Institution: Liverpool John Moores University (LJMU)
Unit of Assessment: Sub-panel 12 (UoA 12)

a. Overview

Research in UoA 12 has been actively carried out in two research strands: LOOM (Liverpool Logistics, Offshore and Marine Research Institute) and MEMARC (Mechanical Engineering and Materials Research Centre). These are based within LJMU's School of Engineering, Technology and Maritime Operations from which UoAs 13 and 15 are also returned in REF 2014. In this submission, thirteen Category A staff members are returned, nine of whom are from LOOM (Darlington, Jenkinson, Matellini, Nguyen, J. Ren, Riahi, Wall, Wang & Yang) and four from MEMARC (Jones, Nieves, X. Ren & Yu). Five of those returned are ECRs (Darlington, Matellini, Nguyen, Nieves & Riahi). The research publications produced over the assessment period include 115 SCI cited journal papers (55% increase compared to the previous REF period), 14 other journal papers, 62 conference papers, 6 invited book chapters, and 1 research monograph. Over the assessment period, the returned members have generated £3m of external income, had 31 PhD completions, managed 8 PDRA completions, and achieved a substantial level of international visibility.

In 2008, the School undertook a strategic review with the aim of achieving sustainable research in mechanical, maritime, materials and manufacturing engineering. The overall target set was to develop a critical mass of no less than 10 research-active FTEs, for a submission in this UoA of REF 2014. Since then, our strategy has been to focus on core research areas (e.g. maritime engineering, maritime transport, materials and mechanical engineering) and support new academics through targeted financial support of both PDRAs and PhD studentships (internal research funding of £0.75m from the Faculty/School has been spent over the assessment period).

Overall, the research in this unit has achieved the set target over the 2008-2013 period in terms of research publication, a healthy research environment and academic and industrial impact.

b. Research Strategy

Operational research structure of the University, Faculty and School

The University Research & Scholarship Committee (RSC) sets an overall research framework and a research strategy which are further refined and implemented through the faculties. Research at the faculty level is monitored and managed by the Faculty Research Committee (FRC). Research within the School is managed by the School Research Committee (SRC) which is responsible for research planning, management of research members and distribution of the School's funding to support both researchers and research infrastructure. Jenkinson, X. Ren and Wang are SRC members. Jenkinson is a member of the Faculty Management Committee while Wang sits on the FRC. Members of a research group are encouraged to develop their own individual areas of expertise, where appropriate under the mentorship of more experienced staff; collaboration between researchers across groups and across schools and faculties is actively encouraged.

Operational research structure of the Unit

LOOM - A distinctive strength of LOOM's research is security and risk-based design/operation of large ships, offshore installations, port systems and maritime logistics [research outputs 1-4 of Jenkinson, Wall, Wang, Yang; research outputs 1, 3, 4 of J. Ren; research outputs 1, 2 of Riahi]. An analysis of all journal papers on the topics of "Maritime Security", "Maritime Safety" and "Offshore Safety" published over the assessment period in the ISI WoS indicates that LOOM has the highest number of publications (22 papers) compared to other research centres worldwide. The research in LOOM has been supported by both internal and external grants from many sources including the EPSRC and EU as described in Section 4. More recently LOOM has developed a new research area in modelling and optimisation of design and operational aspects of maritime engineering systems such as port terminals by the appointment of two ECRs [research output 1 of both Darlington and Nguyen]. The support and funding from industry, government agencies, charitable organisations, EPSRC, EU, and internal sources have enabled the development of a number of highly novel and flexible assessment tools to facilitate design and operation of large maritime and other systems. Each research project in LOOM aims at striking a balance between

academic originality and industrial applicability, ensuring that every researcher benefits from a promising career development. Fifteen industrial collaborators including the UK Maritime & Coastguard Agency and ABS Consulting Ltd have provided direct financial or in-kind support of more than £250,000 through 3 EPSRC funded projects completed over the assessment period. LOOM has had 5 PDRAs supported by external grants over the assessment period. The research quality has attracted 15 PhD students funded by external organisations including MoD (Franks) and Commonwealth Scholarship (Atehnijia). LOOM has also financially supported additional 12 PhD members using other external EU/KTP/EPSRC grants (e.g. Matellini) and internal grants (e.g. McNamara).

MEMARC - Research in MEMARC encompasses modelling of thermo-elasticity, thermal striping fatigue and wave propagation in structures (Jones & Nieves), the mechanics of engineering and biological materials (X. Ren), and dynamic modelling and fault diagnosis of engineering systems (Yu). The research work has covered areas relevant to a number of key industrial sectors (e.g. energy and nuclear) and emerging multi-disciplinary research areas (e.g. sport technology and health care). Such research areas have been specifically chosen with consideration given to both sustainability and industrial importance. For example, MEMARC has formulated the main theoretical models used world-wide in thermal striping and has built significant momentum through collaboration with UK Atomic Energy Authority, Serco and AMEC over the past twenty years. An indication of the top international quality of the work in this area is the production of six papers in Proceedings of the Royal Society over the assessment period (Jones). This area has been strengthened by Nieves' appointment as an ECR [research output 1 of Nieves]. The research work in the mechanics of engineering and biological materials, led by X. Ren, has been supported by investment in a modern materials and structural testing laboratory together with a manufacturing and product development laboratory and a high performance computing system for mechanical and manufacturing simulation. In addition, MEMARC is working closely with external laboratories (e.g. Key State Key Laboratory for Advanced Metals and Materials, China). All such collaboration has resulted in tangible research outcomes such as research output 3 of X. Ren. The research in MEMARC has attracted significant support from industry, including Unilever Research and Development who have donated an advanced injection moulding machine, and Swedish Steel who have provided new steel samples for the research in spot welding. Research in dynamic modelling and fault diagnosis of engineering systems, in particular internal combustion engines, has been undertaken in development of new nonlinear modelling methods. These proposed new methods have been applied to automotive engine control and on-board monitoring, process control and new energy sources [research outputs 1-4 of Yu]. Yu's collaboration with Prof. Zhao at the China University of Petroleum has led to the award of a grant of £80k from China Natural Science Foundation. The research on gasoline engines has been supported by the BMW E30 with one PhD studentship (BMW E30 Munich). A paper published in IFAC's Engineering Applications of Artificial Intelligence (EAAI) was awarded the "EAAI Top Cited Article 2005-2010" by Elsevier. Over the assessment period MEMARC has attracted, 3 PDRAs, 20 PhD students and involved the joint supervision of 5 research students both within LJMU and externally.

LOOM and MEMARC have closely worked together to conduct joint research programmes. For example, X. Ren and Jenkinson have jointly supervised 2 PhD students (Krywonos & Elkut). Jenkinson and X. Ren have jointly managed one KTP project. Jones was an advisor for a maritime fracture and fatigue modelling PhD project in LOOM (Chukwuka). Given the common research interests (e.g. fracture and fatigue modelling) shared by LOOM and MEMARC, more joint projects are being developed.

Significant effort has been directed to transfer the research knowledge in the Unit to industry. Jenkinson, the first Professor of Enterprise appointed at LJMU, has led such knowledge exchange activities with other members actively involved. The Unit has had 6 KTP projects described in Section 5 over the assessment period. Jenkinson has also led two consulting contracts of £175k on port security studies and simulator-based training from the Saudi Ports Authority.

Main research objectives over the next five years

The main research objectives for UoA 12 over the next five years are to:

- Continue to support ECRs to become research leaders in their research fields, by providing one-to-one mentoring support.

- Enhance the research facilities through continuing and increasing external funding and industrial partnerships.
- Increase engagement in interdisciplinary research nationally and internationally with both industry and external research organisations.
- Further develop the strengths of the established research areas (e.g. risk assessment) and to exploit future growth of emerging areas (e.g. bio-materials and sports materials).
- Facilitate continued development of a research culture based on creativity, scholarship, interdisciplinary cross-fertilisation and industrial relevance.
- Sustain the Unit's development in terms of PhD and PDRA supervision, external research income generation, research publication and international esteem.

c. People, including:

I. Staffing strategy and staff development

University's research strategy for developing and supporting staff in their research

The University's Research and Innovation Services (RIS) runs a series of informal induction events for new staff members (on average four times each semester). An overview of the professional services offered by the University to support research is provided, alongside the policy and procedural frameworks that underpin research at LJMU (e.g. research ethics and library resources). The University provides a range of career/skills development opportunities targeted specifically at ECRs (e.g. Being an Effective Researcher). All five ECRs returned in this unit have taken up the various training opportunities. On an annual basis RIS through the Director of Research operates an Early Career Fellowship Fund to support and foster collaborative research. Researchers can apply for funding to spend time working with some of the best academics at other institutions or research centres world-wide. Three members (Nguyen, J. Ren and Yang) have received Fellowships (£3k each). An example of a significant outcome is the best paper award in a prestigious international conference received by Yang (IAME 2012 conference in Taipei).

Institutionally, the Careers in Research Online Survey has been used to identify areas for improvement. In response to feedback from researchers, attention has been given to research as a distinct element in the context of the University's standard personal development and performance review process and implementation of specific training needs analysis within this. The University has a formal workload allocation model operating across all faculties. RIS provides a range of research-related training, skill development and networking opportunities for staff at all levels of experience and capability. It also disseminates information about internal and external training opportunities in a dedicated electronic research bulletin. Internal training events include: 1). grant bid clinics, 2). grant incubator workshops, and 3). research grant training for new staff members. All five ECRs have attended each of the above events. The number of other returned members attending each of the events in this submission is 4, 6 and 6, respectively.

The University invites applications on an annual basis for conferment at Reader and Professorial levels. Over the assessment period, three of the submitted staff members were conferred with a Professorship (Jenkinson-2008, Jones & X. Ren-2010) and two were conferred with a Readership (Yang-2010, J. Ren-2013). Academic appointments and promotions to Readership and Chairs are routinely monitored and reported in terms of equality and diversity. The University holds membership of the Athena Swann Charter. Finance and Research Support Officers deal with all financial and contractual aspects of research grants/contracts. Academic staff members' teaching duties are re-allocated for sabbaticals, ranging from a few weeks to twelve months (e.g. Wang for 1 month at Hong Kong Polytechnic University in 2011, funded by Royal Society Kan Tong Po Visiting Professorship (£6k)).

The University was awarded the European Commission's HR Excellence in Research award in May 2012. The University has a robust action plan to continue to support researchers and researcher development which is delivered through the Concordat Task Group and overseen by the University's RSC.

University's research strategy related to the Unit's development

The Unit's strategy fully aligns with the institutional strategy (2012-17) but has more specific features in the areas that LOOM and MEMARC address. During the assessment period, LOOM achieved its research institute status (recognised as a unit of excellence) in 2011 while MEMARC

was awarded its research centre status in 2013. The University has a rigorous procedure for approving research institute/centre status where both track records and research sustainability are considered through the University's RSC. Staff members have been given a commensurate reduction in teaching and administrative duties taking into account their research commitments in terms of managing external grants, producing research publications and supervising PhD students and PDRAs. For example, Yang has been given no more than six teaching hours per week over the assessment period. ECRs have also been given a significant reduction in teaching and administrative workloads. For example, Nguyen has been given no more than five hours of teaching per week since his appointment. All research active members have been given support to attend up to one conference per year subject to approval from the school's research committee. In particular, the School has provided both financial and administrative support to allow its members to enhance the development, promotion and dissemination of their research outputs. For example, Riahi has been supported to network with external researchers in maritime human error assessment, leading to an award of a research grant of $54k in the development of seafarers' reliability assessment model from the Nippon Foundation. Staff members have been encouraged to focus on research quality and submit their research publications to leading international journals in the research areas. Before each manuscript was submitted to a journal, a routine in-house peer review was undertaken by a professor who was not one of the authors of the work.

Development and integration of new staff into the research culture

In 2012 the University made a significant investment to attract a number of outstanding academic researchers into its core areas of academic achievement. Three ECRs (Darlington, Nguyen & Nieves) returned in this submission were the result. The School has a strategy of engaging itself with both public and private organisations in research planning and dissemination of the research outcomes and new appointments are given an opportunity to engage in this. For example, one ECR (Matellini) submitted is 50% funded by an industrial collaborator, Risktec Solutions Ltd. Each new member recruited into the Unit is provided with an experienced mentor for regular informal meetings to discuss their research ideas, for support and guidance with obtaining research funds and also an initial interface with the rest of the School. Regular informal meetings take place between the Director of the School, the mentor and the new academic members to discuss long-term research plans and resources; the Director of the School also conducts formal annual reviews with new academic members during their probationary period. Seed-corn funding is provided during the first three years of appointment for computing and small laboratory equipment, consumables, and travel to meet potential industrial and research collaborators. The School actively arranges ECRs to get involved in PhD supervision and normally provides ECRs with a full PhD studentship. All five ECRs returned are now on the supervisory team for a PhD student. Furthermore, the Faculty operates an annual competitive call for research bids open to all the academic staff with preference given to the bids of new academics (e.g. £2.5k each for Yang, J. Ren & Nguyen in 2010, 2011 & 2012, respectively).

Staff posts are identified against the School and Research Institute / Centre 5-year strategic plan. Over the assessment period, this has led to a number of key appointments in areas of research that both compliment and extend the research activities of the Unit (e.g. Darlington, Nguyen, Nieves and Riahi). The School also has a policy to specifically support those emerging research areas with significant industrial impact.

c. II. Research students

Research student training and support mechanisms at the university/faculty level

The Unit has had 31 PhD and 7 MPhil completions over the assessment period. The number of both full time and part time research students registered in the Unit was 26 in 2008, 33 in 2009, 36 in 2010, 44 in 2011, 44 in 2012 and 46 in 2013 respectively.

Postgraduate research student induction is compulsory and provided by the University's Graduate School within RIS (six times per year). All research student supervisors are required to complete the University's Research Supervisors Workshop. Institutional data from the Postgraduate Research Experience Survey is analysed at the faculty level and is available at the school level. Each UoA is given feedback in order for any deficiencies to be addressed through remedial measures. The Unit has performed well without any major deficiencies identified although a pro-active approach has been in place to ensure that all research students progress as planned.

RIS manages (2011-2013) a conference travel fund specifically to enable eligible research students to attend a conference (UK or overseas) and disseminate the findings of their research. Four PhD students in this unit have been awarded funding for attending a conference. The University's Research Degree Regulations require that all registered postgraduate research students and their Directors of Study report annually on progress in line with the University's Code of Good Practice for Annual Monitoring. Annual Monitoring reports are collated at the faculty level and reported to the University Research Degrees Committee. RIS operates a comprehensive research development training programme in line with the Researcher Development Framework (Vitae) in response to researcher needs.

The Faculty has a PhD recruitment unit with a designated person responsible for PhD applications relating to LOOM and MEMARC. Wang is the academic PhD admissions tutor for this unit. The success rate over the assessment period is 100% for those who have undergone their viva. Each research student who completed within the required period of completion has had his/her PhD binding fees covered by the School.

Research student training and support mechanisms at the local level

Research students are usually grouped into clusters of four to eight in separate offices, according to their research areas. The School has a policy that each research member is provided with a new PC/laptop with all research related expenditure (e.g. photocopy costs and stationery costs) covered by the School. The School also provides funds for PhD students to present results of their research at one major conference during their PhD research. 10 PhD students (e.g. Lee) have been given support of this nature for attending conferences.

The policy for research student recruitment in the Unit is to recruit good quality PhD students, using predominantly home-grown talents and international links and then, upon successful PhD completion, to provide a post-doctoral post for the most promising ones. An example of this policy is Matellini in LOOM who, after completing his PhD at LJMU, was employed as a PDRA in 2012 using the funding provided by the Faculty and then took up a lecturing post in 2013. When beneficial, a PhD student is appointed with an established external supervisor. One example is that Prof. Zio of Politecnico di Milano acted as an external supervisor for a LOOM PhD student, Cunningham and hosted him for two research visits, each being of two weeks duration.

d. Income, infrastructure and facilities

Income

23 external grants totalling about £3m have been won from external funding sources over the assessment period. The major external grants led by LOOM or MEMARC are:

1. EPSRC grant "Asymptotic and numerical modelling of faults and thermal striping in materials" (EP/H018239/1, Jones, £249k, 2010-2013) in collaboration with Serco (linked with EP/H018514, Movchan of Liverpool University, £111, research output 3 of Jones).
2. EPSRC grant "Enabling security and risk-based operation of container line supply chains" (EP/F024436/1, Wang & Jenkinson, £247k, 2008-2012) in collaboration with five industrial partners) and linked with (EP/F024606, Yang of Manchester University, £315k) led by LOOM.
3. EPSRC grant "A risk-based fire and rescue management system" (EP/F041993, Wang, Wall & Jenkinson, £135k, 2009-2012) in collaboration with Mersey Fire & Rescue Authority [research output 1 of Matellini].
4. EU grant "Intelligent Transport for Dynamic Environment (INTRADE)" (Yang & Wang, €542k of €3.5m to LOOM, 2009-2013) with six other partners including AG Port of Oostende (a major WP led by LOOM).
5. EU grant "Strengthening east and west logistics flows in North West Europe (WEASTFLOWS)" (Wang & Yang, €350k of €4.5m to LOOM, 2011-2015) in collaboration with other fourteen partners including the Port of Dublin (a major WP led by LOOM).
6. EU grant "REFERENCE: Research network on flexible risk assessment and decision science" (Wang & Yang, €383k, 2012-2016).
7. EU grant "ENRICH: EC-China research network on integrated container supply chains" (Yang, Wang & Riahi, €590k, 2013-2017).

Staff within the Unit have also been successful in wining external grant income from the following external sources: KTP (6 awards), EPSRC CASE (2), RCUK's Travel Grants Fund (2), the Nippon

Foundation (1), Leverhulme Trust (1), Royal Academy of Engineering (1) and industry (3). In addition, external income has been attracted from overseas organisations to support 20 PhDs.

Enhancement in research infrastructure and facilities

The University RSC (chaired by a PVC) is responsible for LJMU's over-arching research strategy. Working with the Faculties it identifies the main infrastructure requirements and priorities to deliver the strategic objectives of the institution and its research institutes and centres. It provides leadership for staff within the University and quality assurance support for research and PGR programmes. In addition to its Code of Practice for Research, the University operates formal protocols/procedures for research governance and the investigation of alleged misconduct in research. Additionally, core principles and expectations with regard to publically-funded research data and research outputs are explicit in LJMU's research data management policy.

Over the assessment period the University has invested approximate £1m in research infrastructure, resulting in major improvements in capability in the LOOM and MEMARC sub-areas. Funding sources include RCIF (£200k), the Faculty's facility grant (£300k) and the School's research investment grant (£500k). Key developments include a new materials and structural testing laboratory, a modern manufacturing and product development laboratory, two modern design studios, a research laboratory for seminar facilities, various research software suites, and a new ship bridge simulator research suite. The School has an estates strategy that all research rooms and laboratories are provided with sufficient space with respect to the number of active researchers and that all research spaces are refurbished every 5 years. All the research rooms and laboratories in the Unit have been refurbished over the assessment period. Furthermore, the strategic merging of the School and Lairdside Maritime Centre, which hosts the UK's only 360^{o} ship bridge simulator for training and research purposes, enables the researchers in LOOM (e.g. Chen) to use the state-of-the-art facilities for their research projects.

e. Collaboration and contribution to the discipline or research base

Promotion of research activities and research culture

The School has a lively research culture, promoted through regular seminar programmes held by the School (promoting interdisciplinary opportunities), LOOM and MEMARC. The Unit has monthly research seminars. In all such events, eminent international academics and industrial researchers (e.g. Prof. Nikitakos from University of the Aegean) are invited to give presentations. Attendance at the School's Annual Research Seminar is mandatory for research students and each student is obliged to give at least one presentation during the period of his/her PhD research. Keynote research lectures are also delivered through invited external leading academics and industrialists at a frequency of 4 times per year (e.g. Dr. Hughes of Marine Accident Investigation Branch). Secondments of staff to leading research centres and industry have taken place. X. Ren received the support of £18k from the Royal Academy of Engineering for an industrial secondment of 6 months from October 2010 at Serco Technical Services. Wang was awarded a Leverhulme Fellowship of £42k to investigate the performance of maritime regulations in collaboration with three overseas universities in 2011-2013.

RIS and Library & Student Support services jointly organise Research Café events to encourage inter-disciplinary networking and to increase the visibility of research internally, particularly amongst student populations (four times each semester). They regularly attract 30-50 researchers from across the University.

The members returned in this unit have also made wide, energetic and significant input to the development of the discipline areas over the assessment period. Examples of such contributions include:

- 16 editorships/editorial board memberships of international journals (e.g. Journal of Marine Science and Technology).
- 6 research awards including 1). Research Leadership Award to Wang from Society for Reliability Engineering, Quality & Operations in 2008, and 2). American Welding Society's A. F. Davis Silver Medal Award to X. Ren and his researchers/collaborators for their work "*Effect of titanium content on microstructure and wear resistance of Fe-Cr-C hardfacing layers*" in 2012).
- Involvement in organisation of 25 international conferences (e.g. ESREL 2008-2013).
- 10 national/international policy/investment panellists (e.g. International Maritime Organization's Formal Safety Assessment Experts Group member since 2009).

Interdisciplinary and collaborative research

The research in maritime risk assessment and logistics modelling areas is interdisciplinary in nature and as a result requires international collaboration and cooperation with researchers in areas such as decision sciences and business studies. As part of our strategy, we have therefore developed a strong network of collaborations around the globe, working with some of the best recognised teams in the key areas we work in for both LOOM and MEMARC. This is reflected in the list of collaborative grant awards listed in section 4 above. In LOOM, there are other examples given as follows. Yang has collaborated with Prof. Fang of Shanghai Maritime University throughout the assessment period [research output 2 of Yang]. Wang has collaborated with Prof. Yan at Wuhan University of Technology and hosted one PhD exchange student (Zhang) for a period of twelve months in LOOM. J. Ren has collaborated with Prof. Burns at Loughborough University in supply chain management [research output 2 of J. Ren]. J. Ren also collaborated with Prof. Celik at the Technical University of Istanbul and hosted one of his PhD members for six months (Cecik). Nguyen has collaborated with Prof. Yao from Birmingham University. In LOOM, 25 SCI cited journal papers have been published with collaborating institutions nationally and internationally over the assessment period.

The research in MEMARC has also been interdisciplinary and collaborative with industry and other universities. Jones hosted an international research visitor, Dr. Gei of the University of Trento in May 2008 and 2009 to investigate modelling of defects in welds and heterogeneous media [research output 4 of Jones]. Jones as a co-investigator collaborated with Prof. Movchan from Liverpool University through a joint EPSRC grant “Thermal vibrations and localisation phenomena for solids (EP/D035082, £145K, 2005-2008)” [research outputs 1 & 2 of Jones]. Jones has co-organised, with the universities of Brunel, Sydney, Manchester, Aberystwyth, Cagliari and Liverpool, 6 international workshops in solid mechanics over the assessment period. X. Ren has collaborated with several external leading researchers including Prof. Silberschmidt at Loughborough University. All such collaborations have resulted in joint journal publications (e.g. research outputs 1-4 of X. Ren). In MEMARC, 45 SCI cited journal papers have been published with collaborating institutions nationally and internationally over the assessment period.

Supporting relationships with industry

The Unit has close relationships with industry which enables identification of the research needs and knowledge transfer to industrial users. For example, LOOM has engagement with industrial partners (e.g. ABS Consulting Ltd and Peel Ports) through two EPSRC grants. The two EPSRC CASE projects led by X. Ren have involved direct R&D work with industrial partners. For example, the project with Clatterbridge Centre for Oncology has enabled an improved understanding of the mechanics of the human pelvis system and the effect on radiotherapy treatment planning. The research work in MEMARC has also attracted several industrial projects with financial support of over £200k. One of the industrial research projects in MEMARC has resulted in a new sport footwear design with improved safety performance (Anta, Hong Kong). The research outcomes from the Unit have led to significant commercial and social benefits (e.g. £1.2m of new business for Risktec Solutions Ltd from 2011 to 2013; £2m new sales worldwide for ANTA in 2012).

The Unit has been actively engaged in transfer of knowledge to industry. For example, over the assessment period the Unit has had six KTP projects with Lewis Reed Ltd, Vista Panels Ltd, Delta Fluid Products Ltd, Northstone Ltd, Risktec and Cubis. These projects range from risk management to engineering optimisation. The project with Delta has created a new design methodology on electronic flow measurement (which won the Best EPSRC funded Partnership Award 2009). The project with Northstone has created an engineering knowledge base for modular lightweight glass reinforced plastic (GRP) sealed chambers (which won the Business Leader of Tomorrow Award 2009). The project with Risktec has developed a new training business in risk management in high-risk industries (which was awarded the highest grade of “Outstanding” by the KTP Grading Panel in 2010 and the best North West KTP in 2011). A current KTP project with Cubis (KTP Programme No. 8079, Jenkinson, £78k, 2012-2014) allows the Unit’s knowledge to be transferred to design and manufacture of large lightweight sealed GRP chambers for underground applications.