Examining intangible controls
Part 2: Case Studies

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Nuclear Technology

Atomic energy has a duality in that the same materials and facilities that are required for peaceful uses can also be put to military uses. A key challenge of the nuclear age has been in designing and implementing a system of controls that would prevent the military risks of nuclear technology while also facilitating its civil uses.

The current system includes three principal and interlocking elements: the non-proliferation commitments of states as enshrined primarily in the Nuclear Non-proliferation Treaty; the Safeguards verification system as primarily enacted by the International Atomic Energy Agency (IAEA); and the system of strategic trade controls as enacted primarily by the main nuclear supplier states.

A particular strength of these measures is their interlocking nature. Each measure can contribute to the implementation of another. Of particular importance is the ability to utilise data from one measure to verify the declarations from another. For example, under the IAEA's Additional Protocol safeguards measures, states are required to submit notifications of export of nuclear technology. The IAEA can then cross-check that the import has been declared by the recipient country and ask questions of that country if it has not.[1]

This point highlights that export controls contribute not only by affording the possibility of stopping an export from taking place, but also by providing information that can be used to verify declarations. It follows that a failure of export controls could both allow an undesirable transfer to take place and prevent the collection of information that could be used for verification purposes.

In this context, it is notable that under the model additional protocol, States are obliged to notify the IAEA not only of exports of nuclear technology, but also of nuclear-related research undertaken within the country. The IAEA in turn uses both sets of information in fulfilling its mandate to confirm the correctness and completeness of states' safeguards declarations

The ability of the IAEA to cross-verify information from different sources means that it is important that nuclear-related research is not unduly excluded from export control provisions. Even if a transfer is subsequently authorised by the exporting state, the collection of information through the licensing process can allow the IAEA to verify that the research has been declared.

This principle applies mainly to research conducted by or between non-nuclear weapons states, or between nuclear weapons states and non-nuclear weapons states. However, it is valuable to examine one set of projects that are underway between a nuclear weapons state (the UK) and a non-party to the NPT (India). Examination of this case helps to answer

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[1] "Additional Protocol". IAEA Website. Available online at https://www.iaea.org/safeguards/safeguards-legal-framework/additional-protocol (Accessed 26/05/2016).

the question of what type of cooperation might be problematic from a proliferation perspective. The second case that is examined in this section relates to contracted research conducted on behalf of a non-nuclear weapons state.

Case Study 1.1: Nuclear Technology – UK/India Civil Nuclear Research Cooperation

In 2010, the British Prime Minister announced the commencement of civil nuclear research cooperation between the UK and India during a visit to New Delhi. The initiative was launched after UK scientists undertook several fact-finding missions to India with support from the UK's Science and Innovation Network and concluded that pursuing research synergies between the two countries would be mutually beneficial. The main participating agencies are the Research Councils UK (RCUK) and India's Department of Atomic Energy (DAE), represented by the Bhabha Atomic Research Centre (BARC) and the Indira Gandhi Centre for Atomic Research (IGCAR).

Both sides have contributed £4.7 million each to the collaboration.[2] So far, 12 research projects have been initiated as part of the collaboration, including on smart monitoring and control systems, waste management and public engagement. These are:

- Six projects on the safety and sustainability of nuclear energy (£1.2 million from the Research Councils UK Energy programme with matched resources from India's atomic organisations);
- Six further projects with an emphasis on nuclear safety, assessment of systems and material reliability (£3.5 million from the Research Councils UK Energy programme with matched resources from India's atomic organisations).

The Indian partners in the research collaborations (Department of Atomic Energy, Bhabha Atomic Research Centre and Indira Gandhi Atomic Research Centre) are involved in both the civil and non-civil aspects of India's nuclear programme, which raises questions about the possible contribution of the proposed joint research to nuclear weapons development and other activities of concern. Nonetheless, the proposed projects have been rigorously analysed by export control authorities in the UK. None of the projects have been classified as subject to control under the EU list and, based upon the fact that the projects are going ahead, it can also be concluded that the WMD end use control has not been invoked.

In this context, it is valuable to examine each of the projects in terms of both its potential control status and contribution to India's nuclear programme. It is also helpful to examine these projects through the lens of the TRL-enhanced Capability Acquisition Model in order to understand the relevance of export controls.

About the Projects

To date, eleven projects have begun. These are outlined in Table 2 below. None of these projects have been rated by the UK export control authorities as requiring a licence, although each has been closely scrutinised. Several of the projects are clearly outside the

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[2] UK Government Website. Available online at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/262633/FINAL_RCUK_India_Timeline_-_electronic_version.PDF (Accessed 26/05/2016).

scope of controls. For example, project 9 relates to management of nuclear risk issues to the environment, economy, and human health. Others are non-technical in nature, such as project one, related to 'Sustainability and proliferation resistance assessment of open cycle thorium-fuelled nuclear energy'. Other projects focused on vitrification of waste materials, which is of low proliferation concern. Discounting these projects leaves a list of nine projects that are worthy of examination.

Of the projects that remain, all have been rated as not controlled. The assessment on whether or not research projects are controlled is often a difficult one since the outcome of research is generally unpredictable. For many of the projects, there are control entries that are potentially relevant – as illustrated by Table 8 below. The question for authorities in these cases was whether the research would result in an export of controlled technology. British officials involved in assessing the projects noted that "The projects virtually all were generic in their potential for application and not really specific to the development, production or use on controlled equipment or software".[3]

There could evidently also be a desire to oversell the real-world relevance of research to increase the likelihood of funding being received. Nonetheless, it is clear that such projects are making some contributions, otherwise these projects are unlikely to have gone forward. The question therefore is how to gauge whether the contributions of such projects meet the threshold at which controls apply. The starting point for such an assessment is the definition of technology, which states: information "required for the development, production or use of a controlled item".

This raises a question on whether any of the projects will result in the transfer of technology. A challenge, however, is that it is usually difficult to assess whether something is necessary. Is it necessary to validate a model in order to build a component? Reference to the TRL model is helpful in making such judgements. An assessment of the projects against TRL is also contained in the table below. The TRL model highlights the relative importance of 'validation' in turning research into real-world applications.

Examination of Table 1, which provides an analysis of the cases, highlights that the projects contribute to a range of TRL levels.

Technology Readiness Levels	Number of projects
TRL 3	1
TRL 3/4	2
TRL4	2
TRL 5	1

The questions that arise from this examination are whether any of the projects should be subject to control and whether higher TRL projects are a higher priority from a control

[3] Comments by government officials, November 2015.

perspective. This will be examined further through consultation with practitioners, but the author is of the view that all of the projects with a TRL level should be subject to control in order to ensure that the IAEA has visibility of the nuclear-related research that is being conducted.

Table 1: Overview of UK/India Civil Research Project's in Phases 1 and 2[4]

Number	Title	Description	Potential Control entry	TRL
1	Sustainability and proliferation resistance assessment of open cycle thorium-fuelled nuclear energy (University of Cambridge and Bhabha Atomic Research Centre (BARC))	This project sought to characterise the nuclear sustainability and proliferation resistance of a 'once through' thorium nuclear fuel cycle and to devise assessment criteria for this purpose. A three stage approach would be taken: 1) review of proliferation resistance and sustainability assessment methodologies, 2) review of proposed open cycle thorium fuelled nuclear reactor designs, including review of fuel composition and design, and 3) assessment of designs against a newly developed sustainability and proliferation resistance criteria. The results would be published.[5]	N/A	N/A
2	Irradiation effects on flow localisation in zirconium alloys	This project sought to understand the damage caused by radiation to nuclear fuel cladding which can limit fuel burn up. The research was designed to take advantage of the fact that the UK and India each had facilities that could use different mechanisms to model such damage. Comparative analysis of the results could then take place. The proposal noted that Indian scientists would also learn how to undertake advanced electron back scatter diffraction (EBSD) and synchrotron x-ray diffraction experiments.[6]	0A001f f. Zirconium metal tubes or zirconium alloy tubes (or assembles of tubes) specially designed or prepared for use as fuel cladding in a "nuclear reactor", and in quantities exceeding 10 kg 0E001 "Technology" according to the Nuclear Technology Note for the "development", "production" or "use" of goods specified in this Category 1C234 Zirconium with a hafnium content of less than 1 part hafnium to 500 parts zirconium by weight, as follows: metal, alloys containing more than 50% zirconium by weight, compounds, manufactures thereof, waste or scrap of any of the foregoing, other than those specified in 0A001.f. Note: 1C234 does not control zirconium in the form of foil having a thickness of 0.10 mm or less.	3/4. The research involved the use of experimental facilities to better understand how radiation affected fuel cladding. This would appear to fall within the definition of "technology validated in lab", although it is not clear that actual components or subcomponents were used in the experiments.
3	Indo-UK civil nuclear	This project sought to develop collaboration around the study of radiation	N/A	

[4] Based upon the Author's assessment
[5] EPSRC Website. Available online at http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/I018425/1 (Accessed 26/05/2016).
[6] EPSRC Website. Available online at http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/I012346/1 (Accessed 26/05/2016).

	collaboration on damage and radiation effects in amorphous material	damage processes in nuclear waste glasses and glass composite materials. UK collaborators will contribute in two principal areas: provision of expertise in application of X-ray spectroscopy methods to radiation damaged materials and application of advanced analytical electron microscopy to glass and glass composite characterisation. Indian collaborators will bring many years of expertise in preparation and characterisation of radionuclide-containing nuclear glasses by electron spin and positron annihilation spectroscopies.		
4	Characterisation of the atomic-scale structure of yttria-based particles in strengthened steels	The project sought to study the potential of utilising Oxide Dispersion Strengthened alloys in place of structural steels in the construction of high temperature (Gen IV) reactors. The proposal noted that: These alloys offer much improved performance than more conventional structural steels at the temperatures above 600 C that will be experienced in these new reactor designs. However, there are a number of issues that are very poorly understood in these alloys.	0A001 "Nuclear reactors" and specially designed or prepared equipment and components therefor, as follows: a. "Nuclear reactors"; b. Metal vessels, or major shop-fabricated parts therefor, including the reactor vessel head for a reactor pressure vessel, specially designed or prepared to contain the core of a "nuclear reactor"; e. Pressure tubes specially designed or prepared to contain both fuel elements and the primary coolant in a "nuclear reactor"; h. 'Nuclear reactor internals' specially designed or prepared for use in a "nuclear reactor", including support columns for the core, fuel channels, calandria tubes, thermal shields, baffles, core grid plates, and diffuser plates; Technical Note: In 0A001.h. 'nuclear reactor internals' means any major structure within a reactor vessel which has one or more functions such as supporting the core, maintaining fuel alignment, directing primary coolant flow, providing radiation shields for the reactor vessel, and guiding in-core instrumentation.	5. The material was irradiated in a reactor to understand its material properties. This qualifies as validation in a relevant environment.
5	Validation and verification for critical heat flux and CFD	This project sought to validate computational fluid dynamics (CFD) codes, used to simulate fluid flows in nuclear reactors, against good measurements made in suitable experimental rigs. The experiments were conducted at BARC which has excellent experimental facilities. The results are intended to help provide better validated CFD models to improve the ability to asses new nuclear reactors' abilities to meet ever higher economic and safety criteria.	0A001 "Nuclear reactors" and specially designed or prepared equipment and components therefor, as follows: a. "Nuclear reactors"; 0D001 "Software" specially designed or modified for the "development", "production" or "use" of goods specified in this Category	3/4. This involved comparison of experimental findings with computer codes. It is not clear that components were subject to validation (as opposed to some simulant material).

6	Thermal hydraulics for boiling and passive systems	This project sought to develop a better understanding of where the transition between water coolant and steam occurs in water-cooled nuclear reactor operations, and developing better techniques to predict this. New nuclear power reactors for energy generation will almost certainly be water-cooled. The project used experimental measurements of boiling systems conducted at BARC in India.	0A001 "Nuclear reactors" and specially designed or prepared equipment and components therefor, as follows: a. "Nuclear reactors";	3
7	Transferability of small-scale specimen data to large-scale component fracture assessment	This project sought to assess tests that had been performed on reactor grade piping components of the Indian Pressurised Heavy Water Reactor (PHWR) to examine their structural integrity. One of the inputs to demonstrating structural integrity is a fracture mechanics assessment to demonstrate defect tolerance. The R6 procedure, which contains a hierarchy of assessment approaches, is the UK nuclear industry standard. However, a difficulty in using the higher level methods is demonstrating transferability of fracture parameters determined from specimens to application at component level. A large number of tests of PHWR piping components had been performed on straight pipes and elbows, with a variety of cracks and loadings. These tests were assessed using a range of defect assessment approaches to demonstrate transferability for practical piping components.	0A001 "Nuclear reactors" and specially designed or prepared equipment and components therefor, as follows: a. "Nuclear reactors"; e. Pressure tubes specially designed or prepared to contain both fuel elements and the primary coolant in a "nuclear reactor"; h. 'Nuclear reactor internals' specially designed or prepared for use in a "nuclear reactor", including support columns for the core, fuel channels, calandria tubes, thermal shields, baffles, core grid plates, and diffuser plates; Technical Note: In 0A001.h. 'nuclear reactor internals' means any major structure within a reactor vessel which has one or more functions such as supporting the core, maintaining fuel alignment, directing primary coolant flow, providing radiation shields for the reactor vessel, and guiding in-core instrumentation.	3. Experiments were conducted on components in a simulated environment.
8	Fundamental properties of thoria-based mixed oxides	This project sought to use advanced materials simulation techniques to investigate the behaviour of thorium dioxide based materials when irradiated in a nuclear reactor. Comparison with experimental data was also performed, both using pre-existing data and new data being developed by collaborators in India. This work will aid development of better predictive capability to establish that fuel being irradiated in a civil reactor will behave in a manner consistent with its design criteria, which is required to rapidly develop experience in the use of thorium based fuels for civil power generation. There is an interest in using a thorium dioxide fuel approach as there are concerns that uranium reserves are not sufficient to facilitate a large scale international nuclear new build.	0C001 "Natural uranium" or "depleted uranium" or thorium in the form of metal, alloy, chemical compound or concentrate and any other material containing one or more of the foregoing;	4. Comparison of results of experiment and simulation in order validate a model.
9	Management of nuclear risk issues: environmental, financial and safety (NREFS)	This project sought to evaluate mitigation options following a possible large-scale nuclear accident in the future. The research used data on post-accident contamination and doses from the Chernobyl accident and how data from the Fukushima incident. Mitigation was then considered in four national contexts: Ukraine/Belarus, Japan, India and the UK using a variety of decision-making techniques. Subsequently scenario-based multi-criteria	N/A	N/A

		decision analysis was used to investigate differences between recommendations from the objective methods and decisions taken on the ground. Recommendations were developed from the various methods.		
10	Atomistic modelling and experimental verification of vitrified matrices for waste encapsulation	This project sought to develop computer models of the radiation induced structural changes in the encapsulation materials over long time scales. Principal materials investigated were borosilicate and iron phosphate glasses, for which experimental verification of the computer models were performed. The outcomes from this work were to be used to make predictions to enable engineers to choose the best materials for long time structural integrity of encapsulated spent nuclear waste.	N/A	N/A
11	11. DMW-Creep: Influence of Inhomogeneity on Creep of Dissimilar Metal Welds	This project sought to improve understanding of the characteristics of welded joints between austenitic stainless steels and ferric steels that are widely used in many nuclear power plants. In the steam generator circuit of sodium cooled fast breeder reactors stainless steel pipes are required to join with ferritic steel pipes. The welds are dissimilar metal welds and incorporate a nickel alloy pipe insertion. Premature creep failure is encountered in such joints. This project is aimed to model and test the effects of metallurgical and structural aspects of welds, develop material models and develop reliable methods to monitor the material, in order to improve understanding of the operating life of the weld.	Heat exchangers as follows: 1. Steam generators specially designed or prepared for the primary, or intermediate, coolant circuit of a "nuclear reactor"; 2. Other heat exchangers specially designed or prepared for use in the primary coolant circuit of a "nuclear reactor"; Note: 0A001.i. does not control heat exchangers for the supporting systems of the reactor, e.g., the emergency cooling system or the decay heat cooling system.	4. Comparison of results of experiment and simulation in order validate a model.

Case Study 1.2: Nuclear Technology – Norwegian Nuclear Cooperation with Brazil

In September 2010, Brazil's Centro Tecnológico da Marinha em São Paulo (CTMSP), the operator of the Brazilian navy's (PNM) nuclear programme, enquired whether Norway's Institute for Energy Technology (IFE) could provide support for the development of fuel pellets for a Brazilian nuclear project. IFE, which operates the Norwegian Halden research reactor, regularly provides such assistance on a commercial basis to other states.[7] IFE entered into a contract with CTMSP on 30 September 2011. Brazilian newspaper *O Estadão de Sao Paulo* has reported that a 'technical qualification of nuclear fuel' using 20.2 grams of uranium was undertaken for the PNM at the Halden facility. The report stated that the fuel sample was manufactured in Norway to Brazilian specifications and that no uranium had been exported from Brazil due to bureaucratic reasons. Electronic results from the test were reportedly submitted back to the PNM in Brazil. [8]

The case has attracted public attention as the cooperation was not authorised by the Norwegian government under relevant export control laws. A police investigation was launched to investigate whether a violation of these laws occurred. This investigation is understood to still be underway. [9]

While findings of the investigation have not yet been made public, it can be speculated that the Norwegian government has concluded that the 'export' of the intangible technology to Brazil required a license, either because it was subject to control or because the technology was related to a WMD-end use. Given that this was a commissioned experiment, there can be little doubt that the information gathered from the experiments qualified as information which is 'required' for the development, production or use of a controlled item. Contracted research is invariably intended to produce research extremes that are necessary. For the same reason, the 'basic scientific research' could not apply as the research is 'applied' in nature.

The case evidently raises questions about compliance with export controls. Indeed, IFE has admitted that cooperation with several other countries might include export control

[7] The Halden Project is a joint undertaking of national organizations in 19 countries sponsoring a jointly financed programme under the auspices of the OECD - Nuclear Energy Agency. Discussions are under way for enlarging the member circle. Collaborations with East-European countries in support of plant safety and reliability are also expanding. The programmes are to generate key information for safety and licensing assessments. "The Halden Reactor Project", available online at: http://www.ife.no/en/ife/halden/hrp/the-halden-reactor-project (Accessed 04/02/2016).

[8] Godoy, Roberto. (2013) "Marinha testa combustível nuclear na Noruega". *Estadão*, 12 May 2013Available at http://politica.estadao.com.br/noticias/geral,marinha-testa-combustivel-nuclear-na-noruega,1031078(Accessed 01/09/2013).

[9] Haugan, BjØrn and Johsen, Alf Bjarne (2013) "PST overtar atom-etterforskningen". VG, 12 September 2013, available online at http://www.vg.no/nyheter/innenriks/pst-overtar-atom-etterforskningen/a/10126195/ (Accessed 01/09/2015).

issues.[10] However, beyond these issues of compliance, the case is of interest for several reasons.

First, the business model of the Halden Reactor involves irradiating cladded nuclear fuels in its reactor in order to generate data on the performance of these cladded fuels. As the clients are usually outside of Norway, the export is often solely in the form of intangible technology (data) rather than physical exports.

Second, one purpose of the irradiation of the fuel in the reactor is often to provide data to certify the performance of the fuel from a safety perspective.

Third, the cladded fuel that is irradiated is produced not by the client but by IFE to the client's specifications. In this context, it can be concluded that the results can verify only the predicted performance of the fuel against a defined specification rather than the actual performance of the fuel as would be used in practice (as a different producer would produce the actual fuel pellets for use in the client's reactor). Bearing these factors in mind, it is helpful to examine the contribution of controls in this case.

Utility of Controls

Consideration of these points leads to the question of the utility of controls in such cases. Utilising the enhanced Capability Acquisition Model, it can be observed that the work undertaken in this case relates to around TRL 7: 'system prototype demonstrated in an operational environment'. This is a relatively advanced stage of capability development. The results in this case appear to be primarily electronic in nature (i.e. explicit information), although the possibility that assistance was also provided on either interpreting the results or resolving any issues found with the fuel cladding (tacit knowledge) cannot be discounted. The export of electronic information is controlled in Norway (which subscribes to the EU Regulation (EC) No 428/2009 even though it is not a member of the EU). Technical assistance would be subject to control only where it related to a WMD-related end use.

The implementation of export controls in this case – which did not occur – would have otherwise served at least two main purposes. First, it should have provided the government of Norway with visibility of the export so that it could have intervened by blocking the export or imposing conditions on the export, as appropriate. Second, as Norway has implemented the IAEA's Additional Protocol, details of the export would be shared with the IAEA which would utilise the data, in turn, during the evaluation of Brazil's declaration to the IAEA.

In this case, neither of the decontrols appears to be applicable: the experiment was undertaken for a specific client and the results are not in the public domain. The research is also applied in nature and linked to a specific application. This case thus appears to be

[10] Haugan, BjØrn and Peters, Tim (2013) "Innrømmer ulovlig atomsamarbeid med fem lan". VG. 4 September 2013, available online at http://www.vg.no/nyheter/innenriks/miljoevern/innroemmer-ulovlig-atomsamarbeid-med-fem-land/a/10143127/ (Accessed 01/09/2013).

consistent with the argument that the decontrols are less likely to be applicable for higher TRL levels.

Analysis of the IFE case is insightful as it involves the intangible export of a technology relevant for a relatively high TRL level. Regardless of the outcome into the investigation of potential non-compliance by IFE, it appears that there is a strong rationale for ensuring that such activity is subject to control. In this context, the case appears to support the argument that controls should be invoked for higher levels of technology readiness.

Section Conclusions

Examining both nuclear case studies together helps to address the question of at what TRL should the control threshold be set. From the IFE case study, it is evidently the case that TRL7 warrants control. This therefore sets a minimum control threshold. However, there is still a question about whether lower TRLs should also be subject to control.

Case Study 2: Cloud computing

The concept of computing as a service has begun to mature in recent years, particularly with the rise of the market-dominating Amazon Web Services platform.[11] The concept of computing as a service is a natural evolution of the very idea of information technology, which itself has revolutionised how business, engineering, and research is conducted. Sharing and centralising computing infrastructure allows for the realisation of economies of scale and the exertion of market forces on price. It also allows for the scaling of infrastructure to meet the needs of the organisation.

At the same time, the concept of computing as a service brings into focus certain long-standing non-proliferation and export control questions. These include practical questions, such as whether an export licence is required for information stored in 'the cloud'. However, there are also more basic conceptual questions about the contribution –and hence the need for control – of electronic information, which is a type of explicit information as defined in the main report.

The purpose of this case study is to examine factors around the need for control of two types of 'computing as a service' concepts. These are 'cloud storage' and 'cloud computing'. In examining these two concepts, the potential contribution of the service to proliferation is considered - as are some of the practical considerations around controlling each. While the focus of this case study is on the computing as a service concept, it is argued that the lessons gleaned from this examination are applicable to controls on electronic information more generally – including information held on local (as opposed to the cloud) computing platforms (i.e. local IT servers). Specifically, it is argued that companies holding electronic information related to controlled products should implement certain minimum protections to prevent the unauthorised access of the data in a similar way to which the companies might already do in relation to confidential customer data.

Computing as a service

The concept of computing as a service (otherwise known as 'infrastructure as a service'), is one of three service models of cloud computing.[12] It can be defined as a form of cloud computing that provides virtualised computing resources over the internet.[13]

[11] The New York Times "With Amazon Atop the Cloud, Big Tech Rivals are Giving Chase". Available online at http://www.nytimes.com/2015/04/24/technology/amazon-reports-big-profits-in-its-cloud-computing-business.html?_r=0 (Accessed 29/01/2016).
[12] The other two being, "platform as a service" and "software as a service" Interoute, 'What is IaaS?' available from http://www.interoute.com/what-iaas accessed 29th January 2016
[13] TechTarget. "Infrastructure as Service". Available online at http://searchcloudcomputing.techtarget.com/definition/Infrastructure-as-a-Service-IaaS (Accessed 29/01/2016).

In effect, computing as a service allows users – be they businesses, researchers, or individuals - to access pooled common IT resources as their use scenario requires. (Its opposite would be the acquisition by the company of a a dedicated computer server or a mainframe located in-house.) In practice, computer infrastructures are often a mix of in-house and outsourced components that grow and evolve over time. A key feature of the computing as a service concept is that its operation can be set up in a way that is indistinguishable from the users' perspective from an in-house solution.

In practice, there are fundamental differences between the in-house solution and the computing as a service concept. For the purpose of this examination, perhaps the main difference relates to location. While historically companies may have had a dedicated server or mainframe room that was either physically or programmatically firewalled from the outside world, computing as a service can be located anywhere and must thus be accessed only via a network connection. Proficient IT security staff can ensure that either type of setup is 'secure', although the concept of security is important in the context of this study and is thus examined further below.

By virtue of the free market, the physical location of the hardware for computing as a service could be anywhere. Nominally, the location of the server should not matter. However, in practice, service providers typically locate their server sites in a handful of countries often driven by factors related to data governance.[14]

It is helpful when examining the implications of the computing as a service concept to bear in mind that it is not the availability of computing capability that poses a proliferation concern, but instead it is the information that is computed that can be problematic. For the purposes of this study, it is helpful to examine two specific types of computing as a service. These are Cloud Storage and Cloud Computing.

Cloud Storage

Cloud storage is one of the main services offered under the 'computer as a service' concept.[15] Under the concept, the user may have little or no visibility or control over where) data will be stored geographically. Allocation of storage space is done automatically according to some predefined parameters, such as price. Businesses are increasingly using cloud storage approaches instead of local storage options for reasons of economics.

As electronic information associated with a controlled item can itself be subject to control, the concept of cloud storage is potentially incompatible with the concept of export

[14] Forbes "The 10 Best Countries for Cloud Computing". Available online at http://www.forbes.com/sites/joemckendrick/2013/03/07/the-10-best-countries-for-cloud-computing/#1d92f0615887 (Accessed 29/01/2016).
[15] Technet Magazine. "What is Infrastructure as a Service". Available online at https://technet.microsoft.com/en-us/magazine/hh509051.aspx. (Accessed 29/01/2016).

controls.[16] Certainly, the export of technology would require authorisation. However, in practice, some states have allowed for the reconciliation of the two concepts through an interpretation of the definition of ‘export’. In the UK, for example, an export is only considered to have taken place when it is accessed outside of the EU. Data can thus be stored on a server outside the EU without being considered an export provided that it is encrypted.

Interestingly, this approach was developed not in response to cloud storage, but in relation to outsourced IT support. It has become commonplace for firms in the UK to outsource IT and server services to countries such as India, thus driving the creation of this definition. This raises the question of whether there is anything inherently different about cloud computing over outsourced IT services that means some other approach is required. No such considerations were identified through the course of this study.

There are practical challenges with the United Kingdom’s definition of export that might explain why it has not yet been adopted in other jurisdictions, such as in the United States.[17]

The definition requires that information not be accessible when it is stored outside of the UK, but data can be stored outside of the UK provided that it is encrypted. This leads to the question of what level of encryption is required to ensure that the data cannot be deliberately accessed. It also leads to the question of who would be liable should data be deliberately or inadvertently accessed when stored outside of the UK.

Importantly, these two questions are not unique to cloud computing. Indeed, it could be argued that the same questions could be asked about data stored on a company’s local (as opposed to remote/cloud) server. This raises the question of whether entities holding technology in an electronic form should be required to have in place some minimum level of IT security. The principle of consistency would suggest that this should be the case. However, this then raises the same questions that arose with regards to remote access to information stored in the cloud: what level of protection would be required and who would be liable if the data were accidently or deliberately accessed? An added complication is that any failure of such IT security would not necessarily result in an ‘export’ taking place. Instead, the ‘export’ would take place only if someone was able to access the data from outside the country.

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[16] Department of Business, Innovation and Skills (UK Government). “Guidance: Export of Technology”. Available online at https://www.gov.uk/guidance/export-of-technology (Accessed 29/01/2016).

[17] However, on June 3, 2015 the U.S. State Department’s Directorate of Defense Trade Controls (DDTC) and the Commerce Department’s Bureau of Industry and Security (BIS) published proposed regulations endeavouring to change the definition of the term ‘export’ in the regulations to allow cloud storage of information in servers located in foreign countries if certain provisions are met (i.e. if the information is appropriately encrypted). The proposed regulation was published as part of the so-called process of harmonisation as envisioned by the Export Control Reform initiative, which sets out to revise key definitions in the Export Administration Regulations (EAR) in line with those of the International Traffic in Arms Regulations (ITAR). For more information see Federal Register / Vol. 80, No. 106 / Wednesday, June 3, 2015 / Proposed Rules 31529.

Another possibility would be to conclude that any data accessed as a result of a violation of computer security is considered 'in the public domain' and thus exempt from control. Several challenges are apparent with this approach. This approach would act to lessen the incentives of firms to maintain adequate control over controlled electronic data, for example, by removing the threat of punishment if a violation were to take place.

Cloud Computing

Cloud computing is the second main service offered under the 'computing as a service' concept. Cloud computing has seen a particular rise over the last few years, following the launch of services such as the Amazon Web Service and the Google data engine, just to name a few. These services offer users the opportunity to run code on a remote environment – an environment that is scalable to the task that is to be undertaken. These services are often billed on a time-used basis, meaning that there is no upfront hardware investment required for the end user.

Users are also able to acquire computational power without having to procure hardware. High speed computing equipment is controlled by the Wassenaar Arrangement, with the control threshold usually resting slightly above the power offered by the current generation of video games consoles.[18]

It is not only through dedicated services that computational power can be acquired. The business model of software vendors is generally moving towards a subscription model (as opposed to one-off sales). Such subscriptions often include access to the software house's own processing engine. As the additive manufacturing case study below shows, the Autodesk Within software package is an example of this trend: users can utilise Autodesk's processing power when undertaking the generative design function rather than relying on the users' own hardware, which is likely to be considerably less capable.

One key question that arises from the 'computing as a service' model is whether it undercuts existing export controls. Certainly, it is apparent that computing as a service model allows users to access computing power that would historically be required for the procurement of controlled equipment. The major cloud computing providers likely also have control measures in place to ensure that their services cannot be accessed either by entities known to be of concern or countries that are subject to sanctions and embargos even if it is

[18]Engvig, Einar. "All Your Games Belong to Us: A Case Study of the Eighth Generation of Video Game Consoles and the Export Control of High-Performance Computers". Available online at http://local.droit.ulg.ac.be/jcms/service/49/pdf/str01/to%20Us-%20A%20Case%20Study%20of%20the%20%20%20Eighth%20Generation%20of%20Video%20Game%20Consoles%20and%20the%20%20%20Export%20Control%20of%20High%20Performance%20Computers.pdf (Accessed 29/01/2016).

unclear how effective such measures could be in practice.[19] Entities engaged in proliferation-sensitive research may also be reluctant to utilise cloud-based computing for fear that the code that they are running – or the results that would be obtained – would be intercepted by intelligence agencies. Recent revelations about the purported extent of US and UK information surveillance capabilities might compound this reluctance. Nonetheless, there appear to be few effective barriers that would prevent a determined party from utilising cloud-based computing capabilities for nefarious purposes.

Perhaps a more important question, therefore, is whether there is any reason that an entity of concern would need to utilise cloud-based computing capabilities at all. Standard commercial and home personal computers provide vastly more computational power than supercomputers did a generation ago. Moreover, it has been demonstrated that games consoles can be chained together to produce supercomputers whose stand-alone performance would be controlled by the Wassenaar Arrangement. Software packages such as Autodesk Within offer the possibility of executing its code locally. Overall, it is likely that the need to acquire high-powered computing capacity is reducing. Nonetheless, for consistency, it is evidently the case that cloud computing processors exceeding the current computational control threshold should be controlled in some way.

[19] Programs of concern have long used front companies to procure physical goods. In comparison to the effort that this can require, it would seem to be relatively easy to disguise one's identity so as to access cloud-based computing services.

Case study 3: Additive Manufacturing

Recent years have seen growing prominence placed on additives manufacture processes as a possible 'disruptive technology' – a technology that fundamentally changes the nature and shape of industry. In fact, additive manufacturing processes may have the potential of going even further: they could potentially reshape the very nature of supply chains. If additive manufacturing processes can be utilised to produce near-finished items or parts, there would be no need to ship the item. An item could instead simply be produced at any facility with the appropriate equipment assuming that both the design and prerequisite materials are also available.

This case study focuses on the intangible technology required to produce an item using additive manufacturing processes. In a limited sense, this relates to the 'digital build file' that is loaded into the additive manufacturing machine in order to provide it with the instructions that are necessary to create the desired part. In a more general sense, however, it also includes the creation of this digital build file, including where relevant through the use of generative design techniques. A key argument that is supported by this examination is that additive manufacturing technologies increasingly negate the tacit knowledge requirement for production of products. This said, further engineering steps will always be required in high performance systems, which means that the tacit knowledge component of design will never be removed completely.

Introduction to additive manufacturing

Additive manufacturing, or '3D printing' is a rapidly-developing and now widely-established engineering manufacturing process. In its basic form, it involves the laying down of layers (or threads) of material in order to produce a part-finished component. Some amount of material removal is occasionally also necessary, particularly when producing two or more interlinked and movable components at the same time. Additive manufacturing processes have multiple benefits over traditional build methods, such as milling. A key benefit relates to waste minimisation: there should be little to no material waste from an additive manufacturing machine. Other benefits include the ability to produce certain uniquely complex designs that could not be produced by any other manufacturing method. Importantly, for the purpose of this case study, a final benefit is that parts and components can be produced entirely from a 'digital build file' simply by virtue of having a compatible machine and feed material. The skill level of the operator could be substantially less than that of an operator in traditional production processes. This also means that the repeatability of the process can be substantially higher than in traditional build processes.

The public image of additive manufacturing may now be generally linked to the production in 2013 of a 'printed handgun' that made headlines around the world.[20] However, in practice, the capabilities of additive manufacturing go well beyond this. Several additive manufacturing processes exist that allow for the production of metal and alloy components from highly specified feedstock materials, including high-strength metals which have traditionally been subject to export control. Additive manufacturing processes are also being used to produce parts and components from everything to satellites to aircraft engines. A beneficial aspect of additive manufacturing processes in such applications is weight saving: the processes allow for the production of designs that include only performance structures without corresponding filler materials.

There are seven main categories of the AM process, four of which are capable of manufacturing metal parts.[21]

Digital Build Files

Like computer number control (CNC) manufacturing equipment, additive manufacturing machines are operated from instructions contained in digital build files. Two main standards exist that are compatible with most additive manufacturing machines, although the file must correspond to the type of material to be processed and the capabilities of the machine (i.e. the process to be utilised). Two main standards exist for digital build files. The first is an STL file. The Second an AMF file.

An STL file "contains information only about a surface mesh and has no provisions for representing colour, texture, material, substructure, and other properties of the fabricated target object. As additive manufacturing technology is quickly evolving from producing primarily single-material, homogenous shapes to producing multi-material geometries in full colour with functionally graded materials and microstructures, there is a growing need for a standard interchange file format that can support these features". [22]

AMF (additive manufacturing file): "AMF serves as an alternative to the STL file format, which has been in use to transfer 3D model data to AM systems since 1987. AMF is based on XML (an open standard markup language) and supports units, colour, textures, curved

[20] Rebecca, Morelle. "Working Gun Made with 3D Printer". Available online from http://www.bbc.co.uk/news/science-environment-22421185 (Accessed 29/01/2016).
[21] ASTM International. "Standard Terminologies for Additive Manufacturing Technologies". Available online at http://www.astm.org/FULL_TEXT/F2792/HTML/F2792.htm (Accessed 29/01/2016)
[22]ASTM International. "Standard Specification for Additive Manufacturing File Format". Availableonline at http://www.astm.org/Standards/ISOASTM52915.htm (Accessed 29/01/2016).

triangles, lattice structures, and functionally-graded materials—features that the STL format does not support. An AMF file is about half the size of a compressed STL file."[23]

These STL and AMF files are inherently transmittable. At present, there is no capability built into these formats to restrict dissemination of the design. There is no reason that designs could not be encrypted, though, with keys used to unlock the encryption being disseminated separately or perhaps even embedded in individual manufacturing equipment. However, this is not standard practice at present.

Developing Designs

The purpose of additive manufacturing machines is to execute a digital build file in order to produce a finished component. The build file itself can be produced through relatively standard Computer Aided Design (CAD) software, which is utilised widely in industry and research. Such software was originally developed to replace the draftsperson's drawing board, but it has evolved over recent years to include numerous functional components. Importantly, such software can now also be utilised to simulate the drawn part under various use scenarios. In order to inform this simulation process, the material characteristics of specific real-world materials can be programmed in to the software. In practice, there is nothing to prevent the material characteristics of a material produced from additive manufacture processes from being included in the software. A trained engineer can thus now design and prove a component entirely on his computer up to around technological readiness level 6 or 7.[24]

A port produced from a standard CAD package has undergone no validation and thus would not be assessed at TRL 4. If FEA had been undertaken, this level would rise to TRL 4. Higher TRLs could be obtained only through an iterative process of development in which the produced item was validated in different environments. Additive manufacturing can be used to produce parts of components. The TRL of a produced part without subsequent validation will be limited.

Process	TRL
CAD	2
CAD + modelling	3

[23] Wholers Associates. "Appendices". Available online at http://www.wohlersassociates.com/2013glossary.pdf (Accessed 29/01/2016).

[24] Technological Readiness Level (TRL) is a type of measurement system used to assess the maturity of a particular technology. There are nine TRLs. TRL 6 corresponds to; 'technology demonstrated in a relevant environment. TRL 7 corresponds to; 'System prototype demonstration in an operational environment' Horizon 2020 General Annex, "Technological Readiness Levels (TRL)"Available online from http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf (Accessed 29/01/2016).

CAD + lab validation	4
CAD + operational environment validation	6-7

In fact, the industry trend appears to be towards removing – at least in part – the need for a trained engineer to operate the software at all. In recent years, 'generative design' techniques have been progressed that allow CAD software programmes to determine how to solve design problems based upon a variety of input factors.[25] Such generative design techniques typically leverage the power of cloud computing to generate designs from first principles with little involvement from engineers. For example, the problem posed to the software could be how to join two parts or how to produce a single part capable of enduring a given load. The software would then simulate millions of possible solutions to this problem, refining the design where necessary utilising finite element analysis and other techniques to identify the optimum design based upon predetermined criteria. Importantly, such software is now commonly optimised for additive manufacturing processes. This means that software can now design and build a component with the only external inputs required being the feed material characteristics and desired output. In practice, the feed material characteristics would likely be drawn from a material library – at least initially.

There are limitations to additive manufacturing design processes, however, meaning that some real-world interaction is required. Principally, this relates to material characteristics. In practice, an engineer may not be able to rely upon libraries containing material properties – especially for high-performance products. It is possible, for example, that different additives manufacturing processes (and indeed, different machines utilising the same processes) could produce components with different material properties. It is also possible that small variations in the composition of material feed stock from batch to batch could have a substantial impact on a finished product. As a result, some feedback loop would always be required to produce and refine a high performance product. This would involve design of the item, construction of the item, performance testing of the item, and then further refinement of the design of the item and so on. In practice, these two processes do not need to be co-located.

Application of the Adapted Capability Acquisition Model

From the analysis above it is evident that additive manufacturing processes have implications for non-proliferation efforts. In order to understand these, it is helpful to examine the problem of additive manufacturing through the lens of the capability acquisition model as outlined in section one of this report.

Tacit knowledge: Additive manufacturing processes are less reliant on tacit knowledge than traditional manufacturing techniques. The prospect of generative design processes further

[25] For example, see autodesk within. Available online at: http://www.autodesk.com/products/within/overview (Accessed 29/01/2016).

reduces the necessity of tacit knowledge. This may have the implication of removing one of the fundamental barriers to capability acquisition. The need for tacit knowledge can never be entirely eliminated, however, and tacit knowledge would certainly be required to take a high performance part towards TRL 9.[26] It is unclear how non-proliferation controls can contribute to controlling such tacit knowledge, however.

Explicit knowledge: The evolution if software in this area means that electronic data (a form of explicit data) is becoming increasingly central to the overall design process.

It is not the purpose of this case study to examine the controllability of materials or equipment (a separate study is being undertaken by the author on this issue). Nonetheless, in the interests of completeness, it is helpful to summarise the possible contribution of supply-side controls in relation to both in order to complete the application of the capability acquisition model.

Materials: Presently, feedstock for additive manufacturing processes is not subject to export control. Given that the composition of feedstock must be carefully controlled in order to ensure the performance of a product, it seems plausible to control feedstock when it is specifically intended for additive manufacturing processes to produce items made of, for example, maraging steel. As production of feedstock is a highly specialised process that requires specialist equipment, such measures could go some way to contributing to non-proliferation efforts.

Equipment: Given that additives manufacturing equipment capable of producing high-performance components is highly specialised, it would at first appear to be relatively easy to subject to export controls. There are concerns that the technology may already have spread too far to make such controls viable. Nonetheless, such controls should be considered.

Overall, therefore, the trend in the additive manufacturing domain is towards the production of high-performance products while minimising the involvement of engineers. In practice, it is of course impossible to eliminate the necessity of trained and educated staff. However, the tacit knowledge required to produce a component through additive manufacturing processes is certainly decreasing. While it is beyond the scope of this study, if additive manufacturing processes can be utilised to produce critical items from a non-proliferation perspective, the implications of additive manufacturing processes are very severe indeed as the present system of non-proliferation controls is poorly suited to controlling additive manufacturing processes. [27]

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[26] TRL 9; 'Actual system proven in operational environment'
Horizon 2020 General Annex, "Technological Readiness Levels (TRL)". Available online at http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf (Accessed 29/01/2016).

[27] C. Grant. "3D Printing: A Challenge to Nuclear Export Controls". Strategic Trade Control Review, Vol. 1, 1, Autumn 2015, p. 18,

Case study 4: British universities conduct research with Chinese aerospace manufacturer linked to Iranian missile programme

In June 2015, the *Financial Times* reported research connections between two British universities and a Chinese state aerospace manufacturer which had been placed on a United States watch-list for supplying goods to Iran's ballistic missile programme.[28]

According to the report, both Imperial College London and Birmingham University had signed research agreements with the Beijing Aeronautical Manufacturing Research Institute (BAMTRI) and its parent company AVIC, a Chinese state aerospace group. Birmingham University and BAMTRI were both members of a European consortium involved in research on large titanium casting processes.[29] Imperial College, BAMTRI and AVIC are partners in a £2.5 million centre aimed at 'forming lighter and stronger aircraft components'.[30]

BAMTRI was founded in 1957 as a Chinese state-owned centre for synthetic research for the aeronautical manufacturing technology. Its self-proclaimed mission is to 'provide advanced manufacturing technologies and associated equipment for the aviation industry, meanwhile apply comprehensive technologies to contribute a great deal of efforts in R&D [research and development] of civil products.'[31]

BAMTRI has reportedly been involved in supplying Iran's missile programme. In 2014, the United States Department of Commerce placed BAMTRI and several other Chinese entities on an export control watch-list 'for their roles in supplying Iran's ballistic missile program' through a notorious Chinese middleman named Li Fangwei, also known as Karl Lee.[32] It is unclear what sort of technology or expertise BAMTRI has supplied to Karl Lee, although Lee is known to have supplied Iran with advanced materials and guidance components suitable

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http://local.droit.ulg.ac.be/jcms/service/49/pdf/str01/STR%20Final%20Full%20Version.pdf, (Accessed 29/01/2016).

[28] Clover, Charles (2015)"UK universities face scrutiny over high-tech Beijing ties". *Financial Times*, 24 June 2015, Available online at http://next.ft.com/af5ea60e-1578-11e5-be54-00144feabdc0, (Accessed 03/02/2016).

[29] "Members and partners of the COLTS project". Birmingham University. Undated. Available online at http://www.birmingham.ac.uk/research/activity/irc-materials-processing/themes/colts/people.aspx (Accessed 04/06/2015).

[30] "New partnership takes off". Imperial College London. 17 April 2012. Available at http://wwwf.imperial.ac.uk/blog/reporter/2012/04/17/new-partnership-takes-off-2/. (Accessed 04/02/2016)

[31] Beijing Aeronautical Technology Research Institute (BAMTRI) Website. Available at http://bamtri.en.busytrade.com/about_us.html. (Accessed 05/02/2015)

[32] United States Department of Commerce Bureau of Industry and Security "U.S. Commerce Department Adds Nine Persons Associated with Missile Proliferator to Entity List". 29 April 2014. Available online at https://www.bis.doc.gov/index.php/about-bis/newsroom/107-about-bis/newsroom/press-releases/press-release-2014/667-u-s-commerce-department-adds-nine-persons-associated-with-missile-proliferator-to-entity-list (Accessed 04/02/2016).

for missile use, and has been repeatedly censured by the United States government for this activity.[33]

Both Birmingham and Imperial College have defended their research involvement with BAMTRI and AVIC. Birmingham has stated that its involvement with BAMTRI ended before BAMTRI's inclusion on the Commerce Department watch-list.[34] Imperial College, while acknowledging that its involvement with BAMTRI has continued, has stated that it conducted due diligence of AVIC before signing the agreement, and that it liaised with the UK Export Control Organisation on the project before commencement.[35] Imperial has also stated that its joint research centre with AVIC 'supports fundamental, non-classified research into new materials and manufacturing methods'.[36]

Imperial College's stated research projects with BAMTRI are listed in the table below. At least some of them may involve exchange of intangible technology requiring licenses. Also, an application of the enhanced Capability Acquisition Model to the case of Imperial College's involvement with BAMTRI may help provide further guidance as to the relevance of the concept of basic scientific research in this context.

Interestingly, one of the projects relates to the validation of materials produced through an additive manufacturing process. In the context of the previous case study, such a project would correlate to TRL 4.

It is notable that the University describes these projects as 'fundamental research'. This term equates to 'basic scientific research'. The University is thus arguing that even if the technology was controlled, a basic scientific research decontrol would be applicable.

[33] Salisbury, Daniel and Stewart, Ian (2014) "Li Fang Wei (Karl Lee)". Proliferation Case Study Series, Project Alpha, 19 May 2014. Available online at http://www.projectalpha.eu/proliferation/item/319-li-fang-wei-karl-lee-proliferation-case-study-series (Accessed 04/02/2016).

[34] In Clover, Charles (2015) "UK universities face scrutiny over high-tech Beijing ties". *Financial Times*, 24 June 2015. Available online at http://next.ft.com/af5ea60e-1578-11e5-be54-00144feabdc0 (Accessed 03/02/2016).

[35] In Clover, Charles (2015) "UK universities face scrutiny over high-tech Beijing ties". *Financial Times*, 24 June 2015. Available online at http://next.ft.com/af5ea60e-1578-11e5-be54-00144feabdc0 (Accessed 03/02/2016).

[36] Clover, Charles (2015) "UK universities face scrutiny over high-tech Beijing ties". *Financial Times*, 24 June 2015. Available online at http://next.ft.com/af5ea60e-1578-11e5-be54-00144feabdc0 (Accessed 03/02/2016).

Table X. Imperial College London/BAMTRI research projects[37]

Number	Title	Description	Potential control entries	TRL
1	Creep age forming	The advantages of replacing conventional structures with lightweight alloys are many, however significant challenges in forming lightweight alloys, such as aluminum, remain. The focus of my research is new lightweight alloy forming processes such as the creep age forming (CAF) technique. In comparison with conventional metal forming processes, CAF can form structures with better mechanical properties and lower residual stresses at lower manufacturing costs. This technique, which is suitable for forming large integral panels with complex curvatures and abruptly changing thicknesses, is considered to be one of the most important metal forming techniques for next-generation aircraft. CAF is a forming method combining forming and ageing heat treatment, in which the creep phenomenon takes place. In a CAF process, the alloy is elastically loaded onto a former and held at its artificial ageing temperature for a predetermined period of time. Under thermal exposure, material constituents of the metal precipitate and alter the microstructure and the mechanical properties of the alloy. While partial permanent deformation in the material is achieved through the synchronous occurrence of age-hardening and stress relaxation by creep. When the loading is released, the material sheet springs back to a shape somewhere between its original shape and the tool shape due to elastic recovery of stress. The key issues in this process are to control the change of the material properties and the springback of the formed alloy, which will be the central objectives of my work.	1B002 Equipment for producing metal alloys, metal alloy powder or alloyed materials, specially designed 1B003 Tools, dies, moulds or fixtures 1C002 Metal alloys, metal alloy powder and alloyed materials N2C13 Titanium alloys N2C1 Aluminum and magnesium alloys 1C002 Metal alloy powder M4C2c Aluminum powder 1C116/M6C8/N2C11 Maraging steels 1C202 Aluminium and titanium alloys 2D001 Software 2E003 Technology, tools and data related to superplastic forming, diffusion bonding, and direct-acting hydraulic pressing of titanium and aluminum alloys	3

[37] "AVIC centre for structural design and manufacture". Imperial College London. Undated. Available online at http://www.imperial.ac.uk/avic-design/projects/transient-liquid-phase/ (Accessed 04/02/2016).

2	Structural integrity of high power fibre laser and electron beam welded lightweight alloy aircraft structures	Light weight alloys, such as high strength aluminum alloys, have attracted increasing attention due to their superior strength to weight ratio, that provide for many applications in aerospace and similar structures. Future aircrafts have challenging design objectives to reduce cost and weight of the structure while getting quicker, safer and also reducing carbon footprint. Innovative use of material form and advanced joining methods for example, high power fibre laser beam welding (LBW) and electronic beam welding (EBW) are crucial for welding and machining lightweight alloys to obtain a highly integrated structure. It is noted that there can be many changes to the microstructure, metallurgical state and associated mechanical properties of the lightweight alloys in the weld zone. Such changes can result in residual stress and defects in the structure, thus significantly influencing the structural integrity and service life of the lightweight alloy product.	1B002 Equipment for producing metal alloys, metal alloy powder or alloyed materials, specially designed 1B003 Tools, dies, moulds or fixtures 1C002 Metal alloys, metal alloy powder and alloyed materials N2C13 Titanium alloys N2C1 Aluminum and magnesium alloys 1C002 Metal alloy powder M4C2c Aluminum powder 1C116/M6C8/N2C11 Maraging steels 1C202 Aluminum and titanium alloys 2D001 Software 2E003 Technology, tools and data related to superplastic forming, diffusion bonding, and direct-acting hydraulic pressing of titanium and aluminum alloys	
3	Structural integrity assessment of additive manufactured products	The research aim is that Additive Manufactured (AM) components would be provided by BAMTRI who have world-leading AM facilities and these materials would be assessed for their structural integrity. A possible path to follow might be to explore the general concept of micro-lattice components for lower weight and enhanced properties to reduce the weight of transport vehicles. A novel aspect of the proposed research could be to explore the advantage of pseudo-random lattice structures that would have benefit over regular lattice configurations. In the first instance, these structures would be modelled with their failure process simulated. Subsequently, laboratory scale experiments would be conducted on Additive Manufactured structures with the pseudo-random		TRL 4

		configuration. Once the finite element analysis approach has been validated, appropriate engineering components would be fabricated and their enhanced performance demonstrated. The main objectives of the project are: • Assess the types and variety of materials that can be manufactured by BAMTRI and identify those for which Structural Integrity should be assessed. • Perform structural integrity assessments of BAMTRI Additive Manufactured materials. • Perform computational finite element simulation to predict mechanical response, sequence and type of failure. • Optimize the Additive Manufactured material to achieve a desired combination of structure and material properties		
4	Microstructures and properties of transient liquid phase bonding joint of single crystal alloy	Currently, single crystal superalloys have been widely used for turbine blades and nozzles in aero engine and industrial power plant. Joining technologies become more and more essential during manufacturing those complicated components, among which Transient Liquid Phase (TLP) bonding has the most potential because of its high compatibility in terms of microstructures and properties with base alloy. However, experiences have shown that excellent joining between single crystal alloy samples can be attained only on the basis of precise mating of grain growing direction, such as with angular deviation strictly controlled to be lower than 15°. Otherwise the mechanical properties of joints decrease significantly even after they are heat-treated using the same braze alloy and process parameters. It has seriously restricted joining of single crystal alloys and affected the reliability of brazed components. However, it is still unclear which microstructural change has happened in the joint during TLP bonding of single crystal alloy and how it affects the mechanical properties of samples. The answers to these questions are very important for manufacturing and repairing of single crystal components The research project involves TLP bonding of single crystal superalloy, especially focussing on the microstructures and properties of TLP-bonded joints. The main aim is to grasp the microstructural formation mechanism of TLP-bonded single crystal alloy joints and understand its effect to mechanical properties of joints. The microstructural characterisation in the solidified zone and the diffusion zone of the joints will be understood, including γ' precipitation and sub-boundary formation. The micro and macro mechanical behaviours of joints will be evaluated, such as micro hardness of phases in the joints, micro crack initiation and propagation. Finally, the relationship between the microstructures and properties of TLP-bonded joints will be identified.	1B002 Equipment for producing metal alloys, metal alloy powder or alloyed materials, specially designed 1B003 Tools, dies, moulds or fixtures 1C002 Metal alloys, metal alloy powder and alloyed materials N2C13 Titanium alloys N2C1 Aluminum and magnesium alloys 1C002 Metal alloy powder M4C2c Aluminum powder 1C116/M6C8/N2C11 Maraging steels 1C202 Aluminum and titanium alloys 2D001 Software 2E003 Technology, tools and data related to superplastic forming,	TRL 1-4

			diffusion bonding, and direct-acting hydraulic pressing of titanium and aluminum alloys	

Whether the involvement of these universities with BAMTRI has been in violation of any United Kingdom export control law would depend on factors that are not on the public record. And while the reported connection between BAMTRI and Iran's missile programme (as well as between BAMTRI and Li Fangwei) does present a risk for the leakage of technology or expertise from the United Kingdom to an undesirable end-user, the risk is admittedly small.

Still, steps should be taken by universities in Imperial's position to mitigate these risks – particularly through the development of a risk management strategy. This could involve:

- A thorough assessment of the infrastructure (i.e. laboratory equipment) being used in the United Kingdom in any proposed research activity to determine its sensitivity and utility in prohibited applications.
- An assessment of the proposed end-uses of the technology to ensure that risks of it being diverted to military or WMD-related end uses or end-users are understood.
- Vetting of domestic and visiting personnel involved in research and administration.
- Site visits to partner institutions abroad to ensure respective compliance processes.
- Requesting that anti-proliferation measures also be undertaken by the foreign research partner in order to further assure compliance with international requirements regarding non-proliferation.38

[38] See Stewart, Ian. (2012) "Antiproliferation: Tackling Proliferation by Engaging the Private Sector". Discussion Paper 2012-15, Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, November 2012. Available online at http://belfercenter.ksg.harvard.edu/publication/22460/antiproliferation.html. (Accessed 04/02/2016).

Case Study 5: Plasma Actuators

The case of John Reece Roth, an American academic who has recently been imprisoned for export control violations, highlights several key issues when considering how export controls apply to the transfer of intangible technology.

On July 1 2009, John Reece Roth, a 72 year-old former emeritus professor of electrical engineering at the University of Tennessee (UT) in Knoxville was sentenced to four years in prison, and another two years of supervised release for non-compliance with the Arms Control Export Act (ACEA). The charges in this case centre on Roth's noncompliance with export control requirements for a United States Air Force (USAF) funded-project subcontracted through the private company Atmospheric Glow Technologies (AGT) from 2005-2006. Roth began serving the sentence on January 18th 2012, after an unsuccessful appeal.

The Case

In April 2005, the USAF awarded a $749,751 contract to AGT, a private company part-owned by Roth and co-founded by his former student and protégé, Daniel Sherman. The contract was for research on the application of plasma actuators to control the motion and direction of air and enhance flight performance of unmanned air vehicles (UAVs). AGT gave Roth and UT a $73,000-a-year subcontract to continue developing plasma actuators to control the flight of military drones.

Plasma actuators typically use a system of insulators and electrodes to create a plasma of ionised air on a surface.[39] In the aerospace context, these systems can be used to manipulate the flow of air over a surface layer such as a control fin or a re-entry vehicle. Potential advantages of plasma actuators in the aviation context include 'lower take-off and landing speeds, shorter runways, increased endurance, improved maneuverability and lower fuel consumption'.[40]

Roth's subcontract with AGT and USAF explicitly stated that the project was liable to United States export controls.[41] Despite this knowledge, Roth insisted that a doctoral student of Chinese nationality, Xin Dai, assist him on the USAF project. Xin had been employed at UT as a graduate research assistant and a graduate teaching assistant under Roth's supervision

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[39] See, e.g., Erfania, Rasool, Zare-Behtash, Hossein, Hale, Craig, and Kontis, Konstantinos (2015) "Development of DBD plasma actuators: The double encapsulated electrode". Acta Astronautica, Volume 109, April–May 2015, Pages 132–143. Available online at http://www.sciencedirect.com/science/article/pii/S0094576515000028 (Accessed 05/02/2016).

[40] See, e.g., Erfania, Rasool, Zare-Behtash, Hossein, Hale, Craig, and Kontis, Konstantinos (2015) "Development of DBD plasma actuators: The double encapsulated electrode". Acta Astronautica, Volume 109, April–May 2015, Pages 132–143. Available online at http://www.sciencedirect.com/science/article/pii/S0094576515000028 (Accessed 05/02/2016).

[41] US Supreme Court. "John Reece Roth vs the United States of America: Brief for the United States in Opposition". Available from http://www.justice.gov/sites/default/files/osg/briefs/2010/01/01/2010-1220.resp.pdf (Accessed 05/02/2016).

since August 2002. Sherman, who was concerned about a potential leak of sensitive information to the PRC, agreed to appoint Xin to work on basic research, whilst a graduate student of American nationality conducted the more sensitive applied research. This arrangement did not prove sustainable, and the two began to share research with the support of both Sherman and Roth. Sherman later admitted that he had known that research sensitive applied should have been restricted to US citizens.[42]

On several occasions Roth was warned not to take sensitive files to China, nor discuss the project on which he was working. In May 2006, upon his return from a lecture trip to China, US federal customs agents met Roth at Detroit airport and photocopied documents in his briefcase and luggage. These documents included one of Xin's reports on the USAF project, and an agenda that showed Roth had lectured on the plasma actuator project whilst in the PRC. The FBI then seized Roth's computer and thumb drive from his Knoxville home. Another report from Xin was discovered on these devices, as well as a draft paper on plasma aerodynamics that Xin had emailed to Roth in China via a Chinese professor. This method of transmission meant that a document that the US government considered to be highly sensitive had been sent to a Chinese scientist.[43]

Roth was accused of one count of conspiracy to export defence articles and services to foreign nationals, 15 counts of exporting defence articles and services without a license, and one count of wire fraud for defrauding UT of his honest services. Sherman, in the hope of avoiding multiple charges, pleaded guilty to one count of conspiring to violate export controls and supplied emails and journal entries for the prosecution. Sherman was sentenced to 14 months in prison and prohibited from working on federal contracts in the future. AGT tried for bankruptcy protection in March 2008 and pleaded guilty to 10 counts of export control violations in August 2008. The University of Tennessee was not prosecuted, as they claimed to be ignorant of Roth's actions and disclosed his violations to the government as soon as they became aware.

Implications

This case highlights a couple of important and potentially problematic aspects of the intersection of academic research and export controls. Much of this conflict stems from differing interpretations of key terms.

Defining "Export"

While Roth was not responsible for the physical removal of sensitive physical goods from the USA, his actions in transferring expertise and data indeed constituted exports, and thus

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[42] Golden, Daniel. "Why the Professor Went to Prison". Available online from http://www.bloomberg.com/bw/articles/2012-11-01/why-the-professor-went-to-prison#p3. (Accessed 04/02/2016).

[43] Golden, Daniel. "Why the Professor Went to Prison". Available online from http://www.bloomberg.com/bw/articles/2012-11-01/why-the-professor-went-to-prison#p3. (Accessed 04/02/2016).

violated the controls placed on the project. The case is useful, in that it highlights several different examples of technological transfers that may not be immediately identified as exports. This is primarily due to the fact that the transfers involved intangible technology, that is, technology that does not necessarily need to take a physical form.[44] First, the employment of a Chinese national on the project and the subsequent sharing of sensitive research and knowledge while on US soil. Even though no goods had left US soil, this was still an export of technology.[45] During his trial Roth testified that he was unaware that hiring the foreign graduate students was a violation of his contract, and that he would not have participated himself had he known.[46] Roth knew the project material was subject to export control laws and did not contend he was unaware of the AECA or its license requirements.[47]

His visit to China involved three methods of transfer that again, may not be hard to identify as exports. The act of bringing a laptop containing sensitive documents relating to the USAF project, presenting on aspects of the project to audiences in China, and the emailing of documents to Chinese nationals, all represent technology transfers.

"In the public domain" and "Fundamental" or "basic research"

The Roth case appears to demonstrate a perceived tension in academia between academic activities and export controls, in terms of what activities should subject to control. The academic world enjoys exemption from export controls if supplied information or technology is deemed to be in the public domain. That is to say; it is 'technology or software which has been made available without restriction upon its further dissemination.'[48] Information in the public domain has been published generally and is accessible to the public.

The research being conducted by Roth on the use of plasma actuators for aerodynamics, it could be argued, was in the public domain. There were several countries researching the same technology at the time. However, the Air Force specifically restricted the contract because the research was part of a weapons program. Governmental restrictions on

[44] This includes, but is not limited to, software, instructions, working knowledge, design drawings, models, operational manuals, skills training, and parts catalogues.

[45] Golden, Daniel. "Why the Professor Went to Prison". Available online from http://www.bloomberg.com/bw/articles/2012-11-01/why-the-professor-went-to-prison#p3 (Accessed 04/02/2016).

[46] Borrell, Brendan (2009). "Tennessee physicist sentenced to 4 years for sharing drone plans with foreign students". Available online from http://blogs.scientificamerican.com/news-blog/tennessee-physicist-sentenced-to-4-2009-07-03/ (Accessed 04/02/2016).

[47] US Supreme Court, "John Reece Roth vs the United States of America: Brief for the United States in Opposition". Available from http://www.justice.gov/sites/default/files/osg/briefs/2010/01/01/2010-1220.resp.pdf (Accessed 04/02/2016).

[48] Export Control Organisation. "Guidance on Export of Technology". Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/15203/Export_of_technology_Guidance_-_URN_10-660_-_new_logo_-_2012.pdf (Accessed 04/02/2016).

dissemination and access made as a condition of funding supersede any exemption that could be made on the grounds that the work was already in the public domain.[49]

Academic research is also exempt from control if it is deemed to be “fundamental” or “basic”. That is; it is work undertaken principally to acquire knowledge of fundamental principles or phenomena and not primarily directed toward a specific practical aim or objective.[50] Though Roth had a contract with USAF that he clearly violated, opening him up to criminal prosecution, Roth still perceived the research he was conducting as ‘basic’ or public. This disagreement illuminates the gap between what some academics might perceive to be ‘basic research’ and what the law actually considers to be ‘basic research’.

[49] University of Missouri. “Exclusions/Exemptions from Export Control Regulations”. Available online from https://research.missouri.edu/compliance/export_controls/exclusions, (Accessed 04/02/2016).

[50] Project Alpha and the Association of University Legal Practitioners “Higher Education Guide and Toolkit on Export Controls”. Available online from http://www.projectalpha.eu/academia (Accessed 04/02/2016).

Case Study 6: Dr. Germ

Dr. Rihab Rashida Taha, nicknamed “Dr Germ” by UN inspectors, was a key member of the Iraqi biological weapons program during the late 80s and early 90s. She worked as a weapons scientist for Saddam Hussein and was involved in the development and testing of warheads with anthrax, botulinum toxin and other biological agents. While Taha undertook her undergraduate education in Iraq, she received her PhD, in biology, from the University of East Anglia in the UK. The case of Dr Germ, and other similar cases, raises interesting questions about the extent to which western education establishments unwittingly aided the Iraqi WMD program, and whether she, and other prominent western educated Iraqi weapons scientists, were deliberately sent to foreign universities to receive instruction that could aid such a program.

It is unclear to what extent the knowledge that Taha gained during her doctoral studies contributed to her work on Iraq’s biological weapons program. On one hand her expertise was in plant pathogens, specifically diseases which affect tobacco. Indeed her supervisor stated "We don't work on things like animal diseases here," he added. "We study plant pathogens." While she will have received some basic instruction on animal diseases, the subject matter that she covered during her time at UEA would not have been directly applicable to a WMD program. Furthermore, Taha was considered to be a relatively uninspired student, who was not especially gifted in her field, but did work hard. She was not considered to have any particular management skills. Yet after her return to Iraq in 1984, she quickly became responsible for a 150 person bio-weapon operation at the now infamous Salman Pak facility. It appears that, much like the British educated head of the Iraqi nuclear weapons program, Jafar Jafar, Taha’s tangentially-related expertise in the field was fitted into the WMD program. Her experience in the UK was helpful however. Taha knew how to procure anthrax from specimen houses obtained abroad, with one Washington-based house sending 27 separate specimens to Iraq.

Taha was just one of several prominent figures in Iraq’s WMD program who received training in the West. Huda Salih Mahdi Ammash, who was nicknamed "Mrs Anthrax", received a Master’s degree in microbiology from Texas University and was thought to have masterminded the reconstruction of Iraq's biological weapons facilities after the Gulf War. And while it is not clear whether these figures in particular were sent to the west to procure specific knowledge, hundreds of Iraqi engineers and scientists were sent with a with the specific purpose of obtaining certain knowledge and expertise during this period. Vetting schemes have since been put in place to ensure that sensitive WMD related knowledge is not transferred to foreign individuals that may have links to WMD programs. One example of this is the ATAS vetting scheme operated by the UK government. What remains unclear is whether had such a scheme been in place in 1980, whether Taha would have been prevented from studying in the UK.

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