1. INTRODUCTION

The history of Liquefied Natural Gas (LNG) can be traced back to the experiments in gas liquefaction of British chemist and physicist Michael Faraday. Soon after Faraday’s discoveries the German engineer Karl Von Linde built the first practical compressor refrigeration machine. In the early 1900s LNG became commercial with the construction and operation of the first liquefaction plant in West Virginia, United States. By the middle of the century the industry had evolved to the point where the large scale transportation of LNG became viable. In 1959 the LNG tanker, Methane Pioneer, delivered the first Trans-Atlantic cargo of LNG to Canvey Island, United Kingdom and the business and operation of LNG importation began.

The last 40 years has seen a growth of the LNG importation industry to the point where, as of 2004, the number of LNG receiving terminals around the world reached 47. In addition to the numbers of terminals built over the last 40 years, the global diversity of the industry has increased with 13 countries spread over 3 continents involved in the importation of LNG. To service these terminals 173 LNG vessels and 15 sites of liquefaction have been built and are in operation.¹

Currently LNG accounts for over 20% of the total gas traded and is expected to be the fastest growing component of global energy consumption. The consumption of natural gas worldwide is predicted to increase by an average of 2.3 percent annually from 2002 to 2025.² The expected percentage growth for the LNG industry surpasses even these estimates for the overall natural gas sector. It is currently expected that the worldwide demand for LNG will continue to increase at 8 percent a year or more for the foreseeable future. Some forecast estimate increases as high as 71% by 2010 and 172% by 2020.³

To meet this demand, industry has responded with the planning of more than 120 new LNG receiving terminals. The number actually constructed will undoubtedly be far less than this number but will be substantial none the less. With all of these planned terminals it becomes easy to overlook the fact that the success of the industry’s response to the expected demands is in part predicated on the continued operation of the existing LNG facilities. It is within this context that the Reliability, Ageing and Life Extension (RALE) of these terminals have become relevant to all participants involved in the trade of LNG.

While the challenges faced by the existing LNG terminals may become increasingly more difficult every year, with care in operation and appropriate upgrading, LNG installations can be made effectively evergreen. To meet the demands of the current market, terminal operators must make dedicated efforts to continuously improve their maintenance and operational practices. The existing terminal operators have substantial information relating to the maintenance of their own LNG installations and also have developed extensive

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operational experience. However, because each operator tends to operate a relatively small number of LNG installations, the build-up of an extensive database is not possible and may be one factor contributing to the conservative approach to maintenance prevalent in the LNG industry.

By undertaking a broad study of the maintenance and operational experience of existing terminal operators, all operators will benefit as each will be better positioned to review and improve their own operations. Furthermore, LNG importation operators will benefit in issues relating to the ageing and life extension of existing installations. While the LNG industry has previously addressed issues relating to technical reliability of LNG projects, it has, as far as we know, never undertaken such a detailed examination on the reliability, maintenance and life extension activities of active LNG importation terminals.

2. AIM OF THE STUDY

As the leading industry user organization, The International Group of Liquefied Natural Gas Importers (GIIGNL) determined that it was imperative that the issues associated with the reliability, ageing and life extension activities of LNG import terminals worldwide was examined in detail. This work, and in turn the results presented in this paper, was completed by GIIGNL’s permanent Technical Study Group comprised of industry experts from the most experienced LNG operators.

By investigating and analyzing the different approaches of numerous companies in multiple geographical regions worldwide, GIIGNL hoped to develop a broad understanding of how company policies and strategies for asset maintenance and management can affect the reliability of LNG installations. By examining and understanding the total life cycle cost of facilities and equipment, benchmarking the maintenance strategies and reviewing case histories of life extension initiatives, the work was anticipated to provide new tools for the LNG industry to review and improve its operations and investment strategies.

The main objective was to undertake a broad study of worldwide maintenance and operational experience of LNG installations, thereby providing GIIGNL members with:

- Benchmarking of their present operations to allow them to improve maintenance schedules and move toward maintenance best practices.
• Exchanging commercial and general technical information to support decisions relating to developing new projects or extending the life of existing installations.
• Providing a basis for discussion with safety and environmental regulators when seeking approval for extending existing operations or starting new ones.

3. METHODS

GIIGNL addressed the initiative to study reliability, ageing and life extension of LNG importation facilities by undertaking three distinct initiatives while maintaining a focus on the overall objectives. In summary, the steps included the development of a broad understanding of plant reliability and maintenance issues associated with LNG importation facilities worldwide. This effort was followed by a compilation and analysis of pertinent facility aging issues with particular attention paid to life extension activities. Finally, the benchmarking of maintenance practices was performed. The three steps have been detailed herein.

3.1. Reliability and Maintenance Policy

The philosophy behind this first step was to develop an understanding of reliability issues for LNG facilities and how these can be affected by company policy and strategies for asset maintenance. The aim was to provide understanding of the total life cycle costs of facilities and the equipment used in them by investigating and analyzing the different approaches followed by companies involved in LNG activities.

Building upon the previous GIIGNL efforts in the areas of technical reliability and surveys of plant equipment at LNG facilities the GIIGNL Technical Study Group and in particular the RALE Sub Team (Group) collected information from members through a questionnaire process on the following topics:

• inspective and preventative maintenance philosophies
• equipment/LNG facility reliability
• operational philosophy
• regulations/standards
• political issues
• safety/environmental issues

Information to supplement that gained through the questionnaire process was sought from active GIIGNL members, public bodies, research organizations, manufactures and other industry contacts. The broad practical study, in which 33 LNG installations contributed, included both peak shaving plants and receiving terminals. It was focused on the major plant items of tanks, vaporizers, pumps,
boil-off compressors, unloading arms and pipe work fittings. Associated ancillary equipment and instrumentation was only considered in terms of existing regulations.

### 3.2. Life Extension Activities

With the increased demands of today’s global LNG market, existing LNG terminal operators must become increasingly competitive in their operations. One way to achieve this is to understand the total life cycle costs of facilities and the equipment used within them.

Traditionally, equipment has been selected by looking at initial capital cost, power consumption, equipment reliability, design life, operation and maintenance costs. Now, companies understand that a project’s total lifecycle cost can be reduced by looking also at delivery times for critical spare parts, cost of parts, availability of technical support and life extension.

The competitive market has changed equipment selection criteria to include these items. Life extension in particular comprises those activities specifically lengthening the life of the facility beyond its design life or beyond some shorter life brought about by unexpected circumstances. It is distinct from maintenance, which is solely to ensure that the facility operates effectively for its expected lifetime.

The aim of this step in the initiative was just to focus on life extension by means of analyses of the different approaches followed by companies involved in LNG activities. The fields investigated regard: life extension policies, life extension programs and ageing countermeasures. A replacement history was also investigated in order to better understand the replacement frequency for the main equipment / components and the relevant replacement causes.
Contributions to this effort were made by more than 30 LNG installations with detailed and specific case histories prepared for 9 of the GIIGNL members’ installations.

### 3.3. Maintenance Benchmarking

This step was initiated to gather and evaluate information associated with the maintenance practices of LNG facilities worldwide. This effort was largely dependant upon individual operating facilities completing detailed and specific questionnaires.

To complete this effort GIIGNL first had to identify the suite of critical plant items pertinent to the majority of LNG importation facilities. Then, as with the earlier step of developing the broad understanding of RALE issues, this step built upon work previously completed by the GIIGNL organization. Existing GIIGNL questionnaires were evaluated for content, and new questionnaires developed to meet the specific needs of this effort. The GIIGNL questionnaires were then sent out and completed by operating personnel at the GIIGNL members’ facilities.

Once the information was compiled, applicable maintenance strategies were identified with a clear understanding of how such strategies fit within an overall maintenance program. The variations, benefits and weaknesses were then considered and where possible, optimum practices were identified. These efforts would enable GIIGNL members to position themselves and identify if they were in the range of best practices.
4. RESULTS

The results of the three steps were compiled and analyzed by the Group and formal reports were produced for distribution within GIIGNL for each of the steps. To maintain structure and ease of reading, the results for each of the steps have been kept separate. Conclusions will include separate sections for each of the steps but will also include an overall assessment of the Groups findings.

4.1. Analysis of Reliability and Maintenance Policies

The following results were obtained through the efforts of the GIIGNL initiative with respect to reliability and maintenance policies.

- All respondents have a maintenance policy document, the majority of which have been developed in house. Only 10% used specialist support and 3% had used a specialist only.

- 95% of respondents have developed policy objectives - all of which using in house facilities and only 3% using specialists jointly.

- 25% of respondents have not linked their policies to their safety management system. Only 10% of those having a link relied solely upon specialist support to develop.

- 20% of respondents had not based their policy on concepts of safety criticality (identification of critical safety components). Of those that did 70% undertook the exercise in house, 8% with a combination of own and specialist resources, none undertook the work solely with external expertise.

- 80% of respondents have introduced systems for best practice into their maintenance policy and operational systems. All respondents who undertook this did the exercise internally.

- 80% of respondents have introduced systems for monitoring and controlling compliance with their maintenance policies and operational systems. Again, all respondents who undertook this did the exercise internally.
• 86% of respondents have introduced formalized procedures for managing changes to their maintenance policy and strategies, with all work being undertaken in house.

• All responding companies claimed to have appointed responsible persons for ensuring implementation and compliance with their maintenance policy. This appeared to have been done on the basis of company organization with 27% of respondents undertaking this globally throughout their business, 34% on individual sites and 14% at the level of operators. The remaining companies reported a combination of individual and third party operation.

• 20% of respondents had not linked their policies to a formal procedure for analyzing and defining failure modes and utilizing this as the basis for their maintenance policy. Of those that did, 42% claimed to have done this purely through experience with the remainder using reliability targets or a combination of reliability and experience. (The use of experience alone would indicate that a structured approach to failure mode analysis such as FMEA or RCM has not been adopted).

• 90% of respondents reported that they utilize maintenance strategies that can be deployed generically across their plant or facilities.

• Only 15% of respondents claimed to deploy procedures for whole plant shut down as part of their maintenance strategy.

• 12% of respondents had not provided for communication of their policies to their staff or other stakeholders. Of those that did two thirds were using electronic media or a combination of electronic and paper copy to communicate the policy.

• 20% of respondents do not undertake a structured review of their policy on a regular basis. Of those who did, almost half report to doing this on an ad hoc basis. Only 38% of the total population exercise regular structured reviews on an annual basis.
• Where maintenance strategies were updated all companies claimed to involve their staff in the process to some extent. 75% do this routinely while 25% only occasionally.

4.2. Results of Analysis of Life Extension Activities

Life extension is defined as activities lengthening the life of the facility beyond its design life or beyond some shorter life due to unexpected events whereas maintenance activities ensure the expected lifetime for the facility. The study had focused on the different approaches followed by LNG companies for life extension and the analysis had covered 33 different LNG installations (30 import terminals and 3 peak shaving plants). Some of the results are as follows:

• Lifetimes for LNG storage tanks are not described in years. Fatigue life of tanks is limited to thermal cycling conditions and, in particular, to the number of complete warming and re-cooling of the tank itself.

• 33% of LNG facilities have a given lifetime. No one was aware of the existence of any benchmarking groups on life extension. Only one facility uses specialist consultants for life extension and 13 facilities used company staff.

• 33% of facilities have in-house programs for life extension. The main drivers for life extensions are equipment obsolescence and replacement scheduling, increasingly stringent safety or environmental requirements, update of the business plan, renewal of permits, new market realities and deregulation of the gas market.

• The main expansions are for send-out increase, co-generation plants and LNG truck loading and unloading. The main safety and environmental improvements are for the installation of safety automated systems, relocation of control rooms to a safe area, annual inspection of cryogenic pipelines. The main replacements have been control systems/ESD, instrumentation and electrical equipment, LNG vaporizer refurbishment and LNG pumps.

Figure 7 – Expansion activities at the Fluxys LNG Receiving Terminal. Zeebrugge, Belgium. Photo Courtesy of Fluxys LNG
• Ageing countermeasures are strictly connected with maintenance activities and include periodical checks and inspections, replacement of protection measures (coating, insulation, concrete structures, pipe supports, cathodic protection), topographic surveys, operating practice and maintenance practice.

4.3. Results of Maintenance Benchmarking

The following results were gathered through the data questionnaires and the subsequent analysis of the data set. The following sections provide a commentary which is intended to characterize the main aspects of the maintenance regimes for each of 27 critical equipment groups identified at the initial workshop.

These groups of equipment were selected using the criteria that the equipment types should be those which are generic to most members of the group and where analysis and comparison of the maintenance strategies would provide the most significant benefit to the member companies.

The following areas were also considered and discussed in some detail but were considered to be too extensive to incorporate in the current study. It is considered that these areas could be usefully benchmarked as a separate exercise at some time in the future.

• Corrosion management & cathodic protection systems
• Vessels and pressurized plant
• Facility / Grounds maintenance

The following section seeks to establish a benchmark for each maintenance strategy. This was done by establishing the overall norms from the sample data supplied by the member companies, and in some cases generally accepted best practice is also indicated. These norms provide an indication of optimum maintenance practice against which member companies can consider their position.

It should be noted that local regulatory requirements, statutes and safety and environmental considerations may override the maintenance strategy norms identified by the study. This should be taken into consideration when companies are considering their position with respect to these norms. Warranty conditions for new or replacement plant equipment may also restrict the choice of maintenance strategy to those specified by the Original Equipment Manufacturer (OEM).
4.3.1. Offloading

4.3.1.1. Offloading Arms

80% of the responding members have LNG/Vapor Offloading Arms installed at their facilities and provided data on the maintenance activities associated with them. Frequency and type of maintenance varied amongst the responding members.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG Offloading arms:

**Periodic** – Perform a functional test of offloading arms by actual movement of the arm structures, prior to each ship offloading.

**6 Monthly** – Perform a general visual inspection which would include checking hydraulic fluid levels, general corrosion, cable fittings etc. using direct labor.

**5-10 Yearly** – Perform an OEM assisted major inspection/overhaul of each offloading arm. The extent of the maintenance performed and the time interval shall be determined by the general visual inspections based on the actual condition of the equipment.

**Note 1:** Intrusive maintenance (dismantling) of the equipment is not generally performed unless indicated by the periodic or detailed inspections.

4.3.1.2. Offloading - Gas Return Compression

80% of the responding members have compressors used for the return of gas to the ships during the offloading process. Each of the members (100%) performs at least a yearly maintenance of the equipment. While all members use a calendar based schedule for their task, 20% uses the equipment’s running hours for scheduling some of the maintenance activities.

The most common maintenance activities associated with the gas return compressors are functional tests. Only 20% of the members have scheduled a major replacement (controls) of the gas return compressor equipment.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG Offloading gas return compressors:
Annual – Most companies undertake periodic preventive maintenance schedules covering such items as gearbox alignment, bearing checks, instrumentation function checks, surge control tests etc..

Note 1: Generally recognized best practice for this type of equipment is to maintain by duty (running hours) or predictive schedules based on condition monitoring regimes.

4.3.2. Storage

4.3.2.1. LNG Tanks / Tank Insulation

Information was received from all members (100%) on maintenance activities associated with LNG storage tanks. Visual inspections were common with frequencies ranging from daily to yearly. Some members (40%) have annual infrared or thermographic surveys performed.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG Tanks and tank insulation:

Monthly – Perform a visual external inspection of the storage tank identifying such items as leakage checks at all accessible connections, paint condition, anchor bolts, base heaters, concrete foundations etc..

Annual – Perform checks for “cold spots” due to insulation degradation using thermographic inspection techniques or physical measurement depending on type of construction. Undertake tank settlement surveys and corrosion surveys.

Note 1: It is generally recognized that visual external inspection of tanks on a regular basis is performed by both operational and maintenance personnel and is in addition to the optimum practice identified above.

Note 2: It is generally recognized that internal inspection of LNG storage tanks is not safe working practice, though any opportunity for internal inspection resulting from tank modifications or repairs should be fully exploited to check on internal condition of the tank.

4.3.2.2. In Tank Pumps

Information was received from all members (100%) on maintenance activities associated with LNG pumps installed in LNG storage tanks.
Functional testing was common, as was the “on condition” general overhaul of the pumps.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG In-tanks pumps:

- **Annual** – Perform general condition, performance and function checks depending on the duty of the pumps

- **On Failure** - Major intrusive overhauls are only undertaken on failure of equipment

*Note 1:* General condition performance should be monitored by operation personnel as part of their routine activities.

### 4.3.2.3. LNG Tank Instrumentation / Electrical

Information was received from all members (100%) on maintenance activities associated with instrumentation and electrical systems for the LNG storage tanks. All members (100%) have functional testing (loop check & calibration) of instruments associated with LNG tanks. Frequency of testing is consistent with all members (100%) performing testing on at least an annual basis. 20% of the responding members perform testing on a six month interval.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG Tank instrumentation and electrical equipment:

- **Annual** – Perform function test for all instrument and control loops associated with the LNG tank operation. Densitometers are also normally calibrated and serviced by the OEM on an annual basis.

### 4.3.3. Export

#### 4.3.3.1. Ex Tank / Booster Pumps

Information was received from all members (100%) on maintenance activities associated with LNG pumps used for the pressurization of LNG prior to the vaporizations systems. The majority of responding members used a calendar interval for scheduling maintenance while 20% of the responding members used running hours of the equipment to determine the interval between maintenance.
The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG Ex Tank / Booster Pumps:

**Periodic** - Where the drive motors are accessible perform routine checking of vibration, alignment, bearing temperature etc. at intervals dependent on duty and condition of the pumps.

**Annual** – Perform general condition, performance and function checks depending on the duty of the pumps.

**On Failure** - Major intrusive overhauls are only undertaken on failure of equipment.

**Note 1:** General condition performance should be monitored by operation personnel as part of their routine activities.

**Note 2:** Generally recognized optimum practice for this type of equipment is to utilize condition monitoring regimes to predict impending failure, allowing appropriate intervention at the optimum time for replacement or repair.

**Note 3:** Account should be taken of pump starts and amount of standby service.

### 4.3.3.2. LNG Vaporizers Direct Fired / Shell Tube

Numerous responses were received from all members (100%) in conjunction with LNG vaporizers. The questionnaire covered both direct fired and external heated heat exchangers and included the maintenance of the burners and fuel trains.

Frequency of maintenance ranged from daily to 4+ years. The majority of activities were based upon a calendar based schedule while 20% of members used running hours of the rotating equipment (fans/blowers) to schedule maintenance.

Functional testing and visual inspections were the most numerous entries on the questionnaire. Many of the members (60%) reported regular pressure testing of the heat exchanger tube bundles (LNG side) as part of the maintenance program.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of LNG Vaporizers Direct Fired / Shell Tubes:
Annual – Perform yearly preventive maintenance (PM) for cleaning and check on combustion fans, flame scanners, spark plugs, control valve linkage, refractory condition, instrumentation calibration checking and function testing etc.. Inspect tube bundles and vaporizer internals for cracks and corrosion.

4-6 Years – Undertake internal inspection, non-destructive testing (NDT) and pressure testing of tube bundles according to the scheme of examination. Where age and condition of the equipment dictates, these inspections may be required on a more frequent basis.

Note 1: General condition performance should be monitored by operation personnel as part of their routine activities.

Note 2: Some companies are beginning to use endoscopic inspection techniques for internal examinations and checks.

4.3.3.3. Gas Metering / Analysis

All members (100%) responded with information on the maintenance of metering and analization equipment involved in the send-out of vaporized LNG. The majority of responses centered on the checking and calibration of such equipment. Frequency of maintenance ranged from daily to yearly.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Gas metering and analysis equipment:

Periodic – Dependant upon the commercial and regulatory requirements periodic inspections, calibrations, renewal of calibration gases and data checking should be performed at appropriate intervals.

Annual – Perform yearly PM for cleaning, checking and calibration of meters, analyzers, flow computers, etc..

4-6 Years – Removal and recertification of all meters.

4.3.3.4. Gas Blending / Stabilization

Information was only received from a limited number of members (40%) on maintenance activities associated with equipment used for gas blending or stabilization. This was due to limited current use of blending and stabilization equipment. However, it was still considered important to
include this in the suite of critical plant items, so that any further expansion of participating companies would provide the ability to expand the data set. On the limited information received, activities were primarily focused on functional test of the equipment.

It was not possible to identify optimum practice within the benchmark group for the maintenance of Gas blending and stabilization equipment due to the limited data set returned by the member groups.

4.3.3.5. Gas Compression

Information was received from many of the members (60%) on maintenance activities associated with equipment used for the compression of vapor (not including Gas Return to ship) from the terminals. Of those that responded two-thirds use a calendar based or “on condition” system for the scheduling of maintenance. The other members use a running hour method for its scheduling.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of gas compressors:

Annual – Undertake periodic preventative maintenance schedules covering such items as lube oil systems, gearbox alignment, bearing checks, instrumentation function checks, surge control tests etc.

Note 1: Generally recognized best practice for this type of equipment is to maintain by duty (running hours) or to predictive schedules based on condition monitoring regimes.

4.3.3.6. Truck Loading

60% of the responding members reported on maintenance activities associated with equipment used for the loading and or offloading of LNG “over the road” trailers and associated scales, hoses, etc. The majority of responses were functional testing and calibration related activities, with periodicity being dependant on equipment type.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Truck loading systems:

Monthly - Annual – Functional test and calibration of scales, based upon the type of equipment in service.

Note 1: Additional maintenance activities such as the maintenance, testing and certification of transfer hoses vary across the sample
group. No optimum practice has therefore been identified for this category

**4.3.4. Safety Systems**

**4.3.4.1. Relief Valves**

All members (100%) responded to the questionnaire with activities associated with maintenance of relief valves. The functional testing of the valves is the most common activity.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Relief Valves:

- **Annual** – Functional test, servicing and calibration of relief valves

**Note 1:** Most companies would like to extend this periodicity but are restricted by local regulatory requirements.

**4.3.4.2. Deluge Systems**

All members (100%) responded with information on the maintenance of equipment associated with water deluge systems. The questionnaire requested information on such equipment as fire curtains, water monitors, pumps, etc.

Functionality testing of the equipment was the most common response with frequencies ranging from weekly to yearly. In addition, 20% reported that maintenance/testing was scheduled based upon the arrival of an LNG ship.

All companies undertake functional testing of deluge and sprinkler systems taking remedial action to investigate any “dry” areas. The periodicity associated with the testing varied widely across the sample, due to local safety and regulatory requirements. Therefore no optimum practice has been identified for this area.

The maintenance and testing of the firewater pumps again varies widely across the sample companies and depends upon the equipment types, company policy and local safety requirements.

**4.3.4.3. Safety Systems - Detection & Alarm Systems**

Information was received from all members (100%) on maintenance activities associated with equipment used for the detection of fire, gas and smoke as well as equipment used for temperature deviation. Functional
testing and visual inspection were the only maintenance activities noted. Replacement or overhauls of such equipment were not recorded. Frequency of testing ranged from weekly to yearly with many scheduled activities scheduled for a quarterly or bi-annual interval.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of fire and gas detection systems:

**Six Monthly** – Functional test of detection loops and detector heads

### 4.3.4.4. Fire Suppression Systems

Many of the members (60%) reported on maintenance activities associated with equipment used for the suppression of fire throughout LNG Terminals. Functional testing and visual inspection accounted for the vast majority of the maintenance activities noted. Frequency of testing ranged from weekly to yearly.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of fire suppression systems:

**Monthly**- Checking of hand held and vehicle mounted fire extinguisher equipment

**Annual** – Function testing of suppression systems depending on the type and service of systems installed.

**Note 1:** General condition of local installed safety items should be monitored by operation personnel as part of their routine activities.

### 4.3.4.5. ESD Systems

All members (100%) responded with information on the maintenance of equipment associated with Emergency Shutdown Systems. Functional testing and visual inspection accounted for all of the activities noted.

Frequency of testing was varied. 20% scheduled testing around plant shutdowns while another 20% scheduled testing around the arrival of LNG ships.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of ESD systems:
**Periodic** - Functional test of the ESD system at the jetty prior to ship arrival

**Annual** – Function testing of plant wide ESD systems

**Note 1:** Intervals may be more or less than that identified due to local regulatory requirements for ESD testing.

### 4.3.5. Utilities

#### 4.3.5.1. Fuel Gas System

Information received from most of the members (80%) on maintenance activities associated with equipment used for the distribution of fuel gas used in firing process equipment. Functional testing accounted for the majority of the activities.

Most activities were done on a yearly basis with 20% reporting that they pressure test some components on a 6 year interval and another that they scheduled activities on a quarterly basis.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Fuel Gas systems:

**Annual** – Function testing of pressure regulators, system control loops, relief valves and burner systems.

#### 4.3.5.2. UPS / Standby Power

All members (100%) identified maintenance activities that were associated with equipment used for uninterrupted power supplies and emergency power generation.

Frequency and the types of maintenance activities performed varied widely amongst the responding members. Calendar based maintenance activities ranged from weekly to every two years. 20% used running hours as the basis for the scheduling of maintenance activities.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of UPS / Standby Power systems:

**2 weekly** - Off load running test of standby generators

**Annual** – Load test and annual PM on UPS batteries and standby generators including function testing of associated control loops,
discharge testing of batteries and inspection and servicing of generators.

4.3.5.3. Instrument Air Compression

All members (100%) responded with information on the maintenance of the equipment used to produce instrument air for operational and maintenance purposes. This section of the questionnaire does not include the compressors used for gas blending.

Frequency and the types of maintenance activities performed varied widely amongst the responding members. Calendar based maintenance activities ranged from monthly to every two years. 20% used running hours as the basis for the scheduling of maintenance activities.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Instrument Air Compressors:

Annual – Most companies undertake periodic preventive maintenance schedules covering such items as drier efficiency, motor inspection, fluid levels, bearing checks, instrumentation function checks etc.

Note 1: Generally recognized best practice for this type of equipment is to maintain by duty (running hours) or to predictive schedules based on condition monitoring regimes.

4.3.5.4. Nitrogen Supply

The majority of responding members (80%) detailed maintenance activities associated with equipment used to produce or store nitrogen for operational and maintenance purposes. All responding members reported yearly maintenance activities. Only 20% of the members reported something other than a yearly activity and that was the testing of relief valves every two years.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Nitrogen Supply systems:

Annual – Perform annual PM including such items as instrument calibration, general condition of ambient vaporisers and storage tanks.

4.3.5.5. Domestic Water / Process Water
Most members (80%) detailed maintenance activities associated with equipment used for domestic and process water distribution. Frequency and the types of maintenance activities performed varied widely amongst the responding members. Calendar based maintenance activities ranged from daily to every three years.

All companies undertake functional testing and other maintenance activities of water systems on a yearly basis, though the scope of work undertaken varied widely across the sample due to differing water systems and local safety and regulatory requirements. Therefore no optimum practice has been identified for this area.

### 4.3.5.6. Steam Boilers / Generators

Information was only received from 40% of the members on maintenance of equipment used to produce utility steam for operational and maintenance purposes. This was due to limited current use of utility steam systems. However, it was still considered important to include this in the suite of critical plant items, so that any further expansion of participating companies would provide the ability to expand the data set.

Maintenance of steam system is often governed by local statutory or safety requirements.

It was not possible to identify optimum practice within the benchmark group for the maintenance of steam systems due to the limited data set returned by the member group.

### 4.3.5.7. Instrumentation Control Loops

Information received from all members (100%) on maintenance activities associated with instrumentation control loops including but not limited to periodic calibration and functional testing. The majority of members (80%) reported yearly scheduled testing while the remaining members (20%) reported testing on a six month interval.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Instrumentation Control Loops:

**Annual** – Perform annual function testing of instrument control loops, undertaking calibration where necessary.

**Note 1:** Where control loops are associated with equipment identified as being particularly critical for whatever reason, the frequency of testing should be adjusted accordingly.
4.3.5.8. **Hazardous Area Enclosures**

Many of the members (60%) responded with information on the maintenance of enclosures used within hazardous areas. All of the responses detailed visual inspections of the equipment. It was indicated that the frequency of such inspection were intervals of a year or more.

Although the returned data set is limited, it was still considered important to include this in the suite of critical plant items, so that any further expansion of participating companies would provide the ability to expand the data set.

Though it was not possible to identify optimum practice within the benchmark group the maintenance is characterized by close (non intrusive) visual examination of enclosures on a 3-4 yearly basis, but with a % sample of enclosures being opened for detailed examination annually.

In Europe this is being driven by specific legislation to provide conformance of the condition and maintenance of equipment located in hazardous areas.

4.3.5.9. **Electrical Power Distribution**

Extensive information received from all members (100%) on maintenance activities for equipment associated with the distribution of power inside the boundaries for the LNG Terminals.

The frequency and the types of maintenance activities performed varied widely amongst the responding members. Calendar based maintenance activities ranged from monthly to every ten years.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of electrical power distribution equipment:

- **Annual** – Most companies undertake periodic preventive maintenance schedules covering such items as cleaning and inspection of components and contacts, infra red inspections, dielectric oil sampling, etc..

- **2 – 4 Years** – Functional testing and calibration of circuit breakers, motor protection relays, current transformers, power transformers etc.
4.3.6. Miscellaneous

4.3.6.1. Security Equipment - Cameras, Detection, Fencing

All members (100%) responded with information on the maintenance of equipment used for plant security and operational visual detection. Monthly, six month, and yearly intervals were identified for a variety of maintenance activities.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of security equipment:

- **6 Monthly** – Functional testing and general inspection of perimeter fencing and gates.

- **Annual** – Sensitivity adjustment and general inspection of plant cameras and perimeter detection.

**Note 1**: General condition of security equipment should be monitored by operations personnel as part of their routine activities.

4.3.6.2. Communication Systems - Radios / Plant PA

Information received from the majority of members (80%) on maintenance activities associated with equipment used for plant communications. Daily, weekly, six month, and yearly intervals were identified for a variety of maintenance activities.

The following strategies have been identified as optimum practice within the benchmark group for the maintenance of Communication Systems:

- **Weekly** – Functional testing of evacuation alarms.

- **Annual** – Reconditioning and inspection of portable radios and recharging systems.

5. CONCLUSIONS

5.1. Conclusions with regard to Reliability and Maintenance Policies

Basic operational differences such as baseload vs. peaking drastically affect the reliability and maintenance strategies of the responding members. In having such an assorted group of responding members and LNG installation details it
was difficult to provide anything but high level conclusions from the Maintenance strategy responses.

It was apparent that all respondents utilize a variety of strategies to deliver their maintenance.

Time based maintenance is still widely used throughout the respondent population.

Duty based maintenance is utilized as the primary strategy for only a few of the equipment areas, namely:

- LNG Pumps
- BOG Compressors

There is a significant level of condition monitoring indicated for most equipment areas. However, the interpretation of the phrase conditioning monitoring can be broad. For almost all the equipment areas where condition monitoring is the most popular strategy (e.g. dredging berth, jetty structures, cryogenic pipework and insulation, LNG storage tanks etc.) it seems likely that this is the application of visual inspection. Furthermore, the number of occasions where condition monitoring is linked to other strategies is high. This may infer that condition monitoring is being used as a tool to protect against early failure, particularly where the strategy is in fact time based. In these cases condition monitoring is apparently being used as a negative cost protection rather than as a positive cost saving strategy – i.e. as a tool to extend maintenance periodicity to defer maintenance costs.

Fix on failure strategies are normally utilized only where sufficient redundancy exist or for non-critical equipment. Not surprisingly, few areas were identified where fix on failure was the most prevalent strategy. These were:

- Process valves
- Flare/vent
- Freshwater systems

The results indicated a broad range of statutory requirements or a range of interpretations as to the meaning. However, two areas were identified as not subject to statutory maintenance anywhere in the world. These were:

- Dredging berth and channel
- Freshwater systems
5.2. Conclusions with regard to Life Extension Activities

The following conclusions were primarily drawn from a diverse pool of responses to the questionnaire and illustrate the global nature of the GIIGNL organization. The details contained in the Life Extension Case Studies that were compiled as part of this effort have provided the GIIGNL members much insight into the pros and cons of actual Life Extension efforts but have largely been omitted from this paper. However, the authors, where possible, have tried to include the lessons learned from that exercise into these results.

It appears that generally LNG facilities have been considered evergreen, that is, capable of being upgraded to operate indefinitely. Equipment can of course have wear but actual experience has proven that the Terminals can be upgraded and re-generated as required. While many consider the storage tanks to have an indefinite life they are normally only limited by their fatigue life, which can be very long indeed, and depends on accumulated duty rather than elapsed time. In addition to proper life extension programs, the facility can be considered evergreen with the proper and complete maintenance management. Finally, enhanced safety and environmental standards have been identified as contributing to the life extension of LNG facilities.

Life extension through expansion of facilities continues to be one of the most common activities of existing terminal. Increasing gas demand has been the primary motive behind the majority of these expansions. Such activities initiated by this motivation include, but are not limited to, the following:

- Send-out increase with expansions provided by: new tanks, LNG pumps, SCV, ORV, sea water pumps and BOG compressors
- Liquefaction system increases
- Larger recondensers
- Vapor return lines to ship
- Cogeneration plant
- LNG truck loading bays
- Liquid nitrogen plants for quality adjustment

Improvement of safety and environmental standards has also provided motivation for life extension activities. As improvements to safety and environmental standards, it is possible to mention:

- Installation of safety automated system
- Relocation of control rooms to safe areas
- Vapor fencing or walls to prevent heavy gas dispersion
- Annual inspections of cryogenic pipelines
• Rearrangement of LNG piping to enable top and bottom filling in an effort to avoid stratification
• Rearrangement of LNG piping to eliminate bottom penetrations
• New fire water reserves and pumps
• Fire and gas detection systems

Replacement of unsuitable, obsolete, unreliable and unrepairable equipment was also identified as a motive for the initiation of life extension works. Examples include:

• Control systems/ESD
• Instrumentation
• Jetty structures
• Firewater piping systems
• BOG compressors
• SCV refurbishment
• LNG pumps
• Obsolete electrical equipment

The prevailing trend amongst the responding members is to have programs, which have been developed in house, for life extension of their facilities. Some have even combined programs of preventive and predictive maintenance with multi-year forward projects of equipment obsolescence and replacement scheduling. However, many of the existing facilities still have no formal programs of life extension established.

Programs designed to comply with increasingly more stringent environmental requirements, avoiding or reducing the risk of air, water and soil pollution have been implemented by a few of the members and are expected to be required for many of the Terminals in the near future.

Due to the reliability issues associated with many of the uses who are primary suppliers to end uses (“city gas”) many programs have been developed that include intensive inspection and repair procedures. Most of these procedures are far more rigorous than comparable procedures for facilities that are part of larger more diverse gas networks.

The majority of established LNG importation operators use internal company staff to work on the definition of life extension activities. In only a limited number of cases are external specialists used for support.

5.3. Conclusions with regard to Maintenance Benchmarking
The main objective for this part of the study was to attempt to establish a benchmark level for each maintenance strategy. This was done by establishing the overall norms from the sample data supplied by the member companies, and in some cases indicating the generally accepted best practice. These norms are intended to provide an indication of the optimum maintenance practice against which member companies can consider their position.

During the analysis of the data and the subsequent definition of the maintenance norms it became evident that some of the strategies were quite straightforward to identify appropriate benchmark criteria and to establish norms whilst in some other areas this proved to be very difficult. The main factors surrounding this were that some areas of maintenance were just inherently more diverse and in some cases analysis were made more difficult by varying levels of detail reported by the contributing companies.

Though the size and format of the data set did not allow any robust statistical analysis of the results, it is considered that, in most cases, the details returned were sufficient to allow adequate benchmark levels to be established for each of the strategies being considered. It is considered that these benchmark details are sufficiently robust to allow companies to establish their practice within or outside the norms provided.

It is considered that a common suite of LNG maintenance Key Performance Indicators (KPIs) would have made the benchmarking process much easier and would have contributed to a more consistent and technically accurate data set. This would also have provided an insight into the overall effectiveness of the maintenance strategies being deployed by the member companies.

During the analysis of the data submitted by the Group companies the following trends were also identified:

- Despite current Industry trends to move toward condition based maintenance, there was still a predominance of periodic maintenance schedules based on historic practice rather than reliability based criteria.

- Many of the maintenance activities identified were still consequent on the requirements of local regulatory authorities rather than strategies which have been developed to directly address the predominant failure modes of the equipment items concerned.

- The participating companies of the Group all reported continuing reliance on regular feedback from plant personnel for the determination of equipment condition and performance.
• Considering the diverse geographic spread of the Group companies and the age type and history of the plant, a reasonable amount of overall conformance of maintenance was observed.

5.3.1. **Recommendations for Moving Toward Maintenance Best Practice**

The following list is a summary of the actions that the Group recommend for companies to move toward maintenance best practice.

1. **LNG Maintenance Strategy Benchmarks**

Companies should identify their maintenance strategies and compare against the norms established in this report. GIIGNL has developed its own quick reference checklist for use by its members for this purpose.

2. **Reliability Centered Maintenance**

Wherever possible design and deploy maintenance strategies which directly contribute to the prevention of the most predominant failure modes for equipment items. In particular the adoption of Condition Monitoring equipment, either as a cost benefit project or when replacing existing rotating machinery.

3. **LNG Maintenance KPIs and Common Standards**

Companies should wherever practicable try to utilise industry (LNG or Oil and Gas) standards such as ISO14224 to move toward common equipment classification and terminology, failures code systems and standard maintenance code libraries. ISO14224 also specifies guidelines for Maintenance Key Performance Indicators which could be utilised for both internal performance assessment and for comparison with other companies in the Oil & Gas or LNG specific sectors.

4. **Utilisation of LNG Facility Personnel**

Companies should actively encourage operations and maintenance staff to become the “eyes and ears” of the plant, providing a human interface for the identification and action for plant condition and status. These “human systems” are important factors in ensuring that mechanical alert systems and processes for managing plant condition and reliability are fully supported and reinforced by the vigilance and skills of the operational workforce.

5.4. **Concluding Remarks of the RALE Study**
The analysis of reliability, aging and life extension of LNG facilities performed by GIIGNL has provided the Group with invaluable insight into how company policies and strategies for asset maintenance and management can affect the reliability of the existing LNG receiving terminals. While each of the Groups members has different approaches to meeting the maintenance demands of their facilities, the broad and comprehensive review performed during the study provided each member the opportunity to benchmark their present operation and find areas for improvement.

In addition to the results of this global initiative, which have been outlined within this paper, the actual process fostered the exchange of information and ideas that assist the GIIGNL members in supporting decisions relating to maintenance policy development and implementation. The process, and its results, helped highlight the value of comprehensive and integrated maintenance policies that accommodate the safety management framework of the individual facilities. In addition, the results supported the emphasis on bringing a holistic approach to asset health care in which policies of maintenance management and life extension are integrated and support one another.

The results of the study have also provided the Group with a source of information for discussions with safety and environmental regulators. This information will be of benefit for the existing operations and is expected to assist in the approval for expansion of existing operations or the initiation of new ventures.

REFERENCE CITED