# The Train 7 Fire at PETRONAS' LNG Complex, Bintulu, Malaysia

*Norrazak Hj. Ismail, MLNG Tiga Sdn Bhd, PETRONAS and Thomas Roy Stuart, Foster Wheeler Energy Ltd, Malaysia*

**A major fire occurred in 2003 in the exhaust system of the propane compressor gas turbine in the first train (train 7) of the MLNG Tiga project. The authors describe the consequences of the accident, the analysis of the causes, the management of the plant recovery process, and the re-design of the system in both train 7 and train 8 to ensure enhanced integrity and increased safety.**

The PETRONAS LNG Complex in Bintulu, Malaysia covers a land area of 276 hectares and with a combined production capacity of about 23 million tonnes per annum (Mtpa), it is the world's largest LNG export facility in a single location. It is made up of three LNG plants (see Figure 1):

- Malaysia LNG Sdn Bhd (Trains 1, 2 and 3), which began operation in 1983.
- Malaysia LNG Dua Sdn Bhd (Trains 4, 5, and 6), which began operation in 1994
- Malaysia LNG Tiga Sdn Bhd (Trains 7 and 8), which began operation in 2003.


*Figure 1: Overview of the PETRONAS LNG complex*

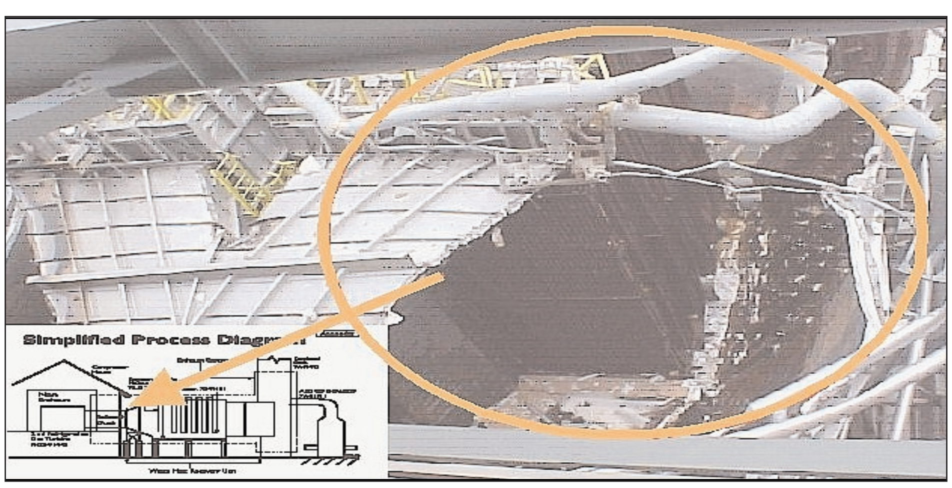


*Figure 2: Top View of MLNG Tiga C3 GT Exhaust Plenum Damage*

The MLNG Tiga project has a total annual capacity of 7.8 Mtpa for two trains, which are among the largest ever built. The application of several significant innovative ideas makes this project one of the most significant achievements in the LNG industry. A fire at the MLNG Tiga plant in August 2003, however, forced a temporary shutdown for repairs. This article provides a thorough analysis of the incident and the enhanced modifications instigated in resolving the problems encountered. In accordance with the recovery plan, the facility managed to resume its normal operation in April 2004, three weeks ahead of the original target of seven months.

## Overview of the Train 7 Fire Incident

In March 2003, Train 7 of MLNG Tiga plant had started its operation. It had successfully passed its performance test in June 2003 and was soon to be offered for provisional acceptance to the owner. Two months later, the Propane Compressor Gas Turbine ($C_3$ GT) exhaust system of Train 7 was involved in a fire incident (Figure 2). It occurred on 16 August 2003 at 22:21 hours and led to a temporary shutdown of the train. After thorough investigation and analysis, appointed teams identified the specific damages that had occurred and developed a step-by-step recovery process to ensure that the Train 7 could resume operation quickly and safely.

The design utilised within the MLNG Tiga plant seeks to recover the heat from the exhausts of the main turbine drivers of the refrigeration compressors. Hot oil for general heating duties and hot natural gas for regeneration of dryers recover the exhaust heat with the use of heat exchanger coils. The exhaust gas from the $C_3$ GT passes through an exhaust plenum and then splits in a Y piece to enter the two halves of the Waste Heat Recovery Unit (WHRU). Each half contains a regeneration gas coil and 5 hot oil coils. A schematic of the arrangement is shown in Figure 3.

The regeneration coil has an inlet and outlet header with 32 tubes connecting them, each tube with a U bend at the top. The entire regeneration coil, including the headers, is housed within the WHRU duct. Under normal operation, the duct, which is refractory lined, reaches temperatures in excess of 500 °C.

Prior to the incident, unbeknown to the operations personnel, a crack had developed in the joint between the tube and header of the regeneration gas coil. This leakage was not obvious to the Operator from the instrumentation arrangement but could be detected on the instrument records during subsequent investigations.

The propane compressor and turbine experienced a trip that was unrelated to the gas leakage. This resulted in fuel gas to the turbine shutting off and the turbine speed running down before stopping. The procedure was then for the turbine to go into a slow rotation of 6 rpm using the barring motor, which successfully occurred. Because of the rotation of the turbine blades and the chimney effect of the turbine exhaust stack, air was drawn in through the turbine and into the exhaust duct. During slowing down (about 14 minutes), the oxygen ($O_2$) content rose from 14% in normal operation to 21% by the intake of fresh air through the gas turbine air intake compressor

The natural gas escaping from the regeneration coil mixed with the air inside the WHRU that was still at a very high temperature, near the normal operating exhaust temperature of 570 °C. High pressure leaking gas, mostly methane ($CH_4$+), only required 4% volume in air to reach its lower flammability limit and auto ignition temperature of 537 °C. This was achieved and led to an explosion inside the WHRU.

## Damages Occurred

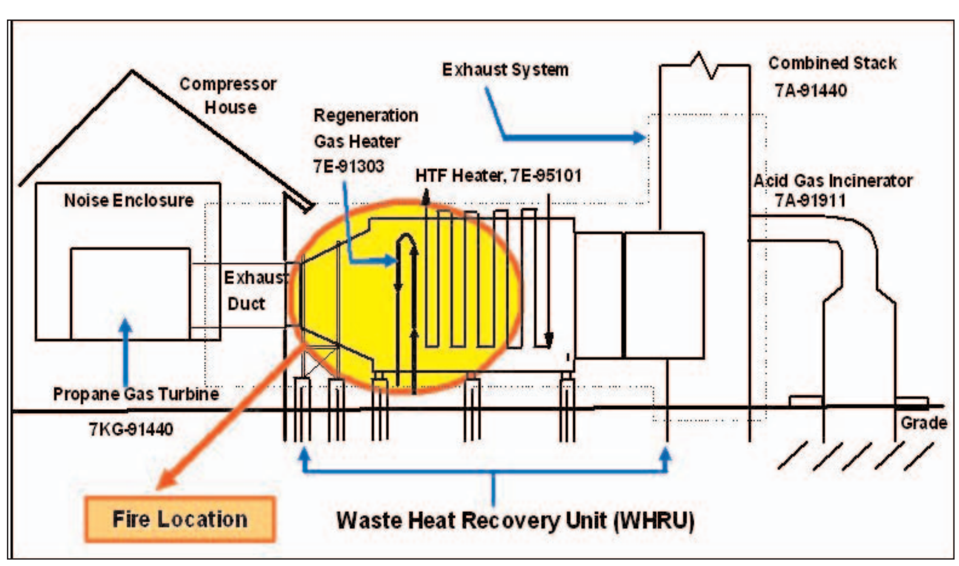
- The WHRU ducting was damaged beyond repair
- The hot oil coils were damaged beyond repair
- The regeneration coils were recoverable
- The gas turbine plenum was extensively damaged
- The housing around the compressor / turbine was extensively damaged
- The compressor was undamaged but needed to be stripped down for examination
- The turbine moved on its base but only sustained damage to ancillary equipment. It required disassembly for internal inspections
- The building suffered superficial damage
- No injury occurred to any personnel.

## Recovery Process

In an effort to recover production safely in the quickest possible time, it was decided to establish multiple teams to tackle the various challenges. The teams included:

- Initial Investigation Team to find the root cause
- Business Recovery Team
- Interim Production Study Team
- Demolition Team
- Engineering Team to develop a safe redesign
- Reconstruction Team
- Re-HAZOP Team
- Insurance Claim Group

*Figure 3: Side View of MLNG Tiga C3 GT, WHRU, Exhaust System, and Incinerator*



The participating personnel were from the following:

- Owner : MLNG Tiga
- Operator: MLNG
- EPCC Contractor: JGC / KBR / SIME
- Project Management Consultant: Foster Wheeler / OGP Technical Services
- Technical Services: Shell Global Solutions International

Whilst the plant had commenced operation, contractually it still remained the EPCC Contractor's responsibility to repair the damage. However, the majority of the costs were recoverable against the owner's Construction All Risks Insurance.

As soon as access was possible to the regeneration coil, the crack between the tube and header was observed and extensive studies conducted into the design of the coil. During normal operation the coil undergoes several heating and cooling cycles per day and high stresses occur. However, the area where the failure happened has relatively low stress factors.

A section of the coil was sent to The Welding Institute in the United Kingdom for analysis. The tube to header joint was sectionalised and examined. It could be clearly seen from a connection adjacent to the failed weld that the root pass had not been carried out correctly. Several other such joints were examined and found to be poorly welded. The failed weld connection was maintained by a very small section of weld that was sufficient to withstand hydrostatic pressure test but not the cyclic stresses induced during operation as shown in Figure 4. This type of weld cannot be fully tested using radiographs, whilst Ultrasonic Testing (UT) is not suitable for use with incoloy material. The inadequacy of the weld could have been determined during the inspection of the root weld.

The redesign team selected the use of nipolets between the header and tubes to allow easier welding and full radiographic testing of each joint. The original design of welding is shown in Figure 5 and the new design is shown in Figure 6. Additional springs were added to the coil supports to eliminate the high stresses experienced elsewhere in the coil (the U bend at the top of the coil).

The original estimated duration for reconstruction of Train 7 WHRU section was twelve months, mainly due to the long delivery of the replacement hot oil coils. The original coils could not be reused due to the extensive damage. Analysis by the Interim Production Team concluded that by sharing hot oil from Train 8, Train 7 could operate near to its full capacity. Piping modifications to allow this operating mode were implemented and the revised target for interim production was set at seven months.

A large number of equipment items were associated with the GE / Nuovo Pignone compressor turbine arrangement, particularly the exhaust arrangement on the turbine outlet. Nuovo Pignone established a special task force team to place and expedite orders for replacement parts. Critical items were regularly air freighted. The purchase order for WHRU ducting was placed with Ishikawa Heavy Industries (IHI) within a very short schedule as agreed. The WHRU ducting was completed on time and was transported by a specially chartered ship travelling non-stop from

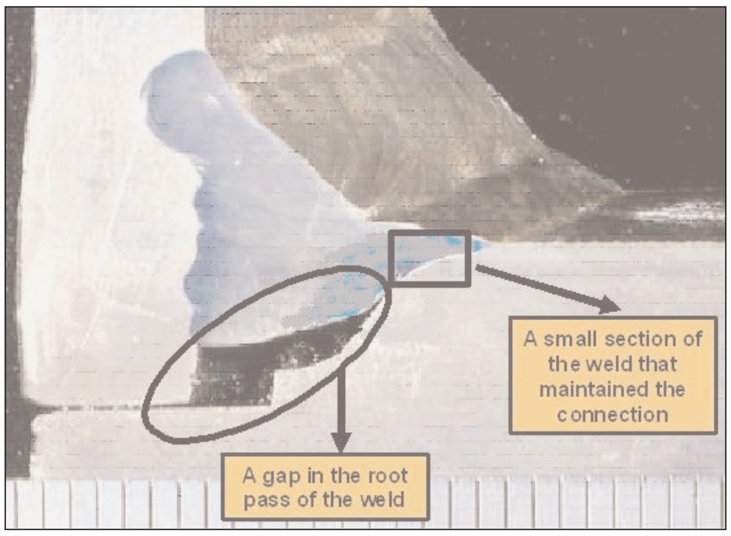



*Figure 4: Cross Sectionalised between the Tube and Header of the Original Weld*

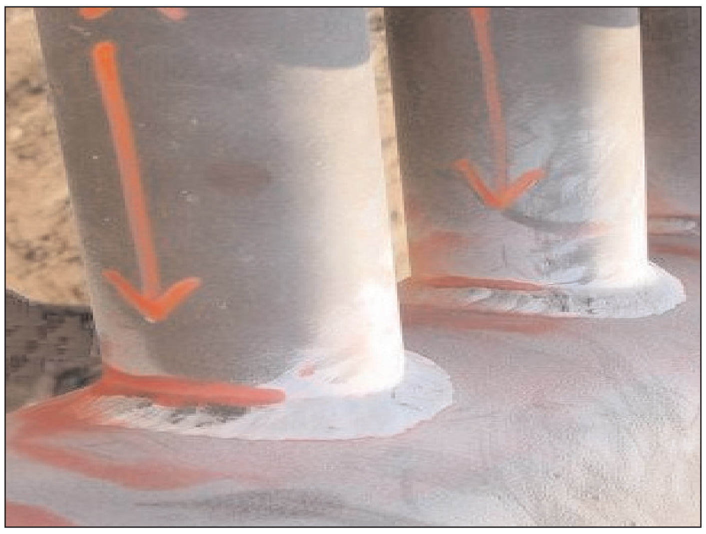


*Figure 5: Original Welding Design between the Header and Tubes*

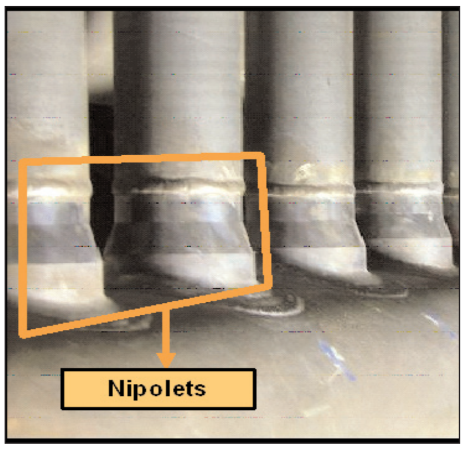



*Figure 6: Improved Welding Design that use Nipolets between the Header and Tubes*

Japan to Bintulu. Owner's spare parts were utilised within the rebuild wherever they were available.

The co-operation of all parties was essential to complete the project and the success was measured by an efficient and safe start-up three weeks ahead of the target.

## The Re-Hazop Analysis

The MLNG Tiga LNG liquefaction train design utilises Propane Compressor Gas Turbine ($C_3$ GT) Exhaust Gas duty to regenerate the Drier Beds. $C_3$ GT Exhaust Gas passes through a WHRU, which contains the Regeneration Coil (heat exchanger used to provide the necessary heat input for regenerating the drier beds). When the $C_3$ GT trips and there is a Regeneration Coil tube leak an explosive mixture can form in the WHRU. The Re-HAZOP team recommended a new safeguarding system such that, in the event of a hazardous situation arising, the regeneration gas in the coil should be isolated (using existing motorised valves) and then vented from the coil (via a new relief system). Depressurisation of the regeneration coil was initiated by a $C_3$ GT trip or shutdown; or by high differential flow between the inlet and the outlet of the regeneration coil; or by the loss of pressure in the regeneration coil. The new system employed the existing process instrumentation around the regeneration coil.

These modifications were immediately incorporated into the adjacent Train 8 that was ready to enter service in two months time and later made to Train 7 prior to its restart. For future designs, the Re-HAZOP team recommended that consideration should be given to locating the coil header and connection outside the waste heat recovery duct.

***$C_3$ GT Trip or shutdown:*** With reference to Figure 7, when the $C_3$ GT trips or shuts down the new safeguarding system automatically closes valves A to D, thus preventing further Regeneration Gas and Purge Gas entering the regeneration coil. Next valve E is opened, allowing the regeneration coil to fully depressurise to flare. Extra isolation is provided as inlet valves FC1 and FC2 are also closed. The check valve provides sufficient extra isolation on the regeneration coil outlet.

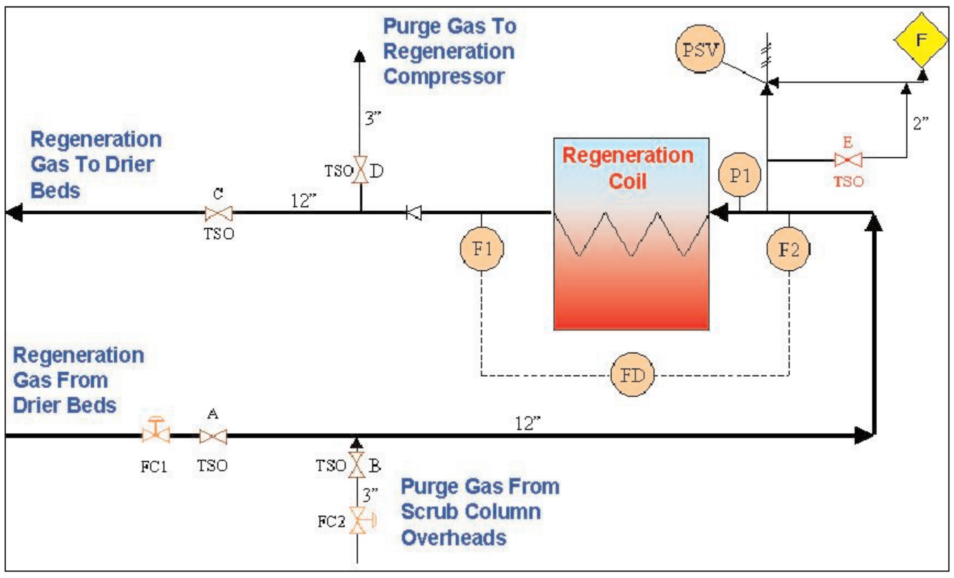



*Figure 7: Regeneration Coil Isolation and Depressurising*

***High flow differential:*** Figure 7 shows a flow differential instrument (FD), which measures the difference between regeneration coil inlet and outlet mass flowrate. If the differential exceeds approximately 15% the new safeguarding system automatically initiates the closure of valves A to D as per the $C_3$ GT trip or shutdown scenario where extra isolation is provided by inlet valves FC1 and FC2 and the outlet check valve.

However, in this case valve E remains closed unless the operator chooses to manually depressurise the regeneration coil. The operator monitors the new regeneration coil inlet pressure instrument (P1); if it indicates falling pressure, hence a leaking regeneration coil, manual depressurisation would then follow.

As the Drier Bed sequence proceeds, transitions between certain steps allow the mass flowrate through the regeneration coil to vary quickly between approximately 0-1400 tonnes/day. For this reason the mass flow differential input to the new safeguarding system is temporarily inhibited until steady flow resumes. This inhibition only lasts for a few minutes of the 8-hour Drier Bed cycle.

***Low pressure:*** Once the pressure drops to a low enough level (approximately 70% of the normal operating pressure, as measured by P1) the new safeguarding system initiates the same response as flow differential instrument (FD). Again, if P1 continues to indicate falling pressure, hence a leaking regeneration coil, manual depressurisation would then follow.

***Start up/Shutdown***: The question of when to pressurise the regeneration coil had to be addressed as part of the new safeguarding system design. This is because the regeneration coil will always be depressurised during a $C_3$ GT trip or shutdown.

When the $C_3$ GT is starting up an explosive mixture can form if a fully pressurised Regeneration Coil is leaking. This is due to lower $C_3$ GT Exhaust Gas flow and higher oxygen content in the WHRU. For this reason a permissive is provided whereby the regeneration coil can only be pressurised once the $C_3$ GT reaches 95% of its full operating speed.

## Conclusion

The inspection plan for the regeneration coil was adequate but due to the complexity of the weld details and the critical nature of the equipment, additional surveillance should have been carried out in the fabrication workshop. The redesign of the tube to header connection is vastly superior to the original design and facilitates the application of Non Destructive Examination (NDE) reducing the need for day-to-day surveillance.

The damages of the Train 7 fire incident at the Petronas LNG Complex were repaired successfully. Instead of the estimated twelve months of the recovery process, Train 7 managed to be brought back into production within seven months. The multiple teams established in the recovery process shared the common objective of getting the plant onto line quickly and safely again. These teams, who were made up of the best members from each organisation, worked together in an environment where information was shared freely with an excellent spirit of co-operation. It saved a lot of time, energy and cost as duplication of effort was appropriately avoided. Decisions were made quickly and followed up with the most suitable actions.

The outcome of the investigations provided an improved welding design of the regeneration coil and also a new safeguarding system that not only is useful for rebuilding of Train 7, but was also of use for Train 8. These modifications were immediately incorporated into the adjacent Train 8 that was ready to enter service and later made to Train 7 prior to its restart. Besides the long hours of work, the teams also took ownership of the problem. This helped to expedite the recovery of Train 7 and the facility managed to resume its normal operation safely three weeks ahead of the original target of seven months. Currently, both Train 7 and 8 are in operation producing a total annual capacity of 7.8 Mtpa as the design intends.

*Norrazak Hj. Ismail is the General Manager for PETRONAS Malaysia LNG Tiga Sdn. Bhd. He has a Bachelor of Science in Chemical Engineering from the University of East London, England. He has been with PETRONAS for 20 years in the gas business and for the last 13 years in LNG Projects as Process/Commissioning and Start-up Manager for Malaysia LNG Dua Plant Project. In 1995 he was appointed General Manager for Malaysia LNG Tiga Project.*

*Roy Stuart is a Senior Project Manager with Foster Wheeler. He has an Honours Degree in Mechanical Engineering from Loughborough University, England and is a Chartered Engineer and Member of the Institution of Mechanical Engineers. He has 20 years experience in the Oil and Gas Contracting Industry, completing projects for many of the major oil companies. From 2002 until 2004, he resided in Bintulu, Malaysia where he was the Project Manager of the Project Management Consultant for the construction of Train 7 and Train 8 of the Malaysia LNG Tiga Project.*