



## MIDLINE TIE-INS & REPAIRS ON LIVE OIL & GAS PIPELINES UTILISING REMOTELY OPERATED INTELLIGENT PIGGABLE ISOLATION TOOLS

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### Abstract:

The development in intelligent plugging and pigging tools has evolved from the outdated umbilical operated tools that were operated through penetrations in pig trap doors.

The new intelligent plugging and pigging tools allow remote local pressure isolations at any water depth and at any position along a pipeline. The remote through-wall communication system reduces the number of vessels required during the flooding and commissioning of pipelines since pigs can communicate wirelessly their arrival and departure through the pipewall, through water and through air.

This paper presents the remote controlled pipeline isolation and pigging tools and describes the function and operation of each main sub-system. The paper presents historical applications with focus on subsea and midline pipeline isolations and interventions.

### Introduction

The development of the intelligent plugging and pigging tools evolved from the first intelligent, tetherless remotely controlled pipeline pressure isolation tool installed by PSI at the BP Dimlington Gas Terminal in the UK in May 1999. The purpose of the installation was to pressure isolate a 150 kilometre long high-pressure offshore pipeline about 50 meters from the beach valve at the onshore gas terminal such that the pipeline valves at the terminal could be replaced while the pipeline was kept at full operating pressure.

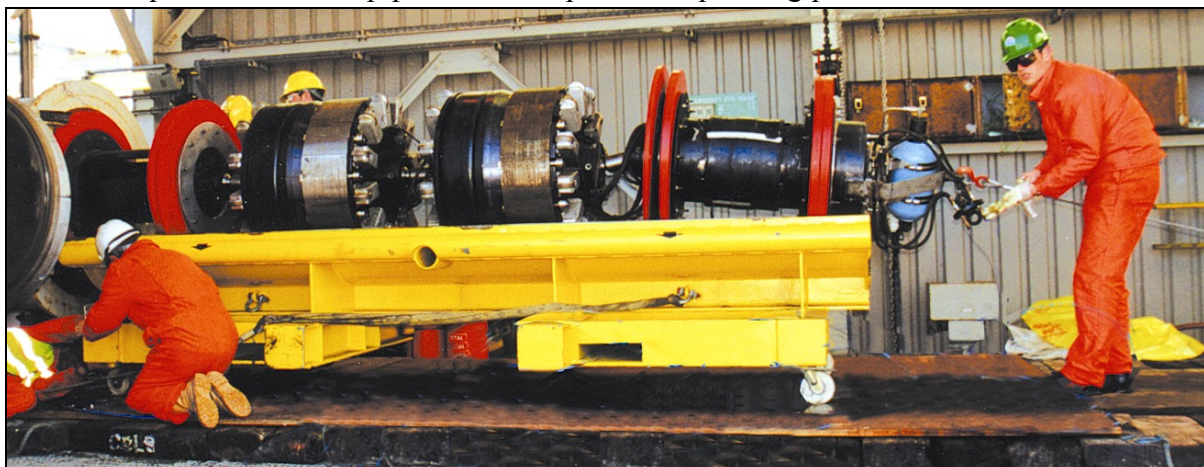


Figure 1. World's first piggable dual module intelligent isolation plug train used at the BP Dimlington terminal.

An intelligent piggable plug, controlled and operated via through-wall communications, was installed using the existing sphere receiver without depressurising the pipeline, thus avoiding spending time to depressurise, flare gas and gas up upon completion of the valve repair work.



*Figure 2: Typical configuration of a piggable intelligent isolation train*

The intelligent piggable isolation system consists of several sub-systems. Since the first pipeline application in May 1999, the various subsystems have been developed further and have been used in a range of remotely controlled plugging and pigging operations.

This first installed intelligent piggable isolation system was the PSI SmartPlug. An overview of the system is shown in Figure 3 below.

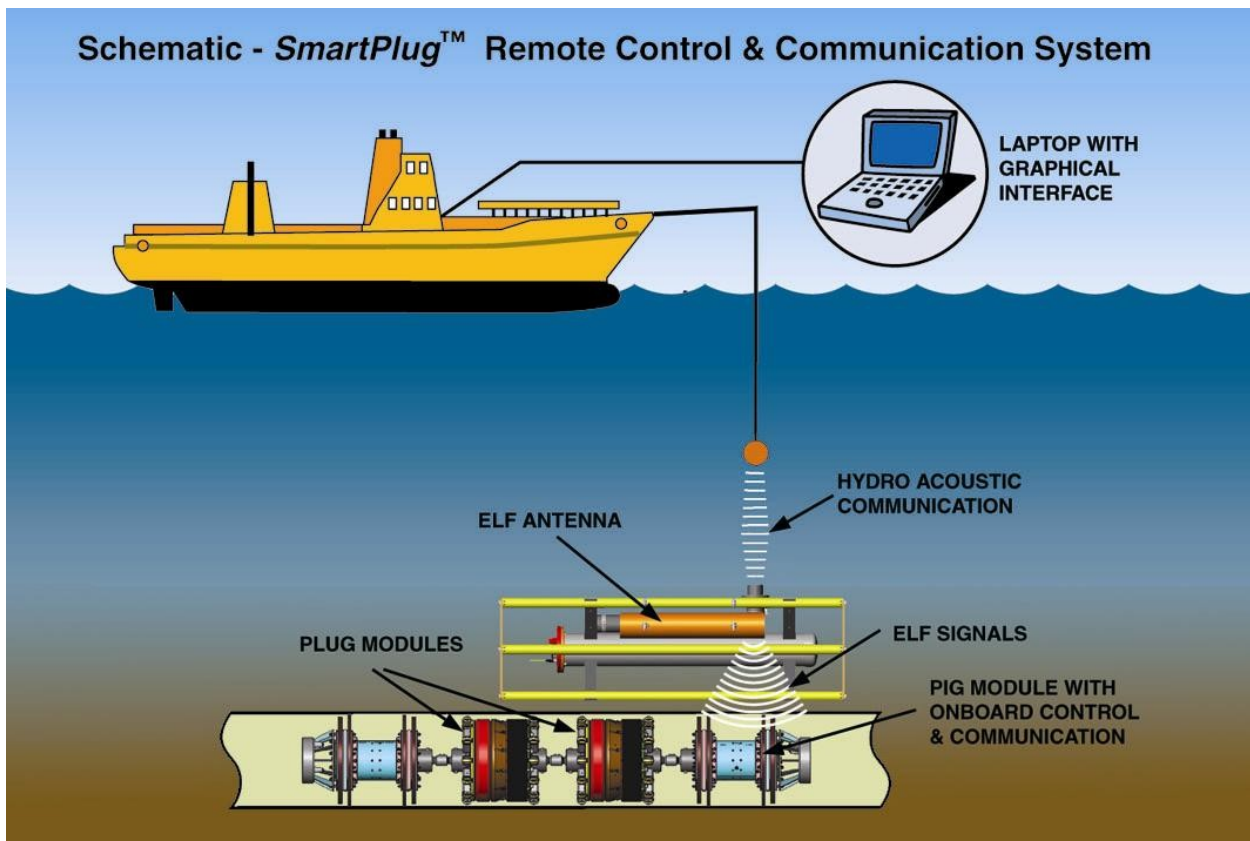


Figure 3. Overview of intelligent piggable isolation plug system

The system component design is based upon proven technology and use of reliable components designed to ensure 100% redundancy. The standard tool is designed to seal against 200 barg (3,000 psi) operating pressure.

The Isolation Plug System design and operating philosophy emphasizes plug reliability, redundancy and safety. Safety aspects of the operation have been considered and back-up components incorporated for all essential systems. In the following sections the principal system components will be presented and discussed.

### Environmental Advantages and Cost Savings

One of the most important features of applications of pipeline pressure isolation tools is the ability to perform the project with loss of content, typically negating the need to flare or dispose of content. Since these tools are non-tethered, they can be pigged into position in the same manner as pigging any other tool, maintaining full pipeline operation pressure.

Once set, only the section where the work is to be performed needs to be free of content, so that the remainder of the line can stay under pressure. In a typical application this:

1. Avoids the need to blow down the line, thus avoiding wetting the line,
2. Reduces the amount of chemicals required to re-commission,
3. Thus saving time, the value of the content, and
4. Avoiding the environmental impact of flaring or releasing gas or disposing of hydrates, chemicals and contaminated water.

### The Bi-directional Piggable Intelligent Isolation Plug Train

The free flowing plug train can travel in any direction inside the pipeline. The plug train is highly piggable and will travel with any pipeline medium, including hydrocarbon gas, crude oil, and distillates, treated or untreated water, glycol, diesel, etc.

The standard intelligent isolation plug train (see figure 2 above) consists of two independent plug modules. These plug modules travel on a wheel systems, and each plug module is independently capable of isolating the full pipeline pressure, thus providing a true double-block isolation.

A typical isolation plug train has one pig module fitted at each end. The pig modules house the onboard control and communication system and assist in driving the plug train in and out of the pipeline. The onboard control and communication system inside the pigging modules communicates wirelessly with the external antenna placed on or above the pipeline.

The typical lifetime of the control and communication system inside the pipeline is one to three years.

The first intelligent piggable isolation trains had the entire micro-hydraulic units installed inside an atmospheric chamber housed inside the pigging modules.



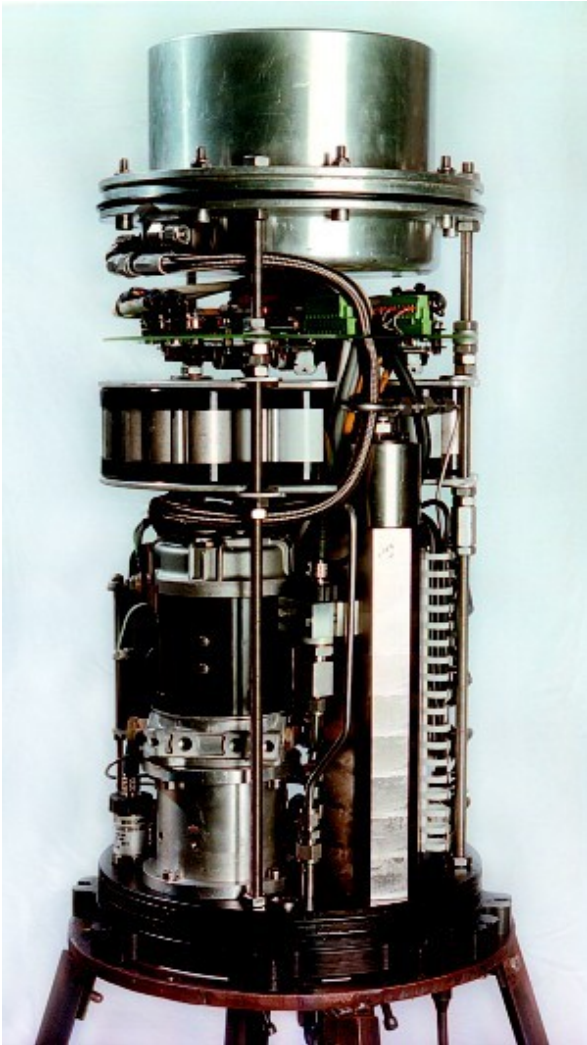


Figure 4. Micro-hydraulic control module

The micro-hydraulic system includes a hydraulic reservoir (on top), a battery package, a hydraulic pump, valves and valve controllers. All hydraulics are run through a special manifold valve with a built-in contingency system. The contingency system is activated by increasing the pressure on either side of the isolation plug to a pre-set pressure. When the manifold is exposed to this pressure, a pressure activated piston releases the hydraulic pressure from the set side of the piston insuring a safe unset of the isolation train in case of a failure in the micro-hydraulic system.

The micro-hydraulic unit is connected to the plug modules by hydraulic tubing.

In the second-generation intelligent piggable isolation plugs the micro-hydraulic system is integrated into the plug module as shown in figure 5 below. The hydraulic pump is fitted inside the hydraulic piston and the valves and control board are both integrated into the hydraulic cylinder allowing a system entirely free of tubing.

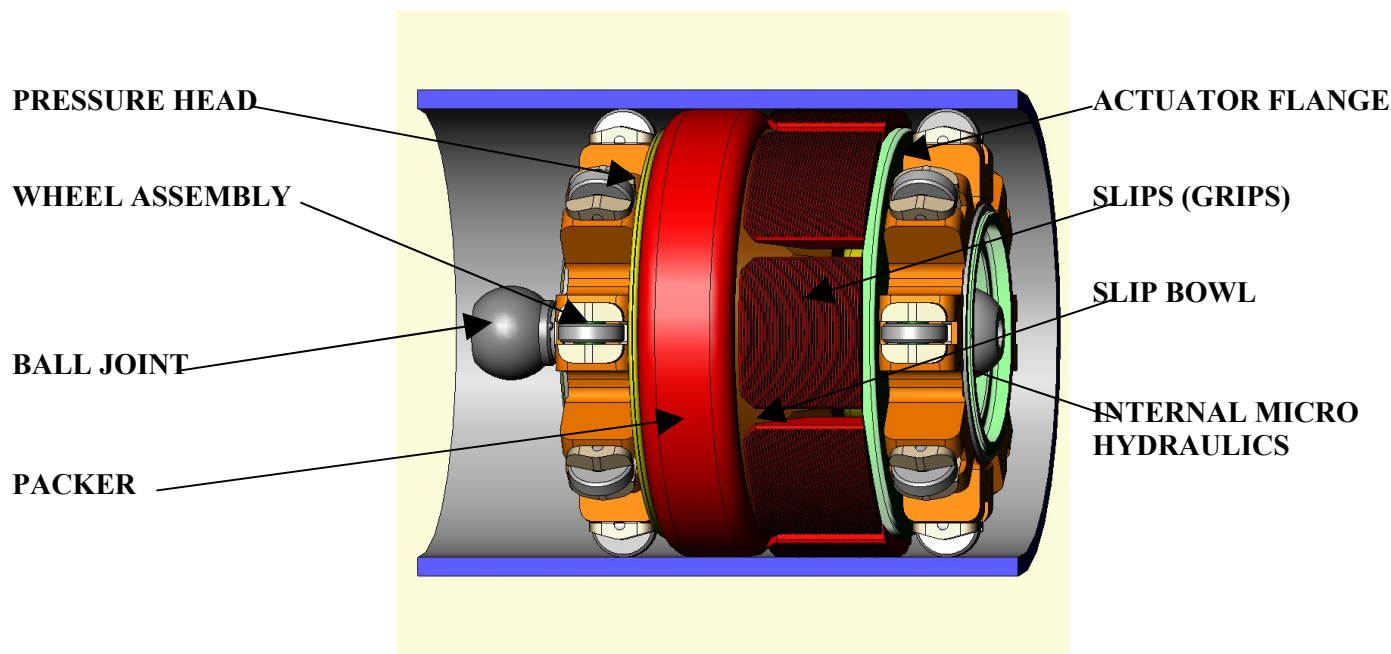
The battery and communication unit remain placed in the trailing pigging modules.

Figure 5 shows a view of the second-generation intelligent isolation Plug Module. As with the first generation Plug Modules, the two Plug Modules perform the seal and lock function, and each module provides this function independent of the other, creating 100% redundancy.

The Plug Modules, linked together by ball joints, have two primary functions (see fig. 2):

- Set and lock to the inner pipe wall via the threaded metal segments or “slips”.
- Differential pressure sealing with the large volume packer.

Load transfer is accomplished by the use of threaded radial-oriented metal segments or “slips” made from hardened steel. The slips are activated by pressurizing the set-side of the hydraulic cylinder, resulting in the piston moving to the left, causing the slips to slide up the bowl and expanding radially.



*Figure 5. View of a single Plug Module with integrated micro-hydraulic system*

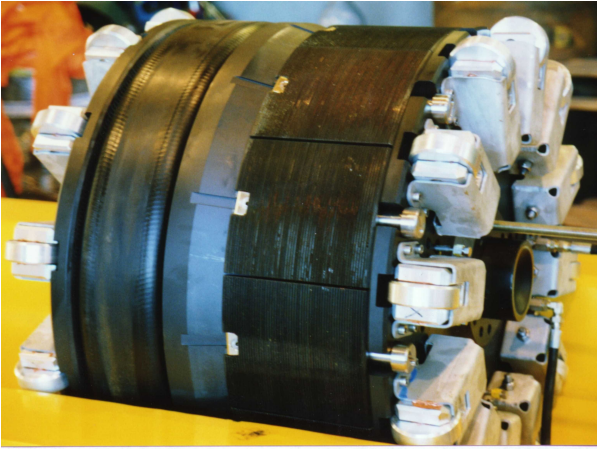
Once the slips are in contact with the pipe wall, the movement of the actuator flange against the pressure head will begin to compress the packer radially, expanding it to seal against the inner diameter of the pipeline. The outer surfaces of the slips are machined with threads that are made as sharp as possible to enable the slip teeth to penetrate the surface of the pipeline inner wall. This penetration is only a few thousandths of a millimetre since the slips make uniform contact with the pipe wall. The penetration is well within the tolerances specified for scratch marks as published by API.

Further, engaging only one third of the slips with the inner diameter of the pipeline is sufficient to provide the gripping effect required for an acceptable isolation.

The Plug Modules are self-locking. I.e., once they have been expanded against the pipe wall, a continued application of differential pressure across the Plug Module will maintain or intensify their sealing and gripping ability without use of an actuation load (i.e., the hydraulics are no longer required to maintain the set position). Differential pressure is acting on the pressure head and produces a thrust load against each Plug Module, which transfers the load into the pipe wall through the slips and packer.

Each Plug Module is equipped with 12 spring-loaded wheels at each end, providing the means of supporting and centralizing the Plug Module inside the pipeline (see fig. 3). In addition, the wheels also prevent seal distortion and improve the efficiency of the packer by keeping the system centralized in the pipeline, as well as facilitating smooth travel in the pigging mode.

Unsetting the tool can be done in several ways. The primary method is to equalize pressure across the Plug Module and unset it via remote hydraulic actuation. Pressure in the set side of the hydraulic cylinder is vented and the piston side of the cylinder is pressurized, causing the piston to retract.



**Fig. 6. Plug Module with Wheel Assembly**

This forces the actuator flange to pull the slips off of the slip bowl ramp and the pressure head to relieve the set on the packer, thereby releasing the module. The secondary method of unsetting the Plug Module is to vent both the rod and the piston sides of the hydraulic cylinder and then equalize differential pressure across the system. By doing so, a number of compressed springs will force the actuator flange and pressure head apart, allowing the slips and packer to retract to their pigging positions.

A third method of unsetting the Plug Modules, should the communication and control systems fail, is to use the mechanical fail-safe unsetting mode. Pressure on the actuator flange side of the Plug Module (i.e., the non-pressure side) is increased to a pre-set pressure to activate a dump valve in the hydraulic circuit, thereby venting pressure from both sides of the hydraulic cylinder. The compressed springs will force the actuator flange and pressure head apart, allowing the slips and packer to retract to their pigging positions.

Each Plug Module has one Packer, made from a medium-hard elastomeric material. The outer edges of the Packer have steel springs moulded inside to prevent extrusion of the edges of the Packer. The Packer is actuated (set) by applying the system hydraulic operating pressure to the rod side of the actuator cylinder. This applies a compression load over the annular area of the packer, and results in compression of the Packer. This compressive action causes the Packer to expand radially and form high-pressure contact with the ID of the pipeline.

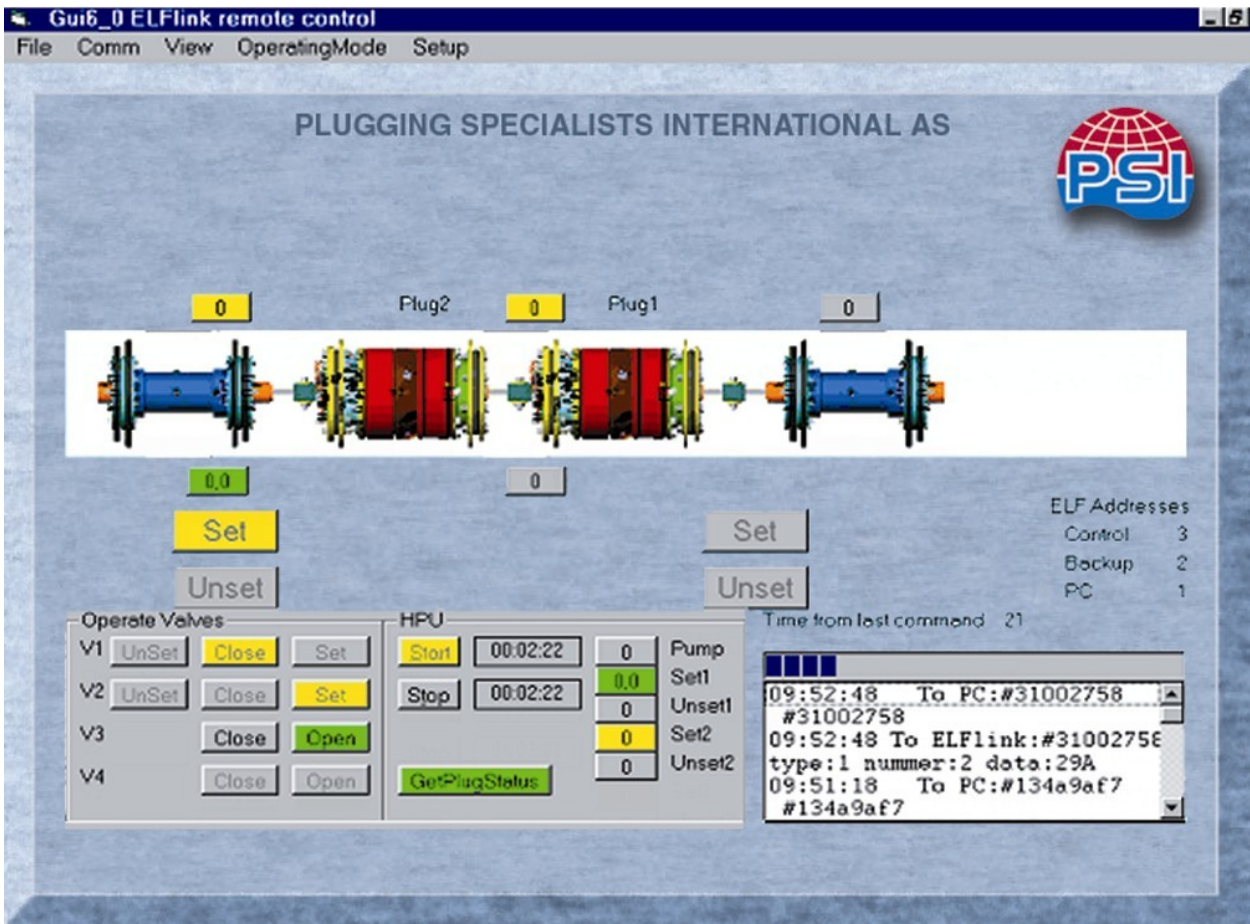
The individual Plug Modules of the isolation system are joined together by ball joints, which allow the modules to swivel freely to eliminate the destructive joint forces encountered while traversing elbows and mitre joints. As a safety backup feature, the ball joint between the two Plug Modules is also capable of supporting the thrust load under full differential pressure.

Slip and Packer “sealing” redundancy is achieved through the use of two independent and identical Plug Modules, each containing a single Packer and a set of slips. Each Plug Module is designed and tested to seal against the full pipeline differential pressure. Once set, the slips and Packer remain self-energized by differential pressure to prevent an accidental release. The design provides the ability to test the sealing and gripping capability of each module.

### **The Control and Communication System**

The control and communication system can be divided into three logical sub-systems: The Surface Control Center, which is a lap top or a PDA with a graphical interface, the external ELF antenna, which performs through-wall wireless communication with the intelligent isolation plug train, and finally the onboard micro-hydraulic system with its built-in control and communication system.





**Figure 7. Example of graphical interface**

The graphical interface allows the operator onboard a surface support vessel or platform to send and receive commands and data to and from the intelligent isolation plug train. A standard off the shelf acoustic modem system is typically used to transmit the operator's signals from the laptop to the subsea antenna. Via the industry standard portable computer the operator may instruct or query the SmartPlug via the acoustic modem and the subsea antenna, and display the results of the query on the computer monitor.

The graphical user interface system is protected against user errors by halting the operations and requiring passwords for performing functions that are directly related to isolation safety. There are 10 pressure indicators, all of which provide the operator with all relevant pressures for both the hydraulic system and the pipeline pressures.

Further, alarm switches can be activated to alert the user if the annulus pressure (the volume between the Plug Modules) should rise above a given pre-set value. A log file is started when the program is started, and all information is stored for later retrieval.

### **Tracking**

The early installations of the intelligent piggable isolation trains used isotopes for tracking and positioning of the tools. The restriction in use of isotopes, combined with their limited capability of handling pipeline burial depth and inability to identify individual pigs, led to the development of a new tracking system for plugs and pigs. The SmartTrack pig tracking system was launched in October 2003.



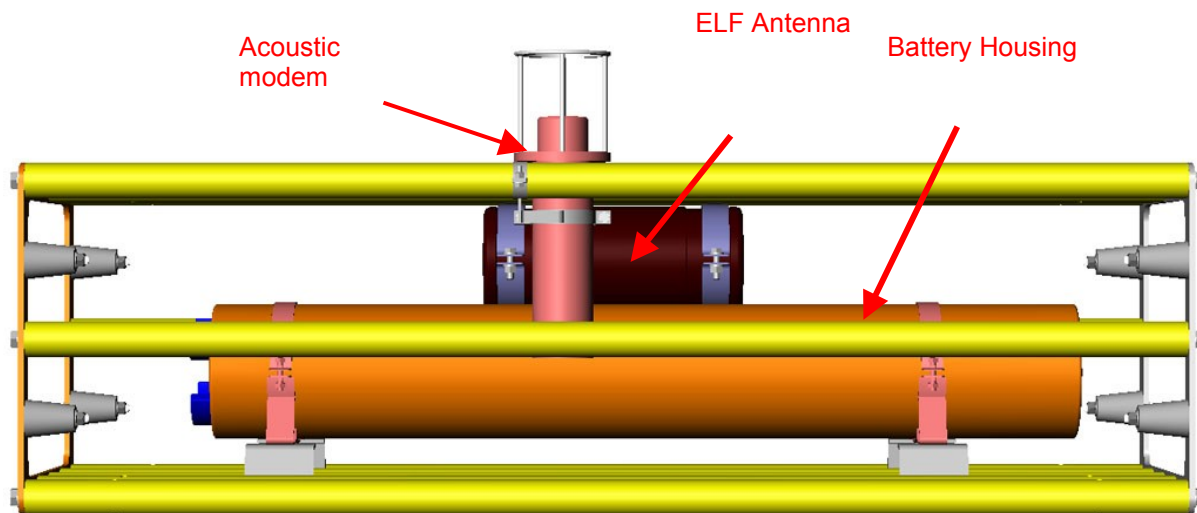


Figure 8. Subsea antenna with acoustic modem

The tracking system is based on the control and communication system developed for the piggable intelligent isolation system but has been modified for pig tracking and designed such that it can be used in any piggable plug or pipeline pig.

The external to the pipeline tracking and communication units are identical to those used for the intelligent isolation plug system.

The internal units, called pingers, have built-in two-way communication antennas which allow the operator to interact with the pinger from the units external to the pipeline. This allows the pingers to be remotely stopped, started or even programmed using the remote through-wall communication technology developed for the piggable intelligent isolation systems.

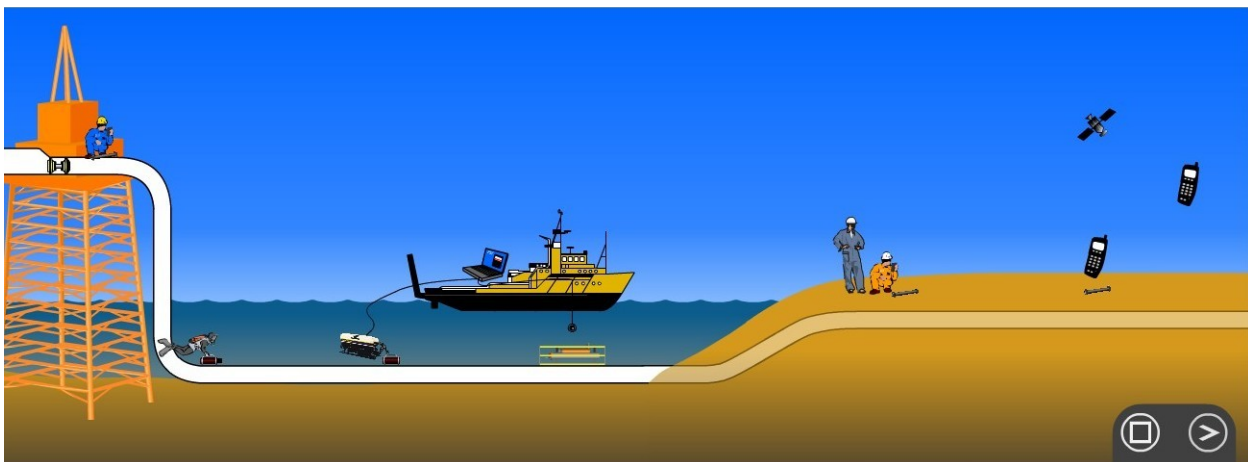


Figure 9. Plugs and pigs fitted with the intelligent pig tracking system can be tracked wirelessly, locally or remotely.

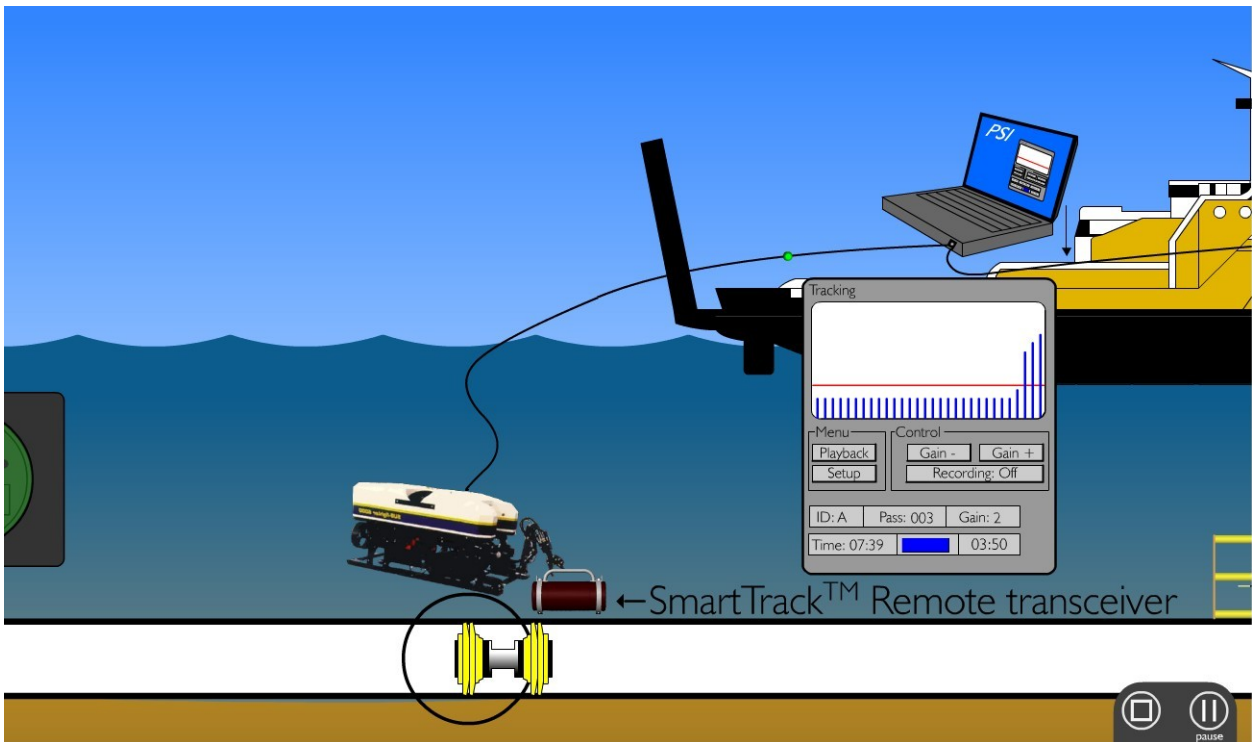


Figure 10. The ROV mounted transceiver tracks the pig or plug using a graphical interface on a laptop or PDA in the ROV control room. The transceiver is linked through the ROV signal cable.

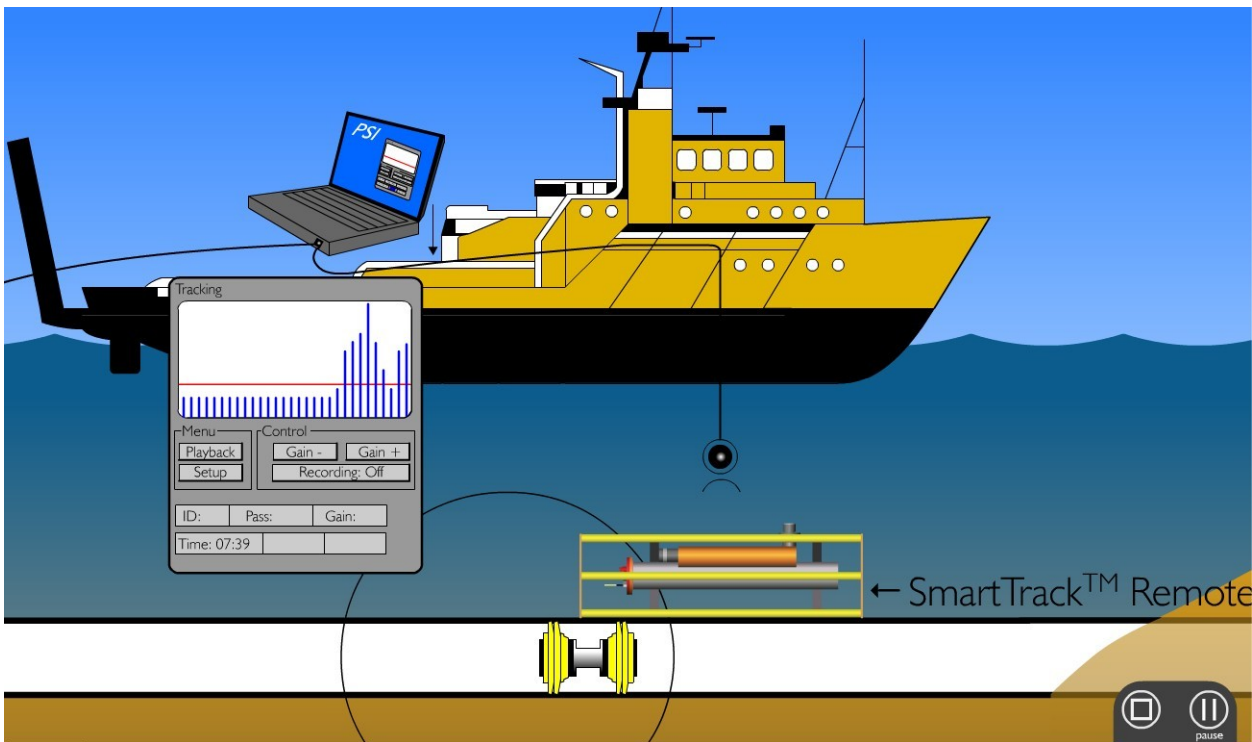


Figure 11. The subsea transceiver is fitted with acoustic communication and can communicate wirelessly through water to a modem on the vessel or on the platform.

### Qualification and Testing of the Intelligent Isolation Plug System

PSI initiated and financed research work in early 1997 that included joint resources from PSI and the Norwegian Institute of Technology. From the beginning this research was verified and guided by Det Norske Veritas. Eighteen months later the first generation of

stable ELF communication systems were unveiled, and the first SmartPlug was born, marking the end of umbilicals or tethers. Following a period of theoretical work, a period of testing was undertaken, and eventually a complete working system was produced.

Since the pipeline isolation system is inserted into major oil and gas export pipelines, a failure could have immense consequences, so it was considered vital for a recognized third party to verify and approve the system. To satisfy the operators or other users of the system, the complete isolation system was given Type Approval by DnV in 1999. See figure 4.

The Factory Acceptance Testing (FAT) program is conducted in two-phases: Pigging of the tool through a mock up pipeline system (where required) and pressure testing by setting the tool and holding at full isolation pressure for a pre-defined length of time.



Figure 12. 10 inch and 32-inch piggability test rigs

The mock up pipeline system is typically designed to resemble the pipeline system on site as close as possible, including the ID of the pipeline, bends, valves, and other pigging restrictions (see fig. 13). It is also common to simulate any pipeline defects in the exact setting location, i.e., corrosion pits and other damage or irregularity.

By pigging the isolation tool through the mock up test rig, a situation close to the actual project can be simulated, and any potential difficulties can be addressed in the shop, and rectification made prior to shipment. Pigging medium and pressures are also variables that are specified for each project, in order to accommodate exact site conditions.

The current version of the isolation tool contains an internal housing that is rated to a depth of 7,000 feet, as is the external antenna array. At such depths the external antenna is ROV operated or operated via acoustics. All units can easily be upgraded for use at 10,000 feet water depth.

#### **Milestones in the Development of the Intelligent Piggable Isolations Tools**

May 1999: First remotely operated intelligent isolation. An isolation plug train was installed for the first time at the onshore terminal of an offshore pipeline in the UK.

October 1999: First subsea installation completed. One 26 inch and one 30 inch intelligent isolation system were installed subsea, saving 25 days of production from 3 fields in India.

November 1999: Longest isolation duration. A 30 inch intelligent isolation system was pigged 7 miles into an oil line and isolated one branch of a pipeline for 400 days prior to being remotely unset and then pigged another 50 miles to shore, completing the longest remotely operated pipeline isolation to date.

2002: Prizes. The pipeline isolation tool (of PSI) is awarded the NHO export award, the *Erling Skalgson* Prize for the county of Rogaland, and the NHO Prize *Forsknings og nyskappingspris for 2002*, from the Norwegian government.

October 2003: Pig tracking using ELF communication and identification. The SmartTrack pig tracking and communication system is released and used for a subsea pipeline tie-in for an Australian oil company, allowing unique identification of each pig and allowing the internal pig trackers to be started and stopped while inside the pipeline.

### **Historical Application and Achievements**

Historical applications for the use of the intelligent piggable isolation plugs include:

- Pipeline valve replacements or repairs – Approximately 50 such operations have been performed around the world to date.
- Riser replacement or repairs – Several significant projects have allowed pipelines with multiple downstream platforms to remain in production.
- Pressure testing of risers or a repaired section of a pipeline. This application simply allows the operator the ability to test the replacement or repair immediately upon completion of the isolation.
- Midline pipeline repair – This unique method of performing a pipeline repair mid-line is a new application that has proven to significantly reduce cost and prevent downtime and loss. It is described in Historical Application 3 in Malaysia below.
- Dry tie-ins of risers or pipelines – This application has become the standard method of laying and tying-in new pipelines for pipelay. Its use saves several days of use of the pipelay vessel per tie-in, and allows dry tie-ins using less expensive vessels at later dates.

Recently, the following applications have been added:

- Platform abandonment – Saving the shut-down of other attached platforms and negating the need to find and shut subsea valves. This cost saving and quicker application is typified by Historical Application 1 in the USA below.
- Midline bypass of platforms on live pipelines. The single largest pipeline isolation project has just been completed for the bypass of platforms in the North Sea, sealing two pipelines mid-length, other platform tie-ins, and providing a pressure test barrier of the result.

Common achievements for the pipeline operators using intelligent piggable isolation systems for these applications have included one or several of the following:

- No displacement of pipeline content
- No flaring or loss of gas
- No emissions to atmosphere
- No production loss
- Significantly reduced pipeline or platform downtime
- No wetting of dried pipelines

Some of the above applications are exemplified below.



## Historical Application Example 1: Long Term Midline Isolation of a 30 inch oil line in Abu Dhabi

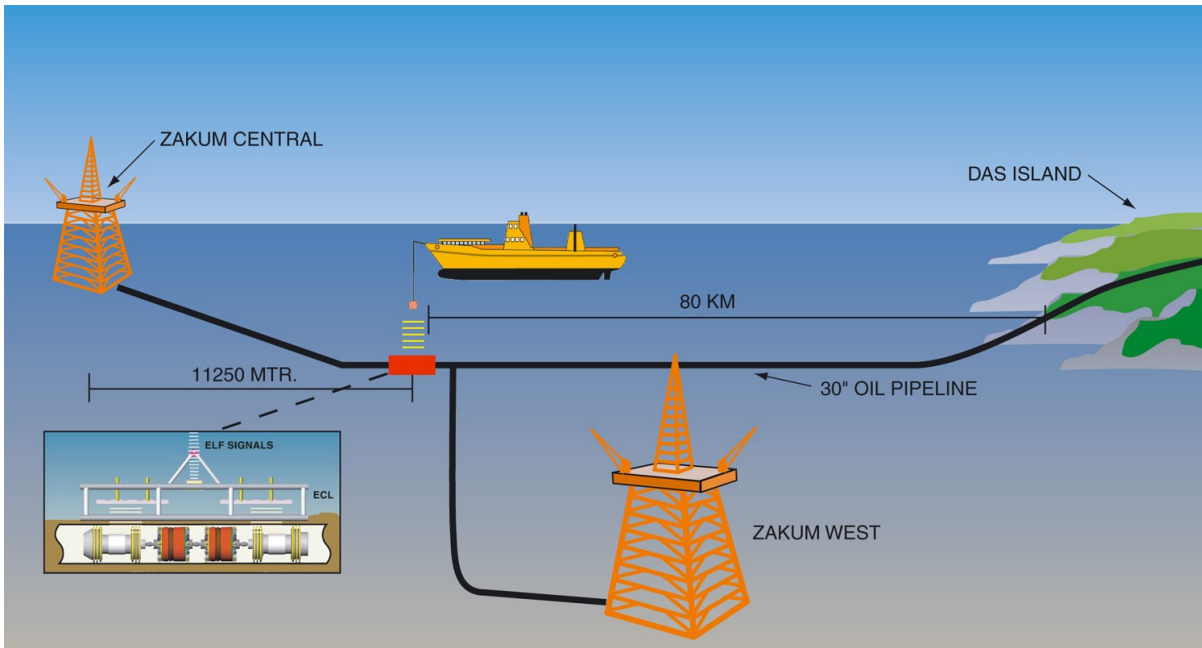


Figure 13. Overview of the 30 inch Zakum Central to Das Island oil export system

Adma Opco needed to reroute the oil export from Zakum Central and Zakum West. The 30 inch oil pipeline from 1967 had severe corrosion from Zakum Central up to the tee at Zakum West, and the remaining part of the pipeline needed replacement over time.

To minimize production loss, Adma Opco decided to reroute the production from Zakum Central and isolate the 11250 meter section of the pipeline between Zakum Central and Zakum West to allow the oil to flow from Zakum West while a new pipeline was laid from Zakum West to Zakum Central.

PSI was contracted to pig in an isolation plug and set it accurately at the subsea tee and isolate the branch from Zakum Central while a new pipeline was laid.

The isolation plug train had to meet the following challenges to the isolation plug system:

- Pigging through reduced bore 1.5 D elbows
- Pigging through 22.5 degree mitre bends
- Duration of the isolation was expected to be in excess of 12 months

PSI built a test rig simulating all known pipeline restrictions and developed a dual module 30 inch SmartPlug™ system that was capable of overcoming all the pigging challenges. The test rig incorporated defects simulating the internal pipe wall corrosion and defects to prove that the isolation plug would seal on any known or expected pipe wall defect.

The isolation plug was successfully installed early November 1999 and 400 days later it was remotely unset and pigged to Das Island.

## Historical Application Example 2: Repair of a 30 inch midline subsea valve

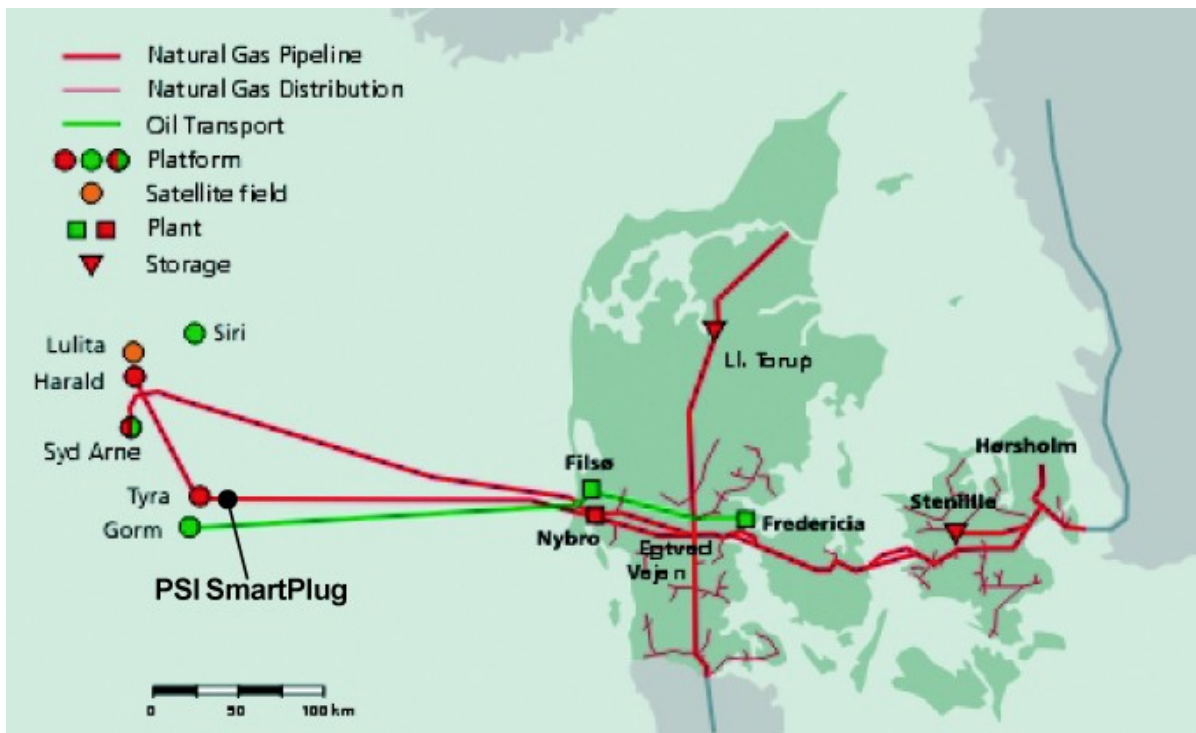


Figure 14. From Tyra the 240 kilometers long 30 inch pipeline exports dry gas to Nybro

DONG transports all the gas produced in the Danish sector of the North Sea to the shore from the Harald, Tyra and Syd Arne fields through their gas pipelines to the gas treatment facility in Nybro. From there, the gas goes on through their pipelines to Danish customers and for export. As shown in the map there is one gas pipeline which runs from the Syd Arne field and one from the Tyra field to Nybro.

During the shutdown in August 2002, a subsea valve located 1,6 km downstream of Tyra needed to be repaired. Dong wanted to position an isolation tool just downstream of the subsea valve and then reduce the pressure between Tyra and the isolation plug to seawater pressure.

Upon completed repair work the isolation plug was to be pigged with produced gas to the onshore terminal. Since the pipeline transports dry gas, and the isolation plug has to travel to the onshore terminal it was decided to run the SmartPlug from Tyra to the isolation point with the gas flow.

Pigging and positioning of a high pressure isolation plug with gas in gas was a new experience and challenged the procedures used for launching, positioning and receiving of the isolation plug train.

A pigging procedure was developed which included stopping trials ahead of reaching the isolation point to determine the travel length of the isolation plug from the time a “stop order” was given until the isolation plug had come to a complete halt.



*Figure 15. 30 inch SmartPlug ready to enter the vertical pig launcher*

The 30" SmartPlug was launched from Tyra and pigged past the Subsea valve using the gas production from the platform. The onboard tracking equipment was used to track the plug to the set location from a Dive Support Vessel.

The isolation plug was accurately set a few meters downstream of the subsea valve creating a double block isolation at 80 bar.

The isolation plug was monitored via an acoustic link from the dive support vessel during the repair of the valve.

Upon completion of the repair, the pipe section between the isolation plug and Tyra was re-pressurised to 80 bar and the isolation plug unset. Once the isolation plug was unset it was pigged 240 km with gas to the Nybro gas terminal and retrieved. Travel speed was 3 to 4 meters per second.

This project added new important milestones to the isolation plug technology:

- Long distance travel at high speed in dry gas pipelines
- Accurate positioning of an isolation plug in a gas pipeline with produced gas as pigging medium.

### **Historical Application Example 3: Mid-line Repair of a Live Gas Pipeline.**



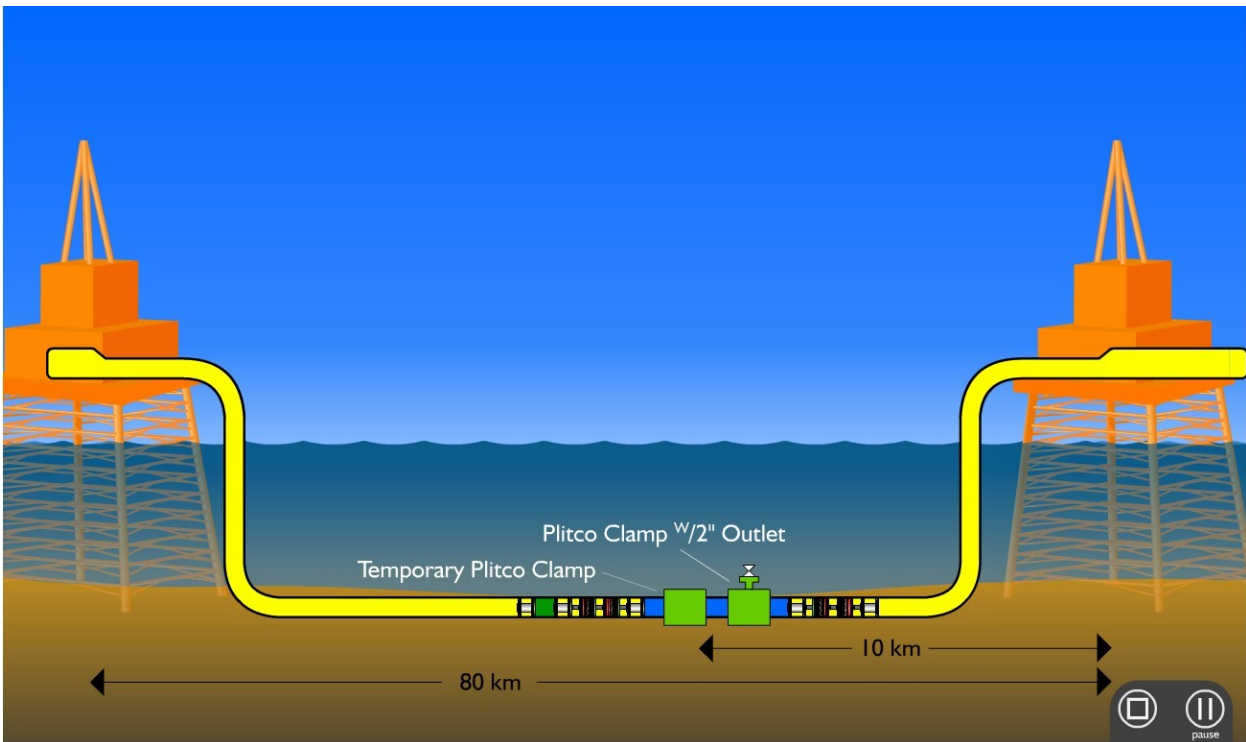


Figure 16. Mid-line replacement of a faulty joint by having one intelligent piggable plug on each side of the joint

An operator in SE Asia discovered a faulty joint of pipe during pressure testing of a newly laid 24-inch gas transport pipeline. The gas delivery contract called for severe penalties if gas was not delivered on time. To avoid penalties, the operator installed a temporary PLIDCO clamp on the damaged joint and received a 12-month operation permit for the pipeline.

During the 12-month permit period a detailed repair was planned, with focus on minimizing pipeline downtime. A second clamp, including a two-inch outlet, was installed on the same joint of pipe.

Two intelligent piggable isolation trains were pigged into position using produced gas, separated by water between them. The isolation train was positioned such that one intelligent piggable plug was positioned on each side of the faulty joint. Both isolation trains were set, the 2-inch outlet of the clamp was tapped and the pressure between the two isolation plugs was bled to atmospheric pressure.

The distance between the two isolation plugs was only 40 meters, and the joint to be isolated was 12 meters long and the pigging procedures developed secured timely and accurate positioning of both isolation plugs.

The faulty joint with the two clamps was cut out and lifted to the surface. Each end of the pipeline was then lifted to the surface and each was fitted with a welded flange. The pipeline ends were then laid back on the seabed. A flanged spool piece was installed and leak tested prior to the intelligent piggable isolation train being pigged back to the launch platform using the pressurized gas.



Use of the pressure isolation tools saved the operator 7 days of gas delivery compared with traditional repair methods, and also saved the operator severe penalties for not delivering gas.

**The procedure developed for this midline repair project can be used for future midline tie-in projects on live pipelines using the intelligent piggable isolation tools.**

### **Safety Summary**

The intelligent piggable isolation plug train is designed to be self locked in the set position, thus being fail-safe as long as there is delta pressure across the Plug Module.

The entire intelligent piggable isolation plug system has received a Type Approval Certificate from Det norske Veritas (DnV).

Each individual Plug Module is tested and receives a DnV Product Certificate.

The intelligent piggable isolation train has fail safe unsetting systems so that even if all communication fails the isolation plug train can be unset and recovered.



# DET NORSKE VERITAS

## TYPE APPROVAL CERTIFICATE

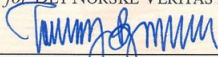
CERTIFICATE NO. P-11273  
This Certificate consists of 4 pages

*This is to certify that the*  
**Pipeline Isolation Plug**  
*with type designation(s)*  
**SmartPlug & SmartPlug Compact**

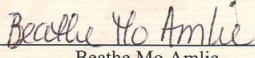
*Manufactured by*  
**Plugging Specialists International A/S**  
STAVANGER, Norway

*is found to comply with*

*Application*  
May be used as isolation plug for oil and/or gas pipelines.  
Conditions and limitations are given below and in reference documents.  
Design to follow approved design documentation and test procedures given in the reference documents.

*Place and date*  
Høvik, 2002-07-12  
for DET NORSKE VERITAS AS  
  
Tommy Bjørnsen  
Head of Department

*Local Office*  
DNV Stavanger

*This Certificate is valid until*  
2004-12-31  
  
Beate Mo Amlie  
Surveyor

Notice: This Certificate is subject to terms and conditions overleaf. Any significant change in design or construction may render this Certificate invalid.  
The validity date relates to the Type Approval Certificate and not to the approval of equipment/systems installed.

If any person suffers loss or damage which is proved to have been caused by any negligent act or omission of Det Norske Veritas, then Det Norske Veritas shall pay compensation to such person for his proved direct loss or damage. However, the compensation shall not exceed an amount equal to ten times the fee charged for the service in question, provided that the maximum compensation shall never exceed USD 2 million. In this provision "Det Norske Veritas" shall mean the Foundation Det Norske Veritas as well as all its subsidiaries, directors, officers, employees, agents and any other acting on behalf of Det Norske Veritas.

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Figure 17. Front page of PSI's current Type Approval Certificate

## Conclusion & Recommendations

### Conclusion:

**The intelligent isolation plug system is fully qualified to perform Midline Tie-in of flow lines and pipelines.**

The remotely controlled and operated high-pressure pipeline isolation tool uses field proven technology (approximately 70 projects to date), and has been used all over the world, for almost all of the major oil companies and most of the major pipeline operators. It is a fail-safe device (i.e., once differential pressure is applied across the tool it fails to the set

position, and any increase in differential pressure causes increased setting force), and is not reliant on the communication system to be unset. I.e., it is able to be unset and pigged out of the line even if all communication systems fail.

Typical installations result in the prevention of flaring, the release or disposal of content, watering or blowing down of the pipeline, and allow for no loss of pipeline operating pressure. They provide a true double block, and reduce emissions, hydrate removal and chemical usage.

These tools are ready for 7,000 feet of water and are currently available, so that the applications in shallower, diveable waters, can now be performed, with the same advantages, in deep-water applications.

### **Recommendations**

All new pipelines should be designed to be plugging friendly to secure effective future pipeline intervention in connection with valve repairs, tie-ins, hook up of flow lines, pressure testing, etc.

Sufficient length of straight pipe between the pig trap valves and the production tee allows for valve repair and maintenance without production interference.

Installation of valves can be avoided. When a barrier is needed, an isolation plug is deployed.