Introduction

Project GRAID is developing innovative technology to inspect complex gas transmission underground pipework at high pressure installations.

National Grid Gas Transmission (NGGT) and its partner organisations are engaged in an exciting project that is addressing the issue of how to inspect complex, below-ground pipework found at High Pressure Installations. The project is developing ground-breaking robotic technology that will be able to provide real-time data on the condition of high pressure underground assets.

National Grid is collaborating with three British Small Medium Enterprises (SMEs) to develop ways to accurately assess the condition of its pipework assets that cannot currently be inspected via conventional Pipeline Inspection Gauges (PIGs). The complexity of pipework at High Pressure Installations (up to 94 Barg) presents a significant challenge for any robotic solution. The solution being developed will enable NGGT to look inside this complex pipework for the first time since their construction, in some cases dating back nearly 50 years. The current asset management strategy for these pipes rely on above ground survey techniques, and is based on good design and construction practices having been applied previously. If corrosion is suspected the only way to confirm this presently is through excavation, which is both financially expensive and detrimental to the environment. This project will enable a proactive, risk based approach to the management, maintenance and replacement of these ageing assets.

The project highlights NGGT’s commitment to delivering innovation that provides a more reliable and environmentally friendly approach to managing its assets and building value for gas consumers.

Synthotech Ltd specialises in providing innovative engineering and technical services to the utility and infrastructure sectors. They are designing and building the robotic platform comprising of the visual, sensory and non-destructive testing (NDT) systems as well as developing the user interface and control systems.

Premtech Ltd provides engineering, consultancy and design management services for on-shore pipeline and associated installation projects of various sizes. Premtech are designing the robot’s launch and receive vessel, the offline test facility, the online site connections and providing design consultancy services.

Pipeline Integrity Engineers (PIE) Ltd offers consultancy services relating to the integrity management of high pressure gas pipelines and associated installations. PIE are providing third party assurance, supporting the technical team in developing and implementing the technical strategy, and providing integrity consultancy support in translating inspection results into asset management strategies and operational procedures.
The two additional partners that have joined since the last Progress Report are still assisting in the project to help deliver the Launch and Retrieval vessel and the Offline trial facility.

**DNVGL**

DNVGL provides classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas and energy industries. The company also provides certification services to customers across a wide range of industries. DNVGL operate their own testing and research facility in Spadeadam, Cumbria, UK, a world-leading research and testing facility working for heavy industry and government agencies. Its remote location on more than 3500 hectares of secure Ministry of Defence land means DNVGL can carry out explosion, fire and gas dispersion testing within a secure exclusion zone. As a result National Grid has chosen DNVGL to construct an off-line test facility at Spadeadam for use during Stage 3.

**RMA Ltd**

RMA is a family run business (540 employees worldwide) with its headquarters in Baden Kehl, Germany. It is a manufacturer of fittings and instrumentation for the gas sector. Four fields of economic activity “Gas Distribution”, “Gas Transportation”, “Gas Measurement” and “Services” involve RMA activities in the global market. RMA has manufactured GRAID’s launch and retrieval vessel at its facility in Germany that includes the unique through wall shaft and internal railings.

“\[There are 350 kilometers of ‘unpiggable’ pipework in the National Transmission System\]”
This is the fifth progress report for Project GRAID following the successful Gas Network Innovation Competition award in November 2014. This report documents the progress made through Stage 3 since the last project report submitted in December 2016, and the key activities that will take place over the coming months. In response to the revised NIC Governance (v3) the Project Progress Reports are to be supplied on an annual basis, as such the next report will be the Project Closure report submitted in December 2018.

Summary
Since the last report the project has progressed on schedule and within budget completing the milestones set for Stage 3 which is the largest of the 5 stages of Project GRAID and covers both the Offline and Online testing.

Both the RMA launch vessel and DNV GL test rig have been manufactured, built and over-pressure tested successfully. This has allowed Offline trials to begin, providing the opportunity for the GRAID robot to be put through its paces and complete a series of defined tests.

The robot and umbilical management system (UMS) which connects the robot to the outside world have also both passed their 100 bar(g) pressure tests in nitrogen. This is a culmination of all of the hard work by everyone involved over the past year.

There have also been several team changes to the project team:
- David Hardman was appointed as GRAID Project Lead for NGGT in March 2017 allowing Quentin Mabbutt to return to his role as Gas Transmission Innovation Delivery Manager,
- The Project GRAID Communications Lead decided to leave the team in May 2017.
- Louis Salisbury joined the team in September to assist in the technical aspects of the project.
- There has also been a replacement of the Technical Lead role within the project with Josh Blake now taking over.
- David Salisbury – Head of Network Engineering and appointed Sponsor for Project GRAID has been replaced with Karl Yates - Head of Delivery Services.

Thank you to those that have left the team this year, without your hard work none of the recent successes would have been possible and welcome to those who have taken over.

The Project Partners have also made alterations to those involved in response to the changing deliverables of the project with both Synthotech and PIE increasing those working on Project GRAID.

Key Deliverables
During this reporting period, the following notable deliverables have been the focus:

Robot Gamma development
Synthotech Ltd has continued to develop the robotic platform, focusing on the Gamma design and responding to the early test scenarios to make the required enhancements. Following the change to a more agile twin chassis design the team were able to begin testing in an atmospheric pressure environment to understand how the robot would respond to the trials.

The umbilical management system or UMS which has been designed to house the tether, additional cameras and the connection for power to reach the robot and data to be returned from the sensors was completed and built.

The non-destructive testing (NDT) method of choice on Project GRAID will be Electro-Magnetic Acoustic Transducer or EMAT and this was further developed and integrated into the rotating arm fixed onto the front chassis of the robot.

Offline Test Rig
The Offline test rig was designed to give the Project GRAID team the opportunity to test the capability of the robotic platform, control station and launch vessel in a similar environment as being on a National Grid gas installation. The rig was designed by Premtech Ltd and built by DNV GL at their dedicated research and testing facility at RAF Spadeadam in Cumbria.
Executive Summary

Key challenges

- From the documentation side of the project there is a significant challenge in writing the non-routine operation (NRO) documents that cover operating GRAID on a live National Grid site.

  In order to address this, Pipeline Integrity Engineers were appointed to provide this documentation using their considerable technical experience.

- Finally the challenge of securing a live transmission site to operate the GRAID robotic platform on remains present, competing against the maintenance and upgrade work already arranged.

Key Risks

- Risk to Online trials
  Several live sites have been selected for Online trials based on their age, significance to the network and accessibility for the launch vessel however the team is still constrained by operational site availability due to other asset health project work. Regular communication between the teams is happening in an effort to mitigate this risk.

- Risk of becoming stuck in the pipeline
  There will always be a risk that the robot may become stuck in the pipeline. To mitigate against this a disaster recovery plan was created and scenarios are being tested to understand what is possible using the manual winch back mechanism.

- Risk of contamination
  There is a risk that the GRAID robot will collect both grease and naturally occurring radioactive material (NORM) whilst carrying out inspections. This material could affect the vision systems and will be collected in the launch vessel once the robot is back. There will be a requirement to clean the robot and UMS and dispose of the material in accordance with National Grid environmental standards.

Project GRAID Launch Vessel

The unique RMA launch vessel was successfully built to the specifications defined by Premtech Ltd and delivered to site in April. Once on site it was over pressure tested ready for use in all of the test scenarios and specialist training was provided by RMA staff on operating the door mechanism and loading the UMS / robot onto the rails.

Offline testing

As part of the successful delivery reward criteria (SDRC) 9.3 deliverables the robot was to successfully complete 10 tests within the offline test rig. Following several weeks at the DNV GL research and testing facility many more than 10 tests were successfully completed and full details of this is supplied in an Appendix to this report.

SDRC Changes

As the team approached the end of the 3rd year of the project there was an opportunity to revise the internal stage gates and successful delivery reward criteria (SDRC) delivery dates. These changes were presented to Ofgem and as it did not constitute an alteration to either the overall cost, time or scope of the project the changes were accepted.
The key activities over the past 12 months have revolved around preparing the robot to begin the Offline trials and complete these ahead of live site trials in Spring / Summer 2018.

Robot development has continued throughout Stage 3 and has responded to the challenges along the way.

During this time the team were able to continue testing and training using the original chassis simply at atmospheric pressure.

This was the first real opportunity that the National Grid Pipeline Maintenance Centre (PMC) team could get to see Project GRAID in action and start to learn the controls and how the system could work.

It is the view that once the Ofgem NIC project has finished in November 2018, PMC would take over GRAID and look to bring the technology into business as usual and offer the inspection as a service to Gas Transmission and potentially other interested parties.

Along with the robot itself, several other aspects of the GRAID platform were finalised:

- The UMS which forms the connection for power to the robot and data back from the sensors was designed, built and pressure tested successfully. The UMS also holds the tether reel and includes several strategically placed cameras to monitor the reel as it unwinds and winds the coil back on the return journey.

- In order to facilitate movement around the site a trolley was also built to transport both the UMS and robot; additionally it has been designed to be elevated to the correct height of the launch vessel allowing safe and easy loading prior to use.

- The GRAID control station and software were also a source of focus for the team ensuring that the where the operators sit, what controls they have access to, how they view the incoming data and if the software is intuitive to use were all addressed.

The EMAT sensors that are housed in the rotating arm have been tested as well, ensuring that the team understand what type of data will come from the sensors and how this can be interpreted.

There will be the ability to control the exact position of the NDT arm to allow the operative to return to a specific location on regular basis.

Two cycles were designed on the robot; the first is to provide a scan of the pipeline where a series of measurements are taken around the whole circumference of the pipe. This will highlight areas of interest where the second scan would be engaged and is a far more in depth scan to build up a picture of the feature.
The Project GRAID test rig and launch vessel were both completed ahead of the Offline trials and located at the DNV GL test facility at RAF Spadeadam in Cumbria.

The rig covers an area of 20m by 8m, includes several 90 degree bends, a T joint, a 45 degree incline and a vertical section to complete the loop. In one of the spools, fans were installed to provide flow and in another a manufactured defect was attached to the inside of the pipe for testing on. The rig was over pressure tested to prove its capability and will be available for use until the project is closed in November 2018.

The launch vessel was specially manufactured by RMA Ltd in Germany. At just under 6 tons when empty the launch vessel is very similar from the outside to a conventional PIG trap but on the inside there are a couple of GRAID specific features.

Alongside writing the NRO, PIE Ltd are also responsible for creating a condition model of each of the live sites. The model will take the data from Project GRAID and combine it with various other sources of inspection data for example, cathodic protection and create a holistic view of that site. The data collected could then be extrapolated to sites of a similar age and setup.

Once completed this model can be used by National Grid to help make decisions on the asset health of their sites and will contribute to the RIIO T2 submission that will need to be provided in the coming years.

In order to operate Project GRAID on a National Grid live transmission site many important documents need to be written and approved, a key one of these is the non-routine operation (NRO) document.

This highlights all aspects of arriving to site, connecting the launch vessel, carrying out an inspection and removing the equipment from site, all in a safe and controlled manner. Pipeline Integrity Engineers Ltd (PIE) were instructed in writing this document as they were best placed to do with many years of experience in this area.

Alongside writing the NRO, PIE Ltd are also responsible for creating a condition model of each of the live sites. The model will take the data from Project GRAID and combine it with various other sources of inspection data for example, cathodic protection and create a holistic view of that site. The data collected could then be extrapolated to sites of a similar age and setup.

Once completed this model can be used by National Grid to help make decisions on the asset health of their sites and will contribute to the RIIO T2 submission that will need to be provided in the coming years.
Once the launch vessel and test rig passed their over pressure tests, Offline testing could begin, at this time the second set of chassis were being manufactured so these tests were carried out under atmospheric conditions.

The Offline tests are designed to prove the functionality of the robotic platform in simulated conditions, enabling sign off for use on live gas assets. They were designed to test the robot’s ability to:

- Operate in pressures of up to 94 bar (g) and gas flows up to 5 m/s.
- Negotiate up to two 90 degree bends
- Travel up to 100m.
- Provide live footage (visual) of the internal pipe condition.
- Undertake simple wall thickness measure of the pipework.

The future of the Offline trials will look to pressurise the test rig and utilise the fans that are installed to simulate a flow of up to 5m/s, once this environment is met, wall thickness measurements will be taken.

Once the team is satisfied with these results then the test rig will be depressurised and re-configured to match the planned live site layouts to allow training to be completed.

The completed tests are summarised here and detailed in the appendices of this report.

<table>
<thead>
<tr>
<th>Number</th>
<th>Test Name</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Can the robot successfully drive past a ball valve?</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Can the robot rive past a Tee junction?</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Can the robot successfully drive around a 90-degree swept bend?</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Can the robot reach the top of the 45 degree slope?</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Can the robot drive around a tee?</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>Can the robot drive through a reducer?</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Can the robot drive around two bends (one 90-degree, plus two 45-degree bends)?</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>Can the robot drive past a 2” outlet (sweepolet)?</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>Test UMS fit in the launch tube</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>Can the robot drive around two 90-degree bends?</td>
<td>Yes</td>
</tr>
<tr>
<td>11</td>
<td>Can the NDT take pipe thickness measurements?</td>
<td>Yes</td>
</tr>
<tr>
<td>12</td>
<td>Can the robot be pull back to the launch vessel</td>
<td>Yes</td>
</tr>
<tr>
<td>13</td>
<td>Test if the robot can travel 100m from the UMS?</td>
<td>Yes</td>
</tr>
<tr>
<td>14</td>
<td>Can the UMS withstand and operate at 100 bar(g)?</td>
<td>Yes</td>
</tr>
<tr>
<td>15</td>
<td>Can the robot chassis withstand 100 bar(g)?</td>
<td>Yes</td>
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<tr>
<td>16</td>
<td>Can the whole robotic system withstand and operate in an environment of 100 bar(g)?</td>
<td>Yes</td>
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<tr>
<td>17</td>
<td>Can a robot run be completed under pressure?</td>
<td>Yes</td>
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<tr>
<td>18</td>
<td>Can a robot run be completed under pressure and flow?</td>
<td>No</td>
</tr>
<tr>
<td>19</td>
<td>Can a robot run be completed under pressure and reverse flow?</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 1 – Offline test schedule for Project GRAID
In the previous Project Progress Report it was stated that the Online trial sites would be Bacton, Cambridge and Aylesbury. As Project GRAID continued, the asset health teams within National Grid were also looking for sites which required maintenance work. As the two project teams were interested in similar sites it was decided that the Cambridge and Aylesbury sites would be left to the planned maintenance work and new sites would be selected.

The subsequent review carried out by the GRAID team outlined the sites of Pannal and Moffat as good locations that live trials can be carried out on. As such Premtech were then instructed to create connection drawings for these sites based on a laser scan and 3D model of the sites.

A considerable design feature of the launch vessel and UMS is the ability to wind back the robot in the unlikely event of a power failure allowing the team to retrieve the robot with no impact to the flow of gas in the network. To build up the disaster recovery plan for GRAID several scenarios were simulated including a pull-back round a 90 degree bend, simulating several camera and instrument failures and even driving back over the tether.

The plan is a working document and will be developed with time and experience in using the GRAID platform during Offline testing.

Mid Stage 3 Financial Performance

As this Project Progress Report falls within the middle of Stage 3 the complete financial status will be presented as part of the end of stage report which coincides with the SDRC 9.4 and 9.6 and will be submitted on or before the 6th August 2018.

National Grid Labour

Less operational staff time was recorded to the project between the start of stage 3 and current day as result of amending the date of Online trials from Autumn 2017 to Summer 2018. Additionally a change to personnel in the core project team reduced the amount of labour used during the start of stage 3 which has subsequently increased the underspend on the project. At this point, due to the Online trials and additional Offline testing it is expected that this underspend will be returned to budgeted amounts by the time the project closes.

Contractor costs

Amendments to contractor costs have been reported to Ofgem, due to the financial nature of this data, it has been removed from this report.

Forecasts

The forecast for the rest of the project shows a steady spend during the remaining Offline trials and then an increase due to the additional Operational staff time needed during each of the 3 Online trials. This will bring the actual spend in line with the budgeted amounts.
Financial Performance against Forecast

The current financial performance against programme forecast is presented in the chart below. The chart reflects the underspend highlighted in the Finance section above which has continued into the beginning of Stage 3. Once the Online trials commence in spring 2018 it is expected the underspend will be bought inline with the planned costs and this can be seen in the forecast.

Programme Husbandry

There have been natural changes to the core National Grid team as expected within large organisations. These have had short term impacts on communication and partner relationships, but while these are regrettable, they have not been to the detriment of the project or timelines.

Key lessons learned are:

Effective Team Working

- Face to face, meetings remain an invaluable form of communication and must continue to be done so regularly.

Change Management

- The ability to respond to changes in the project plan and continue to work towards the final objectives.

Liaising with the Pipeline Maintenance Centre (PMC) early

- As PMC will be utilising Project GRAID after the Ofgem project concludes it was vital to bring them on-board at an early stage to help train the staff, share best practices and make use of their extensive industry knowledge.
Project Bank Statements

Bank statements have been provided to Ofgem. Due to the confidential nature of the project’s bank statements they have not been included in this report.

Over this period, SDRC 9.3 was successfully signed off by the project Sponsor (Mr Karl Yates). The 9.3 report was supplied to Ofgem on the 30th November and outlined the progress against the set criteria:

<table>
<thead>
<tr>
<th>SDRC 9.3 Criteria</th>
<th>Completion</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Launch and retrieval device manufactured to withstand pressure of 100Barg and minimise venting.</td>
<td>Completed</td>
<td>Passed from SRDC 9.2 Stage Gate</td>
</tr>
<tr>
<td>Offline test rig manufactured and positioned at readiness to conduct offline trials;</td>
<td>Completed</td>
<td></td>
</tr>
<tr>
<td>Functional robotic platform manufactured and tested on offline testing facility to conduct visual inspection and wall thickness measurements – a minimum of 10 offline tests will take place</td>
<td>Completed</td>
<td>In reality a greater number than 10 tests were completed if the disaster recovery scenarios are included.</td>
</tr>
<tr>
<td>Establish and publish Disaster Recovery Plan for live trial sites;</td>
<td>Completed</td>
<td>This is a working document and will be added to as testing continues</td>
</tr>
<tr>
<td>Successful data collection/problem identification by robotic platform in response to test scenarios.</td>
<td>Passed to SDRC 9.4</td>
<td></td>
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Table 2 – SDRC 9.3 criteria – Ofgem approved moving the final SDRC 9.3 criteria to 9.4 as wall thickness measurements have not been taken at the full range of flow and pressure scenarios.

Figure 3 – Josh Blake, Project GRAID Technical Lead explaining the details at the Low Carbon Networks & Innovation conference in Telford, December 2017
In response to finding more efficient, better ways of working, operating within the restrictions of a live asset base and to challenges experienced during the project, there was a requirement to amend the remaining SDRC stage gates for Project GRAID.

This proposal does not affect the overall scope, cost or time of the project and so was not classed as a material change as outlined in the revised NIC Governance document. However the request was sent in the form of a letter and a face to face meeting to discuss the changes and to provide a project update.

The changes focus on providing more time for Offline and Online testing and allow the data deliverables to be provided in parallel to prevent any delays. The Delta build stage of the project has been reduced in length, however in reality there have been changes to the chassis in response to the failed pressure tests.

The overall stage gates were then amended to match and the remaining reports were amended so that multiple SDRC reports could be combined with an end of stage report. The proposals were accepted by Ofgem and the revised dates adopted.

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<tr>
<td>Delta Prototype</td>
<td>26/03/2018</td>
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Figure 4 – A diagram of the proposed changes (current on top and proposed below) complete with dates for the completion of the SDRC criteria.
Project GRAID Knowledge Sharing

This year Project GRAID has been showcased at a number of events, several of which have been internal such as the launch of the twin chassis event at the National Grid Head Office in Warwick and the Operation Safety Stand down days. Externally, the International Pipeline and Pigging Integrity Management conference (PPIM) in January 2017 and the Low Carbon Networks & Innovation (LCNI) conference in Telford, December 2017, were fantastic events and generated a lot of interest.

All of the events were a great opportunity to discuss the project with like minded people, develop contacts, discuss shared challenges and promoting Project GRAID to the wider industry.

Patent Application

Throughout 2017 the Project GRAID patent application was discussed between the interested parties. This included a review of all of the other patents which could potentially clash and also which aspects could be defended if applied for. These discussions will continue until project closure.

Award winning Project GRAID

2017 has been a fantastic year for the Project GRAID team winning two high profile awards.

- Innovation Project Award at the 2017 IGEM Gas Industry Awards
- Winner for the Land based / Onshore pipeline category

These fantastic awards recognise all of the hard work and dedication from the entire project partner team, well done everyone!

Communication

As always, communication is key to a successful project and GRAID is no different, our multiple methods of knowledge sharing ensure that everyone who is interested gets to hear about the progress:

- Articles – Several pieces have been written on Project GRAID this year including the above article in The Times newspaper and an extensive update in the Gas International magazine.
- Newsletter – Monthly project progress newsletters are distributed to over 2000 individuals from over 23 countries thanks to showcasing the project on a global scale
- Website – The online material on the website is updated regularly and is a great source of information. The website is projectgraidd.com
- Social Media – LinkedIn, Twitter and Yammer are also used to access social media channels, with LinkedIn seeing the highest level of activity.
- Brochure – A Project GRAID brochure has also been developed which goes into more detail about the project for those interested.

Future Focus

Over the next six months the project will continue to conduct stakeholder engagement activities in line with the project communications plan.

The team will disseminate learning through industry associations and conferences. There will also be a Stage 3 demonstration event which will help to explain the project to the Operations staff of the sites the Online trials will be at.

Additional conferences and showcase events internally will continue to occur including the upcoming Pipeline Maintenance Centre (PMC) Safety Stand Down days.
Accuracy Assurance Statement

We hereby confirm that this report represents a true, complete and accurate statement on the progress of Project GRAID in the twelve month period from December 16 to December 2017 and an accurate understanding of our activities for the next reporting period.

NIC Data Sharing Policy
In response to the revised Gas NIC Governance document (version 3) National Grid have produced a NIC/NIA Data Sharing Policy that is externally available from the company website (click here to view) and is compliant with Ofgem’s requirements.

Appendices:
A – Project GRAID RAID Log (Risks, Assumptions, Issues and Dependencies)
B – Project GRAID Synthotech Offline Test report sheets
C – Project GRAID Premtech Launch & Receive Vessel Report
D – Project GRAID DNV GL Offline Test Rig Report
E – Project GRAID SDRC 9.3 Report
F – Project GRAID Bank Account 151217