spares on replacement basis from another industry using similar equipment.

Lastly, the overseas manufacturer should always look for manufacturing a few items of equipment or spares in the country either on his own or in association with a local firm. Even though such venture could initially be marginally commercially attractive, it will stand the manufacturer in good stead in the years to come.

In spare parts inventory for imported items, the western norms of a very low ratio of inventory with respect to invested capital is not practicable in developing countries. This percentage should be very much higher say 8 to 10%.

6. Skills:

In developing countries, mechanical skills/expertize/services as are readily available in a western country are either absent or inadequate. Hence the industry itself has the primary responsibility to train their personnel not only in skills but also in a sense of responsible attachment, in all facets of operation and maintenance to make it a successful and good business venture. For a complex like N.O.C.I.L., the skills can be perfected only by on the job experience, in spite of best efforts at training. In the light of this, it is important that the overseas erection and commissioning engineer speaks the business language (English, in case of India) of the country and imparts the necessary skills to the local workmen and supervisors. In addition, it is worthwhile, that the overseas supplier sends out a specialist every year to trouble shoot on equipment supplied by him to all countries in a particular area as part of his after sales service, instead of sending an expert only on request. The expert is advised to carry all special tools with him.

c. Organisation, manpower, planning and execution:

An area-central type maintenance organization has been set-up with centralized workshop facilities and centralized planning. The entire complex has been divided into 3 areas, each of them in charge of an area engineer. The manpower is based on carrying out with own workers running maintenance only. For information the ratio between the number of pieces of equipment to be maintained and the workers as existing is given below.

Equipment	Approx. No.	Ratio worker:equipment
Mechanical	2,400	1:24
Electrical	600	1:90
Instruments	3,600	1:200

These ratios are by no means on the liberal side taking into account the types and complexity of equipment installed and the inadequate experience of local craftsmen in maintaining such equipment. All civil works as well as new construction and turn around work are contracted out. The ratio between the first line supervisor and worker is on an average 1 : 7.

Maintenance work is carried out only on receipt of a duly authorized work-order originated by the concerned department. For works which have to be carried out at regular intervals, standing work-orders have been established to avoid unnecessary paper work. On receipt of the work-order, the supervisor estimates the time required to carry out the job as well as the cost. The planning section allocates a work-order number and the cost centre and obtains higher authorization if necessary. Weekly planning meetings which are attended by area engineers and operations, the priorities of work in each area are decided upon and the manpower allocation is done. Normally the same craftsmen are allotted to a particular area to make use of the experience they already have. The finalized areawise work-lists are sent to all involved and the operating departments keep work permits ready in time for the maintenance supervisor to commence work as planned.

When assistance from workshops or civil, electrical or instrument crafts are required, the area engineers raise separate sub work-orders on these services.

In order to cut down overtime work, a skeleton mechanical crew is kept in shifts with a supervisor in charge of all the areas and this supervisor can always seek guidance in emergencies from senior mechanical staff who are on weekly duty rota.

Works of such nature as cleaning tube bundless, loading of catalysts and chemicals are charged to operating cost centres. Modifications to the plant involving relocation of existing equipment and minor piping alterations for better operation, but not adding to the capital value significantly are called as plant changes and are costed separately. The maintenance costs and manhours spent are collected by cost centres and by equipment codes for purposes of management reporting and trouble shooting.

Backlogs in each area are periodically cleared by allocation of more manpower.

For minor stops, the planning is done by hand arrow diagrams whereas for a major turnaround which is generally planned once in 2 years, critical path planning by computer is employed. Inspection work lists based on statutory requirements and on non-destructive testing reports and the operations worklists are closed out sufficiently in advance to enable maintenance department to carry out such planning. After the final list is decided upon the maintenance department works out and arranges materials and tools at site, organizes contractor services, carries out in advance such works as delagging and scaffolding and sets up detailed planning boards in each area giving details of work to be done and manpower availability. During the shut down, progress of planned work is marked each day and corrective measures are taken to ensure that the schedule is maintained.
For accurate critical path planning by the computer, the data on manhour estimates for jobs should be as accurate as possible and this information is being regularly collected and updated.

Lubrication of rotating equipment etc. is the responsibility of the operations, who are provided with necessary supply of oils, greases, applicators, etc. and all information on the type of oil/grease to be used, frequency of lubrication etc. All concerned are made very well aware that irregular lubrication as well as too little or too much lubrication is as bad as no lubrication. The maintenance supervisor as part of his daily routine also makes sure of this.

When he finds that a bearing is excessively hot or the vibrations are too high, he will ask the operations to hand over such equipment for maintenance to eliminate an unplanned interruption. For rotating equipment in critical services in the course of 4 to 6 months running period the supervisor determines if it is necessary to drain, flush and renew the lubricants and does so at a time agreed upon with operations.

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