FIRST LNG FROM GIANT NORTH FIELD:
QATAR GAS LNG

LE PREMIER GNL DE GEANT “NORTH FIELD”:
QATAR GAS GNL

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ABSTRACT

Qatar Gas LNG is the 1st LNG project in the gas development program of the world’s largest Gas Reservoir North Field. The plant has been supplying LNG to Chubu Electric Power Co., Inc., Japan since January 1997. The LNG plant has been successfully completed within the budget and schedule target due to the intimate collaboration between Qatar Liquefied Gas Company and the Contractors.

The project has successfully managed the inherent characteristics:

• Location Feature; First Grass Roots LNG Project in Qatar, Shallow Shore; High Ambient Temperature
• Process Feature; Resolution of Gas Treating Difficulty of High Mercaptan Content
  High N2 Content, and 4 Frame -V Application
• Project Feature; First two trains and Offshore production Facilities. One Month Ahead Schedule for Mechanical Completion and high Construction Safety Record
• Operation Feature; Operator Training Simulator, Plant Operation Information System
RESUME

Le projet GNL de Qatar Gaz est le premier projet d’un programme de développement du plus grand réservoir de gaz naturel au monde, le “North Field”. L’usine approvisionne la Société Chubu Electric du Japon depuis le mois de Janvier 1997. Le projet a été réalisé tout en respectant le délai ainsi que l’enveloppe budgétaire. Ceci grâce à la collaboration entre Qatar Liquefied Gas Company et le Constructeur.

Il était nécessaire pour réussir de gérer plusieurs caractéristiques techniques uniques;

- Caractéristiques Geographiques; Premier complexe de GNL au Qatar, Aménagement du port, un eau peu profonde, Temperature Ambiante tropicale
- Caractéristiques de Process; Résolution des difficultes de traitement de gaz, étant donné haute teneur en mercaptan, Teneur en azote élevé, Installation de quatre (4) turbines à gaz, frame 5, par train de production
- Caractéristiques projet; Achèvement du projet avec un mois d’avance, Record de Sécurite de Construction
- Caractéristiques d’Operation; L’Utilisation de l’ordinateur comme simulateur de process pour formation des opérateurs. Systeme O.T.S., L’Utilisation d’un system informatique pour suivre les paramètres et le process. System P.O.I.S.
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1. INTRODUCTION

Qatar Liquefied Gas Company Ltd. (Qatargas) has achieved the LNG loading of 33 shipments to Japan and 3 shipments to Spain as of 1st December 1997, after several project implementation steps. Qatargas has been established to build, own and operate the LNG Plant (Downstream Project) in Qatar using the giant North Field gas as feedstock, and to export the products. Qatargas is the joint venture company consisting of Qatar General Petroleum Corporation (QGPC), Mobil, TOTAL, Marubeni and Mitsui. And the shareholdings in the LNG Company are:

- QGPC 65.0%
- TOTAL S.A. 10.0%
- Mobil Qatar Inc. 10.0%
- Mitsui & Co. Ltd. 7.5%
- Marubeni Corporation 7.5%

Qatargas shareholders and/or their affiliates are also carrying out North Field Upstream Development (Upstream Project) where Qatar Liquefied Gas Company is under an Agreement to be the Operator of the Offshore and Onshore Reception Facilities, to provide feed gas requirements of Qatargas LNG Plant.

In May 1992, Qatargas concluded its 1st SPA (LNG Sales and Purchase Agreement) for 4 MTA (million metric tonnes per annum) with Chubu Electric Power Co. Inc. for a period of 25 years starting from January 1997 (1997-2021).

Construction of 1st baseload LNG plant in State of Qatar commenced in June 1994 with a scheduled first cargo of LNG to the Japanese buyer, Chubu Electric Power Co. Inc. in January 1997. Deliveries for the 25 year contract are set to build up to a plateau 4 million tonnes of LNG per annum by 2000. The capital expenditure of the project including the Ras Laffan Port, all offshore facilities and LNG carriers amount to the order of US$ 5 billion.

In December 1994, Qatargas concluded its 2nd SPA for 2 MTA (3rd LNG train) with a group of seven Japanese gas and utility companies—
—thereby raising the capacity of the Project to 6 MTA. LNG exports under this SPA are due to commence in September 1998, and to continue till end-2021. The 1st and 2nd train started production in November 1996 and January 1997 respectively. The 3rd train is expected to start up in June 1998.
2. OVERALL QATARGAS PROJECT

North Field Development Program

The Qatargas project is Phase II of Giant North Field Development Program. The development program include domestic gas utilization, Qatargas, Ras Laffan LNG, Condensate Refinery, future LNG projects, etc. which are located in Ras Laffan Industrial Complex. (Fig. 1)

![Ras Laffan Industrial Complex](image)

**Fig.1  Ras Laffan Industrial Complex**

Qatargas LNG Related

The LNG chain of Qatargas project consists of North Field, Upstream Facilities, LNG Plant and Product Shipping.
North Field. The North field is located at the northeast of State of Qatar (Fig. 2) and is the largest single gas field in the world:

- Total Area: 6,000 sq. km
- Gas in Place > 500 TCF
- Proven Reserve > 373 TCF

Upstream Facilities. Other than the LNG plant, upstream facilities were contracted to other contractors;

- Offshore Complex NF Bravo (Photo 1); Wellhead Platforms, Jackets, Flare, Bridges & Living Quarters Topsides (McDermott - ETPM)
- Offshore Complex NF Bravo; Process & Utilities Platform Topsides (NPCC Technip Geoproduction)
- Production Gas Pipeline from Offshore Complex NF Bravo to shore at Ras Laffan (Saipem)
- Onshore Upstream Facilities - gas reception, separation, condensate stabilization & storage/ship loading (Toyo Engineering)

The upstream, offshore production gas pipeline and some of the onshore facilities are capable of supplying over 1,400 Mscfd (million standard cubic feet per day) of production gas and 60 kbbls of associated condensate for the 6 MTA LNG Plant.

Phase II or Qatargas North Field Bravo Offshore Complex facilities (NF Bravo) are capable of producing 900 Mscfd of an average nominal wellhead gas from Khuff K4 formation of North Field to supply the feed gas requirements of the 4 MTA liquefaction plant. It is located approximately 80 km northeast of Ras Laffan and approximately 10 km south-east of QGPC's Phase I (NF Alpha) Platform Complex.
Gas is supplied to the onshore facilities via a single 32 inch subsea pipeline operated in two phases, the dehydrated gas and dewatered condensate are transported 80 km to the onshore reception facilities at Ras Laffan. Condensate (1.3 MTA) is extracted in the Upstream Onshore facilities. Additional facilities to provide feed gas for the 3rd LNG train onshore are in progress; these will raise the exported quantity of condensate to above 1.9 MTA.

**LNG Plant.** Qatargas LNG Plant facilities (and Upstream Onshore facilities) are located at the new industrial complex of Ras Laffan (Fig. 3). Qatargas LNG Plant is a modular project, initially based on two LNG process trains, storage and loading facilities and all offsite and utility systems required for production and shipment of 4 MTA of LNG. Gas turbine is selected as prime mover and the cooling media is a once through sea water system. Addition of the 3rd LNG train, will raising the annual LNG production to 6 MTA, construction of the 3rd LNG train is in progress.

**Product Shipping.** It requires a fleet of 7 LNG carriers, Al Zubarah, Al Kohr, Al Rayyan, Al Wajbah, Broog, Al Wakrah, Doha, each of 135,000 cubic meters nominal capacity, around 300 meters length, to transport annually 4 million tonnes of LNG from Qatar to Japan. Three (3) further carriers are being built to transport the additional 2 MTA of LNG that will be available from the 3rd train. Shipments of condensate (until a planned condensate refinery comes onstream by end-2000) and sulfur are also exported from Ras Laffan Port.
Ras Laffan Port Project (RLP). The port infrastructure was separate from the LNG plant project. In the late 1980s, QGPC established a major project team to draw a Master Plan for the Gas Utilization in Qatar, including the development of a new industrial center of Ras Laffan. The world class port infrastructure is to be constructed according to the master plan. EPC contract for the civil/marine aspects of the Port was excluded from the LNG plant contract.

The contract was awarded to the other contractor in September 1991, with the overall completion date of 31st December, 1996. The other significant contract awarded by RLP was for the civil construction of the Sea Water Intake Structure(SWI) in the Harbour, the Outfall Channel from the LNG Plant to the Northern coast. The contract was awarded to other contractor in July 1994, for completion of the SWI by 30th April 1995 and of the Outfall by 30th September, 1995.

3. LNG PROJECT MILESTONES

Qatargas Company formed in November 1984 to develop the Giant North Field. The Feasibility Study was completed in January 1991. The front end engineering design (FEED) work was undertaken in Houston Office of M.W. Kellogg Company from early 1992 until the 1st quarter of 1993.
In May 1993, Engineering, Procurement and Construction (EPC) Contract for the 1st & 2nd trains/4 MTA plant and associated facilities, with an option for the 3rd LNG train, was awarded to Chiyoda Corporation of Japan (herein after called Chiyoda). The following are actual project milestones from the EPC contract to LNG product export, including Completion Package Number, CP No.

- On October 1, 1995; the site industrial buildings were completed. These facilities included such buildings as the laboratory, fire station, workshop, training center and gate house which were handed over to Qatargas.(CP-1)
- On January 28, 1996; following hand-over of the buildings, the Plant utilities systems, including fuel gas, power generation, fire protection, compressed air, effluent treatment and sea water intake, were the 1st operational facilities and were handed over to Qatargas for start-up and operations.(CP-2)
- On May 29, 1996; the remaining utilities systems required for operation of the 1st LNG train, including desalination and steam generation systems, were completed and handed over.(CP-3)
- On September 1, 1996; the 1st LNG train was completed and handed over to Qatargas one month ahead of schedule. Early completion of this milestone allowed Qatargas to accelerate startup activities.(CP-4)
- On November 15, 1996; produced the 1st drops of LNG, well in advance of the 1st LNG shipment date.
- On December 8, 1996; construction of the 2nd train was completed and handed over to Qatargas three weeks ahead of schedule. (CP-5)
- On December 23, 1996, the 1st shipment, i.e., Al Zubarah, carrying the 1st LNG cargo, left Ras Laffan Port in Qatar. (Photo 2)

![Photo 2](url) Al Zubarah in LNG Loading

- On January 10, 1997, Al Zubarah, the 1st LNG cargo arrived at Kawagoe terminal in Nagoya, Japan whose distance is 12,000 km far from Ras Laffan port.
- On January 17, 1997; produce the 1st drops of LNG from 2nd train.
- On January 23, 1997; turned over other associate facilities of 1st and 2nd train.(CP-6)
On September 30, 1997 Methane Arctic left Ras Laffan port to Spain via Suez Canal, Qatargas’s first customer in Europe, after Qatargas signed a contract in May 1997 to sell 420,000 tonnes of LNG over a 13-month period to the Spanish company Enagas.

On November 30, 1998 3rd train and its associate facilities will be completed.(CP-7)

4. DESCRIPTION OF THE LNG PLANT

Overall Flow Scheme

The Plant process system is supplied with feed gas from the Onshore Upstream facilities. Filtration and fiscal metering then takes place in the Common Reception Facilities before the feed gas flow is divided into three streams, one to each LNG process train. Each LNG process train consists of Reception, Acid Gas Removal, Dehydration and Mercaptan Removal, Mercury Removal, Gas Chilling and Liquefaction Systems, Refrigeration, Fractionation, Nitrogen Rejection, Sulfur Recovery, etc. The block flow diagram is shown in Fig. 4.

Process Units

Acid Gas Removal. In each train, Shell Sulfinol D process was selected to remove acid gases (CO2 and H2S), mercaptans and other sulfur impurities from the feed gas. Two stage flash scheme has been successfully applied to minimize the heavy hydrocarbon content in acid gas for optimal SuperClaus (Trademark) design. The flow scheme is shown in Fig. 5.
Liquefaction. The treated gas is then chilled and liquefied. This is done by propane precooled MR(mixed refrigerant) process of Air Products and Chemicals Inc (APCI). Using two refrigerant closed loops. The configuration is shown in Fig. 6.

The refrigerant cycle requires four(4) GE frame-V gas turbines, one for propane, C3, and three for MR. To liquefy the gas, the stream is then introduced into the main Cryogenic Heat Exchanger, where it is further liquefied by heat exchange with the mixed refrigerant.
The refrigeration load balance between propane and MR shows slightly warmer refrigeration temperature for propane. A booster C3 compressor is used for hot summer to maintain production because of high sea water temperature. The reflux condenser duty of the Scrub column is supplied by MR refrigerant via the warm bundle of Main Cryogenic Heat Exchanger. The Main Cryogenic Heat Exchanger which consists of three bundles.

Nitrogen is rejected from the stream by N2 Stripper which contains around 4 mol% in order to meet the LNG specification. SuperClaus process (licensed by Stork E &C) was applied to Sulfur Recovery Unit, SRU, to recover sulfur from the acid gas. The overview of the trains are shown in Photo 3.

![Photo 3 Qatargas LNG 1st Train and 2nd Train](Image)

**Support Facilities**

Support facilities associated with the LNG trains include: Fuel gas distribution, NGL extraction, refrigerant make-up and NGL return, flare system and liquid burn pit, Process effluent water treatment, Electrical Power Generation, Steam Generation, Cooling Water, Water Desalination, Fire Fighting Water Distribution, Air Compression, Nitrogen Generation, etc..

**Sulfur Loading.** The sulfur is solidified and trucked to the Port for shipping. The sulfur export system at the Port consists of a solid sulfur storage silo and a traveling ship-loader. The silo has a capacity of 20,000 tonnes.

**Electric Power Generation.** Electric power is generated by five GE Frame VI gas turbine, each of 28 MW site rating, with a 6th machine being added for the 3rd LNG train. With this design, at least one machine is always available as spinning reserve or as standby for maintenance.
Steam Generation. Steam is generated at a pressure of 10 barg by three (3) boilers, each rated at 146 tonnes per hour. A 4th boiler is being added for the 3rd LNG train.

Cooling Water. The sea water cooling system includes the intake facilities located in the Port with two sea water pumps per LNG train, the supply distribution and return systems, the return weir box, and outfall channel discharging to the open sea. Maximum water temperature differential from intake to outfall is 10°C. A 5th pump (7th after 3 LNG trains) acts as a common spare on the connecting manifold, from which the LNG trains are supplied. All the pumps are of vertical shaft and their capacity is 17,300 m3/h each. 84 inch sea water supply line is dedicated for each train.

LNG Storage and Loading

The LNG produced in the two trains is stored in three identical full containment, double wall metal inner and concrete outer shell storage tanks for maximum safety. Each tank has a nominal working capacity of 85,000 cubic meters (Photo 4), and is equipped with four top entry column-mounted loading pumps each having a capacity of 1,300 m3/h and one circulation pump capacity 250 m3/h. The tanks are located at the northeast corner of the Plant area, and the loading lines are routed along the Main Breakwater of the Port to LNG Berth No.1.

A 4th LNG tank and a 3rd boil-off gas compressor are being added for the 3rd LNG train. LNG is loaded into carriers through three articulated loading arms, each having pipes of 16 inch diameter and capacity of 3,400 m3/h. This leads to an overall nominal loading rate of 10,000 m3/h, which means that an LNG carrier spends less than 24 hours in the port at Ras Laffan. A 4th arm is used to receive the vapour generated in the ship during loading; the vapour is directed to a discharge flare located outside the Breakwater.
5. ENGINEERING, PROCUREMENT, CONSTRUCTION OF THE LNG PLANT

EPC Contract

The Plant Project uses one overall engineering, procurement and construction (EPC) contract. The EPC Contract for the 1st & 2nd train/4 MTA plant and associated facilities, with an option for the 3rd LNG train, was awarded to Chiyoda Corporation of Japan in May 1993, including assignment of responsibility for three (3) long-lead items previously awarded by Qatargas:

- LNG Tanks to TBMM, a consortium of SN Technigaz & Bouygues of France and Mecon & Midmac of Qatar,
- Cryogenic Heat Exchangers to APCI of the United States
- Compressors to Nuovo Pignone of Italy.

In addition, a few small contracts were awarded and administered directly by Qatargas for such activities as site surveys, site preparation and Qatargas Head Office Building, due for completion in the 2nd quarter of 1997. All of the above contracts were competitively bid and awarded on a lump sum basis, and Completion Packages were divided to facilitate handover during a phased period, with penalties assigned for late completion.

Qatargas LNG Project Task Force (PTF) was established in Chiyoda Yokohama Office to facilitate rapid decision-making and approvals for matters of direct concern to Qatargas.

Engineering and Procurement

Engineering optimization studies were started during the bidding stage, followed by the engineering work started in Chiyoda Yokohama Office. The engineering optimization study was the key to establish the mercaptan removal scheme which was modified after FEED. The engineering work has been done mainly in Chiyoda Yokohama Office.

Work Volume. The engineering man hour was counted as 2.6 million hours and No. of Drawings except Vendor Print was counted as 14,300. Procurement work was done mainly in Chiyoda Yokohama Office, assisted by Chiyoda’s affiliate offices at Houston in USA, Milan in Italy and London in UK. The freight ton was counted as 385,000 tonnes and the numbers of the purchase orders was counted as 3,000. These figures are as on November 31, 1997.

Design and Engineering Topics

The following are topics for the EPC work in which Qatargas and Chiyoda have made effort from the viewpoints of project cost, schedule, safety, and environment focus.

Alternative Mercaptan Removal Scheme. The feed gas of design indicated around 350ppm mercaptan content, although current operation shows lower mercaptan content. No LNG plant has ever encountered such high mercaptan content. FEED applied for the acid gas removal as scheme:

Chemical Absorption Amine+13X molecular Sieve + Physical Absorption + Claus
During the bidding stage, Chiyoda proposed an alternate scheme after an engineering optimization study as:
Sulfinol + 5A molecular +SuperClaus

After the EPC contract, Qatargas selected the alternate scheme based on the following considerations:

- Simple process flow scheme; two step adsorption/absorption(Mol. Sieve and Physical Absorption) to a single step absorption of mercaptan(Sulfinol), and eliminating regeneration gas recycle
- Easy environment control; in the original scheme, the dryer, 13X molecular sieve regeneration desorb the unrecoverble sulfur compound in a high concentration peak for every cycle time.
- Higher Sulfur recovery; the SuperClaus application was proposed to reduce the SOx emission appealing to worldwide ecology concern. For Claus reaction the recovery rate of sulfur is limited by the equilibrium by the partial pressure of H2S and SO2 which becomes low for this case due to the inert gas such as H2O, CO2 and N2. For flame stability, fuel gas co-firing has been considered in reaction furnace. The fuel gas introduction increases the inert gas such as N2 with the increased combustion air and CO2 in the combusted gas.

Consequently, the partial pressure of H2S and SO2 will decrease and 95% of sulfur recovery will become difficult. In order to keep the sulfur recovery rate, SuperClaus process was applied which enables the high sulfur recovery, regardless of the low partial pressure of H2S and SO2. The SuperClaus process was developed by Stork E&C. This reaction forms the sulfur by a partial oxidation reaction instead of the Claus reaction which is an equilibrium reaction.

- **Claus Reaction:** 2H2S + SO2 = 3S + 2H2O (equilibrium reaction)
- **SuperClaus Reaction:** H2S + 1/2O2 → S +H2O(partial oxidation)

The mercaptan content in the acid gas feed to the sulfur recovery unit will increase the sulfur recovery rate and this will reduce the SOx emission to the atmosphere to two thirds(2/3) of the original design.

Eventually the design modification caused new drawings of two thirds of P&ID of the process units, the joint effort between Qatargas and Chiyoda minimized the impact to project schedule.

**Layout Modification from Safety Viewpoint.** From the viewpoint of recent severe consideration on safety against toxic gas, hydrogen sulfide, needed a modification on layout. The hydrogen sulfide rich section i.e. the Sulfinol Regenerator and sulfur recovery unit were separated from the other process units.
**Welded Plate Frame Exchanger**. Welded type plate frame exchanger, Compabloc heat exchanger of Vicarb has been successfully applied for Sulfinol Lean Rich Solution Exchanger. The application reduced the plot area and cost due to its compactness. The welded type promised the safety for toxic gas. Seven plus one spare heat exchangers were installed parallelly due to its counter current heat exchange. The equal solution distribution was carefully designed to get proper performance of the heat exchanger. On-line cleaning can be done using the spare heat exchanger, if required.

**Dynamic Simulation Around Refrigeration Compressors**. Dynamic simulation has been done for various operation mode of the refrigeration cycle by subcontractor SAST. The dynamic simulation revealed that the propane compressor and MR compressors will get surging during the emergency shut down. The surging was caused by the low inertia of the power turbine of Frame-V connected to the compressor as load and the large discharge volume of the compressor. To avoid the surging, modifications were made to provide a hot by-pass valve from the compressor discharge to the suction drum.

**Plant Operation Tool Development**

**Plant Operations Information System (POIS)**. POIS has been introduced to this LNG plant. Recent advances in computer technology have led to the application of total plant-wide information systems in LNG plant operations. In this application, POIS provided a crucial link between the process control system and the business information system.

Functionally, the process control system provides the facility for daily plant operation and is used by the process operation personnel, while the business information system functionality provides for corporate level information relating to activities such as accounting, financial management, business and facility planning.

The main users of POIS are plant managers, operation managers and engineers. POIS enables users to generate LNG production schedules, operator guidelines, summary and shift reports, and provides information on the LNG plant, such as equipment performance, product quality, safety, and environmental monitoring.

**Advanced Process Control (APC)**. In general, APC are increased production throughput, improved product quality, and/or reduced energy costs. LNG plants are usually required to operate at maximum load. In this LNG Project, model-based predictive control algorithms are applied to achieve the following objectives:

- Maximize LNG production at Main Heat Exchanger
- Control the quality at the fractionation section to maximize valuable product and minimize utilities

**Operator Training Simulator (OTS)**. Recent advances in computer and simulation technology have enabled us to provide a high fidelity dynamic simulator containing rigorous dynamic equations of the process.

OTS is an efficient training tool both for new and experienced operators to refresh their skills. The OTS can provide practice (skill learning and development) in start-up, shut-down, normal operations and special or emergency operations. OTS in this LNG project will be one of the first high fidelity training simulators in LNG plants in the world.
It is expected to be a key component for training, since the plant is a grassroots facility, and training of a pool of new operators was required initially.

The model for each unit operation has already been developed by OTS subcontractor HONEYWELL HI-SPEC SOLUTIONS excluding main cryogenic heat exchanger, which is special type heat exchanger.

The model of the main cryogenic heat exchanger was newly developed by the joint effort among Qatargas, Chiyoda and HONEYWELL HI-SPEC SOLUTIONS which took one year. The actual OTS model was the combination of such model based on the actual configuration of the plant. OTS was delivered at February 1996 well before the plant start-up to enable operator training.

The OTS was equipped with an exact replica of the Distributed Control System, DCS, operator consoles to enable operators to familiarize with DCS. Also, the high fidelity simulation of process models in OTS allow for process operation training. In the future, the potential exists that the high fidelity process models can be further developed to serve as useful engineering tools.

**EDMS**

Electronic Data Management System(EDMS). The design of the Qatargas plant was performed entirely by the most advanced computers available. A plant design system by Intergraph was employed within a three dimensional CAD format. Chiyoda’s global information network connects headquarters in Yokohama with offices in the United States, England, Italy, and Singapore through international leased lines. Chiyoda headquarters were linked with the site in Qatar by Intelsat digital communication, which enabled video conferencing, fax, telephone, and complete data transmission capability using E-mail. The transmission route from Chiyoda Yokohama Office to Ras Laffan Site Office through Intelsat is (Fig.7):

- TDM(Time Divided Multiplexer) Chiyoda Yokohama Office - DSU(Digital Service Unit) - NTT communication line - KDD Shinjuku - KDD, Yamaguchi - Intelsat
- Intelsat - CPES(Customer Premised Earth Station) owned by Q-TEL - TDM, Ras Laffan Site Office
Communication between Japan and Qatar was further enhanced by a communication system with internal exchanges for the speedy exchange of voice, fax, and E-mail. Engineering and construction drawings including vendor drawings have been successfully sent electronically over the computer networks. Some 700 thousand pages which size ranged from A0 to A4 were sent and received. Engineers of Qatargas and Chiyoda opened these diagrams with their own PCs to enhance efficiency.

This two-way communication network was also supported by Qatargas, with both parties making use of data to keep the project moving along. At each office on the site, internal LAN and other communication networks facilitated the quick exchange of information for greater efficiency in engineering work, equipment procurement, transport, and project management.

As-built drawings/document, operation manual, and project procedure including vendor prints are electronically stored in form of AutoCAD *.dwg file, Intergraph *.dgn, Microsoft office files, compressed image data *.tiff, etc. At the completion of trains 1&2, the stored data counted 60 disks of CD-ROM. To retrieve and view from such a large database, oracle base software has been successfully developed.

3D PDS Module for Qatargas Process Plant. 3D module of PDS, Piping Design System, of Intergraph Corporation has been successfully applied for the piping design of the process plant(Fig. 8). The 3D module data base includes structure data, equipment data, piping data, raceway data, HVAC data, etc.. The 3D module greatly reduce the engineering man hour by automatic generation of:

- Material take-off, Crash check and Piping general arrangement drawing
- Isometric drawings and Material data for construction for each line

The 3D module generated 160 piping general arrangement drawings and 6,000 isometric drawings for the process plant.
Construction

Work Volume. Construction of the grass root LNG Plant required an enormous effort by Chiyoda and its subcontractors resulting in a peak construction manpower build-up of close to 8,700 personnel in October 1995 from 40 countries.

As of November 30, 1997, a total of over 64 million man-hours had been spent in constructing the facility. Totals of some of the material quantities utilized in Plant construction are:

<table>
<thead>
<tr>
<th></th>
<th>2 Trains and Associate</th>
<th>3 Trains and Associate (expected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Poured, M3</td>
<td>145,500</td>
<td>182,600</td>
</tr>
<tr>
<td>Steel Erected, ton</td>
<td>6,800</td>
<td>9,300</td>
</tr>
<tr>
<td>Piping Installed, ton</td>
<td>21,800</td>
<td>28,000</td>
</tr>
<tr>
<td>Electrical Cable, km</td>
<td>1,900</td>
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<tr>
<td>Main Instrument Cable, km</td>
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<td>1,540</td>
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<tr>
<td>Pieces of Equipment</td>
<td>870</td>
<td>1,100</td>
</tr>
<tr>
<td>Weight of Equipment, ton</td>
<td>24,800</td>
<td>32,000</td>
</tr>
<tr>
<td>Building Space, M2</td>
<td>72,600</td>
<td>75,700</td>
</tr>
<tr>
<td>LNG Tank Steel Erected, ton</td>
<td>7,200</td>
<td>9,600</td>
</tr>
</tbody>
</table>

Consistent with the strategy of the EPC contract, plant construction efforts focused on the phased completion and hand-over of stand alone facilities to Qatargas to allow accelerated start-up and operational activities. The joint effort of Qatargas and Chiyoda
has completed the 1\textsuperscript{st} train & its support facilities and the 2\textsuperscript{nd} train & its support facilities around one month ahead of the project schedule, respectively.

\textbf{Construction of the 3\textsuperscript{rd} Train.} 3\textsuperscript{rd} LNG process train is currently progressing well ahead of schedule of around 5 months, by the feed back of lesson learning from the construction work of 1\textsuperscript{st} train and 2\textsuperscript{nd} train & their associate facilities.

\textbf{Construction Safety Record.} As Work continued, attention was never diverted from safety and environmental considerations. During order and organization checks, safety patrols, the erection of strong scaffolding and barricades, and even the adoption of dress-up methods to reduce the amount of high elevation work, safety was always priority number one. As a result, over 9.9 million man hours of work passed without a single accident, setting several new records for construction safety, as of 4\textsuperscript{th} December, 1997.

\textbf{Pollution Control on Water Disposal.} After water is used in the plant, it is treated and then diverted into a holding reservoir where it is used for the green belt adjoining the facility. In addition, in order to minimize pollution when letting out cooling water into the sea, the water is carefully monitored for temperature and purity before it leaves the facility. In every aspect of operations, environmental protection measures are closely followed in cooperation with Qatargas.

\textbf{Pipe Bending Shop.} Piping bending work was successfully performed with a new method using high frequency electro-magnetic wave to bend the 2-12 inch carbon steel, killed carbon steel and stainless steel pipes. The method shortened the construction schedule eliminating fittings and the welding work, especially for 3\textsuperscript{rd} train.

\section*{5. \textbf{START UP AND OPERATION OF THE LNG PLANT}}

\textbf{Upstream Operations}

First gas from North Field Qatargas Upstream Facilities arrived via the 32inch pipeline in July 1996. A minimum gas flow had to be maintained through the pipeline to prevent excessive slug formation in the slug catcher. The minimum flow has been predicted during the Engineering phase through extensive simulation using two-phase flow modelling and the design of a dynamic simulator that will predict liquid hold up and the slug formation. To date the upstream facilities have been able to meet the LNG plant demand and provide 240 Mscfd of gas to QGPC through an existing 34inch pipeline to Messaied Industrial area.

\textbf{LNG Plant Operation}

The utility plant successfully started operation from the beginning of 1996, which supplied not only to the 1\textsuperscript{st} train but also to the upstream facilities. The phase I pipeline gas was utilized for this start up.

\textbf{1\textsuperscript{st} Train Operation.} After several months from the start of 1\textsuperscript{st} train operation, the 1st train needed to reduce the capacity due to Sulfinol unit foaming. The feed gas from upstream contains heavy hydrocarbons in addition to breakthrough of fine carbon from damaged filter elements, which might have caused the Sulfinol foaming. Several actions
were taken after field research work among Qatargas, Chiyoda as authorized licensor of Shell Sulfinol process.

- Oil skimming from the unit
- Proper stripping steam rate to Sulfinol Regenerator
- Use of the most suitable antifoam agent (self-emulsified and modified silicone type) selected through the site foaming test among several antifoam agents
- Replace with durable filter element of the mercury removal effluent filter upstream of Sulfinol Unit, preventing sulfur impregnated activated carbon leak

After taking above countermeasures, since August 1997, the plant has been operating without any load change to be caused by foaming.

**SRU Operation in Lean H2S Acid Gas with High Content of Hydrocarbon.** During the construction stage, the new well feed stock became available. The new feed stock has lower H2S and higher CO2 together with large amounts of heavy hydrocarbons. Due to the application of the physical and chemical absorption process, a large amount of heavy hydrocarbons are entrained in the feed acid gas to the SRU. The new feed stock had to be incorporated in one of operation cases with the same process performances as the design feed stock.

The treatment of a large mount of heavy hydrocarbons, more than 1 vol% in the low H2S feed acid gas of 10 vol% is believed to be impossible, resulting in the soot formation, deactivation of the catalyst and the lower process performances. For the treatment of this type of the feed acid gas, the enrichment process or the hydrocarbons removal by the activated carbon are normally applied. In order to achieve this task, the investigation of the combustion of heavy hydrocarbons in the substoichiometric conditions were made using the thermodynamic models and by the experiments. It was ensured that the soot was formed at the stoichiometric amounts of air lower than 60 % of the combustible components in the feed acid gas and also, in more air, the sulfur recovery rate was decreased significantly. The fine combustion air control, the higher flame temperature and the sufficient residence time in the reaction furnace, and the excellent high intensity main burner are the key factors for the stable operation with the high process performances, free of troubles related to the soot formation.

Prior to the initial start-up of the SRU, the control system of the combustion air supply was optimized specially for this feed acid gas. Since the initial start-up operation, the task of achieving the high sulfur recovery rate to meet the environment regulation with the production of the good quality and salable sulfur is fulfilled. The actual feed gas specification is now not so lean in the content of H2S, but containing higher heavy hydrocarbons. Due to the well designed advanced control system, this task is achieved in the ordinary operation manner of the SRU.
Performance Test

Process Train Test. Performance test of the 1\textsuperscript{st} liquefaction train has been successfully done from 28th September 1997 for 72 hours with minor outstandings;

- Insufficient purity of propane
- Entrainment from LP Propane Chiller

Insufficient propane purity is mainly caused by the feed gas deviation from the design feed gas composition. The propane purity was achieved by reducing the deethanizer operating pressure. The entrainment from LP Propane Chiller caused level high trip of the Propane Compressor Suction Drum, this was caused by improper level transmitter span of the chiller.

Performance test of 1\textsuperscript{st} sulfur recovery train has been successfully done from 5th October 1997 for 72 hours without outstanding item.

Performance test of 2\textsuperscript{nd} liquefaction train has been successfully done from 3rd November 1997 for 72 hours with minor outstanding items such as entrainment from LP Propane Chiller.

Performance test of 2\textsuperscript{nd} sulfur recovery train has been done from 7th November 1997 for 72 hours, resulting color test failure. Retest is due planned. All test results are shown in following Table. 1

Auto-Consumption Test for 1\textsuperscript{st} and 2\textsuperscript{nd} trains. Auto-consumption is self fuel consumption rate and one of the guarantee items for Contractor Chiyoda. The test has been successfully performed from 21st October, 1997 during 72 hours feed backing the deethanizer operating pressure from 1st train performance test. The auto-consumption of the plant is calculated as 4.09 tera joule/h against the guarantee value of 4.86 tera joule/h, while the LNG production rates are at:

1\textsuperscript{st} train : 309.3 t/h
2\textsuperscript{nd} train : 315.0 t/h

The auto-consumption figure is adjusted for cooling water temperature, although the adjustment for the ambient temperature was not made since it was not necessary.

<table>
<thead>
<tr>
<th></th>
<th>Test</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature, deg.c</td>
<td>30.37(ave.)</td>
<td>29</td>
</tr>
<tr>
<td>Cooling water temperature, deg.c</td>
<td>31</td>
<td>35</td>
</tr>
</tbody>
</table>
### Table 1 Performance Test Results

<table>
<thead>
<tr>
<th>Process Train</th>
<th>Design</th>
<th>Train 1</th>
<th>Train 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feed Gas Data</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed Gas Rate, Nm3/h</td>
<td>477,799</td>
<td>477,798</td>
<td>488,110</td>
</tr>
<tr>
<td>CO2 Content</td>
<td>2.09</td>
<td>2.157</td>
<td>2.171</td>
</tr>
<tr>
<td>H2S Content</td>
<td>0.48</td>
<td>0.41</td>
<td>0.426</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Liquefaction Unit and Refrigeration Unit</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercaptan Contents, ppm mol</td>
<td>356.1</td>
<td>58.68</td>
<td>62.2</td>
</tr>
<tr>
<td>Mercury Content, nano g/NM3</td>
<td>900</td>
<td>13</td>
<td>1.5</td>
</tr>
<tr>
<td>LNG Rate, t/h</td>
<td>300</td>
<td>336</td>
<td>339</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Inert Gas, mol%</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.5</td>
<td>0.36</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>C5+ in LNG, mol%</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.075</td>
<td>0.01</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Sulfinol Unit</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 Content in Treated Gas, ppm mol</td>
<td>50</td>
<td>7.01</td>
<td>6.17</td>
</tr>
<tr>
<td>H2S mg as S/Nm2</td>
<td>7.0</td>
<td>&lt;1.43</td>
<td>&lt;1.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Mercury Removal Unit</strong></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Unit Outlet, nano g/Nm3</td>
<td>10</td>
<td>1.9</td>
<td>95.1</td>
</tr>
<tr>
<td>2nd Unit Outlet, nano g/Nm3</td>
<td>10</td>
<td>1.5</td>
<td>99.8</td>
</tr>
</tbody>
</table>

| **Plant Availability** |        |         |         |

The design life of the plant is 30 years and appropriate consideration has been made for the hot, salt-laden atmosphere at the remote coastal site. The sparing and monitoring philosophy is based on obtaining an annual availability, excluding scheduled shutdowns, of 95% for each LNG train.

Two types of scheduled shutdowns are planned. A major shutdown shall be scheduled every three years for each process train after some adjustment during the first two/four years to enable a regular pattern to develop. This schedule for major train shutdowns satisfies the requirement that only one process train is to have a major shutdown in any single year, while catering for the planned expansion to three LNG trains. A minor
shutdown of each process train will take place annually unless the train is due for its major shutdown.

The process train major shutdown is to be completed in 30 days and shall permit major overhaul of all four compressor gas turbines and cleaning of sea water exchangers. The minor shutdown is to be achieved in 5 days and shall include combustion chamber inspection of the gas turbines and change out of the complete inventory of molecular sieve material or mercury removal bed (if required). Based on two minor and one major shutdowns in a three year period, the average scheduled downtime is therefore 13.3 days per year. In addition to the scheduled shutdowns, each LNG train can experience unscheduled downtime. The annual average unscheduled downtime for an LNG train is not to exceed 5%.

6. SUMMARY

The message in this paper informs the accomplishment of the 1st phase of implementation of the Qatargas LNG Project, which is the top runner of Ras Laffan Industrial Development Program utilizing the world’s largest Natural Gas Reservoir, North Field, the largest resource-based project ever attempted within Qatar and currently one of the largest macro projects being undertaken in the world. To date the results have been extremely successful, on time and on budget, regardless of new technical and globalization attempt. The project has been successfully served to public utility in Japan and Spain in a form of ecological friendly energy source.

The whole represents a fascinating story for which Qatargas and their contractors have taken in a chain of effort. Many have played their part in this achievement, as hopefully has been made clear, and they and their successors will benefit in drawing the rewards of all of this activity.

ACKNOWLEDGMENTS

The acceptance for this paper and providing valuable information by share holders of Qatar Liquefied Gas Co. and process licensors are gratefully acknowledged.

REFERENCE CITED