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ENGAGING UK INDUSTRY IN THE DEVELOPMENT OF NEW STANDARDS FOR QUANTUM TECHNOLOGIES

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Approved on behalf of NPLML by
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GLOSSARY / ABBREVIATIONS

Term	Definition
AG	Advisory Group
AIRQKD	ISCF project addressing short to mid-range quantum secure communication in free-space
AQUASEC	Agile Quantum Safe Communications
BEIS	Department for Business, Energy & Industrial Strategy
BIPM	Bureau International des Poids et Mesures
BIPM	International Bureau of Weights and Measures (BIPM)
BSI	British Standards Institute
BSI(DE)	Federal Office for Information Security (Germany)
CCL	Consultative Committee for Length
CCPR-WG-SP TG7	Consultative Committee for Photometry and Radiometry Working Group on Strategic Planning, Task Group 7
CCs	Consultative Committees
CCTF	Consultative Committee for Time and Frequency
CGPM	General Conference of Weights and Measures
CIE	International Commission on Illumination
CIML	International Committee of Legal Metrology
CIPM	International Committee for Weights and Measures
CPU	Central Processing Unit
DCMS	Department for Digital, Culture, Media and Sport
DI	Designated Institutes
DIN	German Institute for Standardisation
EMN-Q	European Metrology Network for Quantum Technologies
EMPIR	European Metrology Programme for Innovation and Research
ETSI	European Telecommunications Standards Institute
ISG	Industry Specification Group
FG-QIT4N	Focus Group on Quantum Information Technology for Networks
FGQT	Focus Group on Quantum Technologies
FPGA	Field Programmable Gate Array
FQS	Federated Satellite QKD System
FSWG	Frequency Standards Working Group
GPU	Graphics Processing Unit
H2020	Horizon 2020
HAL	Hardware Abstraction Layer
HMG	Her Majesty's Government
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
INRIM	Italian National Metrology Institute
ISCF	Industrial Strategy Challenge Fund
ISO	International Organisation for Standardisation
JTC 1/SC 27	Joint Technical Committee 1, Subcommittee 27
JTC1/WG14	Joint Technical Committee 1, Working Group 14
ITU-T	International Telecommunication Union Telecommunication Standardisation Sector

ITU-T/SG 13	ITU-T Study Group 13
ITU-T/SG 17	ITU-T Study Group 17
JC	Joint Committees
KRISS	The Korean National Metrology Institute
LNE-SYRTE	Laboratoire National de Métrologie et d'Essais-Systèmes de Référence Temps-Espace
NCSC	National Cyber Security Centre
NICT	National Institute of Information and Communications Technology
NISQ.OS	Noisy Intermediate-Scale Quantum Operating System
NIST	National Institute of Standards and Technology (the United States' National Metrology Institute)
NMI	National Metrology Institutes
NPL	National Physical Laboratory
NQCC	National Quantum Computing Centre
NQTP	National Quantum Technology Programme
OIML	International Organisation of Legal Metrology
OPENQKD	Open Quantum Key Distribution
PRISMS	Protocol Randomness and Information Security Measures for Space
QKD	Quantum Key Distribution
QPU	Quantum Processing Unit
QRNGs	Quantum Random Number Generators
QT&E	Quantum Test and Evaluation
ROCIT	Robust Optical Clocks for International Timescales
SDO	Standards Developing Organisations
SME	Small-to-Medium Enterprise
UKSA	UK Space Agency
WG	Working Group

EXECUTIVE SUMMARY

Under the National Quantum Technologies Programme (NQTP), one of the key areas of work is described as “Strengthen engagement in international standards and benchmarking”. The National Physical Laboratory (NPL) has produced two reports which describe the work which NPL has delivered in support of this objective in the period 2020-21. This report covers engagement with the UK quantum community. The second report describes international activity in quantum technology standards development and NPL’s involvement in that process.

In support of a wider awareness and engagement from UK industry in the development of new standards, this report explains the background to standards, why they are needed and how they are developed. Previous work of NPL in the development of standards for nanotechnology is presented as a worked, functional example and offered as a methodology for quantum standards development.

NPL has worked with partners to deliver a well-attended on-line meeting with high-profile speakers involving well over 130 people from the UK quantum community at which were described the value of standards, the process of standards development and the current situation in the development of quantum standards. Multiple parallel afternoon workshop sessions brought together focussed groups looking at the main technology themes of the quantum programme to draw out the key areas for future work. The headline outputs are that:

- Work on standards should encourage efficient innovation and not stifle creativity.
- UK Industry needs to get involved in standards development, supported by government organisations. This must be on an international stage as well as within the UK.
- “Standards” work should include agreements within the community such as standard specifications, best practice guides, standard testing methods, standard nomenclature, and vocabulary; not just the large-scale documentary standards which might develop over time.
- A map of standards activity should be created to inform and guide UK organisations to the most relevant group.
- Government can help industry by setting up a forum for information exchange on standards which could be part of a wider industry grouping, or a standards committee.

This report concludes with a proposal involving NPL and BSI for a new UK approach to engagement in the quantum standards development process for industry and across government. The key elements of this proposal are that:

- A UK national standards committee or panel should be established consisting of key stakeholders from BSI, NPL, industry (especially SMEs), academia (including the QT hubs), and other interested parties.
- A UK quantum industry group should be re-established, and the standards panel should report updates and progress to this industry group.
- NPL should produce a quarterly report on the current position to the Strategic Advisory Board of the NQTP. Significant items can also be transmitted to the main programme board. NPL should also ensure that work on quantum standards is made visible to a wider government audience.

The work in this programme has greatly raised the profile within the UK quantum community of standards development and has started to build a co-ordinated approach for future international engagement.

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1 INTRODUCTION

This report is an output from the NPL quantum programme for the period April 20 – March 21. This period is the first year of a proposed four-year programme to enable the capabilities and expertise of the National Physical Laboratory (NPL) to fully support the UK National Quantum Technology Programme (NQTP) and the UK's aspirations for economic growth based on quantum technologies. The NPL programme is funded by the government department of Business, Energy and Industrial Strategy.

The NQTP vision to create a quantum-enabled economy is described in the 2020 strategic intent document for the national programme (UK National Quantum Technologies Programme Board, 2020). The strategic intent document details four main themes of work and a number of key areas within those themes which are required to deliver the desired outcomes and benefits for the UK.

Under the theme of "Stimulate market growth, unleash innovation, and create a thriving ecosystem", one of the key areas of work is described as "Strengthen engagement in international standards and benchmarking".

NPL has produced two reports which describe the work delivered in support of that objective in the period 2020-21.

The process of standards development is underway around the world. In a separate report NPL describe the current position across many different standards bodies and the engagement which NPL scientists have in this process.

In this report NPL describe the activities undertaken to raise awareness in the UK quantum community of the importance of standards and the importance of the UK community engaging with the standards development process.

The first section of this report details the background to standards, how they are developed and the need for standards and their coordinated development. Previous work of NPL in the development of standards for nanotechnology is presented as a worked, functional example and offered as a methodology for quantum standards development.

The report describes a workshop on standards which was organised for the UK community by NPL and other partners from the NQTP.

The report concludes with a proposal based on the outputs from the UK workshop on how to take forward the stronger engagement of the UK community in the process of standards development.

1.1 WHAT IS A DOCUMENTARY STANDARD AND HOW ARE THEY DEVELOPED?

1.1.1 Introduction

This section provides a short introduction to what standards are, why they are important and how they are developed. A case study in how documentary standards were developed in nanotechnologies and graphene is outlined as a functional example for documentary standards development within the quantum technology area.

International standards provide a strong basis for the development of national and international regulation, helping reduce barriers to international trade. International standards represent the current best practice in a particular application or field as they are made by experts in the field who work together to achieve consensus from all stakeholders. Standards allow comparison of results from an agreed measurement method. Hence by following a standard, results taken on one day are comparable to those taken on subsequent days. In addition, results taken on different instruments, in different laboratories or by different people around the world should be comparable. Standards can also be specifications stating what information is required. Therefore, while there may be an initial cost to comply with standards, organisations save significant time and money in the long run by complying with standards. In addition, there can also be a cost, sometimes hidden, of not complying with standards with the loss of market size, market share and new opportunities. Standards are usually voluntary; they do not have to be used but sometimes they can form the basis of regulations or be referred to in regulations. In these circumstances they are usually mandatory.

1.1.2 Types of Standards

There are two types of standards: documentary standards (‘Norms’) and artefactual standards including reference materials. In this report only documentary standards are considered. A standard is defined by ISO as a 'document, established by consensus and approved by a recognised body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context' [ISO/IEC Guide 21-1:2005, 3.1].

A standard is developed by a committee in a recognised body such as ISO or ASTM – standards development organisations (SDOs). It is not developed simply by one person but by a group of people who are experts in their field, who come together to agree the text of the standard via round table discussions and formal ballot processes. It is a normative document, other types of documents published by ISO are available, as detailed later.

Example steps in the standardisation process are for a member country of the SDO to propose a topic to a relevant standards committee. They will then work up a good draft document often in consultation with experts. It will then be submitted to the standards committee as a new work item proposal. In ISO this consists of a form explaining the purpose and relevance of the standard and a draft ISO standard. The new work item proposal is balloted by experts from member countries inviting their initial comments and the appointment of named experts to assist in the development of the standard. If the draft is approved in the ballot it becomes a “new work item”, and will then progress through a series of discussions, commenting stages and official votes in order to obtain a consensus amongst the experts on the text and contents of a draft standard.

There are three main types of ISO outputs, full international standards, technical specifications and technical reports. A Technical Specification (TS) is a short-term type of standard which addresses work still under technical development. Many of the outputs in nanotechnology standardisation are currently technical specifications. A Technical Report (TR) contains information of a different kind from that of standards or specifications. It may include an informative report, or information of the perceived state of the art in an area of importance to the technical committee.

There are also regional standards. European Standards (ENs) are documents that have been ratified by one of the three European Standardisation Organisations (ESOs), CEN, CENELEC or ETSI. Although they generally deal with different fields of activity, CEN, CENELEC, and ETSI do cooperate in a number of areas of common interest, such as information and communication technologies (ICTs). They also share common policies on issues where there is mutual agreement. An EN (European Standard) "carries with it the obligation to be implemented at national level by being given the status of a national standard and by withdrawal of any conflicting national standard". Therefore, a European Standard (EN) automatically becomes a national standard in each of the 34 CEN-CENELEC member countries. Generically, there are different types of standards. In Europe, these are detailed in CEN/CENELEC, EN 45020:2006, Standardisation and related activities - General vocabulary, 2006 and are listed in Table 1.

Table 1 Types of standards as defined in EN 45020 (not exhaustive)

Type of standard	Definition
Basic standard	Wide-ranging coverage or contains general provisions for one particular field
Terminology standard	Concerned with terms, accompanied by their definitions etc.
Testing standard	Concerned with test methods, sometimes supplemented with other provisions related to testing
Product standard	Specifies requirements to be fulfilled by product or group of products, to establish its fitness of purpose
Process standard	Specifies requirements to be fulfilled by a process, to establish its fitness of purpose
Service standard	Specifies requirements to be fulfilled by a service, to establish its fitness of purpose
Interface standard	Specifies requirements concerned with the compatibility of products and systems at their point of connection
Standard on data to be provided	Contains a list of characteristics for which values or other data are to be stated for specifying the product, process, or service

National level standards also exist and are published by the British Standards Institute (BSI), this includes British standards (BS), publicly available specifications (PAS) and published documents (PD). A PAS is always developed in response to a commission by a sponsor who funds a resource-intensive process which allows it to be developed and published quickly to satisfy an immediate business need. Published Documents (PD) is a catch-all term for UK standard-type documents that are not backed by the same degree of public consultation and consensus as full standards. In many cases they are provisional, and subject to further development on the basis of experience gained during the first year or two of their use.

National metrology institutes, such as NPL do also publish their own good practice guides. These are not standards but can sometimes be used as fore-runners to future standards. Good practice guides can be developed and published quickly and be made freely available for industry use prior to the development of standards. The business of quantum technologies, like most industries, involves interactions between people from different fields and different backgrounds. For example, this could include physicists, engineers, regulators, industrialists, computer and data scientists, and many others. In order to avoid any mistakes or misunderstanding and to facilitate reliable exchange of information, it is essential that all people involved in this field use the same terminology. A common set of terms and their definitions are thus essential. To meet this need, the ISO technical committees typically develop terminology standards. ISO make available for free all ISO published terms and definitions. These are available online via the ISO online browsing platform (OBP). Here users can search for specific terms and see the ISO definitions and also search for standards and be able to browse the terms and definitions sections of any standard at no cost.

Standardised terminology in quantum technologies is best developed with appropriate liaison to avoid duplication. Some important existing terminology documents include:

- ISO TS 80004-12 Nanotechnologies — Vocabulary — Part 12: Quantum phenomena in nanotechnology, developed by ISO TC229 (nanotechnologies)
- ISO CD 18115-3 Surface chemical analysis — Vocabulary — Part 3: terms used in optical interface analysis which contains core optical terminology and is being developed by ISO TC201 (surface chemical analysis).
- ISO 10934-1:2002 Optics and optical instruments — Vocabulary for microscopy — Part 1: Light microscopy, and other parts of 10934 developed by ISO/TC 172/SC 5 Microscopes and endoscopes
- ETSI GS QKD 007 V1.1.1 *Vocabulary (2018-12)*

1.2 CASE STUDY – NANOTECHNOLOGIES AND GRAPHENE

At the beginning of this century an increase in the deliberate application of nanotechnology to commercial products became evident. Alongside this activity there was a growing demand for the standardisation of nanotechnologies. To meet this demand BSI established a committee on nanotechnologies and strategically lobbied for the UK to chair both ISO and CEN committees in nanotechnologies. Hence, ISO established a new technical committee for nanotechnology, TC229 (nanotechnologies), in 2005 with the chair and secretariat being held by the UK. About the same time, ASTM, IEC and CEN also formed nanotechnology standardisation committees.

In the UK and internationally, surveys of standardisation needs were undertaken ranking possible projects in terms of a) priority of need b) timeliness (is the technology ready). It is no use developing standards until the technology is mature enough.

The UK funded and quickly developed BSI UK documents (PD and PAS) on terminology, nanomaterial handling, health and safety that were freely downloadable. These were written as forerunners to ISO documents and often formed the basis of later ISO documents. In 2008, 3 years after the committee was formed, the first ISO technical specification from ISO TC229 was published on key terms in nanotechnologies.

In terms of the structure of the committee, initially study groups were formed which became working groups as work items were developed. These are split into JWG1 - Terminology and Nomenclature, JWG 2 - Measurement and Characterisation, WG 3 - Health, Safety and Environment, WG 4 - Material Specification, WG5 - Products and Applications, a liaison coordination group and a task group on consumer, societal and sustainability aspects of nanotechnologies.

Nanotechnologies is a horizontal technology cutting across many industrial sectors and areas. Hence all the working groups meet in the same location to enable cross working group activity. In addition, ISO TC229 liaises with many other relevant ISO committees for example in particle characterisation, surface chemical analysis and biotechnology. It also liaises with external organisations including OECD and VAMAS.

In the graphene and two-dimensional materials arena, NPL realised early on the important role it had to play in standardisation of these materials. Hence in 2013, a proposal was put to ISO TC229 to develop graphene terminology. This was accepted, and the document developed with UK and international expert input was published in 2017. The committee is now starting a process to look at revising and improving the document.

In 2017 NPL and the University of Manchester worked together to publish an NPL good practice guide (GPG) on the measurement of graphene. This was available as a free download prior to ISO standards being published. In ISO TC229, an informative technical report was developed led by USA and Korea linking measurement methods to measurands. The NPL GPG formed the basis of two work items on structural characterisation of graphene flakes and of CVD-grown graphene. The first of these was published in March 2021 with the latter now being developed. Other standards under development are on graphene oxide characterisation and chemical characterisation. A summary of the standards developed and being developed in the graphene arena is shown in Figure 1.

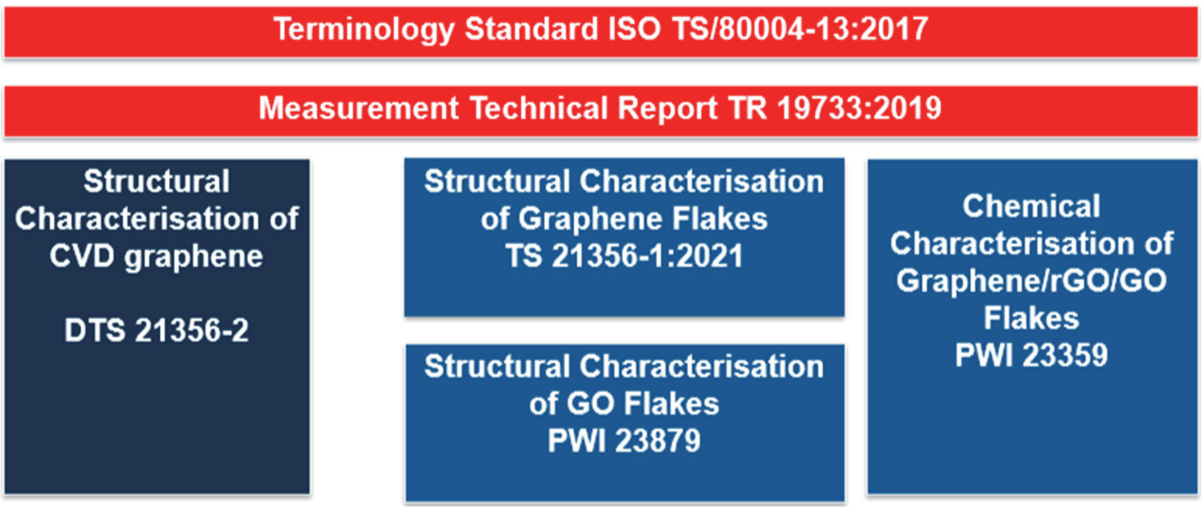

Figure 1 Summary of ISO standards in the graphene area. Items in red are overview standards, those in blue are for material in flake form and those in black for material in sheet form grown using CVD

The standardisation of quantum technologies could use the development of nanotechnologies and graphene as a model. From recent discussion groups focussing on quantum technology standards development, it is apparent that much of this experience is directly transferable and the processes for a model can form supporting future work.

1.3 METROLOGY UNDERPINNING STANDARDS

The measurement infrastructure relies on the existence of standards to support the metrology needed for validation of quantum enabled measurement systems and procedures.

Metrology, the science of measurement, oversees the maintenance and improvement of this measurement infrastructure, continually responding to evolving societal needs. By achieving global agreement on how measurements should be made, expressed, and used, metrology has generated systems and frameworks for measurement quantification and through these underpins consistency and assurance in all measurement. Those using our measurement system benefit from their measurements being stable over time, comparable with others and accurate, allowing known confidence in measurement results. Adopting the principles of metrology has the following benefits:

- Improves the effectiveness and efficiency of science and the trust in its outcomes
- Reduces waste and increases value for money and productivity
- Unlocks the potential of innovation faster, allowing earlier market entry
- Decreases the time to implement change and add value
- Is essential for the development and assessment of evidence-based policy and accelerates progress in science and in society

Each of these benefits is supported by a solid evidence base:

Embracing the measurement infrastructure is an essential requirement for reproducibility of outcomes and therefore progress in science and in society. The virtuous circle of improved measurement, driving improved technology, driving improved measurement, is the motor that propels economic and social progress.

The application of metrology is universally relevant across all sectors and to all users of measurement. Metrology should be part of everything and a partner of everyone.

Nonetheless metrological principles are not always fully embraced. For instance, this is sometimes the case in academia where measurement methods are developed in isolation, not compared or standardised, and hence it takes longer to make progress, with a larger number of studies and at higher cost than necessary. As another example, SMEs often lack appropriate training in good measurement, delaying the development of new products and stifling innovation. With metrology embedded, progress would be faster, cheaper, and more robust.

Increasing the adoption of better measurement will provide significant competitive advantage for the UK, in industry and academia.

‘'It is essential for metrology to identify the weakest links in the measurement chain… and work directly alongside industry, government and academia to strengthen these and build new measurement infrastructure” (NPL, 2021).

2 STANDARDS IN QUANTUM TECHNOLOGY WORKSHOP, 15 MARCH 2021

The UK National Quantum Technologies Programme, within its recently refreshed strategic intent document, identifies the development of standards as an important part of the creation of a thriving quantum ecosystem. The aim of this workshop, was to bring together UK industrial, governmental and academic organisations within the quantum field to exchange ideas about the need for standards, discuss which activities to pursue, and how the UK ensures that it plays a full role internationally in this emerging aspect of quantum technologies.

The workshop was organised by a coordinated NQTP group led by an NPL project manager and consisting of other representatives from NPL, the QCS and other QT hubs, BSI, the KTN and the NQCC. The workshop was structured in two parts. The morning agenda consisted of presentations with Q&A covering subjects around the importance and value of standards. The afternoon sessions were parallel workshops focussed on specific quantum technology areas. The full agenda and the specific questions addressed by the workshop attendees are added as Appendix 1.

2.1 QUANTUM COMPUTING

This section summarises the discussions that were held in two parallel sessions on quantum computing.

The delegates in both sessions expressed a strong interest in standardisation of quantum computing and believed it will be important for their organisations. There is, however, also general agreement that it is important not to try to create standards too early. Quantum computing is very much still an emerging technology, and it is still not clear what a (fully error-corrected) large scale quantum computer will look like. There is therefore some tension between the need to create standards soon to enable interoperability and encourage the growth of a supply chain, and the risk of doing so too early and potentially stifling innovation. Hence, determining the relevant timelines as well as areas where standardisation could start early is seen as being extremely important.

The two areas that were brought up as examples of where work could start immediately were terminology, this being the foundation for all future work, and metrics/benchmarking of both device and system performance. One of the main goals for this work would be to create a framework which allows potential end-users and other stakeholders a standardised way to compare different products and technologies.

Developing standards for the latter will be very complicated, and a lot of pre-normative work needs to be done before a standard document can be written. However, there is also a recognition that existing metrics (number of qubits, quantum volume etc) that are already widely used to e.g. compare existing products from different suppliers have severe limitations. Initiating work on international standards in this area - with the understanding that it might take several years for the work to conclude - would be a way to stimulate relevant research as well as discussions of which parameters are relevant in real-world applications.

In other areas there was agreement that "light touch" alternatives to full international standards will become important. This could take the form of technical specifications (in some cases coordinated by e.g. BSI) or even open-source initiatives. An example of an area which could benefit from this soon include cross-platform programming languages.

On the question "what the UK should be doing", there was broad agreement that it is important for the UK to be active – "if the UK does not take the lead someone else will". It was also highlighted that the UK is quite unusual in that so many different qubit technologies are used in the UK. This puts the UK in a unique position when providing input to international efforts on standardisation of hardware.

Longer term, standards are seen as key for establishing a fully commercial quantum computing sector. The two words that kept coming up when discussing why standards are important for an emerging field such as quantum computing are “verification” and “trust”. Being able to verify the correct operation of both hardware and software is seen as being very important both for end-users, who need to be able to trust the results of a computation, and for system integrators who want to use quantum computers as part of bigger systems. Standards that can be used to build trust in the technology are also seen as important for raising capital: companies need a way to demonstrate to potential investors that their products are competitive and will be trusted by potential end-users.

It was also pointed out that there are a number of important potential real-world applications of quantum computers where their use will only be allowed if a well-established framework for verification is in place.

2.2 QUANTUM COMMUNICATIONS

This section summarises the discussions within the Quantum Communications group at the workshop. The main application area considered was quantum key distribution (QKD), with some comments addressing quantum random number generators (QRNGs) and entanglement distribution. Standardisation in QKD is more advanced than in other quantum areas, in fact there has recently been an explosion in activity; this is driven by regulation in the security and communications sectors which relies on certification based on rigorous testing, for which standards are vital. Adherence to standards is a legal requirement in telecommunications. Various roadmaps have been produced for quantum communication (e.g. the H2020 OPENQKD 10-year roadmap); consolidating a view of the general landscape for quantum communication standards with a roadmap would help to guide UK engagement.

The main SDOs are ETSI, ITU-T and ISO/IEC. ETSI being active in QKD the longest, has a broad collection of experts and works on all types of standards. ITU focus on network standards; awareness of their work has been slower than it should have been. ISO/IEC focus on security has been in the Common Criteria framework (National Cyber Security Centre, 2019) and a standard could take the form of a formal document issued by an SDO such as a technical or group specification, technical report or recommendation.

There is a need to engage with all SDOs to broker a common perspective, promote co-operation, and avoid conflicting standards to make best use of the limited time resource of the relevant experts. NPL working with BSI could encourage this in the UK (at least). This will require identifying the key participating organisations, and their motivations for getting involved in the various SDOs, as well as understanding who will use the standards. The form of the standards was not felt to be too important as long as they were drafted by a reputable standards body. For compliance and procurement, international standards are needed.

The group also identified quantum photonic integrated circuits (an area currently receiving significant EU investment), quantum emitters & detectors (a strength of the UK), and new performance grade connectors and fibres, for instance hollow-core fibres, as areas for which new standards would be required. New technologies, for instance quantum storage, would in time require standardisation activity.

The group recognised the need to be aware of the inter-relatedness of various areas to avoid stove-piping standards – for instance telecommunications relies on timing, timing relies on telecommunications, etc.

For QKD, security standards (including non-quantum aspects such as authentication) are the priority, followed by standards covering the specification of physical components and devices, e.g. lasers, optical receivers, etc. Network standards for current network structures where keys are shared between two parties using point-to-point QKD links, and where key management and handling at higher levels is used to create a network, are also important. Inter-operability with existing standards and systems was required to ensure products work with the existing structure. When technology moves to a quantum internet, e.g. capable of distributing entanglement, then inter-operability at the quantum layer between different 'nodes' will become important. Expanding the current focus on fibre QKD to space and satellite QKD is also required.

QRNGs are a new and important technology, and while adapting current standards for non-quantum random number generators may be possible, it would be important to certify the advantages of QRNGs to advance their commercialisation.

There is also an urgent need to strengthen dialogue with NCSC and the Quantum Communications Hub to work towards a joint vision for the development of this area

2.3 QUANTUM SENSING AND IMAGING

This section summarises the discussions held by the two quantum sensing and imaging groups. In general, there were views that were common to quantum computing and other discussion groups, in that, the timing and the priority for standards development need careful consideration and, in some situations, could prove restrictive. However, there was significant support for standards for quantum sensing and imaging, and development of terminology was considered as a suitable starting point.

The current focus for standards development was component compatibility and component reliability. Within this it was considered that an appropriate route was through initial development of specifications, which could be further developed into full standards. The development of component specifications would need to be supported through QT&E standards that enable verification and bench marking of component performance. Additionally, there should be consideration of systems engineering aspects and instrumentation standards for Sensing and Imaging.

Engagement from industry was considered important as industry was perceived as the primary user and this industrial engagement could start through development and use of national standards test facilities such as those at NPL and via BSI. Maturing of quantum technologies is seen as an enabler for industrial engagement and possible routes could be via standards road mapping.

UK leadership with respect to the development of international standards was seen as important area and one that should be approached from a Sensing and Imaging applications standpoint.

2.4 SUMMARY OF WORKSHOP

The key themes that came out of the event were:

- Work on standards should encourage efficient innovation and not stifle creativity.
- UK Industry needs to get involved in standards development, supported by government organisations. This must be on an international stage as well as within the UK.

- “Standards” work should include agreements within the community such as standard specifications, best practice guides, standard testing methods, standard nomenclature and vocabulary; not just the large-scale documentary standards which might develop over time.
- A map of standards activity should be created to inform and guide UK organisations to the most relevant group.
- Government can help industry by setting up a forum for information exchange on standards which could be part of a wider industry grouping, or a standards committee.
- UK industry needs to get involved in standards development, supported by government organisations. This must be on an international stage as well as within the UK.
- Standardised testing for the comparison of devices or components would be useful to the user community.
- Verification in the field of quantum computing is a difficult but critical area for research. The inherent uncertainty which is a central component of quantum science has to be handled while still providing confidence in the outputs from a quantum machine.

3 PROPOSAL FOR COORDINATION OF UK ENGAGEMENT IN QUANTUM TECHNOLOGY STANDARDS DEVELOPMENT

3.1 INTRODUCTION

This section of the report details NPL's proposal for the co-ordination of UK representation in quantum technology standards development and the raising of awareness among the UK quantum community of current activity. A key part of the proposal is the establishment of a UK quantum standards committee run by BSI with NPL support, in addition to establishing routes for reporting and sharing information on standards development with the NQTP boards and within government.

3.2 URGENCY OF ENGAGEMENT FROM UK

There are a large number of international standards organisations already focussing on quantum technologies. Standards development of some aspects of quantum technologies has already started and is furthest advanced in quantum communications. Some UK organisations, including NPL, have been engaged in developing standards for quantum key distribution for some years and are now engaging in a similar process in other fields of quantum technologies, especially in quantum computing [see NPL Representation and Provision of Technical Expertise in support of QT&E Standards Development report]. In this field some countries, particularly the US and China, are currently much more engaged than the UK community.

It is essential that the UK community fully engages with the quantum standardisation process across the full range of technologies. This will place the UK quantum industry in the mainstream of the standardisation process such that standards developed will not exclude or be detrimental to UK organisations and UK-developed products and services.

If the UK does not engage, then the international standardisation process will of course carry on regardless. Standards will be developed and published with no UK voice involved. They will not be tailored to the UK's commercial and technological advantage. Indeed, they risk stifling UK development and innovation in this key area.

3.3 NEED FOR COORDINATED UK APPROACH

In our opinion, the UK quantum technology community, and particularly UK industry, would benefit from a more co-ordinated approach to its representation in international standards development. Organisations such as NPL and BSI can play an important role in galvanising a shared UK approach. Although individual companies represent themselves and their own interests in standards organisations, NPL think that there would be great value in being able to share information about current work to highlight opportunities for engagement and help ensure that UK interests are present "in the room" when new standards are being discussed in a particular field.

Organisations such as NPL, BSI, and companies experienced in the field of standards development could inform the UK community on best practice in approaching standards development. The previous development of standards in the fields of nanotechnologies and graphene could be used as a blueprint for developing quantum technologies standards.

3.4 ESTABLISH WORKING GROUP IN PARTNERSHIP WITH BSI

NPL propose that a UK national standards committee or panel should be established consisting of key stakeholders from BSI, NPL, industry (especially SMEs), academia (the QT hubs), and other interested parties. It should be focussed on helping industry engage with the international standards development process, and identify the need for other useful forms of standard within the UK such as those identified in the recent UK workshop described above: e.g. standard specifications, best practice guides, standard testing methods, standard nomenclature and vocabulary; not just the large-scale documentary standards which might develop over time.

This panel should meet regularly, at least 3-4 times per year. Over time, it could if necessary be organised with subcommittees to look separately at the quantum technology themes as covered by the hubs and widely recognised as the major themes of the NQTP. This would enable industry partners to engage in a focussed theme of interest to them. Not all parties will be interested in all aspects. The first stage of this committee’s work would be to decide its own structure and to identify areas where industry can get involved.

Recent discussions with BSI have established that this panel can be launched relatively quickly under the auspices of an existing “mirror committee”. BSI and NPL will develop the launch material and arrange the circulation list to promote the existence of the panel.

3.5 POSSIBLE FURTHER WORK TO ESTABLISH PRIORITY AREAS FOR UK STANDARDS FOCUS

In support of this objective to offer greater coordination and focus to the UK work on future standards, it might be appropriate to commission a more detailed market research project on standards in the quantum technology sector.

3.6 UK QUANTUM INDUSTRY GROUP

Discussions are underway within BEIS (Technology Strategy and Security team) and Innovate UK on how to encourage and support the formation of a wider industry group within the quantum technologies community.

Our proposal here is for a BSI standards committee with themed subcommittees which would then report to the wider industry group in the UK. The industry group would have a very wide-ranging agenda and, in our view, would not be the right forum for a detailed discussion on standards but it would be an excellent mechanism for wider dissemination of progress, questions, and opportunities for engagement.

3.7 REPORTING TO NQTP BOARDS

NPL propose that they should produce a quarterly report on the current position to the Strategic Advisory Board of the NQTP. Very significant items can also be transmitted to the main programme board as part of the regular NPL partner report.

3.8 REPORTING WITHIN GOVERNMENT

There should be a forum for cross-government awareness of quantum standards activity. NPL would prepare a regular brief on the current position for this group.

3.9 SUMMARY

In summary NPL proposes that a group be established by BSI in partnership with NPL and others, to be the main forum for discussion within the UK community on the development of new “standards” in the widest sense. This group would discuss priority areas for engagement in international standards and help prioritise the work required to develop standards for UK community use. A report of activity would be shared regularly with a new UK quantum industry group. NPL would take on the responsibility of reporting to the NQTP and into wider government.

4 CONCLUSION

This report has described the work delivered under the NPL quantum programme in support of strengthening UK industry engagement in international standards and benchmarking.

A meeting and workshop on quantum standards organised by NPL with partners from the UK quantum programme has demonstrated an appreciation of the value of standards and an interest and enthusiasm for further engagement. For this engagement to be enabled most efficiently, the framework and opportunities should be laid out more clearly by organisations such as NPL and BSI.

Key themes from the workshop are:

- Work on standards should encourage efficient innovation and not stifle creativity.
- UK Industry needs to get involved in standards development, supported by government organisations. This must be on an international stage as well as within the UK.
- "Standards" work should include agreements within the community such as standard specifications, best practice guides, standard testing methods, standard nomenclature and vocabulary; not just the large-scale documentary standards which might develop over time.
- A map of standards activity should be created to inform and guide UK organisations to the most relevant group.
- Government can help industry by setting up a forum for information exchange on standards which could be part of a wider industry grouping, or a standards committee.

The report concludes with a strategy plan and proposal involving NPL and BSI for a new UK approach to engagement in the quantum standards development process for industry and across government. The key elements of this proposal are that:

- A UK national standards committee or panel should be established consisting of key stakeholders from BSI, NPL, industry (especially SMEs), academia (the QT hubs), and other interested parties.
- A UK quantum industry group should be re-established, and the standards panel should report updates and progress to this industry group.
- NPL should produce a quarterly report on the current position to the Strategic Advisory Board of the NQTP. Very significant items can also be transmitted to the main programme board.
- NPL should also ensure that work on quantum standards is reported to a wider government audience.

The next phase of work will involve setting up a BSI panel involving NPL, other partners and interested UK industry participants and agreeing the reporting processes to offer the widest awareness and opportunity for engagement in the developing global effort on future quantum standards.

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APPENDIX 1: QUANTUM TECHNOLOGY STANDARDS WORKSHOP

Agenda and discussion questions

Standards in Quantum Technology 15 March 2021

Table 2 Standards in Quantum Technology Agenda

Start (am)	Duration (mins)	Presentation	Speaker
9.20	10	Introduction to the Standards Workshop-scope, aim and agenda	Dr Rhys Lewis, Head of Quantum Metrology Institute, National Physical Laboratory
9.30	20	Value and importance of Standards	Sir Peter Knight FRS, Chair of the UKNQTP Strategic Advisory Board
9.50	10	The role of Standards from the Government perspective	Daniel Okubo, Deputy Director, DCMS
10.00	30	Standards: the process of creation, development and worked examples	Emelie Bratt, Lead Standards Development Manager, BSI, Dr Charles Clifford, Senior Research Scientist, National Physical Laboratory
10.30	15	Q&A Session	Dr Rhys Lewis and Prof Dominic O’Brien, Oxford University, Director of Quantum Computing and Simulation hub
10.45	15	Break	
11.00	20	Standards & Standards Strategies in Telecommunications	Jonathan Legh-Smith, Head of Scientific Affairs, BT
11.20	30	Standards and Quantum Sensing	Professor Kai Bongs, Birmingham University, Director of Innovation, PI of the UK National Quantum Technology Hub in Sensors and Timing
11.50	30	Quantum Imaging and Standards	Professor Miles Padgett, School of Physics and Astronomy, University of Glasgow, PI of Quantic hub
12.20	30	Standards and Quantum Computing	Dr Richard Murray, Co-founder and CEO, ORCA Computing Professor Elham Kashefi, Quantum Computing at the School of Informatics - University of Edinburgh, and Senior Science Team in the UK National Quantum Hub in Computing and Simulation
12.50	30	Open discussion and Summary	Dr Rhys Lewis and Prof Dominic O’Brien
1.20	40	Break	
2.00	10	Introduction to parallel workshop sessions	Chair – Tim Prior, Quantum Technology Programme Manager, NPL
2.10	60	WS1-Standards in Quantum Computing	Facilitators; Dr Tobias Lindstrom, NPL and Dr Simon Plant, NQCC

2.10	60	WS2-Standards in Quantum Communication	Facilitator; Dr Richard Pitwon, Resolute Photonics
2.10	60	WS3-Standards in Imaging	Facilitator; Dr Anke Lohmann, Anchored In
2.10	60	WS4-Standards in Sensing	Facilitator; Dr Simon Bennett, University of Birmingham and Prof. Kai Bongs, University of Birmingham
3.10	30	Summary, conclusion and next steps	Tim Prior and Facilitators
3.40		Finish	

Suggested Questions for discussion

1. *What initial focus would be of most benefit to your organisation?*
2. *What would be the best way for your organisation to engage with the development of standards and to receive information about new developments?*
3. *Is it important for the UK to be taking a lead internationally on quantum standards and if so, are there particular areas where the UK should be taking a lead?*
4. *Why are standards important (or likely to become so) for your organisation? In what area of your organisation's activities (quality control etc.) do you believe standards will have the most impact?*
5. *To be most effective what form should these standards take? Would some of the alternatives to full international standard (e.g. specification documents) be beneficial to your area?*

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Figure 2 Discussion Questions