PROJECT FINAL REPORT

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Name of the scientific representative of the project's co-ordinator, Title and Organisation:
Mr. Sieger Terpstra
Principal Inspection Engineer
Shell Projects and Technology - Projects & Engineering Services
Shell Global Solutions International BV
Tel: +31 (0) 20 6303059
E-mail: sieger.terpstra@shell.com
Project website address: http://petrobotproject.eu/
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4.1 Final Publishable Summary Report

4.1.1 Executive Summary

The aim of the PETROBOT project was to develop a series of robotic solutions that can supplement and enhance human skills in the inspection of Pressure Vessels and Aboveground Storage Tanks widely used in the Oil & Gas and Petrochemical industries. This project aimed to open up these markets for inspection robotics by developing two key new robot inspection solutions and validating these in real world use cases, namely off-line internal inspection of pressure vessels and in-line inspection of aboveground storage tanks.

The main proposed benefits of using PETROBOT robotic inspection tools for the internal inspection of off-line pressure vessels (PVs) and in-line aboveground storage tanks (AST) include:

- Avoiding or minimising the need for human entry into assets and thereby increasing safety
- Minimising and shortening operational disruptions that result from asset inspections which in turn could reduce revenue lost due to asset downtime
- Avoiding or minimising environmental risks
- Eliminating or reducing costs associated with the opening and cleaning of assets
- Gathering adequate inspection data which can support important decision-making, like extending internal inspection periods

The key activities of the project are the design and development of 3 robotic solutions for offline Pressure Vessel inspections, and 1 for online Storage Tank inspection, the deployment and validation of these solutions within

PETROBOT has mobilised the complete value chain, consisting of robotic and inspection technology providers, inspection service companies and end-users in order to develop innovative inspection robots and validate these solutions in use cases. This has led to robots satisfying the design specifications, able to deliver effective inspections, as was demonstrated in numerous field tests. Several robots were already used for actual field deployments during the project, for PETROBOT members and non-members. After the project, the robots have to mature further in a commercial setting, not only to provide inspection services, but also the integration with cleaning activities prior to robotic inspection, as well as production of these robots to support a growing service. The PETROBOT Project has seen the initiation of these activities already happening during the final phase of the project.

The PETROBOT consortium members have been active to mobilize the wider industrial community, by playing an active role in the euRobotics community, by establishing an active Topic Group in the domain of Inspection & Maintenance robotics for the energy industry, and by establishing a permanent platform – The SPRINT Robotics Collaborative - to support the use and further development of these Inspection & Maintenance robots in a global market.
4.1.2 Summary Description of Project Context and Objectives

4.1.2.1 Project Aim
PETROBOT opened the Oil & Gas and Petrochemical markets by developing new robotic inspection technologies which were validated in real world use-cases:

Off-line internal inspection of Pressure Vessels (PVs): avoiding the high cost for human entry as well as reducing plant down-time

In-line inspection of Aboveground Storage Tanks (ASTs): avoiding lost revenue by keeping tanks in full operation

Four robotic inspection solutions were developed in the PETROBOT project: three for the inspection of PVs, including the Fast platform, Bike and Snake-arm, and the Tank robot, for the inspection of the floor of ASTs.

4.1.2.2 Objectives of PETROBOT
The scientific and technological objectives of PETROBOT were:

1. To develop and test the robot inspection solutions for the Oil & Gas and Petrochemical industries:
   (i) Off-line internal inspection of PVs
   (ii) In-line inspection of ASTs (while tanks remain in operation)
2. To demonstrate these robots in use-cases, validating that they can meet the requirements
3. To investigate integration aspects in order to optimise market uptake
4. To establish deployment potential and market uptake routes
5. To disseminate the results of the project to target groups

4.1.2.3 Key Challenges within PETROBOT
Selection of business cases: In the phase prior to the Project start, the Consortium Members had the challenge to identify realistic business cases for which robots would be developed. Given the objectives of the project – open up the market for inspection robots in Oil and Gas - the robots would have to provide functionality that is useful for an end-user, and also sufficient to generate viable commercial services with the robots during early market development. By selecting the two types of inspection applications the Consortium drew confidence from small-scale robotic activities in both vessel and tank inspection that indicated a healthy appetite in industry for such robots. Other inspection domains, for instance the large area of pipework inspection, were considered, but could not be worked into well-defined robotic solutions with a clear market potential.

Sharing critical information: At the start of the Project the Consortium had no history of working together on such type of robots. This required a three months Design Phase in which the detailed specifications for the robots had to be developed. During this phase the members had to exchange a large amount of information about each other’s specialisms: robotic and inspection tool providers defining the capabilities (and limitations) of the tools; end-users to define the conditions in which the robots would have to work as well as the requirements for the inspection tasks. It became quickly apparent that robotic developers tended to prefer a well-defined functionality, whereas end-users were keen to obtain a most versatile inspection robot.
Solving this requires an accurate prediction of the realistic robot capabilities as well as an accurate estimate of the range of applications where these robots could effectively replace the traditional human inspection; it made this design phase critical for the early commercial success of these robots at the end of the project.

**Explosion Proof design:** During the design the Consortium had an extensive re-look at the explosion proof aspects of the robots. Compared to many other field of robotics, the Petro-Chemical and Oil and Gas industry has very strict rules to mitigate the risks of instruments and tools applied in hydrocarbons-containing environments that could lead to explosions when ignited. As the Project based the design of the robots on existing technology, quite hard limitations were being faced with regards the feasibility of designing full explosion proof (“Ex”) requirements into the robots. Extra studies were conducted, together with consultants in the “Ex” discipline. It was decided however, not to extend the Project beyond the original scope, but achieve the highest possible Ex-level and design the robots to prepare them for minimal future re-design for Ex. The study generated immense learnings, however, and resulted in the Snake arm robot to reach ATEX 1 level.

**Engineering challenges:** In the development stage many engineering issues had to be addressed. This ranged from the need to fit the many different components together in the robots, taking care of payload limits, magnetic forces to stay attached to a vessel wall on curved surfaces and upside down, building with materials that can withstand aggressive substances (such corrosive hydrocarbon fluids in storage tanks; mercury of benzene contaminated vessels). As an example, the chemical resistance of a flexible umbilical cable is normally designed on the inside, but for the tank robot entering into aggressive fluids it resistance needed to be built on the outside surface of the umbilical.

**Get connected to site staff:** End-users, early on in the Project, faced the challenge to get the attention from their staff in the various types of Field Operations (such as upstream production platforms, either land-based or offshore, and mid- and downstream processing facilities such as Gas Plant, LNG (Liquefied Natural Gas) Plant, Refineries or Chemical Plant. When such Plant are taken out of production for regular Inspection and Maintenance, they enter into a short and highly complex Turn Around process; during such a Turn Around many different disciplines play their role, all highly trained and focused on delivering their tasks in a safe and also reliable manner. These work processes are built up over many years and are fine-tuned to be safe and effective.

To penetrate this world, with new ways of working – in which robotic tools would replace human tasks – creates new, almost game changing conditions, and raises many questions deep in the details of the work processes: can the robot deliver the task; will it always complete it; can it also handle surprises (e.g. unexpected damage), is the task reliably delivered (finished on time); are there risks, e.g. robot break down causing turn around delay; new types of explosion risks? The large variety of conditions during inspections (and the preparatory maintenance) results in a situation that there is no single work process that describes robotic inspection. Therefore, introducing robots in the work processes needs robots to be available, grabbing the attention of all staff involved by selling the benefits, then start using the robots, adapting the work processes, and then broadening their use step by step.

During the course of the Project, when the robots became more tangible, it became increasingly easier to raise the interest of engineers in Operations, e.g. to give input on operational procedures and support field tests.

**Create many field tests:** It was challenging for the end-users to obtain opportunities for testing the robots under real field conditions, for the above reasons that a Turn Around is a highly complex activity, under much time pressure to finish all work and start up and bring the plant back in production again. An actual field test during a Turn Around was realized for one of the vessel robots, but to test the many functions of the robot and inspection systems use was made of test sin vessels taken out of service. Similarly, testing a
new robot in tanks with hydrocarbons is a potentially hazardous activity, and was therefore rehearsed in tanks that created low risks. The Consortium organized tests in a mock-up tank, two tanks at end-user sites, and multiple test conditions (on floor plates removed from service) to supplement the field trials.

4.1.2.4 Project Timeline

The PETROBOT project had a duration of 3 years, starting on 1 September 2013 and finishing on 1 September 2016. During this time, the project had a number of different work packages which dealt with the phases of the project.

4.1.2.5 Consortium Members of PETROBOT

There are 10 consortium members in the PETROBOT project. The partners are listed below.

<table>
<thead>
<tr>
<th>Participant Name</th>
<th>Project Name</th>
<th>Participant Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Global Solutions International B.V. (Coordinator)</td>
<td>Shell</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Oliver Crispin Robotics Ltd</td>
<td>OC Robotics</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>A. Hak Industrial Services B.V.</td>
<td>A.HAK</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Dekra Industrial AB</td>
<td>DEKRA</td>
<td>Sweden</td>
</tr>
<tr>
<td>Gassco AS</td>
<td>Gassco</td>
<td>Norway</td>
</tr>
<tr>
<td>GE Inspection Robotics</td>
<td>GEIR</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Chevron North Sea Ltd.</td>
<td>Chevron</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Quasset B.V.</td>
<td>Quasset</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Innospection GmbH.</td>
<td>Innospection</td>
<td>Germany</td>
</tr>
<tr>
<td>Koninklijke VOPAK N.V.</td>
<td>Vopak</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>

Table 1: PETROBOT Consortium
4.1.2.6 Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AST</td>
<td>Aboveground (or Atmospheric) Storage Tank</td>
</tr>
<tr>
<td>ECT</td>
<td>Eddy Current Testing</td>
</tr>
<tr>
<td>MEC</td>
<td>Magnetic Eddy Current</td>
</tr>
<tr>
<td>PV</td>
<td>Pressure Vessel</td>
</tr>
<tr>
<td>SLOFEC</td>
<td>Saturated Low Frequency Eddy Current</td>
</tr>
<tr>
<td>UT</td>
<td>Ultrasonic Testing</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
</tbody>
</table>

Table 2: PETROBOT Acronyms

4.1.2.7 Robotic Technology

In the PETROBOT project there were two main types of robots: the crawler type and the snake-arm.

For the PV inspection robots, there are two crawler designs, the higher payload flat platform (FAST) and the more manoeuvrable BIKE. The PV crawlers use magnetic wheels to stay in position. The use of magnetic wheels limits their use to PVs of ferromagnetic materials and, where an internal coating is applied to the ferromagnetic surface, this coating has to be thin. The Snake-arm is not dependent on the material of the PV, however it is restricted by the internal reach. The restriction of the crawlers’ magnetic wheels is the main reason for focusing on carbon steel. The use of the Snake-arm makes it possible to include PVs of stainless steel, with thick coatings or cladding, with a limited reach. The Snake-arm has the flexibility to get into much smaller access holes. This enables the inspection of areas within PVs which are not accessible by any crawler, subject to the reach limit of the arm. The reach of the Snake-arm could be compensated for by having access to several holes for a specific PV, thus enabling better combined reach. Larger PVs will still be accessible through larger access holes by the crawler type platforms that have longer reach.

The In-line Tank Inspection Robot (ITIR) is a tracked crawler type which travels on the bottom of the tank floor. The well-known tracks design creates a stable platform for robotic operations in tank. With this design the sensors mounted on the robot have a well-defined position and are protected during operations. The design allows for smooth operations in unknown environments and over unknown obstacles. With the independent control of the tracks the robot is able to correct direction and perform rotations in the tank.
The tracks were designed to reliably move the platform along the tank floor and to deploy the Magnetic Eddy Current (MEC) sensor on the floor of the tank. The sensor system is an 8-channel MEC measurement unit. The MEC sensors are located on the bottom of the tank floor robot sitting between tracks and can scan a 400 mm section of the tank floor at one time. The robot navigates via a sonar system, which also allows for obstacle avoidance. The navigation software is based on the concept of a SLAM-process. (SLAM = Simultaneous localization and mapping). In such a process a mobile robot uses its ability to perceive certain features of an environment in order to build a map of the environment while correcting its own position estimation based on re-observations of such features.

4.1.2.8 Inspection Technology

The inspection technology deployed by PETROBOT was limited to the following types of inspection:
Visual inspection, enabled through camera and lighting - providing visual feedback and support for navigation.
For PV inspection, Non-Destructive-Examination (NDE) testing is enabled by ultrasonic and eddy current tools, while a laser profiling tool is included to aid in corrosion assessment.
For the inspection of ASTs, NDE testing is enabled by means of a Magnetic Eddy Current measurement unit (SLOFEC) module, which allows for the detection of loss of plate thickness.

4.1.2.9 Technology Readiness Level

All of the PETROBOT robots have been tested up to Technology Readiness Level (TRL) 6 and 7 (based on the EU scale: TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies; TRL 7 – system prototype demonstration in operational environment).
4.1.3 Main Scientific & Technical Results/Foregrounds

4.1.3.1 Work Package 1: Development of Pressure Vessel Inspection

4.1.3.1.1 Aim WP1 – Pressure Vessel – WP Leader: DEKRA

The main goals of the Work Package 1 were the following:

- To develop the specifications for the pressure vessel internal inspection robot.
- To develop and test the components for the pressure vessel internal inspection robot according to the specification.
- To develop and test the pressure vessel internal inspection robot in mock-up field according to the specification.

The main design requirements resulting from the specifications are outlined below.

Requirements for the inspection

In vessel inspection the major inspection tool is visual inspection. The outcome of the visual inspection will, if needed, guide the operator to use other secondary inspections.

The main focus is on corrosion detection which is usually detected visually but the overall corrosion in the form of wall loss is mainly inspected by ultrasonic tools. For Inspection Robots it is essential to be able to perform the same inspections as done currently with traditional tools and provide additional capability to evaluate damage with NDT tools. Tools added were: ultrasonic for thickness measurement; Eddy Current Testing to aid with corrosion mapping (when coating or corrosion product makes visual inspection ineffective); laser profiling of the surface (to replace manual pit gauging); Eddy Current Testing for crack detection (as a replacement for traditional magnetic particle testing (MT) or penetrant testing (PT)).

The minimum requirements for the robot platforms were the following:

- Robust, easy to operate and allow safe working conditions during operation.
- Able to be easily controlled by an operator on the surface using a joystick and data link or similar with full control over vehicle movement and operation. The operator control shall have a display screen that allows viewing of all cameras, switching between cameras and also provides the location of vehicle in the vessel.
- Operate independently, not requiring support from any other vehicle in the vessel.
- Have a supply of suitable light, if necessary (as the vessel will not have any light sources).
- Easily recoverable in the event of a breakdown.
- Easily rechargeable or work via mains power (EU Standard).
- Not damage any internal coating or base metal surface, when in contact with them under normal operation.
- Have all vehicle control data (control commands and visual data) transmitted in real time, with the maximum latency below that which enables easy control and accurate positioning of the vehicle in the given context, under all circumstances.
- Have a system to ensure that in case of communication speed and bandwidth deterioration, control data will have priority over real time inspection data.
- Have inspection data that is collected and stored externally and can be retrieved after completion of the inspection.
- The position of inspection data should be related to the approximate position within the pressure vessel.
- Stop and power down to safe mode in case communication is lost.
- Have a data storage that is robust against safety shutdown.
- Be CE-marked with all necessary documentation.
- Have been designed with the goal that in case of breakdown all the devices can be retrieved in some manner (i.e. tether or tow bar), such that they should always be retrieved without human entry.

For wide adoption of robotic inspection in the hydrocarbon processing industry, ATEX hazardous area certification is an important factor to maximize the range of applications. However, there are significant issues moving a product to this stage, related to complexity and costs of design, and added inflexibility in operating and maintaining such robots. The PETROBOT Project decided to give priority to the development and testing of the functionality of such inspection robots, and then decide how each robot would be developed with appropriate ATEX certification. The SNAKE platform, however, would be designed for ATEX readiness.

Interim test solutions will be deployed to gain access to a sufficient number of field applications:

- Install environmental sensors (internal or external) to monitor gas (CH4), hydrogen sulphide (mould growth), air temperature etc.
- Install sensors on the robot that automatically stop and power down to safe mode if gas levels detected reach 10% of Lower Explosive Limit (LEL).

### Main Scientific & Technical Results

As mentioned above, this work package was divided in three main parts:

- Developing specifications for the robotic inspections systems
- Development and testing of components
- Mock up tests of the robotic inspection systems

#### Development of specifications

As a starting point for this work much time was invested in studies of available international regulations to find a common ground to build a specification on. This was shown to be very difficult, so another approach was chosen: To test various combinations of specifications and see how many pressure vessels were estimated to be candidates for robotic inspections with robotic inspection systems fulfilling those specifications. This latter approach was depending on the input from the end users, rather than from national/international regulations.

Based on discussions and research a set of requirements were developed both for the robots and for the inspection tools. To make it measurable, the results were presented as tables with “good-better-best” cases. This to accommodate for different challenges in the development phase. As an example, a small part of the specification for the FAST robot is shown in the table below.
**Development and testing of components**

Three different robots and four different inspection methods have been developed / adapted in PETROBOT.

**FAST – developed by GE Inspection Robotics:**

The FAST robotic platform was originally developed as a multipurpose robotic tool onto which various applications can be integrated. Leading edge mobile robotic technology was translated into a robust and field service proven robotic solution, providing unmatched repeatability and keeping operators safe with a remote operating system.

With a system height below 15cm (6”) the system can access areas that were impossible to access by operators. The weight of the full system is below 14kg (<31 pounds), meaning it can be easily deployed and hand-carried by one operator.

Due to its modular design the FAST platform can be adapted to new applications quickly and easily. All four developed inspection tools: visual, profilometry, UT and ET can be mounted on the FAST platform by a standardized mechanical and electrical interface. Figure 5 shows the FAST with important features highlighted.

**Table 3**

<table>
<thead>
<tr>
<th>Item</th>
<th>Good case</th>
<th>Better case</th>
<th>Best case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Physical Constraints</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Operation Range (distance from access opening)</td>
<td>8 m</td>
<td>10 m</td>
<td>&gt;10 m</td>
</tr>
<tr>
<td>1.2 Speed</td>
<td>30 mm/sec</td>
<td>60 mm/sec</td>
<td>100 mm/sec</td>
</tr>
<tr>
<td>1.3 Payload (including tools and their services, cables)</td>
<td>4 kg</td>
<td>7 kg</td>
<td>10 kg</td>
</tr>
</tbody>
</table>

*Figure 5 Overview of FAST robotic system*
BIKE – developed by GE Inspection Robotics:

The BIKE platform is a very compact magnetic wheeled robot capable of inspecting power plant facilities and multiple applications in the oil & gas industry, such as vessel or pipe inspection. The innovative locomotion concept is capable of climbing complex structures and passing obstacles.

The robot can climb vertical walls, follow circumferential paths inside pipe structures and can also pass over complex combinations of convex and concave step obstacles. It requires only limited space to maneuver as it can turn on spot around the rear wheels.

With a total weight of less than 10 kg the BIKE robot can be deployed through a 12” manway or nozzle. It comes with a cable length of 30 meters which allows a single operator to perform his inspection without entering the confined space. Figure 6 shows the BIKE with important features highlighted.

![BIKE robot diagram](image)

Figure 6 Overview of BIKE robotic system

SNAKE – developed by OC Robotics:

The SNAKE arm is an arm robot that consists of several links. The SNAKE arm developed within PETROBOT is a planar arm, which means that the joints between each link have one degree of freedom. The SNAKE arm is shown extended in Figure 7, left image. The total length of the arm is 4m. At the end of the outermost link, a wrist has been added. The wrist also consists of four links. The wrist facilitates both a certain three dimensional movement of the arm, and allows for a precise positioning of the inspection tools. Figure 1-3, right image, shows the SNAKE arm in its curled, transport shape.
Inspection camera – developed by DEKRA Industrial:

Within PETROBOT, two camera housings have been developed, one for FAST and one for BIKE. Both use the same camera block, Sony FCB-EV7500. The two cameras are shown in Figure 8, FAST to the left and SNAKE to the right. Both cameras incorporate lighting.

The common aim was to reduce weight. The main difference is found in the position of the lights. The camera house for the SNAKE has the lights mounted on arms, to create a shading effect which could enhance evaluation.

Profilometry – developed by DEKRA Industrial:

As a tool for profilometry, the Gocator from LMI was chosen. Two variants were used, the 3110 used for the FAST and BIKE and the 3109 used on the SNAKE.

The Gocator uses structured white light to create a 3D image of the inspected surface, as shown in figure 1-5.
Ultrasonics – developed by DEKRA Industrial:

For measurement of wall loss, ultrasonics was chosen. An Olympus Omniscan with a 16 element array was used. Probe fixtures were developed for FAST and SNAKE. Adopting UT for the SNAKE was a challenge, as the SNAKE was not designed to maintain a constant distance to the surface, while moving the tip. Therefore a probe fixture was developed with a spring loaded, long travel in the direction perpendicular to the surface. This is shown in Figure 10.

Eddy currents – developed by Innospection:

Eddy current tools were developed for all three robots, different for all of them.
For corrosion mapping with the FAST, an eddy current array was designed, see Figure 11. It has eight probes mounted side by side. The eddy current electronics, as well as the dedicated software are also made by Innospection.

![Eddy current array mounted on the FAST](image)

**Figure 11 Eddy current array mounted on the FAST**

For the BIKE, a swivelling pair of absolute eddy current sensors, see Figure 12, attached to the robot platform are used to find surface breaking cracks on a straight or curved line, e.g. a weld. While the robot moves, the eddy current sensors are swivelling transversally to detect longitudinal cracks. By switching off the swivel mechanism, transverse cracks can be found.

![Eddy current sensor for the BIKE](image)

**Figure 12 Eddy current sensor for the BIKE**

For the SNAKE, an eddy current single sensor system, see Figure 13, can be mounted on the SNAKE arm to detect surface breaking cracks in selected spots of a pressure vessel. The sensor is moved by a gearwheel mechanism. Controlled by software (by OC Robotics) the sensor can theoretically be moved in any arbitrary direction. For this application the sensor scans the area in a straight direction line by line.

![Eddy current sensor for SNAKE](image)

**Figure 13 Eddy current sensor for SNAKE**
Mock up tests of robotic inspection systems

Mock up tests were of two kinds:

- Integration tests performed in laboratory environment.
- Tests in different pressure vessels at Europoort.

The laboratory integration tests were performed at GE Inspection Robotics, at OC Robotics and at DEKRA. Shell had provided a vessel cut in two halves, shown in Figure 14, which was placed at OC Robotics and at DEKRA. The main purpose of the integration tests was to test the combination of robot with inspection tools in a controlled environment.

At Europoort, Shell had prepared a test site with four different pressure vessels that had been taken out of service. Figure 15 gives an overview of the test site.

At the test site, there were two different horizontal vessels and two vertical vessels. As can be seen in Figure 15, entry points were different for the vessels; this created different deployment conditions for the robots.

The layout of the Europoort tests was that each robotic system was given one weeks’ time for testing. As the vessels did not contain any defects, these tests were focussed on deployability and manoeuvrability. Different ways to deploy and retrieve the robots were tested.

During these test weeks, the developed inspection tools were tested on tests plates. In the vessels, general feasibility could be shown. General inspection procedures were also developed.
A large number of the tests were performed with a successful outcome, but as this was the first possibility for this kind of tests during PETROBOT, also learning points where identified that needed further development.

4.1.3.1.3  Recommendations

Work Pack 1 delivered three different, but complementing robots. Each of them can be supplied with up to four different inspection tools. Altogether, this forms a set of three capable robotic inspection systems that are suitable for a wide range of vessels in different materials.

The work to create specifications for the robotic inspection systems showed to be a tedious work. This is probably due to the fact that in the environment where these robots need to operate, a large number of different wishes and legislations have to be dealt with.

Through the tests, the robotic systems demonstrated that they can be operated in a realistic environment in the Oil & Gas and Petro-Chemical industry, and that the robots are successful in the execution of inspection tasks.

4.1.3.2  Work Package 2: Development of Inline Tank Inspection

4.1.3.2.1  Aim WP2 – Storage Tanks – WP Leader: GE Robotics

The main goals of the Work Package 2 were the following:

- Collect and find an agreement on specifications for the in-line internal tank inspection robot.
- Develop and test the components for the in-line internal tank inspection robot
- Test the in-line internal tank inspection system in (mock-up) field trials

The main design requirements resulting from the specifications are outlined below.

Requirements for the inspection

The aim of the Tank Inspection Robot is to inspect the floor of the tank; this component is not accessible from the outside and often drives the due-date to take a tank out of operation. The aim of a robotic inspection is to provide an inspection that is comparable to what is achieved with an offline inspection. The main target for an offline inspection is normally to detect corrosion wall loss at the top and bottom surface of the floor plates and annular plates (those plates at the edge of the floor, connecting to the vertical wall of the tank). Differential settlement of the floor (measured by its inclination), notably at the annular plates, is an important structural health check. When tanks are out of service, particularly after floor repairs, it is customary to carry out vacuum box testing of welds between floor plates, to test for through-wall cracks.

The specifications for the PETROBOT Tank Inspection Robot were based on the available technology used also for off-line inspection. It was decided that the system should carry a MEC tool, which is also used by human inspectors, in combination with ultrasonic thickness measurements and visual inspection cameras. Additional sensors should be integrated to detect floor settlement.

The MEC is a variant of the more widely used MFL floor scanner tools. MEC has the advantage over MFL that it has a larger working range with respect to the thickness of the floor plates and the thickness of the top-surface coating it can negotiate. MEC works best in combination with an ultrasonic sensor, to detect wall thickness (to verify correct calibration) as well as uniform wall loss (MEC is strong at detecting local corrosion damage, but will not detect smooth, uniform wall loss).

System Specifications

---

1 MEC (Magnetic Eddy Current) is from the same lineage as the SLOFEC tool (Saturated Low Frequency Eddy Current). MEC and SLOFEC are provided by different equipment manufacturers.
The target capabilities for the inspection tool were defined as follows:

- Determination of pitting corrosion top side bottom plate, with a pitting size threshold of a flat bottom hole with Ø10 mm and minimum detectable wall loss of 20%.
- Determination of pitting corrosion bottom side bottom plate, with a pitting size threshold of a flat bottom hole with Ø10 mm and minimum detectable wall loss of 20%.
- Simultaneous determination of pitting corrosion top and bottom side bottom plate, with a pitting size threshold of a flat bottom hole with Ø10 mm and minimal 20% wall loss.
- Reporting by colour coding of detected features and % metal loss.
- Reporting by size of found pitting, corrosion in mm. (quantification).

The sizing requirements were specified as follows:

<table>
<thead>
<tr>
<th>Defect Sizing</th>
<th>Sizing steps</th>
<th>Extra Analysis</th>
<th>Sizing accuracy</th>
<th>Extra Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>+/- 10% of nominal WT</td>
<td>+/- 5% of nominal WT</td>
<td>+/- 10% of given Wall Loss</td>
<td>+/- 5% of given Wall Loss</td>
</tr>
<tr>
<td>Width (width of Scanner) (8 Sensors x 22.5mm)</td>
<td>+/- 10mm</td>
<td>+/- 5mm to 10mm</td>
<td>+/- 10%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Sizing requirements for the Tank Floor Inspection Robot

The inspection system was to be based on multiple interchangeable modules, each with their own specific function. The overall notion for the PETROBOT Tank Inspection Robot was that the system needs to be robust, easy to operate, and ensure safe working conditions during operation.

The following operational and functional requirements were specified for the robotic vehicle:

- Ability to move around the entire (accessible) area of the tank-floor.
- Not to cause damage to any internal coating or base metal surface.
- Good controllability by an operator using a joystick and data link or similar with full control over vehicle movement and operation.
- Ability to manoeuvre in a semi-autonomous manner whereby a pre-set path can be followed.
- Possibility to overrule the pre-set path so that the robot is controlled by the operator.
- Operator control featuring a display screen that provides the location of the vehicle, visual feedback by the visual inspection module, and the MEC data.
- Real-time transmission of all vehicle control data (control commands and visual data) with a minimum communication latency allowing for easy and accurate robot control and vehicle positioning in the given context.
- Safe data link ensuring that in case of communication speed and bandwidth deterioration, control data shall have priority over inspection data.
- External inspection data storage.
- Inspection data storage robust against unpredictable (safety-) shutdowns.
- A localization system that allows the robot to identify the floor plate it is on.
- Creating partial or full tank floor maps incl. plate orientation and X-Y coordinates.
- The position of inspection data should be related to the position within the tank and to the plate boundaries of the floor-plate under inspection.
- Retrievability of all the devices (without human entry) in case of breakdown or failure (i.e. tether or tow bar).
The desire by the end-users for a system with ATEX hazardous area certification was noted as an important factor to maximize the range of applications. However, there are significant costs in moving a product to this stage. The PETROBOT Project chose to develop and test devices with functionality first. The specifications for PETROBOT were defined such that the project will deliver a design that optimizes inclusion of ATEX requirements, such that later modification towards a fully ATEX certifiable system will require reduced effort.

In order to allow the system to gain field experience (in tanks containing low-flammability fluids) while not being ATEX certified, several safety elements were included in the specifications:

It is highly desirable for end-users that the robot has ATEX hazardous area certification, as this is an important factor to maximize the range of applications. However, there are significant costs in moving a product to this stage. The PETROBOT Project chose to develop and test devices with functionality first. PETROBOT will deliver a design that optimizes inclusion of ATEX requirements, such that later modification in a fully ATEX certifiable robot will require reduced effort.

Several elements are included to allow gaining field experience, including tanks containing low-flammability fluids:

- A system power-up barrier (based on intrinsically safe pressure sensors) which ensures de-energized equipment while transitioning the vapour zone during deployment, allowing for power-up only if the equipment is submerged in liquid.
- Environmental sensors to monitor gas (CH4), hydrogen sulphide (mould growth), air temperature etc.
- Temperature sensor(s) to ensure automatic shutdown when exceeding maximum temperature threshold.
- Double seals to ensure safety against leakage.
- Include inclinometer sensors to ensure energizing only when levelled.

The system was specified to be able to operate under the conditions listed in Error! Reference source not found. and work in environments as specified in Error! Reference source not found..

### Table 5 Operation conditions for the in-line tank inspection system

<table>
<thead>
<tr>
<th>Refined Products</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity [cP]</td>
<td>0.45 – 76.2</td>
</tr>
<tr>
<td>Water</td>
<td>A possibility of presence of free water</td>
</tr>
<tr>
<td>Visibility</td>
<td>visual of 0.5 meters</td>
</tr>
<tr>
<td>Solids</td>
<td>0-50 mm</td>
</tr>
<tr>
<td>Temperature</td>
<td>0-35 °C</td>
</tr>
<tr>
<td>Pressure</td>
<td>max 2.5 bar</td>
</tr>
</tbody>
</table>

### Table 6 Tank specifications for the in-line tank inspection system

<table>
<thead>
<tr>
<th>Tank specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
</tr>
<tr>
<td>Bottom</td>
</tr>
<tr>
<td>Roof</td>
</tr>
<tr>
<td>Liner</td>
</tr>
<tr>
<td>Man way</td>
</tr>
</tbody>
</table>

**Obstacle specification**

<table>
<thead>
<tr>
<th>Inspection</th>
<th>2” from lap joints = potential non covered area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>max height = 30 mm.</td>
</tr>
<tr>
<td>No-go area</td>
<td>= sump</td>
</tr>
</tbody>
</table>

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4.1.3.2.2 Main Scientific & Technical Results

The ambitious specifications for the robotic system performance were challenging to both, the robotic suppliers and the end-users who had to make sure that test environments were in place in the final project year.

The technical results were very convincing. The robot was deployed several times for many hours into liquid filled tanks of different sizes and types without the need for emergency retrieval ever. The inspection data acquisition was shown to be accurately localized and produced a consistent image of the floor plate condition.

Procedures and Safety

The efforts which went into the work procedures in order to obtain the respective work permits from the persons responsible for safety on-site eventually paid off. The operational feasibility of robotic tank inspection was demonstrated successfully in the trials in the 10 meter diameter water filled mock-up tank, see Figure 16.

![Mock-up tank used for extensive testing of robot functionality](image)

Figure 16 Mock-up tank used for extensive testing of robot functionality

The Operational and Inspection procedures were tested under realistic field conditions, see WP4 section below.

Localization and Mapping

The developed tank inspection system was the first in existence to demonstrate:

- accurate floor mapping based on plate boundary detections
- accurate remote high-resolution plate-by-plate inspection
- accurate wall-following capability for annular plate inspection

In Figure 17 below it is shown how the MEC system picks up signals from the floor welds when traversing them. These signals are validated and then combined with the robot localization data to produce a floor map. The floor mapping capability was tested on a large scale during field tests (on Work Pack 4), see section 4.1.3.4.
In Figure 18 below the trajectory is shown that the robot travels autonomously once the boundaries of a single plate are localized.

The demonstrated localization capabilities allow for data reporting on an accuracy and resolution level similar to off-line inspection by human entry.

**Inspection Performance**

The MEC inspection system as it was delivered by the robot was verified by blind trials in the lab using floor-plate samples with natural defects. Figure 19 shows the robot on test plate B8. This plate, removed from service in a tank, has a coating at the top surface and extensive natural corrosion on the underside (showing a large patch plate, typically used to extend the service life of the floor).
The MEC data showed very good correlation with the actual defect patterns from the test-plates and from the cut out pieces of tank-floor. This is illustrated in Figure 20, showing the MEC results in a 1m x 1m section of Plate B8 and a picture in same orientation of the extent of corrosion damage on the underside (the encircles areas in yellow and red contain corrosion damage viz. corrosion scale.

Further verification of the inspection performance took place during the field test, Work Pack 4, see Section 4.1.3.4.

4.1.3.2.3 Recommendations

From the very promising results produced in the field testing it can be concluded that the main recommendation should be to finalize and industrialize the developed technology in order to bring the high-resolution in-line tank inspection service to the market as soon as possible.
The one main technical end-user recommendation for the project continuation is to steer further development in the industrialization phase towards an ATEX certifiable solution allowing for significantly quicker and wider market acceptance of the new technology.

4.1.3.3 Work Package 3: Demonstration of Pressure Vessel Inspection

4.1.3.3.1 Aim WP3 – Demonstration of PV – WP Leader: Shell

Work Pack 3 (WP3) focuses on real field deployment of the pressure vessel robots (FAST platform, Bike platform and Snake arm) to assess their suitability for inspection and to compare the performance of robotic inspection with conventional inspection (i.e. inspection by human entry inside the vessel). As outlined in the scope of work document, main objectives of the WP3 were:

- To demonstrate the pressure vessel internal inspection robot in a real field use case.
- To evaluate the demonstration results of the pressure vessel internal inspection robot in a real field use case against the specifications and requirements developed in WP1.

4.1.3.3.2 Main Scientific & Technical Results

The WP3 activities resulted into two reports, one focussing on risk analysis and procedure for robotic inspection and the other focussing on results from the field trials. Thus, the main scientific and technical results can also be divided into two aspects as below:

Risk analysis and inspection procedure

To be able to conduct successful trials/deployments, it is necessary to understand all the risks associated with robotic inspection and set out guidelines for robotic inspection procedure. As the Petrobot pressure vessel robots are not ATEX certified, it is important to address how the robot is protected whilst operating in a potentially explosive environment. Using gas sniffers and automatic kill switch, it is possible to mitigate the risks associated of using the FAST and BIKE platform in a possible explosive environment. For the Snake Arm, nitrogen purging combined with a gas sensor will allow safe operations. The risk analysis also looked into on several other aspects such as retrieval of robots in case of failure, task risk assessment process etc.

A thorough inspection procedure holds a key for successful robotic inspection. A template for inspection procedure was developed in close collaboration with WP5. The inspection procedure for robotic inspection could be developed based on following main aspects: personnel roles and responsibilities, operational conditions and safety requirements, equipment and inspection requirements, calibration requirements, inspection planning reporting method.

Field testing results

A number of field testing activities of pressure vessel robots were conducted over the course of WP3. Given the 3 different robots and their capabilities to carry multiple NDT tools, an elaborate testing program was planned and executed. The testing program was a combination of tests on real field pressure vessels and redundant vessels on test facilities where vessels with artificial defects were prepared. This testing approach was necessary to cater to needs of three different robots and variety of NDT tools that can be mounted on them.

Number of aspects of the integrated solution (robot + NDT tool), such as navigation, ability to identify and measure defects (detection and sizing), repeatability (ability to find same defect after NDT tool change) etc., were tested through a series of tests. All the end users in the WP3 (Chevron, Gassco and Shell) provided test location, pressure vessels and necessary support to fulfil the objective of the work pack.

All the pressure vessel robots showed satisfactorily performance regarding entering, navigating and reaching to various regions of interest in a given pressure vessel. FAST platform and Snake arm robots are equipped
with visual camera and lighting which enables identifying the visually identifiable defects. FAST platform and Snake arm is also equipped with UT, Eddy current and structured white light tools which were tested for their detection and sizing capabilities and performance met requirements and specifications set out in WP1. Bike platform is equipped with visual camera and eddy current crack detection tools which also met requirements and specifications set out in WP1. Few representative images during the testing program are shown below:

![Image 1](image1)
![Image 2](image2)
![Image 3](image3)
![Image 4](image4)

*Figure 21: Few representative images from the field testing*

The testing program also explored few avenues such as two robots mounted with different NDT tools simultaneously used for inspection in the same vessel, structure white light profilometer integration on the Bike platform for inspecting a pressure vessel with difficult geometry (conical entry pig trap) etc. These testing opportunities helped to understand the needs of real field inspection requirements.

It is also worth mentioning that number of lab tests that were performed for the NDT tools for verifying if the requirements set out in WP1 were satisfied or not. The approach for most of the lab tests was to fabricate a test plate or organise a suitable sample that contained artificial or natural defects. The defects were either made or selected such that specifications of the NDT tools set out in WP1 could be tested. The results of these lab tests confirmed that specifications and requirements set out in WP1 were met.

Through the experience gained during the testing phase, most of the robots and NDT tool combinations can be considered ready for real field deployments and the work pack has been successful in meeting its objectives.
4.1.3.3.3 Recommendations

Actual deployments already took place in the course of this project phase: Already end 2015 the FAST Platform was used in two vessels (non-PETROBOT client), equipped with a camera. In the same way it was applied to a vessel on an offshore installation during 2016, for a non-PETROBOT client. The FAST RVI platform (equipped with only a camera for Remote Visual Inspection) was subjected to an API 510 qualification by Chevron in 2016. The BIKE platform was used by GASSCO for an inspection of a pig trap, and FAST and Bike were again used for inspecting a vessel during a plant shut down.

Based on the testing results in WP3, Table 7 below summarizes the status of each of the robot and NDT tool combination. It is recommended to use the robotic inspection for real field inspection activities within the capabilities of the tools and learn through each deployment to improve the performance of the tools.

<table>
<thead>
<tr>
<th>Robot functionality</th>
<th>Visual testing</th>
<th>Ultrasonic testing (UT) tool</th>
<th>Eddy current (EC) tool</th>
<th>Surface profilometry tool</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FAST Robot</strong>: Capable of navigating in the vessels above 1.8m diameter. Able to crawl on coatings of thickness less than 2mm. Able to locate defects within 200mm.</td>
<td>The camera and lighting quality is proven to be fit-for-purpose and is considered matured for real field use.</td>
<td>UT tool successfully integrated with the robot and capable of obtaining spot and line measurements.</td>
<td>EC tool is successfully integrated with the robot and capable of obtaining corrosion mapping data.</td>
<td>Gocator is successfully integrated with the robot and capable of measuring pit depths and surface irregularities.</td>
</tr>
<tr>
<td><strong>Bike robot</strong>: More nimble platform compared to FAST and Snake arm. Able to crawl on coatings of thickness less than 2mm. Able to pass relatively small openings.</td>
<td>Average quality camera (compared to FAST and Snake platforms) - due to payload limitations. Available camera and lighting combination works adequately within the limitations of camera.</td>
<td>N/A</td>
<td>The eddy current crack detection tool meets the WP1 requirements. Some issues regarding interference with magnetic wheels of the robot. Possible to supress the unwanted noise (e.g. Filter settings, shielding and sensor offset). Not originally in Petrobot project scope but developed during the project due to request from end users. Successful integration as demonstrated in real field deployment at Gassco.</td>
<td></td>
</tr>
<tr>
<td><strong>Snake arm</strong>: Able to navigate through internals and reach of the arm is around 4m. Able to enter through opening greater than 6”. Able to locate defects.</td>
<td>Good quality inspection data was obtained during field tests at Chevron, Gassco and Shell. The camera and lighting quality is adequate for real</td>
<td>UT tool successfully integrated with the robot and capable of obtaining spot UT measurements as well as scanning long sections</td>
<td>The eddy current tool meets the WP1 requirements, however, have some issues regarding stability of the scan frame whilst scanning. Although there are various ways to Gocator is successfully integrated with the robot and capable of measuring pit depths and surface irregularities. The tool is considered to be</td>
<td></td>
</tr>
</tbody>
</table>
Table 7 Summary of the status of each of the robot and NDT tool combinations for vessel inspection.

<table>
<thead>
<tr>
<th>Status</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>within 200mm.</td>
<td>field use.</td>
</tr>
<tr>
<td>(~2m).</td>
<td>stabilise the scan frame (e.g. using spacer pins, appropriate gain settings), further work is necessary before using the tool for a real field deployment.</td>
</tr>
<tr>
<td></td>
<td>ready for field deployment.</td>
</tr>
</tbody>
</table>

4.1.3.4 Work Package 4: Demonstration of Inline Tank Inspection

4.1.3.4.1 Aim WP4 - Demonstration of Tanks – WP Leader: Vopak

- To demonstrate the inline tank inspection robot in a real field use case.
- To evaluate the demonstration results of the inline tank inspection robot in a real field use case against the specifications and requirements developed in WP2.

4.1.3.4.2 Main Scientific & Technical Results

The fully integrated Tank Inspection Robot was tested under field conditions in two steps: an operational test in a tank provided by VOPAK, and an operational and inspection test in a tank provided by Shell.

Firstly, the deployment procedures and lifting requirements were developed and evaluated, preceding the operational trial at VOPAK. The evaluation concluded that the procedures were considered fully acceptable and resembled common practice that would lead to safe work activities, at the sites of VOPAK and Shell. The field test at VOPAK consisted of testing the deployment of the robot in a 10 m diameter, 14 m high tank, filled with water. The robot was launched with a crane on the roof, and entered into the tank with the tripod. The photographs in Figure 22 and Figure 23 illustrate these activities.

During this trial sometime was available to develop experience with navigation of the robot, floor plate detection, and testing the safety systems controlling the operation of the robot. This test demonstrated that the Operational procedures were adequate; the test revealed some useful experiences that allowed improvement and optimization to be implemented for the next trial.

Figure 22 Preparation of the Tank Inspection Robot and Control van during VOPAK Field test
The test at Shell was carried out in a 24 m diameter, 14 m high tank, also filled with water. The tank was coated internally, inspected several years before with a SLOFEC system (Saturated Low Frequency Eddy Current), a similar line of tools as the MEC (Magnetic Eddy Current) system in the Tank Inspection Robot. Navigation in the tank was tested, including obstacle avoidance, using the sonar system, cameras, and the robot localization systems. An example of a sonar image is shown in Figure 24. Note the various obstacles and features (welds) of the floor.

A next activity is to map the layout of the floor and annular plates. For this purpose the robot makes long traverses through the tank, detecting the welds of the plates with the MEC inspection tool, and with that information updating the floor plan. In Figure 25 it is shown how a first trajectory has delivered locations of welds and is mapped on the floorplan. This process can start from scratch or with a known floorplan (e.g. from a previous inspection).
For individual plates to be inspected the edges are mapped, as shown in Figure 26. Several plates were inspected, including a special scanning mode along the cylindrical shell to scan over the annular plates. Inclination of the tank floor plates was measured.

Despite some issues with control systems (due to unusually high ambient temperatures during the test) the major functionality of the robot (see above) could be tested and was found working within the expected range. Several smaller issues were highlighted that are curable.

The inspection results collected with the MEC system were compared with the SLOFEC measurement carried out 2 years earlier. There was discrepancy between these results: in Plate 26 a defect was reported in 2014; however, the MEC results in 2016 showed abundant indications. Therefore, three plate sections (0.5x1m each) were cut out for visual checks.

In Figure 27 below the underside of the plates 1 and 2 are shown, in the same orientation as the MEC results. The plates contained an abundance of pitting damage, in a depth range of 1-4 mm deep and 10-40
mm wide; some defects are deep but narrow, as is illustrated in the detailed image of a pit. It can be observed from Figure 27 that the PETROBOT MEC system imaged the pattern of pits in a consistent manner.

Figure 27: In Floor plate #26 two sections (0.5mx1m) were cut out for verification. The actual pit distribution is shown in the photos. The larger individual pits are typically in the order of 10-30 mm wide and 3-4 mm deep.

The MEC system did show some variation in detection sensitivity between Plate 1 and Plate 2. This is thought to be caused by offset variations of the MEC tool. This has led to a recommendation to measure lift-off during scanning to allow correction of reporting sensitivity offline.

(It is noted that MEC detection performance is well within the detection requirements provided by API-653 Annex G floor scanner qualification: for defects up to a plate depth of 50% a detection probability is specified of 40%).

It is concluded that the MEC system provides a very good detection capability to detect even very narrow pits. The addition of an additional on-line lift off measurements in the robot could increase the detection performance to a very satisfactory level.

4.1.3.4.3 Recommendations

The field tests led to a number of recommendations:

1. to carry out more field tests to harden the systems, to increase the efficiency of the inspection procedures so to achieve optimum production of inspection data; also to optimize annular ring testing and further testing floor settlement/inclination measurement.
2. The sizing performance of the MEC tool needs to be further evaluated, to allow clear and reproducible decisions for follow up actions to be made.
3. Now that the robot is available, cooperation need to be developed with the Tank Cleaning community, to learn to deploy the robot in tanks that may have collected debris on the floor during a long period of operation - and understand minimum cleaning requirements so that the inspection robot can handle the remaining debris layer.
4. Now the robot is available, means can be developed – in cooperation with end-users - to extend the application range of the current robot into deployment in hydro-carbon containing tanks that contain flammable and explosive products, e.g. by inerting the entry area with nitrogen.

5. An ongoing effort will be required to get the industry used to and made familiar with the possibility of online inspections.

**4.1.3.5 Work Package 5: Integration**

**4.1.3.5.1 Aim WP5 – Integration – WP Leader: Quasset**

Work package 5 was the integration package. A major requirement was that the PETROBOT solutions fit in an operational environment with various complicating factors (process operations, reliability of measurements, reporting of results, safety of system operations, safety regulations, inspection regulations) so it was important to consider these factors explicitly. This was done during the whole execution of PETROBOT as part of WP 5. In the beginning the focus was on identifying relevant design factors and using them as input for WP 1 and WP 2. Then the focus shifted to checking that these factors are considered during development. In the second part of the project strong attention was paid to developing new guidelines and standards that can be used by end users and regulators. Furthermore, process plant design guidelines were developed that were used by end users to adapt design standards for vessels and storage tanks to meet the change from human inspections to robotized inspections. Lastly, for the PETROBOT solutions to be commercially viable, business case and the strategy for market uptake and deployment was prepared that addressed costs and benefits as compared to conventional inspection practices considering inspection costs and all other deployment costs, as well as a strategy for market uptake and deployment describing target market segments.

The overall aims for WP5 were the following:

- To determine the requirements for the pressure vessel internal inspection robot and in-line storage tank inspection robot.
- To develop standards and guidelines for application of the pressure vessel internal inspection robot and in-line storage tank inspection robot.
- To develop a strategy for market uptake and deployment of the pressure vessel internal inspection robot and in-line storage tank inspection robot.

**4.1.3.5.2 Main Scientific & Technical Results**

For this work package, there were 4 main areas where results were obtained. These are as follows:

1. Gained knowledge in Inspection Practices for deployment in the industry
2. PETROBOT Application Guidelines: Development of working procedures, guidelines, application guides for the use of PETROBOT in the field
3. Development of the PETROBOT business case
4. Market opportunities and uptake strategy

**Inspection Practices for deployment**

During the first phases of this project, it quickly became evident that the inspection of pressure vessels and aboveground storage tanks require a vast multidisciplinary knowledge base of items such as inspection regulations, infrastructure knowledge, current operation and procedures, as well as sufficient experience in the inspection field including available inspection technology and inspection methods. In addition in-depth knowledge of robotic solutions is required. A knowledge document was written that captured the selection and prioritisation of robot requirements per the information collected throughout the first three months of the project. The design phase was largely built on engineering judgment that was brought in by all consortium members and exchanging that knowledge to drive the robots designs. All the consortium members represent different specialist areas. Current practices were discussed in detail and at length during
PETROBOT: Opening up the Oil, Gas, and Petrochemical markets for robotics

interactive meeting sessions with WP1 and WP2. Thus, that report evolved from providing support to the other WPs in the form of merely an inventory of current practices, to a knowledge base that amalgamates all key criteria that are required to determine the direction of PETROBOT and aid in project decision-making.

Hence the results of this phase was a document that served as a first overview of all the aspects that play a role in robot inspection; it provided a knowledge base that has allowed the other work packages to detail the specifications of the robots that are being developed. It described the current practices for aboveground storage tank and pressure vessel inspection as well as the detailed requirements that are governed by industry and regulatory bodies. This document also provided a knowledge base to translate current industry practices into functional and technical requirements for PETROBOT.

**PETROBOT Application Guidelines**

As robotic inspection is being introduced into the world of the petrochemical industry, guidelines are required for the use of these new robotic tools. The use of guidelines for inspection in the petrochemical industry includes:

- They stimulate quality and completeness;
- They give a framework to structure the entire inspection process and preparation;
- They stimulate continuity over time, locations and assets;
- They stimulate continuity over service providers and personnel.

The above reasons are important for any inspection activities within the industry, but in particular when the use of robotics as guidelines become essential to the effective use and operations of the robotic inspection equipment.

The result of this element of the work package outlined the guidelines for application in practice of the robotic inspection systems developed as part of the PETROBOT project. The documentation found in that report provided contractors and clients with guidance on developing and deployment safe and efficient robotic systems for inspection. These guidelines were based on operational aspects, inspection requirements, and safety aspects, and include generic application guidelines as well as specific guidelines developed by the robotic technology manufactures and inspection service providers. Whilst that report and the information provided highlights a wide range of technical and operational information, it should be the...
duty of the individual persons to satisfy themselves that all robotic operations are conducted safely and efficiently.

Overall, 25 Documents were developed: 6 PETROBOT Templates; 12 Operation, calibration, and Safety manuals; 7 Procedures, Practices, & Applications for use in deployment, which the objective of these reports is to provide a framework for the consortium members to construct the content that will be needed in the industry for deployment.

![Selection of the documents contained in the application guides](image)

**Business Case**

The business case developed provides a starting point for the overall business case for the PETROBOT project to be employed in the Oil & Gas and Petrochemical industries, as well as the required path to the market and the uptake strategies for inspection robotics within these industries, using the PETROBOT solutions. For successful uptake, a business case and uptake strategy was developed. The business case covered: Strategic Context of why robotic inspection; PETROBOT Project scope; Market Analysis (Incl. Market need; Stakeholder analysis; SWOT Analysis); Barriers to Entry and Requirements for Market Acceptance; Market Opportunity; Uptake Strategy within the Industry. PETROBOT has also made an important critical step in demonstrating the technological capabilities and business cases for inspection robotics by mobilising the complete value chain, consisting of robotic and inspection technology providers, inspection service companies, and end-users.

The main findings from this business case analysis are as follows:

1) The use of robotics for inspection in PV and AST adds value by
   a) Avoiding or minimising the need for human entry into assets and thereby increasing safety
   b) Minimising and shortening operational disruptions that result from asset inspections which in turn could reduce revenue lost due to asset downtime
   c) Avoiding or minimising environmental risks
   d) Eliminating or reducing costs associated with the opening and cleaning of assets
   e) Gathering adequate inspection data which can support important decision-making, like extending internal inspection periods.

2) The use of robotics could save
   a) Costs associated with the preparation of assets for human entry
   b) Reduction of turnaround times and asset downtime
   c) Increased inspection cycles
petrobot

4. Considerations to ensure market uptake
   a) Valid business cases for the use of robotics
   b) Target easy, “low hanging fruit” application areas that demonstrate use cases
   c) Change management for technology acceptance
   d) Staircase approach to the development of technology
   e) Investment by the whole value chain
   f) abandoned “try it with my neighbour first”, and, “let someone else try it first” attitude to be eliminated
   g) Apply the Minimal Viable Product approach to technology deployment

For the end-users to truly accept these solutions, viable and valid business cases for deployment must be provided, no matter what technical elements must be overcome. With a staircase approach to the development of technology and conducting deployments that are targeting “low hanging fruit” application areas, end-user confidence will be gained for these new, novel inspection solutions.

In the area of cultural change, human inspection is, and remains, the ‘gold standard’ for the inspection of assets. The conventional inspection procedure for assets has been predominantly human-driven and the associated guidelines and standards have been consistent for many years. One of the biggest challenges for robotic inspection solutions is to gain acceptance from end-users, and a significant human factor change is required to introduce novel inspection techniques. End-users need to change their conventional approach to inspection and have faith in the new technology. This reluctance towards the adoption of new inspection methods poses a key challenge for industry players. The global NDT market is diversified and competitive and there are only a few global players that can roll out technology worldwide. The market is dominated by companies based on their core competencies. New innovation, inspection tools, and inspection methodologies in all areas of the value chain is the key strategy being adopted by industry players to grow in the NDT market.

**Market Opportunity**

Throughout this analysis, the large industry need to perform inspections in a safer, more environmentally friendly, and a more economical way has been demonstrated. With the deployment of robotics for inspection there are a number of acceptance factors to overcome in order for it to truly be a standard inspection solution. With the buoyant Oil & Gas and Petrochemical markets, the cost of oil rapidly decreasing and demand increasing, combined with a drive to gain operational efficiency, robotics is a key technology in minimising asset downtime. The use of the PETROBOT solutions is estimated to save the oil industry €280M per year across the assets, and the robotics industry has a market size potential of €84M per year.

The cost of the technology investment (robot hardware + NDT equipment) is a critical issue when it comes to applying robotics in the industry. A concern is that the initial capital investment for the owners of the technology will outweigh the gains achieved by the time and costs saved in the reduction of man-hours and the assets being offline. Although this concern is understandable, it has been found that even though there is an increase in the time taken to perform the inspection, the reduction or, in some cases, the elimination of tasks to take the asset out of service, coupled with its associated reduction in man power, significantly reduces the time that the asset is out of service, thus savings due to avoiding production deferment
outweighs the inspection costs. With a man hour saving estimated to be between 38-76 hours on certain types of vessels, can be translated into larger savings over the whole operational process (Net saving/year for industry estimated at €500M+ across the assets).

4.1.3.5.3 Recommendations

One of the overarching strategies for success is to connect the value chain further, and in particular educate the business units within the companies. This includes working with several groups, such as Downstream and Manufacturing Management, Upstream Management, Inspection Expert groups, Inspection Business Units and Local Inspection companies, Business Units and Local Turnaround planners, as well as Health Environmental and Safety groups and the technology and knowledge institutes. A vital strategy is to work with local groups and find a champion willing to push the use and uptake of robotics within their part of the business. This education via technical demonstrations, use-cases, business cases, presentations and knowledge sharing will accelerate the use and uptake of robotics.

The uptake within the industry is not hinged on one member of the value chain, or a single set of key elements that will ensure its acceptance. Although there are key players that can really push or pull the technology, the reliance on just one member will not guarantee the industry to grow. Each member requires different requirements and inputs for every other member to buy, sell, accept, implement, invest, develop, and use robotics in their part of the market.

As the market for non-human entry NDT is still at an early stage, the commercial plans of the technology developers include working with businesses at all points within the supply chain, and provide technology as a stepwise approach, accepting that “first version” systems will not cover the full functional scope. Building innovative business models (rental schemes, pay-by-use, etc.) and sales and support channels to increase sales and to assure system support all allow the technology to be adopted easier and help overcoming the self-imposed barriers. For the uptake of robotic inspection for process equipment to be a success, the value chain all need to start changing and rethinking their products, their business models, and all of the processes that support them. The old ways of “try it with my neighbour first”, and, “let someone else try it first”, must be abandoned, and new, more agile ways of working across the ecosystem of inspection must be adopted. This requires a different way of looking at all the business’ moving parts, and particularly its people and culture.

As with other robotic industries that they are active in, they will conduct technology trials and target “low hanging fruit” to build end-user confidence in novel technology, and as a result open up the market for long term deployment. By deploying MVP (Minimal Viable Product) technology development stages where the technology capability is developed over time, thus accepting that not all technical functions are available in the beginning, it will give the whole value chain the ability to learn, improve, adapt and ultimately accept robotics as fundamental inspection tools in their inspection “tool boxes”.

Some simple yet effective recommendations are:

1. Take the MVP approach, accepting that not all functions are available in the beginning
2. Execute as many missions as possible and loop the experience back into operations and build a track record
3. Oil & Gas company R&D / Technology Centers offer an incentive to the plant operator when deploying robotics (free deployment tests, connection to hardware, etc.)
4. Target easy, “low hanging fruit” application areas to add value to the business case

Current application of inspection robotics in the Oil & Gas and Petrochemical industries is promising, supported by a clear business case for the use and uptake of the technologies. With the global inspection robotics market in industry expected to grow at a CAGR of 20.46% over the period 2014-2019\(^2\), the

\(^2\) [http://www.researchandmarkets.com/research/63j7zj/global_inspection](http://www.researchandmarkets.com/research/63j7zj/global_inspection) - this also includes subsea and aerial robotics
introduction of the PETROBOT robotic inspection solutions into the market has opened up the Oil & Gas and Petrochemical markets for the robotics technology and service sector.
4.1.3.6 Potential Impact, Main Dissemination Activities and Exploitation of Results

4.1.3.6.1 Potential impact

Our world is in the midst of a major technology revolution, specifically in the digital arena. With 22% of the world economy will be driven by digital aspects, it’s bringing with it ubiquitous and unprecedented amounts of change. With more data than ever before and new solutions and technologies, old systems and ways of working are rapidly being left behind. For the Oil & Gas and Petrochemical industries this revolution brings rapid change that hasn’t been seen before. The impacts of technology, and the changes that are being brought with it, are making the industry temporarily over-whelmed on how to uptake digital ideas; and for an industry that is notorious for a slow rate of change, it is hard for them to absorb the magnitude of the tasks ahead. This is very true in the case of the impact and uptake of robotic inspection.

Moving past the digital culture shock that the inspection industry finds itself in today sounds daunting, but fortunately there are robotic inspection models already available to provide inspiration. Robotics for inspection has been used in the Oil & Gas industry for years in the subsea domain - the use of robotics for inspection, operations, and maintenance is now the norm. In the mid 1980’s the industry made the transition from human operations using divers, to ROV IRM (Remotely Operated Vehicles inspection, repair and maintenance). This transition was made due to the similar drivers that have been identified for onshore robotic inspection, safety and economics; however, the key driver that enabled the uptake of robotics was that the industry had no other choice but to embrace robotics as they wanted to push to deeper depth and go beyond human safety limits. It was a game-changer in the industry; now subsea robotics are a lot smarter, living 100% on the sea floor (resident robots), and are fully autonomous (known as an AUV – Autonomous Underwater Vehicle).

For the PETROBOT solutions, the biggest impacts are in the areas of safety, Environmental, and Economics. There is a great need to increase the safety of people involved with the inspection-related tasks of PVs and ASTs by reducing or minimising the need for human entry into confined and/or hazardous spaces. In addition, there is also a need to decrease the time in which the assets are non-operational due to being out of service for inspection, while also ensuring that the environment is not harmed as a result of the inspection and production process. Therefore, the 3 industry impact areas (and therefore drivers) for the use of robotics within the industry were identified, listed in order of importance:

1. Safety: Consisting of three important aspects: personnel safety, asset safety and equipment safety.
2. Environmental: The contribution that robotic solutions make towards the reduction of the environmental impact, therefore minimising accidents and maximising environmental protection.
3. Economic: The contribution that robotic solutions make towards the operation and longevity of the assets, and the improvement of the efficiency and profitability of the facilities.

From the asset owner’s perspective, and the wider industry, the main impact of using PETROBOT solutions is to improve the safety of people involved in the inspection of these assets, but the others are also identified as equally important.

The direct economic impact by deploying the PETROBOT solutions can be seen through the market segments. With a potential market demand for annual inspection from within the PETROBOT consortium for Pressure Vessels: 2,284 vessels, for Storage Tanks: 861 tanks, the impact directly at this moment for the industry is large\(^3\). In a huge overall market, with global Non-Destructive Inspection technology spending at

\(^3\) Realizing that these numbers are sensitive for the assumptions made; they are considered as a best estimate at the moment.
Safety Impact

Traditionally, personnel entering into PVs or ASTs to perform asset inspections has been the only way to perform a detailed inspection assessment. It is evident that there are inherent risks when personnel enter a confined and/or hazardous space. Although safety regulations and standards are high, occasionally accidents occur, as the industry fundamentally hosts hazardous environments. Fatalities within confined spaces averages 92 per year\(^4\), with approx. 20 of them being associated with the inspection, maintenance and repair of assets. In addition, incidents may happen in the process of preparing the assets for inspection and human entry. Avoiding (at least some of) these activities all-together should by default further improve safety.

Safety aspects can be classified into three groups:

i. Personnel safety
ii. Asset safety
iii. Technology safety

The health and safety of all personnel is the primary driver for the asset owners. Not requiring personnel to enter hazardous environments is the single most contributing consideration for the use of robotic solutions, in particular within confined spaces (for example entering a PV). By removing humans from these hazardous environments, dramatic improvements concerning the safety of workers can be achieved. It should be noted this is not only limited to inspection and maintenance, but is valid for all aspects of operations of a facility.

The second aspect is asset safety. This is the primary reason for intervention of the asset, i.e. shutting the asset down for inspection. The inspection tasks are designed to keep the asset in good and safe operating conditions whilst the asset is in operation. For example, if there is a loss of containment during operations, there could potentially be personnel and environmental hazards that can occur and consequently result in devastating outcomes. The asset must therefore be kept in a safe working order.

The third aspect is technology safety. The assets that are vital to the industry put strong demands on the robotic technology regarding its design and requirements. Not only must the robotic solutions be safe to use within the environment, they must be robust enough to work in the environment and must conform to the industry’s safety guidelines.

Environmental Impact

All companies work to avoid, minimize and mitigate environmental impacts wherever they do business. In particular, the oil companies strategically review key environmental issues for their business such as greenhouse gas emissions, air quality, energy efficiency, water use and sensitive areas. The Corporate social responsibility (CSR) is a major driver within the industry and functions as a self-regulatory mechanism whereby a business monitors and ensures its active compliance with the spirit of the law, ethical standards and national or international norms. Regular inspection is one of the keys to minimising the adverse impact on the environment. The processes concerning the inspection of an asset, such as cleaning and venting, have an impact on the environment. Often when an asset is opened, there is a release of Volatile Organic Compounds (VOCs) which causes an impact on the environment due to the emissions that are released. Thus robotic solutions should be able to add value towards the reduction of this impact by minimising accidents and environmental contamination.

Economic Impact

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Significant costs are involved with asset inspections. The most expensive aspect by far is taking an asset off-line for inspection and the associated downtime and loss of production whilst the facilities are not operational. An example of this is when an Aboveground Storage Tank is shut down for inspection it can cost up to US$1 million before the inspection can occur. Similarly, it was estimated that the majority of the time spent in the context of an internal pressure vessel inspection was related solely to making the vessel human entry ready. Depending on the type of facility, the required off-line time may range from one day to several weeks, costing millions of Euro’s in lost production. In addition, less than 5% of the time the vessel is out of service is for the actual inspection, while other tasks are required to render an asset safe for human entry. Providing solutions that minimise the need for these tasks, and reduce or eliminate the need to take assets off-line is a key impact point. As mention earlier, with a man hour saving estimated to be between 38-76 hours on certain types of vessels, can be translated into larger savings over the whole operational process (Net saving/year for industry estimated at €500M+ across the assets). Considering the 3 primary impact points above, our solutions are being used to minimise/substitute human entry and optimise the deployment and operational time to minimise the downtime of the assets. Not only will the deployment of robotic inspection solutions significantly increase the safety of people working in these environments, but another critical factor is the reduction of the downtime of assets and thereby offer economic benefits.

**Wider Industry**

For the impact and uptake of robotic inspection for pressure vessel and aboveground storage tanks to be a success, the value chain all need to start changing and rethinking their products, their business models, and all of the processes that support them. The old ways of “try it with my neighbour first”, and, “let someone else try it first”, must be abandoned, and new, more agile ways of working across the ecosystem of inspection must be adopted. This requires a different way of looking at all the business’ elements, and particularly its people and culture. The impact within the industry is not hinging on one member of the value chain, or a single set of key elements that will ensure its acceptance. Although there are key players that can really push or pull the technology, the reliance on just one member will not guarantee industry growth. Each member requires different requirements and inputs for every other member to buy, sell, accept, implement, invest, develop, and use robotics in their part of the market.

Overall, the impact of robotic inspection is positive. With the market size, drives from the industry for uptake, as well as the technology being able to provide solutions for the wider industry. In general, the maintenance and inspection market is very conservative and risk-averse, so the economic and safety benefits must be overwhelming and the perceived additional risk quite low for the market to embrace such innovations. Understanding the market structure and developing economic and business cases for robotics within the market will be key to the success of this technology. Furthermore, involving end-users and service providers’ input at the start of the research and development phase (both blue sky development and technology development) will speed up the uptake of the research and technology development, thus providing quicker adoption and an increase in market size.

**Main Dissemination Activities**

The dissemination of the aims and results of the project throughout its duration was one of the key goals of PETROBOT. Dissemination and communication included the dissemination to all relevant stakeholders and the communication among the partners and outside parties. At the same time, it was recognised that the communication about the project should be treated with the appropriate confidentiality. The PETROBOT consortium fostered a climate of open communication which was vital in reaching the technical and operational objectives, but could potentially expose the intellectual property (IP) or other interests of consortium members. Clear confidentiality guidelines and rules for dissemination outside the consortium were necessary to manage this open communication. The confidentiality guidelines are stipulated in the consortium agreement and are not part of the dissemination plan.
This document provides an outline of the dissemination activities that were planned and executed throughout the project in detail, and was updated with new information about dissemination activities regularly during the project lifetime.

Dissemination refers to the methods by which the results of the project are presented to the public and the industry. This can include, amongst others, press releases, scientific publications, conferences, exhibitions, workshops, master classes, public events, newsletters, websites and social media. In this dissemination and communication plan the “industry” is defined as companies that operate in the Oil & Gas and Petrochemical industries, while the “public” refers to the general public at large.

The PETROBOT results will be exploited and disseminated inside and outside the consortium. The consortium comprises representatives from the above-mentioned organisations. As already indicated, PETROBOT mobilises the complete value chain within the industry, which consists of robot and inspection technology providers, inspection service companies and end-users, in order to develop innovative inspection robots and validate these solutions by means of use-cases. By having partners with the relevant knowledge in the field and from different types of organisations and countries, an opportunity exists to maximise the dissemination channels and to ensure that the project results are utilised optimally. This can be achieved by communicating the project results to other companies, policy makers, business decision-makers, etc. In order to achieve the goal of maximum usage, the project must draw the necessary attention and interest of different potential users and developers to “kick start” the use of robotic inspection methods.

Dissemination Objectives

PETROBOT is committed to an effective internal and external dissemination of the project results and knowledge. The mechanisms to facilitate the dissemination are described in the following sections.

Internal Dissemination

The internal dissemination primarily targets the sharing of information within the consortium. In addition, this could also boost and reinforce the collaboration between the partners. The internal dissemination, overseen by the Executive Board, was achieved through the internal communication channels which include project meetings, minutes of meetings and reports, and circulars distributed by the project execution team within the consortium. A PETROBOT SharePoint facility was also available where all documents that are relevant to the project were shared, and contact details of people and organisations and project planning tools (to monitor progress) were available. The PETROBOT SharePoint facility was managed by Quasset, in its capacity as leader of the communication and dissemination work package of PETROBOT (WP6).

A kick-off meeting took place at the start of the PETROBOT programme. The main purpose of the meeting was to create an opportunity for all the participants to get introduced to all the partners and the contents of the programme. The aim of the meeting was to kindle enthusiasm for everyone involved. In addition, every General Assembly Meeting, Executive Board Meeting, and all work package team meetings are used as opportunities to share and disseminate information.

External Dissemination

The external dissemination activities of the PETROBOT programme have been targeted at the following groups:

- Robot technology developers
- Inspection technology developers
- Plant owners and operators
- NDT service providers
- Regulators and notified bodies
- The scientific community
- The general public
By also spreading knowledge outside to the scientific community and the public we intended to increase the interest, understanding and support for science and technology development in general, robotics and inspection technology development and for the use-cases of PETROBOT in particular.

**Dissemination by the Members**

All consortium members in the project disseminated project results in their own organisations as they see fit, abiding by the rules stipulated in the consortium agreement. Each consortium member detailed its own dissemination intentions concerning the result(s) they are involved with, and provides information on its planned and realised dissemination activities to the General Assembly (GA). Prior notice of any planned publication was given to the other consortium members at least 45 days before publication. Any objection to the planned publication then had to be made in accordance with the GA. Objections had to be submitted in writing to the project Coordinator and to each other consortium members within 30 days after receipt of the notice. If no objection was made within the time limit stated above, the publication was permitted. In addition to this, each consortium member provided content for news articles to be included in the newsletters and website at least twice a year. The dissemination guidelines are further detailed in Chapter 2.

**Editorial Board**

All partners took part in the dissemination of results, gains, benefits etc. of the project, both internally (between all project partners) and externally (industry and general public). Both internal dissemination as well as external dissemination was of great importance during the project lifetime.

To stimulate and streamline activities, PETROBOT formed an editorial board consisting of communication and marketing specialists from each of the consortium members. The editorial board oversaw dissemination activities, the vetting process and generation of content for the website and social media activities.

**4.1.3.6.3 Exploitation of Results**

The Inspection robots will be offered under commercial services to end-users. The development of commercial arrangements with the robots has to happen after the PETROBOT project, as well as the development of a market with these robots.

There are various commercial models possible. The vessel robots are very suitable for re-production by the robotic developers (GE Robotics; OC robotics), and can be integrated with Inspection technology, similar to what DEKRA has demonstrated during the PETROBOT Project. The nature of the Tank Inspection robot leads to using more specific and specialized working procedure to safely deploy the robot in a tank; the robot is also highly integrated with the inspection technology (in terms of mobility across the floor, executing inspection tasks). This may favour a commercial model where a Tank Maintenance & Inspection company takes the lead in commercial deployment, with support from specialist partners, as was demonstrated by the Consortium partners during the project.

It is already observed that the PETROBOT Project is stimulating replication, with companies developing similar robots (notably for inspection of storage tanks). This will most likely provide a strong stimulus for the market development and the uptake of these robots.

After initial use it is likely that initiatives will be taken to enhance the capability of the robots. It is important that this is driven initially by market requirements. Small improvements are likely to be developed by the service providers. If larger improvement steps will be identified that need a joint effort from the value chain, it is anticipated that the more permanent network platforms as euRobotics and the SPRINT Robotics Collaborative – in which the PETROBOT Members played a strong role to establish these - will take initiative to drive such improvements.
4.2 Use and dissemination of Foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 – H).

The plan should consist of:

4.2.1 Section A
This section should describe the dissemination measures, including any scientific publications relating to foreground. Its content will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

4.2.2 Section B
This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.
Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.


These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

<table>
<thead>
<tr>
<th>NO.</th>
<th>Title</th>
<th>Main authors</th>
<th>Title of the periodical or the series</th>
<th>Number, date or frequency</th>
<th>Publisher</th>
<th>Place of publication</th>
<th>Year of publication</th>
<th>Relevant pages</th>
<th>Permanent identifiers</th>
<th>Is/Will open access provided to this publication?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PETROBOT will increase safety for tanks and pressure vessels (Dutch)</td>
<td>E. Orbitaal, T. Bouma, Quasset B.V</td>
<td>Safety!</td>
<td>January 2014</td>
<td>N/A</td>
<td>N/A</td>
<td>2014</td>
<td>N/A</td>
<td>N/A</td>
<td>No</td>
</tr>
</tbody>
</table>

5 A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

6 Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.
<table>
<thead>
<tr>
<th></th>
<th>Robotic Inspection Solutions for Petrochemical Pressure Vessels</th>
<th>B. van den Bos, DEKRA Industrial AB</th>
<th>ADIPEC 2015</th>
<th>November 2015</th>
<th>N/A</th>
<th>Abu Dhabi</th>
<th>2015</th>
<th>N/A</th>
<th>N/A</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Robotic Inspection Solutions for Petrochemical Pressure Vessels, developed and tested in the PETROBOT project</td>
<td>J. Strand, DEKRA Industrial AB</td>
<td>ADIPEC 2015</td>
<td>November 2015</td>
<td>N/A</td>
<td>Munich</td>
<td>2016</td>
<td>N/A</td>
<td>N/A</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A. Mallion, OC Robotics</td>
<td></td>
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<td></td>
<td></td>
<td>C. Wilson, OC Robotics</td>
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<tr>
<td></td>
<td></td>
<td>E. Zwicker, GE Inspection Robotics</td>
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<tr>
<td></td>
<td></td>
<td>A. Schler, Innospection</td>
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<tr>
<td></td>
<td></td>
<td>T. Black, Quasset BV</td>
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<tr>
<td></td>
<td></td>
<td>P. Potnis, Shell Global Solutions International BV</td>
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### Template A2: List of Dissemination Activities

<table>
<thead>
<tr>
<th>NO.</th>
<th>Type of activities</th>
<th>Main leader</th>
<th>Title</th>
<th>Date/Period</th>
<th>Place</th>
<th>Type of audience</th>
<th>Size of audience</th>
<th>Countries addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Workshop</td>
<td>Shell</td>
<td>EuRobotics Workshop</td>
<td>March 2014</td>
<td>Rovereto, Italy</td>
<td>Robotic Community (Academia and technology developers)</td>
<td>N/A</td>
<td>Europe</td>
</tr>
<tr>
<td>2</td>
<td>Conference</td>
<td>GEIR</td>
<td>AUTONOMY IN THE OIL &amp; GAS INDUSTRY</td>
<td>March 2014</td>
<td>Stavanger, Norway</td>
<td>Academia, industry</td>
<td>N/A</td>
<td>Europe</td>
</tr>
<tr>
<td>3</td>
<td>Conference</td>
<td>Quasset</td>
<td>M2M</td>
<td>April 2014</td>
<td>London</td>
<td>Industry</td>
<td>N/A</td>
<td>Europe</td>
</tr>
<tr>
<td>4</td>
<td>Conference</td>
<td>Quasset</td>
<td>KINT</td>
<td>June 2014</td>
<td>Drunen, Netherlands</td>
<td>NDT service companies</td>
<td>N/A</td>
<td>Europe</td>
</tr>
<tr>
<td>5</td>
<td>Conference</td>
<td>GEIR</td>
<td>EURO Maintenance</td>
<td>June 2014</td>
<td>Helsinki, Finland</td>
<td>Maintenance Industry</td>
<td>N/A</td>
<td>Europe</td>
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</table>

A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other (‘multiple choices’ is possible).
<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Organizers</th>
<th>Event Title</th>
<th>Date</th>
<th>Venue</th>
<th>Sector</th>
<th>Region</th>
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</thead>
<tbody>
<tr>
<td>6</td>
<td>Workshop</td>
<td>GEIR / Shell</td>
<td>RCNDE Workshop</td>
<td>June 2014</td>
<td>Glasgow, UK</td>
<td>Industry and Academia</td>
<td>Europe</td>
</tr>
<tr>
<td>7</td>
<td>Conference</td>
<td>Shell, GEIR, Quasset</td>
<td>Operational Excellence Conference</td>
<td>10-11 September 2014</td>
<td>Abu Dhabi, UAE</td>
<td>Petrochemical market</td>
<td>Middle East</td>
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<tr>
<td>8</td>
<td>Conference</td>
<td>OCR</td>
<td>ATFES</td>
<td>October 2014</td>
<td>Lyon, France</td>
<td>Industry</td>
<td>Europe</td>
</tr>
<tr>
<td>9</td>
<td>Conference</td>
<td>Chevron</td>
<td>ASNT Fall Conference</td>
<td>27-30 October 2014</td>
<td>Charleston, USA</td>
<td>NDE Related Industry</td>
<td>Global</td>
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<tr>
<td>10</td>
<td>Conference</td>
<td>OCR</td>
<td>RAS H2020</td>
<td>25 November 2014</td>
<td>London, UK</td>
<td>Industry</td>
<td>Europe</td>
</tr>
<tr>
<td>11</td>
<td>Conference</td>
<td>GEIR</td>
<td>OSEA</td>
<td>2-5 December 2014</td>
<td>Singapore</td>
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<td>12</td>
<td>Conference</td>
<td>Innospection</td>
<td>Tank Storage Middle East</td>
<td>26-27 January 2015</td>
<td>Abu Dhabi, UAE</td>
<td>N/A</td>
<td>Middle East</td>
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<tr>
<td>13</td>
<td>Conference</td>
<td>Innospection</td>
<td>Subsea Expo</td>
<td>11-13 February 2015</td>
<td>Aberdeen, UK</td>
<td>Industry</td>
<td>Europe</td>
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<tr>
<td>14</td>
<td>Conference</td>
<td>Innospection</td>
<td>Offshore Pipeline Technology</td>
<td>25-26 February 2015</td>
<td>Amsterdam, Netherlands</td>
<td>Industry</td>
<td>Europe</td>
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<tr>
<td>15</td>
<td>Conference</td>
<td>OCR</td>
<td>Waste Management</td>
<td>March 2015</td>
<td>Phoenix, USA</td>
<td>Industry</td>
<td>USA</td>
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<tr>
<td>16</td>
<td>Conference</td>
<td>Innospection</td>
<td>StocExpo</td>
<td>17-19 March 2015</td>
<td>Rotterdam, Netherlands</td>
<td>Industry</td>
<td>Europe</td>
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<tr>
<td>17</td>
<td>Conference</td>
<td>GEIR</td>
<td>IEEE ICIT</td>
<td>17-19 March 2015</td>
<td>Seville, Spain</td>
<td>Academia and industry</td>
<td>Europe</td>
</tr>
<tr>
<td>18</td>
<td>Conference</td>
<td>Quasset</td>
<td>Norsk Forening for Automation</td>
<td>11-12 March 2015</td>
<td>Stavanger, Norway</td>
<td>Industry</td>
<td>Norway</td>
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<tr>
<td></td>
<td>Conference</td>
<td>Consortium/Event</td>
<td>Description</td>
<td>Date</td>
<td>Location</td>
<td>Sector</td>
<td>Region</td>
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<tr>
<td>19</td>
<td>Conference</td>
<td>PETROBOT consortium</td>
<td>ERF2015</td>
<td>11-13 March 2015</td>
<td>Vienna, Austria</td>
<td>Academia and industry</td>
<td>Europe</td>
</tr>
<tr>
<td>20</td>
<td>Conference</td>
<td>OCR</td>
<td>International Nuclear Services</td>
<td>16 March 2015</td>
<td>Japan</td>
<td>Industry</td>
<td>N/A</td>
</tr>
<tr>
<td>21</td>
<td>Conference</td>
<td>Innospection</td>
<td>Oil &amp; Gas Asia</td>
<td>2-4 June 2015</td>
<td>Kuala Lumpur, Malaysia</td>
<td>Industry</td>
<td>N/A</td>
</tr>
<tr>
<td>22</td>
<td>Conference</td>
<td>Innospection</td>
<td>Underwater Technology Conference &amp; Exhibition</td>
<td>16-18 June 2015</td>
<td>Bergen, Norway</td>
<td>Academia and industry</td>
<td>N/A</td>
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<tr>
<td>23</td>
<td>Conference</td>
<td>Innospection</td>
<td>SUT Pipeline Design &amp; Integrity</td>
<td>17 June 2015</td>
<td>Aberdeen, UK</td>
<td>Industry</td>
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<tr>
<td>24</td>
<td>Conference</td>
<td>Innospection</td>
<td>SPE Offshore Europe</td>
<td>8-11 September 2015</td>
<td>Aberdeen, UK</td>
<td>Academia and industry</td>
<td>N/A</td>
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<tr>
<td>25</td>
<td>Conference</td>
<td>Innospection</td>
<td>7th MENDT</td>
<td>13-16 September 2015</td>
<td>Manama, Bahrain</td>
<td>Academia and industry</td>
<td>N/A</td>
</tr>
<tr>
<td>26</td>
<td>Seminar</td>
<td>GEIR, Gassco, Shell, Quasset</td>
<td>SPRINT Robotics Seminar</td>
<td>23 September 2015</td>
<td>Amsterdam, Netherlands</td>
<td>Industry</td>
<td>N/A</td>
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<tr>
<td>27</td>
<td>Seminar</td>
<td>GEIR, Gassco, Shell, Quasset</td>
<td>euRobotics Topic Group</td>
<td>24 September 2015</td>
<td>Amsterdam, Netherlands</td>
<td>Academia and Industry</td>
<td>N/A</td>
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<tr>
<td>28</td>
<td>Conference</td>
<td>GEIR</td>
<td>IEEE/RSJ International Conference on Robots and Systems (IROS)</td>
<td>28 September – 2 October 2015</td>
<td>Hamburg, Germany</td>
<td>Academia and industry</td>
<td>N/A</td>
</tr>
<tr>
<td>29</td>
<td>Forum</td>
<td>Chevron</td>
<td>Chevron ETC</td>
<td>12-13 October 2015</td>
<td>Houston, Chevron FE</td>
<td>N/A</td>
<td>Global</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Facilities Engineering Forum</td>
<td></td>
<td>USA</td>
<td>Community</td>
<td></td>
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<tr>
<td>30</td>
<td>Conference</td>
<td>Chevron</td>
<td>ASNT Fall Conference</td>
<td>26-29 October 2015</td>
<td>Salt Lake City, USA</td>
<td>NDE Related Industry</td>
<td>N/A</td>
</tr>
<tr>
<td>31</td>
<td>Conference</td>
<td>DEKRA, OCR</td>
<td>ADIPEC</td>
<td>9-12 November 2015</td>
<td>Abu Dhabi, UAE</td>
<td>N/A</td>
<td>Middle East</td>
</tr>
<tr>
<td>32</td>
<td>Conference</td>
<td>Shell</td>
<td>NAP 55</td>
<td>12 November 2015</td>
<td>Amersfoort, Netherlands</td>
<td>Industry</td>
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<tr>
<td>33</td>
<td>Conference</td>
<td>AHAK</td>
<td>Tank Storage Germany</td>
<td>25-26 November 2015</td>
<td>Hamburg, Germany</td>
<td>End users</td>
<td>N/A</td>
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<tr>
<td>34</td>
<td>Conference</td>
<td>OCR</td>
<td>NDA Supply Chain Event</td>
<td>November 2015</td>
<td>Manchester, UK</td>
<td>Industry</td>
<td>N/A</td>
</tr>
<tr>
<td>35</td>
<td>Conference</td>
<td>OCR</td>
<td>UKTI Energy CETS</td>
<td>February 2016</td>
<td>Warsaw, Poland</td>
<td>Industry</td>
<td>N/A</td>
</tr>
<tr>
<td>36</td>
<td>Conference</td>
<td>Innospection</td>
<td>Subsea Expo</td>
<td>3-5 February 2016</td>
<td>Aberdeen, UK</td>
<td>Industry</td>
<td>N/A</td>
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<tr>
<td>37</td>
<td>Conference</td>
<td>OCR</td>
<td>Waste Management</td>
<td>March 2016</td>
<td>Phoenix, USA</td>
<td>Industry</td>
<td>N/A</td>
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<tr>
<td>38</td>
<td>Forum</td>
<td>Chevron</td>
<td>Chevron ETC Presentation</td>
<td>6 March 2015</td>
<td>Houston, USA</td>
<td>Chevron ETC</td>
<td>N/A</td>
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<td>39</td>
<td>Conference</td>
<td>AHAK</td>
<td>StocExpo2016</td>
<td>15-17 March 2016</td>
<td>Antwerp, Belgium</td>
<td>Industry</td>
<td>N/A</td>
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<td>40</td>
<td>Conference</td>
<td>PETROBOT consortium</td>
<td>ERF2016</td>
<td>21-23 March 2016</td>
<td>Ljubljana, Slovenia</td>
<td>Academia and industry</td>
<td>N/A</td>
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<tr>
<td>41</td>
<td>Seminar</td>
<td>GEIR, OCR, Shell</td>
<td>SPRINT Robotics Seminar</td>
<td>4-5 April 2016</td>
<td>Houston, USA</td>
<td>Industry</td>
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<tr>
<td>42</td>
<td>Conference</td>
<td>Quasset, Shell</td>
<td>LEO Robotics Congress</td>
<td>21 April 2016</td>
<td>Enschede, Netherlands</td>
<td>Academia</td>
<td>N/A</td>
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<tr>
<td>43</td>
<td>Conference</td>
<td>Quasset</td>
<td>Robotics, Vision and Mechatronics 2016</td>
<td>1-2 June 2016</td>
<td>Veldhoven, Netherlands</td>
<td>Academia and industry</td>
<td>N/A</td>
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<tr>
<td>44</td>
<td>Conference</td>
<td>DEKRA, GEIR</td>
<td>World Conference on NDT (WCNDT)</td>
<td>13-17 June 2016</td>
<td>Munich, Germany</td>
<td>NDE Related Industry</td>
<td>N/A</td>
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<tr>
<td>45</td>
<td>Conference</td>
<td>PETROBOT consortium</td>
<td>IEEE/RSJ International Conference on Robots and Systems (IROS)</td>
<td>9-14 October 2016</td>
<td>Daejeon, Korea</td>
<td>Academia and industry</td>
<td>N/A</td>
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<tr>
<td>46</td>
<td>Conference</td>
<td>Chevron</td>
<td>ASNT Fall Conference</td>
<td>24-27 October 2016</td>
<td>Long Beach, USA</td>
<td>NDE Related Industry</td>
<td>N/A</td>
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<tr>
<td>47</td>
<td>Seminar</td>
<td>PETROBOT consortium</td>
<td>Inspection and Maintenance Robotics Seminar</td>
<td>25-26 October 2016</td>
<td>Amsterdam, Netherlands</td>
<td>Industry, Academia, Stakeholders</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Section B (Confidential or public: confidential information to be marked clearly)

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed per the template B1 provided hereafter.

The list should specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

<table>
<thead>
<tr>
<th>Type of IP Rights 10</th>
<th>Confidential Click on YES/NO</th>
<th>Foreseen embargo date dd/mm/yyyy</th>
<th>Application reference(s) (e.g. EP123456)</th>
<th>Subject or title of application</th>
<th>Applicant(s) (as on the application)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9 Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

10 A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.
Part B2
Please complete the table hereafter:

<table>
<thead>
<tr>
<th>Type of Exploitable Foreground</th>
<th>Description of exploitable foreground</th>
<th>Confidentia l Click on YES/NO</th>
<th>Foreseen embargo date dd/mm/yyyy</th>
<th>Exploitable product(s) or measure(s)</th>
<th>Sector(s) of application</th>
<th>Timetable, commercial or any other use</th>
<th>Patents or other IPR exploitation (licences)</th>
<th>Owner &amp; Other Beneficiary(s) involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection robot</td>
<td>FAST: magnetic wheel robot carrying various inspection tools</td>
<td>No</td>
<td>N/A</td>
<td>Transportable Inspection system, commercially available to Inspection Service Providers and End-users</td>
<td>1. Oil and Gas 1. Petro-Chemical Industry; 2. Power Industry 3. Process/Food/Paper Industry</td>
<td>2016</td>
<td>None</td>
<td>GE robotics DEKRA</td>
</tr>
<tr>
<td>Inspection robot</td>
<td>Bike: highly manoeuvrable magnetic wheel robot carrying various</td>
<td>No</td>
<td>N/A</td>
<td>Transportable Inspection system, commercially available to Inspection</td>
<td>1. Oil and Gas 1. Petro-Chemical Industry;</td>
<td>2017</td>
<td>None</td>
<td>GE robotics DEKRA</td>
</tr>
</tbody>
</table>

11 A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

12 A drop down list allows choosing the type sector (NACE nomenclature): [http://ec.europa.eu/competition/mergers/cases/index/nace_all.html](http://ec.europa.eu/competition/mergers/cases/index/nace_all.html)
<table>
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<th>Type of Exploitable Foreground</th>
<th>Description of exploitable foreground</th>
<th>Confidentia l Click on YES/NO</th>
<th>Foreseen embargo date dd/mm/yyyy</th>
<th>Exploitable product(s) or measure(s)</th>
<th>Sector(s) of application</th>
<th>Timetable, commercial or any other use</th>
<th>Patents or other IPR exploitation (licences)</th>
<th>Owner &amp; Other Beneficiary(s) involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection robot</td>
<td>SNAKE: Arm robot carrying various inspection tools</td>
<td>No</td>
<td>N/A</td>
<td>Service Providers and End-users</td>
<td>2. Power Industry</td>
<td>3. Food/Paper Industry</td>
<td>OC Patent ??</td>
<td>OC robotics DEKRA</td>
</tr>
<tr>
<td>Tank Inspection Robot</td>
<td>Tank Inspection Robot with MEC inspection unit</td>
<td>No</td>
<td>N/A</td>
<td>Unit consists of robot (in tank) connecting via umbilical to Control Centre outside tank</td>
<td>Oil and Gas</td>
<td>1. Petro-Chemical Industry; 2. Power Industry; 3. Food/Paper Industry</td>
<td>2017</td>
<td>A-Hak patents? A-Hak Innospection GE robotics</td>
</tr>
</tbody>
</table>
In addition to the table, please provide a text to explain the exploitable foreground, in particular:

### 4.2.2.1 Fast and BIKE Magnetic Wheel robots

**Purpose:** The FAST and BIKE robotic platforms are to be used for internal inspection of pressure vessels when these vessels are taken out of operation. The platforms can be equipped with different inspection tools, such as camera, surface profiling tool, eddy current corrosion mapping tool, eddy current crack detection tool, and ultrasonic thickness measurement probes.

**How the foreground might be exploited, when and by whom:** The foreground might be exploited by the parties that developed the technology (GE Inspection Robotics, DEKRA, Innospection), by selling the hardware, and by service companies (like DEKRA) purchasing the robot and inspection tools and providing inspection services with it.

**IPR exploitable measures taken or intended; N/A**

**Further research necessary, if any.** Optional, dependent on market needs and demand.

**Potential/expected impact (quantify where possible):** see main section on “Potential Impact”.

### 4.2.2.2 SNAKE Arm robot

**Purpose:** The SNAKE Arm robotic platform is to be used for internal inspection of pressure vessels when these vessels are taken out of operation. The platform can be equipped with different inspection tools, such as camera, surface profiling tool, eddy current corrosion mapping tool, eddy current crack detection tool, and ultrasonic thickness measurement probes.

**How the foreground might be exploited, when and by whom:** The foreground might be exploited by the parties that developed the technology (OC Robotics, DEKRA, Innospection), by selling the hardware, and by service companies (like DEKRA) purchasing the robot and inspection tools and providing inspection services with it.

**IPR exploitable measures taken or intended; N/A**

**Further research necessary, if any.** Optional, dependent on market needs and demand.

**Potential/expected impact (quantify where possible):** see main section on “Potential Impact”.
4.2.2.3 Storage Tank Inspection robot

Purpose: The Tank Inspection Robot is to be used for internal inspection of the bottom of storage tanks when these are in operation. The platform is equipped with several inspection tools, such as sonar and cameras supporting localization, a Magnetic Eddy Current tool to detect corrosion wall loss of the floor plates and the ability to detect welds, and ultrasonic thickness measurement probe.

How the foreground might be exploited, when and by whom: The foreground might be exploited by the parties that developed the technology (A-Hak; Innospection; GE Inspection Robotics), by selling/licencing the hardware to a service company (most like A-Hak).

IPR exploitable measures taken or intended; N/A

Further research necessary, if any. Optional, dependent on market needs and demand.

Potential/expected impact (quantify where possible): see main section on “Potential Impact”.
### 4.3 Report on societal implications

**A General Information** (completed automatically when Grant Agreement number is entered.)

<table>
<thead>
<tr>
<th>Grant Agreement Number:</th>
<th>610401</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title of Project:</td>
<td>Use cases for inspection robots opening up the oil-, gas- and petrochemical markets</td>
</tr>
<tr>
<td>Name and Title of Coordinator:</td>
<td>Mr. Sieger Terpstra, Principal Inspection Engineer</td>
</tr>
</tbody>
</table>

**B Ethics**

1. Did your project undergo an Ethics Review (and/or Screening)?
   - If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports?  
     No

   Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 'Work Progress and Achievements'

2. Please indicate whether your project involved any of the following issues (tick box):
   - **YES**

   **Research on Humans**
   - Did the project involve children?  
     No
   - Did the project involve patients?  
     No
   - Did the project involve persons not able to give consent?  
     No
   - Did the project involve adult healthy volunteers?  
     No
   - Did the project involve Human genetic material?  
     No
   - Did the project involve Human biological samples?  
     No
   - Did the project involve Human data collection?  
     No

   **Research on Human embryo/foetus**
   - Did the project involve Human Embryos?  
     No
   - Did the project involve Human Foetal Tissue / Cells?  
     No
   - Did the project involve Human Embryonic Stem Cells (hESCs)?  
     No
   - Did the project on human Embryonic Stem Cells involve cells in culture?  
     No
- Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos? | No

**Privacy**
- Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)? | No
- Did the project involve tracking the location or observation of people? | No

**Research on Animals**
- Did the project involve research on animals? | No
- Were those animals transgenic small laboratory animals? | No
- Were those animals transgenic farm animals? | No

**Research Involving Developing Countries**
- Did the project involve the use of local resources (genetic, animal, plant etc)? | No
- Was the project of benefit to local community (capacity building, access to healthcare, education etc)? | No

**Dual Use**
- Research having direct military use | No
- Research having the potential for terrorist abuse | No

**C Workforce Statistics**

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

<table>
<thead>
<tr>
<th>Type of Position</th>
<th>Number of Women</th>
<th>Number of Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Coordinator</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Work package leaders</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Experienced researchers (i.e. PhD holders)</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>PhD Students</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Engineers</td>
<td>1</td>
<td>70</td>
</tr>
</tbody>
</table>

4. How many additional researchers (in companies and universities) were recruited specifically for this project? 0
   Of which, indicate the number of men:

**D Gender Aspects**

5. Did you carry out specific Gender Equality Actions under the project? | No

6. Which of the following actions did you carry out and how effective were they?
7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- Yes - please specify
- No

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- Yes - please specify
- No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- Yes - please specify
- No

10. Which disciplines (see list below) are involved in your project?

- Main discipline
- Associated discipline

11a. Did your project engage with societal actors beyond the research community? (if ‘No’, go to Question 14)

- Yes
- No

11b. If yes, did you engage with citizens (citizens’ panels / juries) or organised civil society (NGOs, patients’ groups etc.)?

13 Insert number from list below (Frascati Manual).
11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>✗ 0</td>
<td>✗ 1</td>
</tr>
</tbody>
</table>

12. Did you engage with government / public bodies or policy makers (including international organisations)?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>✗ 0</td>
<td>✗ 1</td>
</tr>
</tbody>
</table>

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Yes – as a primary objective (please indicate areas below - multiple answers possible)</th>
<th>Yes – as a secondary objective (please indicate areas below - multiple answer possible)</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>✗ 0</td>
<td>✗ 1</td>
<td>✗ 2</td>
</tr>
</tbody>
</table>

13b If Yes, in which fields?

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Energy</th>
<th>Human rights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audiovisual and Media</td>
<td>Enlargement</td>
<td>Information Society</td>
</tr>
<tr>
<td>Budget</td>
<td>Enterprise</td>
<td>Institutional affairs</td>
</tr>
<tr>
<td>Competition</td>
<td>Environment</td>
<td>Internal Market</td>
</tr>
<tr>
<td>Consumers</td>
<td>External Relations</td>
<td>Justice, freedom and security</td>
</tr>
<tr>
<td>Culture</td>
<td>External Trade</td>
<td>Public Health</td>
</tr>
<tr>
<td>Customs</td>
<td>Fisheries and Maritime Affairs</td>
<td>Regional Policy</td>
</tr>
<tr>
<td>Development</td>
<td>Food Safety</td>
<td>Research and Innovation</td>
</tr>
<tr>
<td>Economic and Monetary Affairs</td>
<td>Foreign and Security Policy</td>
<td>Space</td>
</tr>
<tr>
<td>Education, Training, Youth</td>
<td>Fraud</td>
<td>Taxation</td>
</tr>
<tr>
<td>Employment and Social Affairs</td>
<td>Humanitarian aid</td>
<td>Transport</td>
</tr>
</tbody>
</table>

13c If Yes, at which level?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Local / regional levels</th>
<th>National level</th>
<th>European level</th>
<th>International level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>✗ 0</td>
<td>✗ 1</td>
<td>✗ 2</td>
<td>✗ 3</td>
</tr>
</tbody>
</table>

H Use and dissemination
14. How many Articles were published/accepted for publication in peer-reviewed journals?

<table>
<thead>
<tr>
<th>To how many of these is open access provided?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>How many of these are published in open access journals?</td>
<td></td>
</tr>
<tr>
<td>How many of these are published in open repositories?</td>
<td></td>
</tr>
<tr>
<td>To how many of these is open access not provided?</td>
<td></td>
</tr>
</tbody>
</table>

Please check all applicable reasons for not providing open access:

- publisher's licensing agreement would not permit publishing in a repository
- no suitable repository available
- no suitable open access journal available
- no funds available to publish in an open access journal
- lack of time and resources
- lack of information on open access
- other\(^{15}\): ..............

15. How many new patent applications (‘priority filings’) have been made? ("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).

<table>
<thead>
<tr>
<th>Intellectual Property Rights</th>
<th>Trademark</th>
<th>Registered design</th>
<th>Other</th>
</tr>
</thead>
</table>

17. How many spin-off companies were created / are planned as a direct result of the project?

Indicate the approximate number of additional jobs in these companies:

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

| Increase in employment, or |
|---|---|
| Safeguard employment, or |
| Decrease in employment, |
| Difficult to estimate / not possible to quantify |
| In small & medium-sized enterprises |
| In large companies |
| None of the above / not relevant to the project |

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (FTE = one person working fulltime for a year) jobs:

Indicate figure:

---

\(^{14}\) Open Access is defined as free of charge access for anyone via Internet.

\(^{15}\) For instance: classification for security project.
Difficult to estimate / not possible to quantify

<table>
<thead>
<tr>
<th>I</th>
<th>Media and Communication to the general public</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.</td>
<td>As part of the project, were any of the beneficiaries professionals in communication or media relations?</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>21.</td>
<td>As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>22.</td>
<td>Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?</td>
</tr>
<tr>
<td></td>
<td>Press Release</td>
</tr>
<tr>
<td></td>
<td>Media briefing</td>
</tr>
<tr>
<td></td>
<td>TV coverage / report</td>
</tr>
<tr>
<td></td>
<td>Radio coverage / report</td>
</tr>
<tr>
<td></td>
<td>Brochures / posters / flyers</td>
</tr>
<tr>
<td></td>
<td>DVD / Film / Multimedia</td>
</tr>
</tbody>
</table>

| 23. | In which languages are the information products for the general public produced? |
|     | Language of the coordinator | English |
|     | Other language(s) | |

**Question F-10:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

**Fields of science and technology**

1. **Natural Sciences**
   1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
   1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
   1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 Engineering and technology

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3 Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3 Medical Sciences

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anæsthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4 Agricultural sciences

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5 Social sciences

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary, methodological and historical SIT activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].
6. Humanities

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]
**4.4 FINAL REPORT ON THE DISTRIBUTION OF THE European Union FINANCIAL CONTRIBUTION**

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

<table>
<thead>
<tr>
<th>Name of beneficiary</th>
<th>Final amount of EU contribution per beneficiary in Euros</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>