EVOLUTION OF "ASSET MANAGEMENT"
AT BADAK LNG PLANT, BONTANG, INDONESIA

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1. INTRODUCTION

PT Badak NGL operates a LNG plant in Bontang - East Kalimantan, which has the highest LNG production capacity in the world. The company, a joint venture between the Indonesian Government (Pertamina), TOTALFINAELF Indonesie, VICO Indonesia and Jilco, started with two process Trains A and B in 1977. Since that time, major plant expansion projects have added 6 more trains in line with the PT Badak Master Plan. Currently, the total LNG production capacity of the eight process Trains (A, B, C, D, E, F, G and H) is 22.5 MTPA or 49.6 million m^3 per year. This maximum annual capacity is based on a condition that all process trains always operate at their current Maximum Sustainable Rate (MSR) in the entire year. The more reliable the plant and the feed gas supply, the closer the actual annual capacity approaches to this maximum annual capacity.

To systematically maintain the high actual annual capacity, PT Badak formed the Reliability Improvement Team (RIT) in 1996 that was replaced with the fully dedicated Reliability Engineering Group (REG) in 1999. The function of the reliability team is to assess plant reliability, identify top reliability issues, monitor action programs required to address each issue and evaluate the results.

2. AVAILABILITY AND RELIABILITY CONCEPT

General definitions for production capacity, production losses, plant availability, etc. are defined in the table below and illustrated in Figure 2.1:

Maximum sustainable rate	:	The official individual Train LNG production rate in M^3/hr as used in the annual production forecast
Annual maximum capacity	:	Maximum sustainable rate (MSR) x actual total hours in the entire year
Technical maximum capacity	:	Annual capacity after deduction of schedule down time.
Maximum available	:	Remaining capacity after deduction of scheduled and unscheduled down time.
Available capacity	:	Remaining capacity after deduction of all down time and plant production losses.
Utilized capacity	:	Actual annual production
LNG Production Losses	:	Train LNG production losses in m^3, calculated as the difference between the MSR and the measured actual production rate, multiplied by the duration in hours.
Scheduled down time	:	Planned plant outage to do maintenance job and or special Project.
Un-scheduled down time	:	Unplanned plant outage to do reactive maintenance.
Standby capacity / unsold capacity	:	Available capacity not produced due to market demand / seasonality factors

Plant availability (PAV)	:	Maximum available capacity / annual maximum capacity or (Total Train Hours entire year – schedule and unscheduled down time) / Total Train Hours entire year.

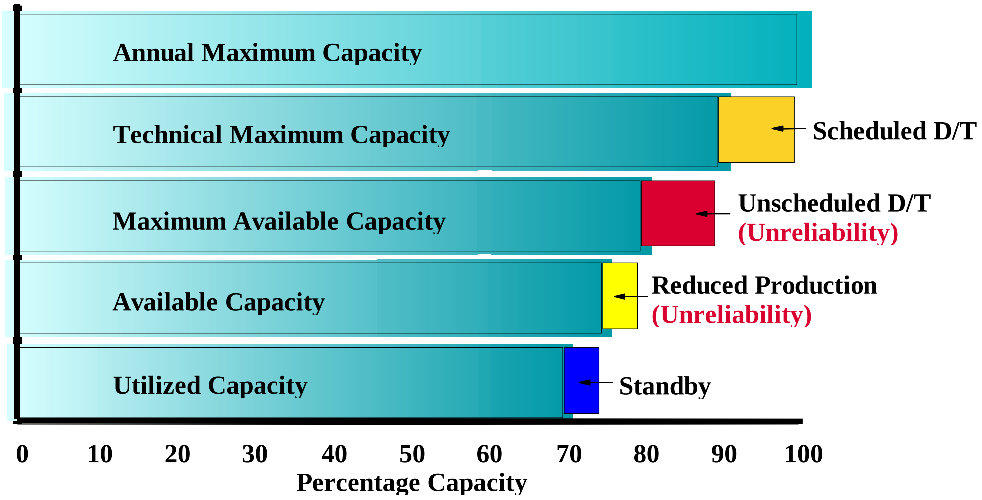

Figure 2.1 - Availability and Reliability Concept

Until 1996 PT Badak used PAV to assess the plant reliability. The PT Badak Plant Availability (PAV) for 1989 - 1996 is as follows:

Year	'89	'90	'91	'92	'93	'94	'95	'96
PAV (%)	94.9	91.8	95.3	93.8	95.5	95.3	94.2	94.7

During this 8 years, the percentages of the total LNG production loss associated with plant equipment problems are as follows:

Category:

- Mechanical : 21.0 %
- Instrument : 2.9 %
- Rotating Equipment : 1.8 %
- Electrical : 0.6 %

The PAV calculation is simple but does not count the difference in the individual train capacity, the transition and the partial load production losses. Therefore, to provide a better method to quantify and categorize LNG production losses, the RIT developed a Production Reliability Factor Reporting System in 1997 which uses the following definition:

♦ Production Reliability Factor (PRF) / Uptime:

PRF = {1 - [Plant Related Losses / (Annual Maximum Capacity)]} * 100%

The PRF is an indicator of Reduced LNG Production due to Plant Related losses only. The PRF is used to measure individual Train reliability performance relative to the annual reliability targets.

PT Badak LNG Plant overall PRF is calculated using the sums of all trains: maximum annual production, utilize capacity/actual maximum production, plant related losses and all losses. The overall PRF statistics for 1997-2002 are displayed and discussed later in Chapter 5.

There are 2 Major Categories and 13 Sub Categories of Production Losses defined and recorded in the PT Badak online Plant Operation Database System (PODS):

A. Plant Related - Loss elements that are under the direct control and responsibility of PT Badak :
   1. Scheduled Shutdown
   2. Train Trip, Train Related)
   3. Train Trip, Utilities Related)
   4. Unscheduled Shutdown)
   5. On-line Repair) Unscheduled Plant Related Production Loss
   6. Mechanical Problem)
   7. Processing Problem)
   8. Utilities Problem)
   9. Export Derime Gas)

B. Outside Related - Loss elements that are under direct control and responsibility of Outside Parties (such as, feed gas supply and LNG cargo shipping):
   10. Inventory Control
   11. Idle Shutdown
   12. Reduced Feed Gas
   13. Other

The REG uses the PODS and the Load Factor Reporting System to identify the equipment or systems which cause the most production losses for determination of the appropriate countermeasures. Figure 2.2. below shows the various production loss categories, transition losses and partial loading.

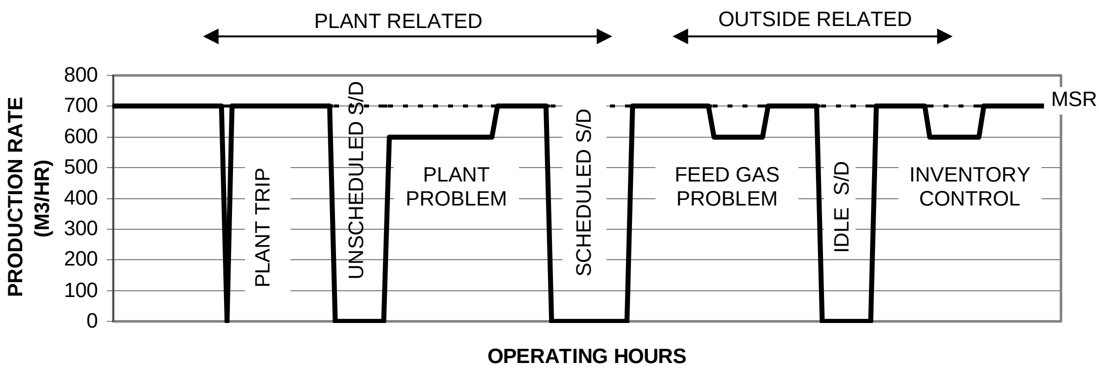

Figure 2.2 : Category of production losses

The difference between PAV and PRF is shown in the calculation example on Table 2.1. The actual PRF values are always lower than the actual PAV because of the transition and partial load losses.

To improve the PRF, PT Badak concentrates on efforts to reduce the Plant Related losses. The REG facilitates discussions between departments responsible for the identified reliability issues. The reliability issues discussed include: finding and eliminating the root causes of the Plant Related problems, PM/PdM optimization through pilot projects, reduction of scheduled shutdown duration, extending time between overhaul, improving logistics practices, setting up reliability database, etc. Two of the top issues and the Pilot Projects will be discussed in Chapters 3 and 4.

Data (Example)	Calculation
MSR Production Rate : 700m3/hr	Annual Maximum Capacity: 700X 8760 = 6,132,000m^3
Down time (excluding idle s/d): 200 hrs	**PAV** = 8560 / 8760 = 97.7 %
Plant Related Losses : 200,000m^3 (Unscheduled + Scheduled)	**PRF** = [1-(200,000/6,132,000)] X 100%= 96.7 %
Unscheduled: 50,000m^3	**Unscheduled**: 50,000/ 6,132,000= 0.8 % of the MSR Production
Scheduled : 150,000m^3	**Scheduled** : 150,000 / 6,132,000 = 2.4 % of the MSR Production

Table 2.1 : Calculation example of PAV and PRF

3. Top Reliability Issues

3.1. CO2 Removal Unit

The problem in the CO_2 Removal Unit (Amine Unit) was one of the major causes of the Plant Related Losses in 1989 – 1999. The major problem in this plant was erosion / corrosion that several times caused PT Badak to partially shut down the CO_2 Removal Unit or the whole Train. In 1995, for example, PT Badak lost potential production equivalent to 243,000 m^3 of LNG due to problems in the CO_2 Removal Unit of Train E. In general, the losses were caused by lowering LNG production due to lower amine circulation rate when one bank of the lean/rich amine cross exchangers was isolated for repair and the shutting down of the amine and dehydration units resulting in a partial train shutdown. Due to this shutdown of the gas treating units in the train, lean gas from other trains that were still in operation was supplied to the affected train by utilizing a cross connection on lean gas between the trains, effectively reducing the maximum LNG production in both trains to 50% during the amine equipment repair.

Modifications of equipment were done by a partial upgrading of piping material from carbon steel to stainless steel, especially reducers and enlargers around control valves. Some parts of carbon steel pipe on the rich amine side susceptible to erosion corrosion were also replaced with 304 stainless steel, which eliminated piping leaks. Modification of the inlet distributor to the perforated pipe type in Amine Flash Drum prevented the incoming solution from falling freely. The new inlet distributor, a standpipe with perforations located below the liquid level, prevented the solution from directly impinging the vessel wall (see Figure 3.1). The new inlet distributor design eliminated the erosion corrosion problem related to the inlet liquid.

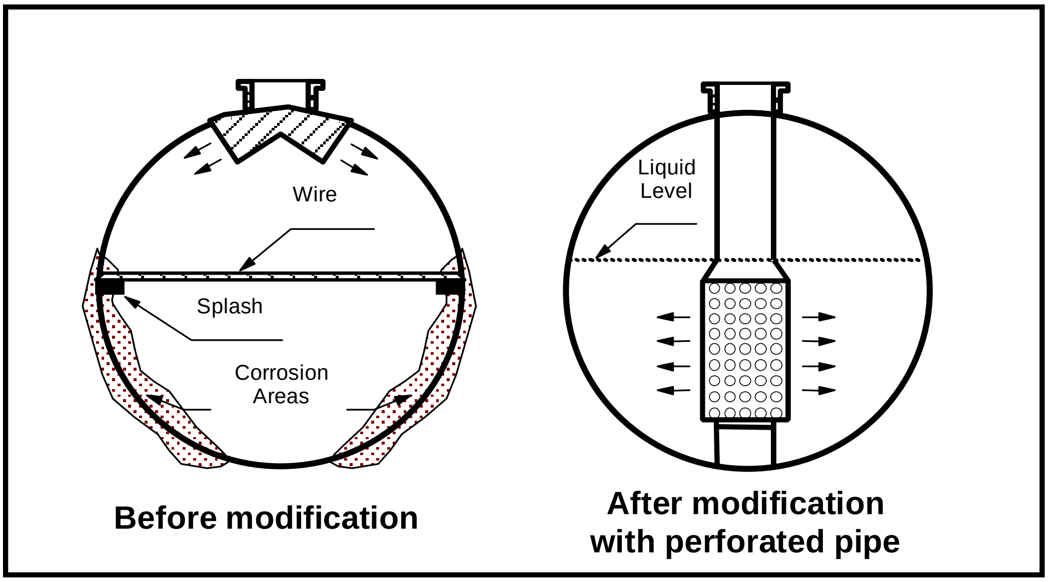

Figure 3.1 : Amine Flash Drum inlet distributor modification

In the Amine Stripper, the inlet distributor was modified from to H-type to Open Gallery-Type. This gallery-type inlet distributor reduced the vibration at the inlet distributor by readily releasing the CO_2 vapor from the amine solution inside the amine stripper column. With the H-type inlet distributor, the two-phase flow caused by the release of CO_2 inside the pipe created vibration due to an impingement effect induced by the shape of the inlet distributor. The shell and Tube Amine/Amine Cross Exchangers were also replaced with Plate and Frame type in Trains D and F to overcome the erosion / corrosion problem experienced in the first MDEA solvent use. However, the replacement has been stopped due to improved conditions after solvent replacement.

In addition to equipment modification, the amine solvent was also converted from formulated MDEA to activated MDEA. Both are MDEA-based solvents but they are different in activator. The solvent conversion took place in the period of 1997-1999 following the good results of an 18-month test period in Train C. After operating with the new amine solvent for three years, the erosion / corrosion of the system has been reduced significantly.

This is indicated by the absence of plant unscheduled shutdown caused by amine unit problems. Other advantages in using the new solvent are a 20% lower amine circulation rate, which contributes to 20% lower steam consumption for amine regeneration and lower erosion / corrosion effect and 50% reduction in amine solvent losses. The iron content in solution, as an indication of corrosion, in activated MDEA was stable at the level of 1.4-1.6 ppm, compared to over 140 ppm in formulated MDEA during the first year (see Figure 3.2.).

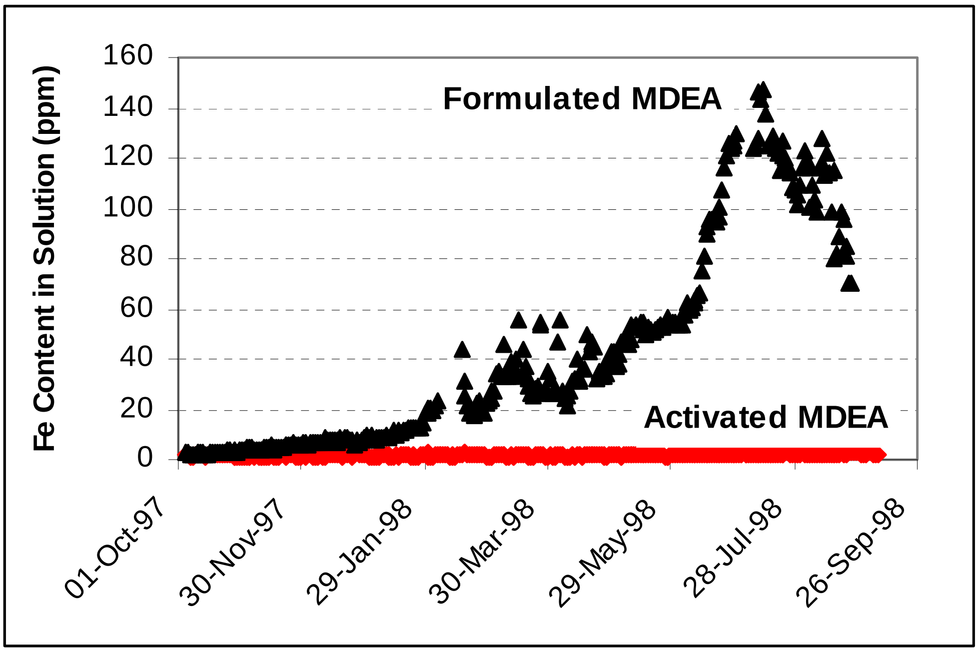

Figure 3.2 : Comparison of iron content in solution during the first one year operating with Formulated MDEA and Activated MDEA.

3.2. Main Refrigerant Compressor Impeller

Problems due to cracks of the first stage impeller of the 4K-2 MCR Compressor have been experienced since March 1994. In some cases, the problem has caused significant production loss. Figure 3.3. shows a case of an impeller crack, which resulted in a compressor failure.

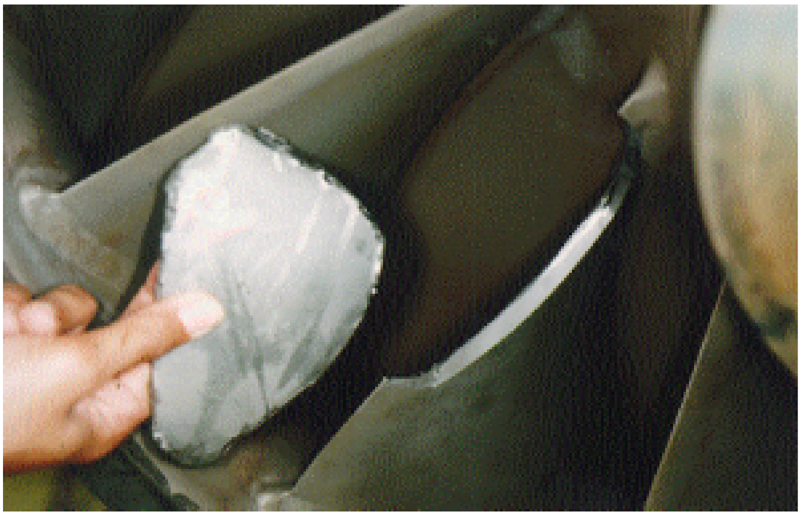

Figure 3.3 : A case of impeller crack which caused a MCR Compressor failure.

Analysis of the problem root cause was very difficult due to the problem complexity and disputes between PT Badak and the compressor manufacturer. PT Badak tried to convince the manufacturer that the original 15 vanes - 3 piece impeller needed to be totally redesigned. The manufacturer tried to collect data with special data acquisition equipment to support their argument that the failure cause was not the design. In any case, the acquired data did not show any evidence of operational error.

Several impeller design configurations, including a 17 vanes - 2 piece configuration, were tested, installed and proposed by the manufacturer as the final solution. PT Badak accepted it as a temporary solution until another failure pushed the manufacturer to come up with a better solution.

South West Research Institute (SWRI), USA was involved to determine the blade natural frequencies of the impeller configuration by conducting impact tests. The result of the natural frequency test was that the blade natural frequency was not acceptable for the design operating speed. Consequently, this finding required a total redesign of the impeller so that the blade natural frequency is shifted sufficiently above the influence of the operating speed.

In the last 2 years, careful monitoring, planning, and opportunity inspections conducted on the trains, have prevented unnecessary unscheduled shutdowns due to the 4K-2 impeller cracks.

During the October 2000 warranty shutdown of the new Train H, the MCR compressor was inspected. Again, cracks were found in the vane-to-back weld area of the first stage impeller which had the latest 17 vanes - 2 piece configuration.

With this latest finding, finally the manufacturer agreed to design a new impeller with a higher impeller natural frequency, increased about 11 % from the previous design.

This increase will eliminate the resonance in the compressor operating speed range up to 4835 RPM. As a short-term measure, to reduce the possibility of cracks in other trains, the compressors speed is limited to a maximum of 4,620 RPM until the new designed impellers are available. This speed reduction will have no impact on the trains LNG production capacity.

The new impeller design is now available and has been installed in Trains A,B,F and H. PT Badak is now monitoring the performance of the new impeller design.

3.3. MCR Compressor Inter & After Coolers (4E-5A/B & 4E- 6A/B)

The problem in these coolers which used Cu/Ni tube was tube leaks due to sea water corrosion and tube scaling. This problem was one of the major causes of lost production due to the plant must be shutdown for tube leak repair.

PT Badak implemented on-line ball cleaning and followed with on-line passivation by injecting ferro-sulphate to produce an oxidation film on tube surfaces for corrosion protection.

However these efforts did not result in a significant corrosion improvement. Therefore, other improvement options were required to be evaluated.

Revamping the coolers from Cu/Ni tube to Ti fine fin tubes which are more resistance to the seawater corrosion and erosion took place in 1989 – 2000. The new Ti coolers employing Phillips Rod Baffle Design have advantages:

1. Provide low pressure drop.
2. Provide more surface area for the same size of the baffle plate cooler due to no dead surface area.

In addition, the fine fin Ti tubes provide three times the surface area of the similar length bare tubes. Revamping the existing Cu/Ni 4E-5A/B and 4E-6A/B resulted in an LNG production increase of 6 m3/Hr and lost LNG production is eliminated by the absence of plant unscheduled shutdowns caused by 4E-5A/B and 4E-6 A/B tube leaks.

3.4. Cooling Water (C/W) Distribution Improvement

The problem was the cooling water was not distributed as per each cooler C/W requirement and the capacity of C/W was less than the C/W requirement after the Train production capacity was increased. This caused the C/W to the critical Propane condensers (4E-2), Multi Component Refrigerant (MCR) turbine condensers (4E-20/25), and propane turbine condenser (4E-15) to be less than the requirement. The 4E-2 is installed in series with 4E-15/20/25.

The lack of C/W to the exchangers 4E-15/20/25 caused C/W outlet temperature of the 4E-15/20/25 to increase resulting in tube scaling. The tube scaling caused a decrease in 4E-15/20/25 performance and tube leaks due to corrosion underneath the scale. This resulted in lost LNG production due to unscheduled shutdowns to plug the leaking tubes. In addition, it also increased the maintenance costs due to replacing the tubes during maintenance down time.

A study of the C/W distribution was done by a PT Badak consultant (Bechtel). The main purpose of the study was to identify and to optimize the distribution of available C/W to the process coolers. The specific concern was increasing the C/W to the critical coolers (4E-15/20/25).

The results of the study were:

- Reduce the pressure drop on the C/W system by increasing the opening of the C/W outlet sparger.
- Install a restriction orifice on all the coolers except 4E-15/20/25.
- Enlarge the inlet / outlet C/W line of 4E-15/20/25 to reduce the pressure drop.

After we implemented the recommendations from the C/W study, the scaling and the tube leak problem was eliminated.

This is indicated the absence of retubing the coolers during Train Shut-downs. The benefit of implementing the C/W study was to improve the cooler performance, resulting in increased LNG production by 6 M^3/Hr per Train.

4. RCM AND RBI PILOT PROJECTS

4.1. RCM Pilot Project

Reliability Centered Maintenance (RCM) analysis was implemented in 1996 on 15 units of 3.5 MW Cooling Water Pumps.

RCM is a comprehensive, but time consuming, tool to evaluate existing PM/PdM tasks or to create new PM/PdM tasks. Implementation of RCM on the 15 pump units required 1200 manhours, or one full month with 6 full time members from various departments, excluding a third party consultant.

In addition, RCM requires the best people with the best knowledge on the related equipment to get the best results from the RCM study.

PT Badak experience indicates that the RCM study results should be reviewed annually to monitor whether the decided PM/PdM task is eliminating the potential failure or not.

Within 3 years of RCM implementation, the maintenance cost per unit decreased significantly. This is mainly because the pump motor overhaul intervals were extended from 5 to 7 years. The second source of cost reduction was the strategy change on the pump impeller replacement from time-based to condition-based.

The largest benefit of the RCM was as a training tool for PT Badak plant personnel to work together on a fixed schedule to improve understanding of a system approach (instead of an equipment approach) and the related failure analysis.

Now PT Badak plans to apply the S-RCM method which is simpler and less time consuming than traditional RCM to review the current PM / PdM tasks. Based on benchmarking with another LNG site, it has been demonstrated that S-RCM provides an effective tool for PM / PdM optimization.

4.2. RBI Pilot Project

Analysing inspection interval requirements for all plant equipment can be time consuming. The Risk Based Inspection (RBI) method is used to minimise the analysis work and to focus on the high-risk items. As we know, RBI is a method to plan inspections based on an analysis of the Risk of events whose probability or consequence can be affected by the inspection.

The prime concern is physical damage caused by corrosion, erosion, fatigue, etc., rather than malfunctions due to improper operation or human error. It is also pertinent to note that Risk is a function of both failure probability and the consequences of failure. In its simple form: **Risk = Probability x Consequence**.

PT Badak has implemented this RBI method on stationary equipment in the CO_2 Removal Unit of a Process Train as a pilot project. This unit consists of 93 pieces of stationary equipment (pressure vessels) and 283 piping items. Tables 4.1. and 4.2 show the Risk distribution for the stationary equipment and piping items resulting from the RBI assessment.

The Risk Distribution for Stationary Equipment Component items indicate that 2 items (2.15%) fall within the High Consequence/High Probability area (Criticality 1) and 10 (10.75%) items fall in the Medium/High and High/Medium area (Criticality 2). This distribution reflects the spread of the majority of the stationary items in the Low Probability and Medium Consequence (Criticality 4).

CONSEQUENCES	PROBABILITY		
	LOW (59.14%)	**MEDIUM (30.39%)**	**HIGH (9.67%)**
HIGH (5.38%)	- (0%)	3 (3.23%)	2 (2.15%)
MEDIUM (93.82%)	55 (59.14%)	26 (27.16%)	7 (7.52%)
LOW (0%)	- (0%)	- (0%)	- (0%)

Table 4.1 : Stationary Equipment Risk Distribution

CONSEQUENCES	PROBABILITY		
	LOW (67.84%)	**MEDIUM (24.38%)**	**HIGH (7.77%)**
HIGH (0.35%)	1 (0.35%)	- (0%)	- (0%)
MEDIUM (96.81%)	183 (64.66%)	69 (24.38%)	22 (7.77%)
LOW (2.83%)	8 (2.83%)	- (0%)	- (0%)

Table 4.2 : Piping Items Risk Distribution

The Risk Distributions for piping indicate that no items fall within the High Consequence/High Probability area (Criticality 1) and 22 items (7.77%) fall in the Medium/High and High/Medium are (Criticality 2). This distribution reflects the spread of the majority of piping items in the Medium Consequence and Low Probability area (Criticality 4).

The interval of inspections can be determined through a scheduling tool that uses grade (confidence factor), probability (likelihood), and consequences of failure. The Inspection Grade indicates the inspection interval depending on PT Badak confidence in the criticality rating. Table 4.3 shows the inspection intervals in months.

Based on the Risk distribution of Stationary Equipment, we have two pieces of stationary equipment that fall in Criticality 1. The confidence levels of both pieces of equipment based on our experience are grade 1. Therefore, the interval of inspections for this equipment is 36 months. By using the same method, we can determine the inspection interval for all of the equipment that has been assessed by Risk Based Inspection method.

The RBI method will continue to be used by PT Badak to determine inspection intervals of other stationary equipment of all process train.

Criticality's	**Grade 0**	**Grade 1**	**Grade 2**	**Grade3**	**Consequence**
1	24	36	N/A	N/A	**H**
2	24	36	96	N/A	**H/M**
3	36	48	96	240	**H/M/L**
4	48	60	144	300	**M/L**
5	60	72	180	360	**L**
Deterioration	**High (H)**	**Medium (M)**	**Low (L)**	**Negligible**	

Table 4.3 : Inspection intervals (in months)

5. Benchmarking and Statistics

Based on Reliability Assessments conducted by The RM Group in 1996, 1999, and 2002 at PT Badak, the consultant advised that World Class Uptime performance is 95%+. This benchmark target was determined based on The RM Group assessment of approximately 80 private industries in North America. As shown in Table 5.1, PT Badak the Uptime / PRF in 2002 was 96.5% which falls in the World Class level.

Recent benchmarking survey among LNG plants by Shell Global Solution (SGS) confirms the following results for 2001:

1. PT Badak LNG plant is one of the best in asset utilization (which is for all practical purposes the same as Load Factor).
2. PT Badak NGL has one of the lowest operating cost indexes.

Table 5.1 below contains Production Reliability statistics in 1997- 2002, taken from PT Badak Production Reliability Factor Reporting System:

LNG Production & Losses	1997	1998	1999	2000	2001	2002
MSR LNG Production	100%	100%	100%	100%	100%	100%
Plant Related Losses:						
Scheduled	4.9%	6.6%	4.5%	4.37%	2.06%	2.1%
Unscheduled	**2.7%**	**3.9%**	**1.3%**	**2.48%**	**0.98%**	**1.35%**
Plant Sub-total	***7.6%***	***10.5%***	***5.8%***	***6.85%***	***3.04%***	***3.45%***
Prod. Rel. Factor (PRF)	**92.6%**	**89.6%**	**94.3%**	**93.3%**	**97%**	**96.5%**
Outside Related Losses:	0.57%	5.1%	2.29%	5.0%	4.35%	9.36%
Plant Availability (PAV)	**93.4%**	**92.0%**	**94.8%**	**94.95%**	**97.76%**	**97.3%**
Std. Cargoes shipped *)	**275.9**	**290.4**	**323.4**	**362.30**	**378.99**	**356.49**

Note:
*) Standard cargo = 125.000 m^3 cargo.

Table 5.1 : Reliability Performance Comparison 1997 - 2002

6. Conclusion

Badak LNG Plant has moved forward in the period of 1997 - 2002, with significant progress or capabilities, i.e.:

1. Establishment of the Production Reliability Factor Reporting System and measurement of all losses from the ideal train production capacity.
2. Use of the Production Reliability Factor report and related information for a root cause analysis process at the executive and managerial level .
3. Overall improvement of the plant LNG production available capacity by eliminating or reducing the probability of major reliability issues that can result in unscheduled LNG production loss incidents.
4. Improvement of Production Reliability Factor (PRF), which supports continued capability for meeting customer cargo requirements.

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