Terminale GNL Adriatico Srl, commonly known as Adriatic LNG, an Italian company established in 2005 by Qatar Petroleum, ExxonMobil and Edison, operates a LNG receiving terminal offshore the coast of Italy. The terminal is a large gravity based structure (GBS) resting on the seabed at 29 meters (m) mean sea level. The structure is 180 meters long by 88 meters wide, with a height of about 47 m. The GBS contains two LNG storage tanks. Topsides and mooring facilities necessary to berth the LNG carriers, perform the LNG regasification process and send the gas onshore into the Italian gas network are installed directly on the GBS structure. This paper presents the steps and the activities carried out to apply the Risk Based Inspection procedure to the topsides facilities of the Adriatic LNG receiving terminal. The RBI approach allows to make a screening of the most critical items in order to optimize the inspections. The paper describes in particular the criteria adopted for grouping all the piping and equipment, belonging to both process and utility systems, into homogeneous circuits. A fundamental step of the RBI process which is being undertaken is the identification of the expected degradation mechanisms due to either corrosion or other sources (e.g. thermal cycles, vibrations, mechanical stresses, etc.), depending on the combination of material, conveyed fluid, service conditions (such as cryogenic / non-cryogenic service), stress level and external environment. The methodology that was followed to accomplish the risk assessment task is also discussed, focusing on the adopted approach for the definition of the probability and consequences of a possible failure and the overall criticality of an item / homogeneous circuit. In addition, the guiding normative and principles for the selection of the most suitable inspection techniques are addressed in the paper. Finally, a brief overview of the applicable regulatory requirements is provided as well as how they were captured when planning the inspections.

1 Introduction
The Adriatic LNG (ALNG) Terminal (Figure 1), located about 15 kilometers offshore the Italian coastline in the Northern Adriatic Sea, is a unique facility utilizing innovative technology to provide a safe and efficient offshore LNG offloading, storage, and re-gasification capability. The terminal is a large gravity based structure (GBS) resting on the seabed at 29 meters mean sea level. The structure is 180 meters long by 88 meters wide, with a height of about 47 meters.
The plant has a regasification capacity of 8 billion cubic meter per year, approximately 10% of the country’s yearly natural gas consumption.

The GBS contains two LNG storage tanks with a total working capacity of 250,000 cubic meters, approximately twice the capacity of a conventional LNG carrier. Major process equipment includes four loading arms, four in-tank LNG pumps, five high-pressure send-out pumps, four Open Rack Vaporizers (ORV’s) which use seawater as the heating medium, a Waste Heat Recovery LNG Vaporizer (WHRV) which uses waste heat from the turbine generators, and two Boil-Off Gas (BOG) compressors. The regasification process is shown in Figure 2.

In order to continue to pursue safe and reliable operation as well as optimal management of inspection related costs, Adriatic LNG and Cescor srl developed a risk-based approach focused on prevention of potential loss of containment from pressure vessels, atmospheric storage tanks and piping in processing and utility facilities.
2 The Risk Based Inspection Methodology

Risk-Based Inspection (RBI) is a decision making technique for inspection planning based on the evaluation of the risk of primary function failure. The risk assessment arises from the probability of failure and the associated consequences.

The RBI methodology optimizes the inspection activities in order to rationalize inspection frequencies and the required level of accuracy, producing as a main result the development of an effective inspection plan: the inspection optimization process reduces the overall inspections costs and increases the level of confidence in detecting equipment degradation phenomena which might produce potential failures.

A risk-based approach for the planning of the inspections has been chosen as it allows to:
- maximize asset value through asset reliability increase;
- achieve an overview of the installation with a systematic and documented potential failure modes and recommended appropriate actions;
- focus the inspection efforts depending on the criticality of the items, minimizing the shut-down that may be needed in case of inspections;
- identify the optimal inspection or monitoring methods according to the identified degradation mechanisms and to agreed inspection strategy.

The RBI methodology, developed and commonly applied for upstream oil and gas assets, has been adapted for the case of an offshore LNG regasification terminal. Therefore the facilities peculiarities have been taken into account, such as the cryogenic service (liquefied natural gas is stored and handled at -162°C), the wide variety of involved materials (e.g. carbon and stainless steel, titanium, glass-reinforced plastic, etc.), the big amount of handled fluids as well as the thermal cycles associated with intermittent services.

The RBI methodology developed for the ALNG assets is based on international standards dealing with RBI (e.g. DNV, API, UNI/TS), Company’s best practices and Cescor’s expertise in the realm of facilities corrosion and inspections.

Figure 1: The Regasification Process.
3 The Risk Based Inspection Steps

The RBI process includes the following steps:

i. data and information collection,
ii. definition of homogeneous piping circuits,
iii. definition of expected degradation mechanisms and related probabilities of occurrence,
iv. risk assessment,
v. inspection program and inspection plan,
vi. inspection execution,
vii. inspection data analysis.

It is worth noting that the Risk Based Inspection is a circular process: the output from one phase is the input to the next and the last phase output is the update of the first step to periodically re-executed the routine.

In the following paragraphs the main steps of the risk based inspection process that have been performed for the Adriatic LNG facilities are described. In particular, those “ad hoc” solutions for specific ALNG features are included.

3.1 Data Collection

The first step in the RBI process consists of the collection and the organization of all the available data that are necessary for the implementation of the Risk Based Inspection process. Data to be collected include design and construction data, operating data, conveyed fluid composition, information on external coating, insulation and exposure conditions, past inspections and monitoring data, etc.

Since more than 2100 lines and about 180 pressure equipment and storage tanks are present on the facilities, an effective and very detailed data organization is of paramount importance to accomplish the target. The wider the set of design data, the clearer the picture of the status of the investigated items.

3.2 Items Grouping into Homogeneous Circuits

2.1.1 Homogeneous Piping Circuits

Complex piping systems shall be divided into homogeneous circuits to better identify degradation mechanisms and the related risk levels (resulting from the risk assessment sessions) and to better focus the required inspections. Each homogeneous piping circuit requires a dedicated equipment strategy.

The driving parameters taken into account for the definition of homogeneous piping circuit have been the following:

- **Handled fluid.** Each circuit shall handle one fluid type only (e.g. LNG, natural gas, salty water, fresh water, dry air, wet air, chemicals, etc.); piping made of the same material and operating at the same conditions but handling different fluids shall be considered into different circuits.

- **Purpose.** All piping of the same circuit shall have the same purpose. Piping conveying the same fluid but having different purposes shall be split in different circuits.
A list of other parameters has been considered for the definition of the applicable degradation mechanisms. A homogeneous piping circuit is allowed to contain piping with differences in the following set of parameters:

- **Construction material.** Piping made of different materials should be grouped in different piping circuits. However, in order to reduce the number of groups to be prepared and managed, it has been considered convenient to allow piping made of different materials to be grouped into the same piping circuit (provided that they handle the same fluid and have the same purpose). The risk assessment phase shall address each degradation mechanism to all the piping belonging to the circuits or to a subset of piping circuit only (e.g. piping made of a specific alloy).

- **Pipe diameter.** A homogeneous piping circuit can contain piping with different diameters. The worst case shall be considered in the risk assessment phase to assess the consequences of each expected degradation mechanism.

- **Operative and design parameters.** Operative and design parameters shall be used to assess the magnitude of an expected degradation mechanism.

- **Regulatory requirements.** A homogeneous piping circuit can contain piping with different regulatory requirements (e.g. Pressure Equipment Directive requirements, see Section 4).

The above procedure led to the creation of No. 30 homogeneous piping circuits.

### 3.1.2 Groups of Equipment

The pressure equipment and atmospheric storage tanks have been mainly grouped individually, i.e. single vessel or vessels working in parallel. However, groups of pressure equipment have been proposed in utility systems when the criteria of the same handled fluid and the same purpose are met (e.g. all wet air handling vessels have been grouped).

No. 30 groups of equipment were classified in the RBI study.

### 3.3 Expected Degradation Mechanisms and Related Damage Probabilities

The purpose of this step is the identification of the expected degradation mechanisms, followed by the probability of occurrence for each identified degradation mechanism. In order to achieve these goals, the following sub-steps have been carried out:

- identification of degradation mechanisms to be considered in the asset;
- determination of the expected degradation mechanisms;
- assessment of occurrence probability for each expected degradation mechanism.

#### 3.2.1 Considered Degradation Mechanisms

The degradation mechanism is defined as any mechanical, thermal and chemical process that might potentially lead to structural degradation and loss of the primary function of the considered component. The proper identification of the damage
mechanisms is essential for the quality and the effectiveness of the subsequent phase of the risk assessment.

The equipment expected degradation mechanisms to be considered come from scientific knowledge standardized by international normative (e.g. API RP 571), Company’s know-how and Contractor’s expertise.

3.2.2 **Expected Degradation Mechanisms**

The possible damage mechanisms depend on the combination of several factors, including:

- the material of construction;
- the type of transported fluid;
- the operating conditions;
- the environmental conditions in which the component is operating.

The evaluation of all the interactions among these factors, for each piping circuit and group of equipment, lead to the expected degradation mechanisms. Due to the existing differences within a single piping circuit, a case by case analysis has been carried out in specific situations. The cryogenic piping is an example of this “ad hoc” analysis: almost no corrosion issues arise when they operate at steadily cryogenic temperature while thermal cycles up to ambient temperature might induce some corrosion as well as mechanical and thermal stresses. Therefore, data regarding frequency of thermal cycle, material property and thermal insulation are to be evaluated.

3.2.3 **Assessment of Probability of Occurrence**

For each potential damage mechanism, two occurrence probabilities are defined. One occurrence probability is related to the initiation of the damage mechanism, while the second is focused on the structural degradation and/or loss of integrity of the considered component.

The potential degradation mechanisms have been qualitatively assessed based on field experience and expertise.

3.4 **Risk Assessment – Development of Equipment Strategies**

The risk associated with a failure from a given degradation mechanism is estimated combining the probability of a failure and the consequence of this failure.

The risk assessment has been performed in workshop sessions. Since many competences are required, the following qualified and experienced personnel has been involved (adapted from DVN-RP-G101):

- equipment strategies facilitators with a specific expertise in the facilities integrity management;
- pressure equipment integrity program owner;
- material and corrosion experts with a specialized competence in materials, degradation mechanisms, corrosion mitigations and inspections, and regulatory requirements;
- plant operations and maintenance personnel with a deep knowledge of the process functioning and troubleshooting;
• ALNG personnel with expertise in SHE (Safety, Health & Environment) as well as in the evaluation of the potential financial losses caused by the investigated failure scenario.

Useful inputs data taken into account to assess probabilities and consequences of a possible failure are:
• HazOp (Hazard and Operability) study;
• applicable regulatory requirements;
• Seveso Law and related Safety Report;
• results from previous baseline inspection campaigns;
• results of field surveys.

The output from the risk assessment is the issue of an equipment strategy for each homogeneous circuit / vessel that provides the inspection / monitoring / surveillance / regulatory tasks and associated frequencies.

3.5 Inspection Plan and Inspection Program

The mitigation tasks as an outcome from the risk assessment produce:
• the inspection program;
• the inspection plan.

3.5.1 Inspection Program

The inspection program is the summary of inspection activities mainly used as an overview of inspection activity for several years into the future. The inspection program provides for inspection management purposes, the tentative inspection frequencies to be further confirmed based on the results of each inspection.

The inspection plan timing is based on:
• matrices risk (the output of risk assessment phase);
• regulatory requirements;
• manufacturer inspection/maintenance recommendations;
• Company operation and maintenance needs as shut-downs.

3.5.2 Inspection Plan

The inspection plan is a detail of inspection activity giving the precise location, type and timing of activity for each individual inspection action that is planned. Accordingly each inspection plan should contain as minimum the following information:
• relevant item data;
• definition of the inspection methods;
• extent and coverage of the inspections;
• definition of inspection location and inspection points;
• time schedule;
• inspection drawings (for each item, groups of item or piping circuit);
• requirements for reporting.

Furthermore, reference should also be made to inspector qualifications, inspection techniques and instrument type and calibration requirements, inspection procedure to be used, applicable codes and standards, and other quality-related information.
3.5.2 Selection of Applicable Inspection Techniques

The selection of the inspection techniques is part of inspection plan and in this respect a review of the applicable inspection techniques for each expected degradation mechanism is necessary. The references listed below has been considered for the present RBI study:

- **DNV RP G101**, “Risk Based Inspection of Offshore Topside Static Mechanical Equipment”;
- **API RP 571**, " Damage Mechanisms Affecting Fixed Equipment in the Refining Industry";
- **UNI/TS 11325 part 1 and 8," Putting into Service and Use of Pressure Equipment and Assemblies”;
- **ISO 14692-4**, "Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 4: Fabrication, installation and operation”;
- Company integrity guides and technical manuals.

Moreover, the following references has been used: **API 510, API RP 572, API RP 574, API RP 575** and national regulatory requirement for pressure equipment (e.g. D.M. 329/04, see next paragraph).

4 Regulatory Requirements

The Pressure Equipment Directive (PED) 97/23/EC concerning pressure equipment applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure greater than 0.5 barg.

Moreover, for the elaboration of the equipment strategies and inspection plan of pressure equipment and assemblies, the applicable Italian laws and regulation addressing the maintenance / inspection tasks for the pressure equipment were taken into account. In particular, according to D.M. 329/04, the following periodical verifications shall be provided during the operating life of each pressure equipment or assembly:

- operating verification:
  - The user shall control the appropriate operation of safety devices and that the actual working conditions of the pressure equipment and assemblies are in compliance with the commissioning attestation.
- integrity verification:
  - Pressure equipment and assemblies shall be inspected through adequate internal and external verifications.

Frequency of the periodical verification of pressure equipment are given in D.M. 329/2004.

In addition, the alignment between the Safety Cases (according to D. Lgs 334/99 as further amended) and risk scenarios considered for ALNG pressure equipment has been completed.

5 Conclusions

The paper presents the main steps of the Risk Based Inspection process performed on the regasification assets operated by Adriatic LNG. The RBI methodology, developed and commonly applied for upstream oil and gas assets, have been adapted for
the case of an offshore LNG receiving terminal taking into account its peculiarities such as the cryogenic service, the great variety of involved materials, the handled fluids and the thermal cycles combined with intermittent services.

The RBI methodology developed for ALNG assets is the result of joined technical methodologies and recommendations defined by applicable international standards (e.g. DNV, API, UNI/TS), ALNG and Company's best practices know-how and approach on RBI and Cescor's expertise in the field of corrosion, materials and inspection planning. RBI activities have been developed considering on one side Company expertise in the facilities integrity management and on the other side the obligations given by the applicable regulations.

On one hand, the great amount of available design data have been useful to conduct a deep and thorough integrity assessment of such a complex and unique facility; on the other hand, only the definition of homogeneous circuits (i.e. groups of homogeneous items) allowed to effectively manage the several hundreds of pressure piping and equipment installed on the ALNG asset.

The assessment of the integrity status of the facilities was limited not only to corrosion issues (both internal and external), mechanical, fatigue and thermal aspects, but also to operation, SHE and business considerations. For this reasons, the risk assessments were conducted in various workshops involving different expertise and producing dedicated equipment strategies.

Inspections have been planned over a medium term period implying the prioritization of the activities: items which resulted to be more critical for SHE / business considerations, operational reasons, etc. are scheduled to be inspected first and more thoroughly.

The challenge of the work stands in combining a complex and strategic offshore structure with the peculiarities of the LNG regasification process and the need of interactions between a variety of highly qualified competences.

6 References

[9] Decreto Ministeriale del 1 Dicembre 2004 n. 329 “Regolamento recante norme per la messa in servizio e utilizzazione delle attrezzature a pressione e degli insiemi di cui all'articolo 19 del decreto legislativo 25 febbraio 2000 n. 93”;


