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Use of 3D Scanning Technologies to Validate Transport Operations Interfaces

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Abstract

International Nuclear Services (INS) is a wholly-owned subsidiary of the UK Nuclear Decommissioning Authority (NDA) and has extensive proven expertise in providing strategic assessments, consultancy services and feasibility studies relating to irradiated fuel management and worldwide nuclear material transportation by road, rail and sea. It has significant experience of package selection, design, finite element analysis, engineering and licencing; and operates a fleet of maritime vessels under a partially owned subsidiary company named Pacific Nuclear Transport Limited (PNTL).

In 2015, INS undertook a feasibility study of nuclear package transports using an NDA vessel. Due to the expectation of reduced clearances between this particular package and ship hold features, there was a requirement to understand the dynamic and static tolerances to significantly greater levels of accuracy than previous transports. Therefore, a new capability was adopted within the INS engineering team to address this, which allowed for manipulation and analysis of 3D laser scans of the ship holds in conjunction with 3D CAD models of the package and its lifting equipment. This provided a desk-top assessment without the risk of and costs associated with a physical interface check.

This paper describes the process that was adopted to confirm the dimensional feasibility of transporting cargo in the hold of a maritime vessel using 3D laser scanning technologies and 3D CAD models. It also draws parallels with typical methods that could be used in the absence of such technologies, thus highlighting significant benefits in respect of costs, resource requirements, personal safety and asset availability.

Definitions and Abbreviations

CAD	Computer Aided Design
FEA	Finite Element Analysis
INS	International Nuclear Services
PNTL	Pacific Nuclear Transport Ltd
ULB	Universal Lifting Beam

Introduction

INS has over 40 years experience of transporting nuclear cargo by road, rail and sea. For each consignment, given the sensitive nature of the nuclear industry, there is significant emphasis on ensuring that every stage of the transport will proceed without disruption and as efficiently as possible. Such transports inherently consist of multiple, complex procedures relying on various interfacing equipment from torque wrenches; vent purging valves; and lifting beams to high-mass nuclear transport packages; ship holds; and nuclear plant facilities. This range of equipment has significantly varying characteristics and therefore, during the transport preparation stage significant effort is dedicated to ensuring maximised confidence in the compatibility between interfacing equipment.

High levels of confidence can be achieved for the smaller examples of equipment through a thorough design process involving detailed desk top investigations, prototyping and relatively low cost trials. However, in most cases (and typically those that involve heavy duty and large equipment), validation of a concept can be more complex with a relatively large proportion of confidence being gained through full scale and expensive trials that in some cases are carried out following full design and manufacture of the equipment. Such complexities can arise as a result of heavy duty equipment presenting logistical challenges; radiological issues presenting health and safety implications; and security issues making access to equipment and/or sites difficult and time consuming.

In general, such cases rely on relatively large tolerances hence gaining confirmation at cold trial stage is not a significant issue, with unforeseen implications being a rarity. However, in 2015 INS undertook a feasibility study to investigate the maximum number of a specific nuclear transport package that could be transported on an NDA maritime vessels. Unlike previous examples of such work, the dynamic and static clearances were expected to be extremely limited prompting the need for increased accuracy and precision throughout the study.

The vessel that was investigated has 24 ‘flask seat’ positions on which a package can be tied-down, distributed through 10 cargo spaces (5 upper and 5 lower holds, Figure 1). The large number of cargo holds combined with the required levels of accuracy rendered physical surveys unsuitable. For this reason, it was necessary to adopt alternative methods with increased accuracy and significantly reduced lead-times. This paper explains the methodology that was used, giving detail on the number of benefits that have been realised in doing so.

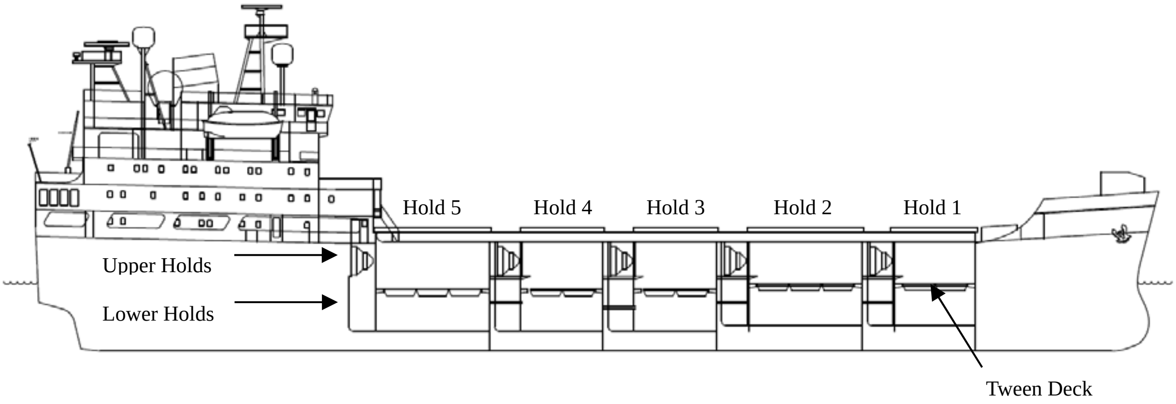


Figure 1 - Schematic of vessel, showing upper and lower holds

Physical Survey

In the past, for feasibility studies investigating the compatibility of a vessel to transport specified cargo, INS would conduct a physical survey of the holds. This would be used to establish the minimum distance to the most intrusive feature on each wall, floor and ceiling, hence building a 3 dimensional envelope in which the package must fit. For this case however, such an envelope was not large enough to accommodate the packages and so increased refinement was necessary. Furthermore, to lower the packages into position without clashes occurring, a combination of horizontal and vertical movements were expected to ‘step’ the package in to position hence driving the need to understand dynamic clearances as well as static.

Given the large number of cargo positions to be investigated and the significant level of detail required for each, the vessel would have to be available for prolonged periods. This would incur significant mooring charges and would render the vessel unavailable for potential transports. Multiple visits would be required as an iterative familiarisation developed from onsite visits in conjunction with desktop-based familiarisation with the package i.e. understanding of the relationship between the vessel and package would need to be shaped through completely isolated investigative environments.

To complete a physical survey, there would be a requirement for two INS staff to visit the ship for an extended period of time. They would need an escort when on-board the vessel meaning 3 people would be required throughout the surveying phase, incurring high expense with associated downtime. Extensive travel and site visits would have health and safety risks associated. This is exemplified by the fact that difficult-to-access areas would need to be surveyed such as the underside of the tween decks (Figure 1). In many cases, access to such areas would require working from height provisions such as scaffolding and harnesses.

The data that could be gathered would be of questionable reliability given the narrow margins and intricate multidirectional movements that were expected when lowering the package into the hold. In addition to this, given the impracticality of recording all relevant dimensions, a prioritised approach would have to be adopted, giving rise to further unknowns and risk. The insufficient accuracy, precision and extent of survey (for this particular investigation) would leave significant concerns prior to any cold trialling. Furthermore, no empty nuclear packages were available before the proposed shipment date, eliminating the possibility of a cold trial with all the relevant assets.

Given the difficulties and resulting delivery risks, INS decided that an alternative approach with increased accuracy and precision was essential, hence 3D laser scanning technologies were utilised. In doing so, INS realised a number of additional and significant benefits over those that were first foreseen.

3D Scanning Technologies

In 2012 INS commissioned 3D laser scans of each of the cargo holds throughout the entire fleet of PNTL operated vessels. The scans logged the position of billions of points and assembled them in a file that, when viewed in appropriate software, shows a highly accurate 3D representation of the ship holds. The software allows for measurements to be taken, importation of 3D CAD models and creation of animations in which clash detection can be enabled. Therefore, 3D laser scanning technologies could be used to bring the existing data for the vessels (cloudpoint data) and package (3D CAD model) together in an integrated virtual environment i.e. direct measurements could now be made between an in-situ package and the hold features. Furthermore, an animation could be created to simulate lowering the package into place in the vessel to fully understand the dynamic clearances and identify any obstructions.

Methodology

Figure 2 shows an image of one of the vessel’s holds alongside a scan of the same that was constructed using the cloudpoint data (working environment for the spatial study). A simplified CAD model of the package and transport frame that was assessed is shown in Figure 3. This was converted to an Object file (.obj) using FEA software before being imported to the working environment where it was then converted to cloudpoint data. Figure 4 shows models of all the assets that were analysed following conversion from CAD models to cloudpoint data. In addition to the package, transport frame and ship hold, a simplified model of the lifting beam was produced to represent the dimensions that extended beyond the maximum dimensions of the package and frame.

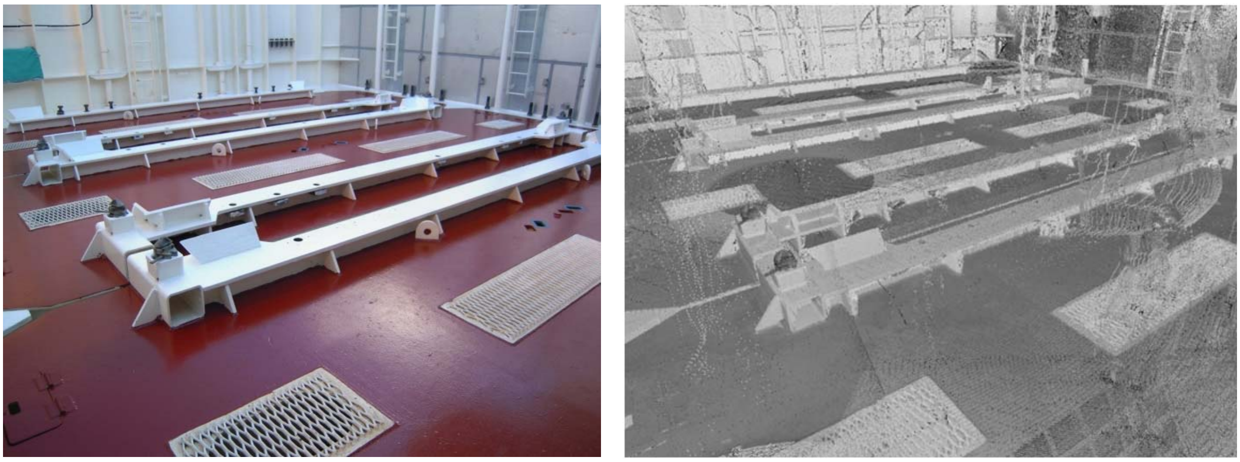


Figure 2 - Image of ship hold (left) and cloudpoint data of scanned ship hold (right)

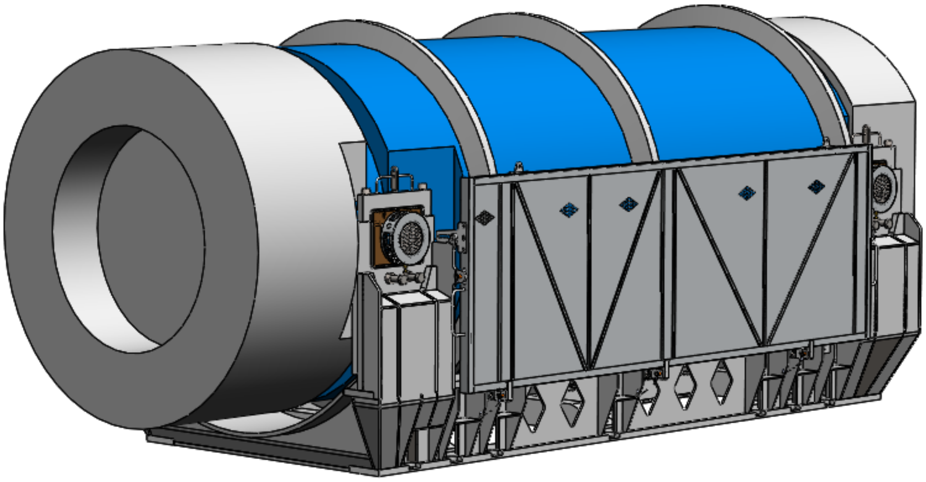


Figure 3 - CAD model of package and transport frame

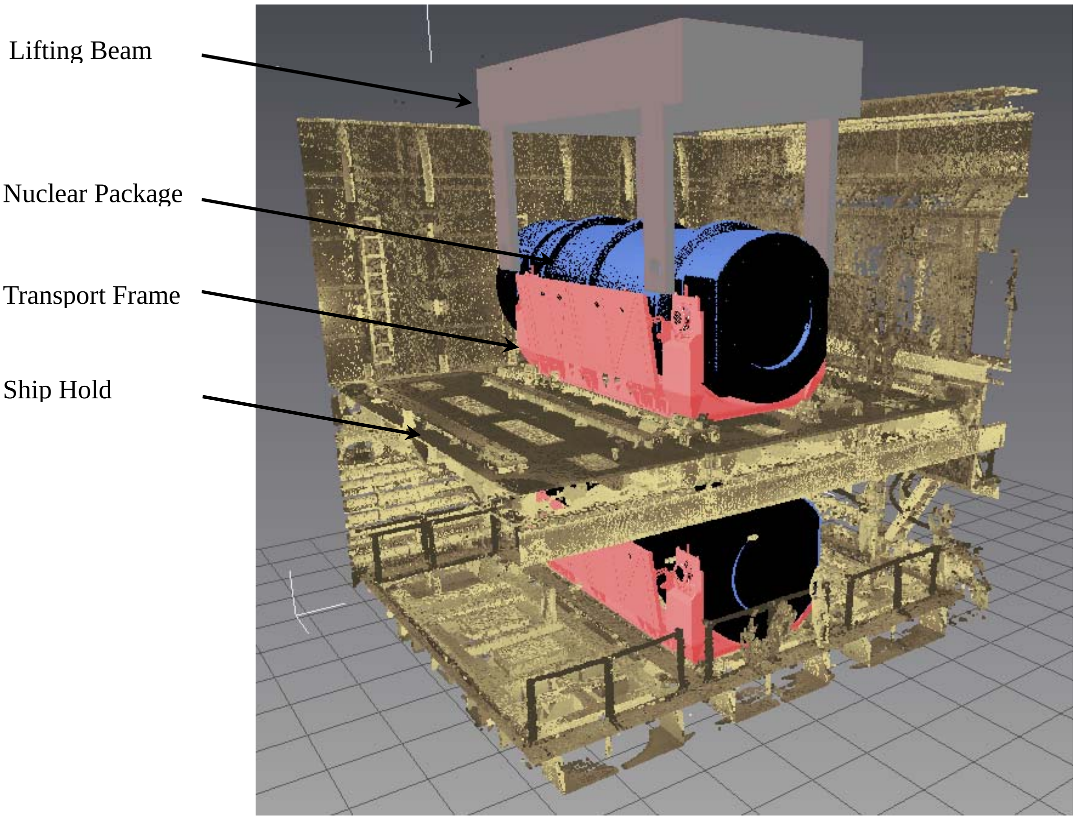
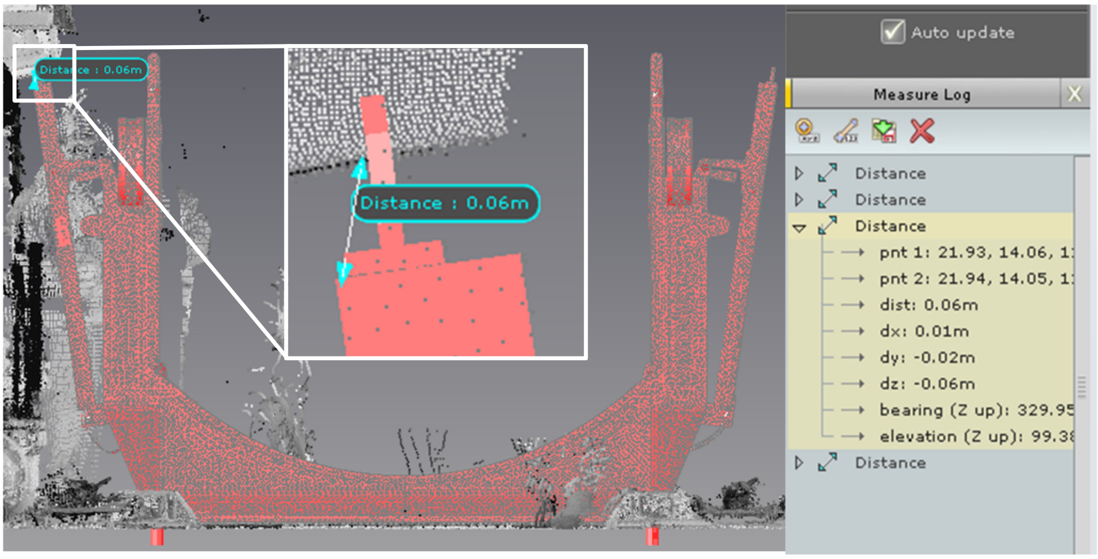


Figure 4 - Equipment to be dimensionally assessed shown in Hold 2 of the ship

At this stage, dimensional analysis could be completed. Figure 5 and Figure 6 show examples of measurements that were taken and results of clash detection analysis that were run. Relatively small clearances can be seen in Figure 5, which following cold trials using the frame and ULB were found to be true representations. Clashes were detected in a number of hold positions, which required varying degrees of modification to rectify. The findings were presented in a report with a graphical summary, which is shown in Appendix A. Note that hold 5 was not considered in the study.



```
Distance
Distance
Distance
    pnt 1: 21.93, 14.06, 1
    pnt 2: 21.94, 14.05, 1
    dist: 0.06m
    dx: 0.01m
    dy: -0.02m
    dz: -0.06m
    bearing (Z up): 329.95
    elevation (Z up): 99.3
Distance
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Figure 5 – Example measurement showing small clearance between transport frame and hold

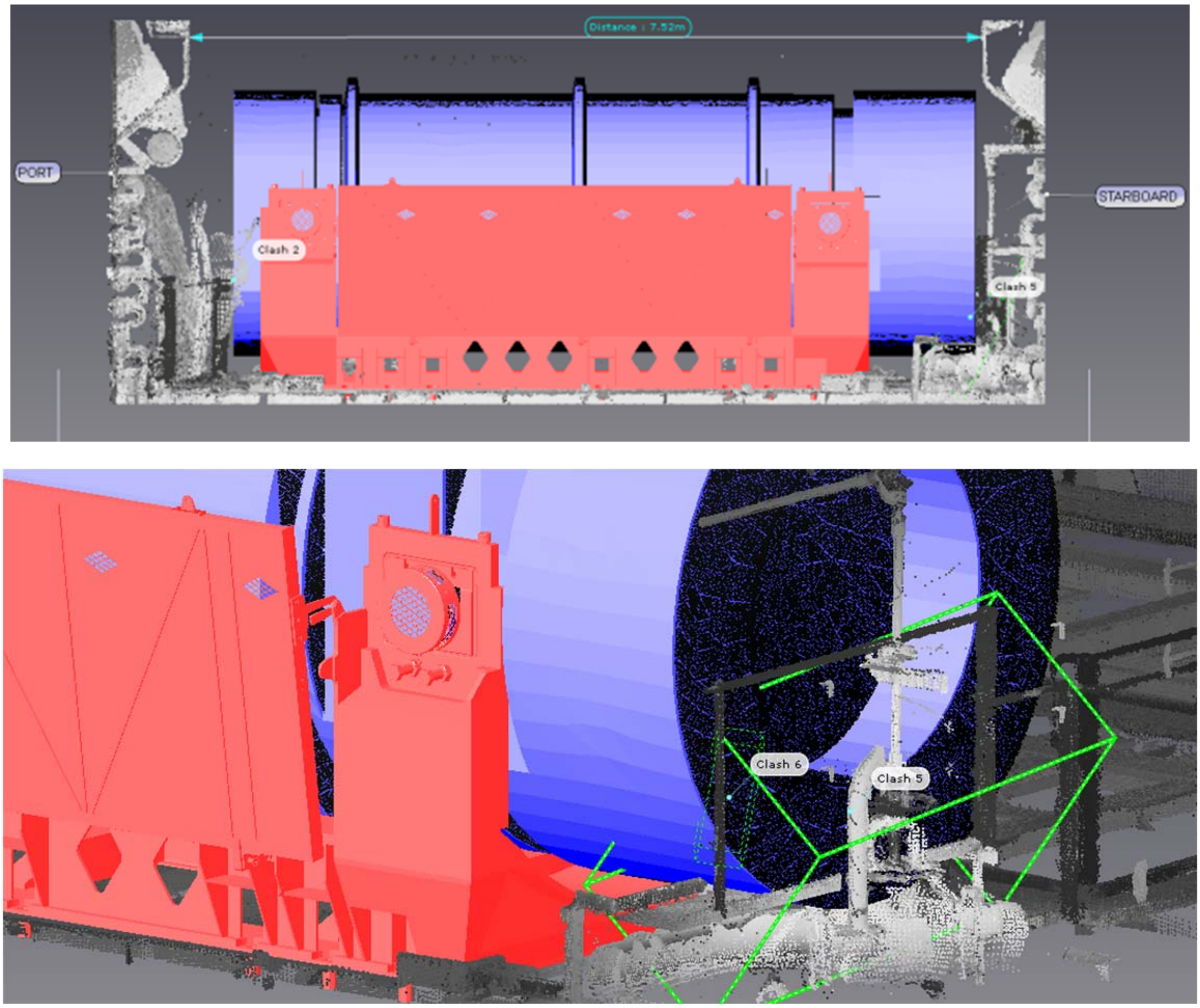


Figure 6 –Example of detected clash between the package and hold

Benefits of 3D Scanning Technologies

Interrogating the cloudpoint data allowed for expert knowledge of the vessel (such as layout, limitations and commonalities between holds) to be gained in a number of days by means of a desktop study. This far exceeded the understanding gained during a yearlong design project that had previously been completed for the same vessel. Furthermore, accurate measurements could be made quickly as and when necessary, addressing questions as they surfaced over an extended period. The previous design project necessitated a small number of measurements to be taken in one of the holds which; took a full day to complete; had detailed planning associated to ensure critical dimensions were not overlooked; and necessitated a site visit with 3 individuals conducting the work. In addition to this, in the final stages of the project, it was deemed necessary to visit the ship before finalisation of the design for a sanity check of four dimensions, the importance of which was not fully understood at the time of the survey (before detailed development of the design). When factoring in travel time, a full day was required to carry this out.

Through interrogation of the data as a desktop study, a detailed understanding of the capability of the vessel to accommodate the nuclear packages was developed without the requirement of a site visit. This is expected to have taken a number of weeks using physical surveys. Although high levels of confidence were gained in this remote manner, it remained prudent to conduct a physical trial at some stage. However, given the detailed understanding of the ship holds, it was possible to design a much more refined trial that pinpointed areas of interest with the smallest clearances, allowing for the trial to be condensed to 3 days (as opposed to 5). Furthermore, prioritisation of each phase was outlined, which became vital due to bad weather delaying the trial, and unavailability of the ship preventing subsequent completion of the remaining stages. Therefore, the study was successfully completed with access to the vessel for 2 days, as opposed to an estimated 4 – 6 weeks associated with the physical survey methodology. The potential for economic savings as a direct result of this is significant as the total cost associated with the vessel whilst located at Barrow Marine Terminal (the location at which surveys can be carried out) is several thousand pounds per day. Additionally, loss of income may be incurred due to the ship's unavailability for alternative movements whilst surveys are being conducted.

Whilst many benefits can be realised with the use of 3D laser scanning technologies, appropriate caution should be applied and it should not completely replace physical trials. In some cases, assets may undergo modification subsequent to being scanned and it is essential that these are fully understood and accounted for. This can either be done through rescanning assets when necessary, or using focussed physical trials in combination with the original scans. Additionally, although very powerful in determining dimensional constraints, judgement is still required for assessing the remaining clearances in line with operability. Examples for this particular case include consideration of rotational movement of the ship (roll, pitch and yaw), and safe access for stevedores when securing cargo.

Additional Activities and Future Opportunities

3D laser scanning technologies have been used by INS to perform a detailed feasibility assessment of the compatibility of multiple assets during transport operations. In addition to this, they have been used by the engineering team for a number of smaller activities to provide quick, inexpensive investigations for a number of internal departments. This has included; confirmation of the location of ventilation systems for the package licencing team, in support of thermal assessments; a feasibility study of stowing bespoke and standard ISO containers on an NDA vessel for the ship management team; and assessment of lowering a nuclear flask into an NDA vessel using a lifting beam that manoeuvres the flask at an angular offset to the ground, for the flask operations team. All of these tasks were simplified using the 3D laser scanning technologies and presented similar benefits to those previously discussed.

In the future, the use of such technologies could be extended to optimise the design process. For instance, if designing a new transport flask, it may be possible to maximise the dimensions by modelling the flask at concept stage in 3D CAD software; converting it to cloudpoint data; then performing a virtual cold trial to see what positions the package could fit, making intricate modifications where necessary. This would eliminate the need to design for a 3D envelope of low resolution that is governed by minimum dimensions, allowing for more efficient use of the available space.

The above opportunity could be taken a step further by creating a 3D working environment that represents all aspects of a transport. For example, if a new package was required to move nuclear material from a power plant to a reprocessing plant. 3D laser scanners could be used to scan aspects of the export facility, conveyance equipment and receipt facility. These could be imported to a virtual environment where any equipment that is designed can be tested to ensure dimensional compatibility. The benefits that have been previously discussed, such as reduced site visits, expense, time and risk could therefore be realised to a greater extent and more frequently. Additionally, in some cases, access to export and receipt facilities may be limited for security and / or health and safety reasons meaning that producing scans containing the specific areas of interest may be more obtainable and effectively give unlimited access to the environments for which equipment is being designed.

Given INS’ more refined understanding of the maritime fleet’s capability and the potential for using the scans to graphically illustrate this, animations, images and measurements could be used to instil greater confidence levels with potential clients when trying to secure business opportunities.

It has also been envisaged that, given the sensitivity of a number of sites and transports in the nuclear industry, there is potential for 3D laser scanning technologies to be used in the assessment of adversarial pathways. This would involve assessing the time it would take for adversaries to reach sensitive areas given specific entrance points. Following this, the guard force would have quantifiable data to compare with their response capabilities and could advise of any modifications that should be made to suitably delay an adversary’s progress in such a situation. This assessment methodology could be applied during the commissioning phase of such sites as part of the validation process; to assess existing sites i.e. to quantifiably ensure compliance with any updates to security regulations; or to further optimise the understanding of existing sites in an industry that demands the highest levels of diligence.

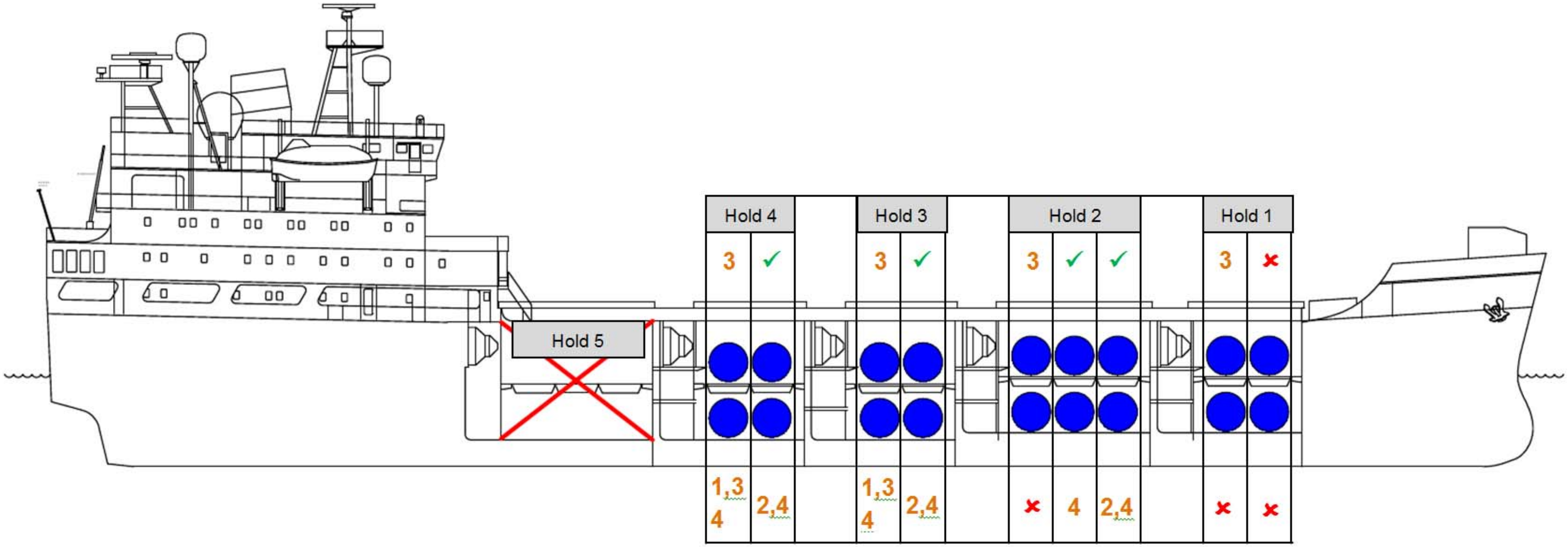
Conclusion

INS has adopted the use of 3D laser scanning technologies to investigate the compatibility of an NDA vessel to carry a number of nuclear packages. This was done to achieve greater levels of detail, accuracy and confidence given the particular challenges presented by the task. As a result, significant additional benefits have been realised as listed below;

- Reduced reliance on asset availability
- Reduced cost for completion of work
- Reduced human resource requirements
- Reduced times scales
- Optimisation of cold trialling
- Quick office based familiarisation of the vessels for anybody who requires it
- Reduced Health and Safety risks

Appropriate caution in using 3D laser scanning technologies has been highlighted, but given suitable stringency, it is believed that the use of such technologies can be further optimised and applied to a wide range of future projects including, but not limited to; simulation of transport operations; design of new transport assets; assessing the security of sensitive sites; and securing future business. Furthermore, the associated long term advantages presented by using such technologies will help to reduce the risk of oversights hence increasing reputation and ultimately contributing to INS' long term strategic aim of being considered an international centre of excellence for transport of nuclear material.

Appendix A



		Possible Mitigation Measures
✓	**Fits with no modification requirements**	
1.	ULB clashes with UA platform girder	→ **Modify existing ULB or commission a new lifting beam**
2.	ULB clashes with fore edge of Tween Deck aperture	→ **Modify existing ULB or commission a new lifting beam**
3.	Open Thermal Guide of Frame clashes with the aft cage	→ **Remove security cage from cargo hold**
4.	Flask Clashes with the inner starboard handrail	→ **Remove (i.e. unbolt) relevant handrails**
×	**Does not fit without major structural modification**	

Note: Adjacent Flask Seats cannot be used simultaneously and the Operational constraints have not been considered.