# Defence Scientific Advisory Council

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**REPORT OF A WORKING PARTY ON**

## MOD SCIENCE AND TECHNOLOGY SPENDING LEVEL REPORT - PHASE 1: WHY MOD SHOULD INVEST IN ITS OWN RESEARCH PROGRAMME

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(Status of Report: Final)

# MOD SCIENCE AND TECHNOLOGY SPEND LEVEL REPORT: PHASE 1: WHY MOD SHOULD INVEST IN ITS OWN RESEARCH PROGRAMME

# Recommendations

DSAC commends the complementary arguments set out in this paper to the MOD. And we offer the following recommendations:

R-1. The collective arguments of this paper suggest a repositioning of Science & Technology research, from the current largely neutered activity, effectively corralled at the early stages of requirements-driven supply chains, to becoming a strategic, influential and essential activity in its own right, mitigating future risks within uncertain futures and being agile in exploiting opportunities whether foreseen or not.

R-2. MOD should consider adopting a “wide and wise” portfolio approach to its research requirements, with a significant portion of activity being responsive to opportunities, or “push”, whilst the majority supports the evolving requirements agenda, or “pull”, as now. We believe that the MOD should further develop excellence by accelerating promising research lines whilst culling others

R-3. MOD research requires a balance of inputs and interests, with large industry, SMEs, academia and Dstl playing the correct part: the current distribution is neither justified nor optimal.

R-4. We commend to MOD the benefits of an open innovation network approach; achieving more through co-investment and leverage, gaining access to wider S&T expertise, and gaining input and challenge from outside of the existing group-think and operational paradigms. This should include the creation of S&T research centres aligned with key world-class universities that can leverage other investments. It should also build on the lessons from the successes of DARPA-style activities, and thus commit to making the most of the SBRI investment opportunities.

R-5. All of this requires the formulation of a clear *research vision* that should be owned, championed, and led from the top; together with a well-defined research mission to develop essential expertise and resources. Then others can confidently align their aspirations, plans, R&D, business activities and financial investment with those of the MOD, and the nation can be assured that the UK will indeed have access to game-changing technologies, addressing “unknown unknowns”, under uncertain futures.

# Contents

# Introduction

**Is the present MOD spend on Science and Technology (S&T)[1] research, which it is committed to maintain at a minimum of 1.2% of the defence budget, sufficient to meet the goals of SDSR[2]?**

1. This paper, the basis of which is outlined in Annex A, seeks to develop a number of complementary narratives, or supportable lines of reasoning, which together:

   - address the question of 'why MOD might require to fund its own research for science, technology, engineering, analysis and mathematics';
   - set out the corresponding rationale to develop a series of research model options with expectations for investment levels and their consequences; and
   - provide justifiable arguments in response to challenges that may be directed at such plans.[3]

2. In this context, DSAC's independence is crucial since we may focus directly on the value of research contributions in developing capabilities to meet MOD's mission, highlighting options both within, and without, the current practices, supplier base, and resources.

3. The context of S&T has been set out in the SDSR and in the National Security through Technology White Paper[4] (see discussion in Annex B). We consider that, to achieve the stated high-level goals, it is necessary to follow a number of complementary routes. These present tactical investment options that follow naturally from the implications of the perspectives driving our narratives.

4. Definitions that are intended to determine which activities actually constitute "research" and which activities relate to its translation, development and

[1] We shall use S&T as the description of a broader range of topics including science, technology, engineering, analysis and mathematics.

[2] Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review, HMSO, October 2010.

[3] In a second phase of this study DSAC will address the issue of what amount (in more absolute terms) should be spent, and why and how, in order to achieve desirable consequences, rather than justifying spending as a percentage of the total budget.

[4] National Security Through Technology: Technology, Equipment, and Support for UK Defence and Security; White Paper presented to Parliament by the Secretary of State for Defence, February 2012.

deployment, are often the basis of argument (see Annex C). However, we believe that such issues must not deter MOD from adopting a very clear position on the rationale for, the desirability of, and the expectations raised by the contributions from “research” activities within its overall mission.

5. It is very clear to us that MOD research and research spending is not, and should not be, completely confined to that funded through the Defence Science and Technology (DST) Head Office, all within the Chief Scientific Adviser’s (CSA) budget and all determined by the Research & Development Board. Research is being undertaken within other areas, sometimes under the guise of "development" e.g. in the Defence Equipment and Support (DE&S) organisation, the Warfare Centres, Defence Academy, and Defence Concepts and Doctrine Centre (DCDC). Consequently, we shall consider this wider activity (and spending) and address the question of why it is necessary and how it could be more beneficial to MOD. We note that budgets for such work may be vulnerable, not least because they may appear less committed, less urgent or insufficiently focused. Therefore, it is essential to be clear about the role of this spending and the expectations that should rightly be raised.

6. **For these reasons, we recommend that MOD clarify its requirement for, and its reliance upon, research of all kinds. MOD needs a justifiable and justified research strategy, resting on arguments and enabling aspirations. It should be owned and led from the top so that it cannot be subverted, or reinterpreted, at lower levels within the organisation.**

7. When we consider S&T 'strategy and policy' there should be clarity at different levels:

- why, how, where and what levels of investments are made within S&T research;
- the MOD position on topics such as risk, resource scarcity, knowledge, skills, and the impacts of trends and emerging technologies; and
- bigger issues such as our international role and relationships, and MOD’s responses to organisational, operational, cultural, and reputational challenges.

8. Here we address (i) with some obvious implications for (ii); and we suggest that a more transparent, justified, “scientific” approach could also assist with (iii).

# *MOD's S&T Research: Complementary Perspectives*

**What position within the international defence community, and what kind of future military capabilities does the UK wish to hold? Is the UK to be a source of leadership, authority and innovation, or merely an effective contributor of supportive, lower-grade capabilities and resources?**

9. Over the past two decades, the UK has been deeply involved in a number of asymmetric conflicts, related to terrorism, peacekeeping and failed and failing state interventions. We posit that MOD would wish to be effective within existing and emerging international coalitions and that our national pre-eminence in many areas of S&T research is a key asset in securing access, advantage, influence, authority, positioning, participation and leverage.

10. In the wider context of S&T, the UK enjoys some natural advantages. We have had a long and distinguished track record of leadership and success in many areas of science. We conduct world class research that attracts world class scientists and engineers; English is the language of science and the UK's Higher Education sector is both world renowned and a highly desirable destination for learning, scholarship and research. Our reputation in S&T is arguably disproportionately high and results from our internationally recognised excellence[5]. Even in the face of tough, on-going, large scale, global competition, this S&T strength has in the past been reflected in the UK's S&T military achievements.

11. **If MOD wishes to remain as a major player in world affairs, where both hard and soft power are key to achieving influence, it should build on the nation's S&T strengths and aspire to be a world leader within those S&T fields that support both its own current military capability and future needs and those of the our international partners. Research, including basic research, has a critical role to play: a role that differs distinctly from almost any other activity currently sponsored by MOD.**

12. Not only does research provide an opportunity to build authority and knowledge ahead of the game, but it is also the single most significant part of

[5] http://www.epsrc.ac.uk/newsevents/pubs/reports/Pages/internationalreviews.aspx.

MOD activity that can be exploited to address the "unknown unknowns", and yield game-changing capabilities. We note that at present there appears to be very little MOD investment that is not explicitly requirement-led, i.e. addressing some of the "known unknowns". Given the uncertainties set out in SDSR, this point is crucial and it implies that research cannot be valued simply as an incremental driver for known, or expected, threats and opportunities. A strong, visible, basic research programme provides an assurance to the nation that MOD will be ahead of the game, whatever the game may be, and will be able to anticipate and respond, in a timely and effective way, to threats emerging in an increasingly complex and uncertain future.

*So why, what, and how should MOD invest in S&T research?*

13. We commend the following narratives drawn from non-exclusive perspectives.

**Influence and authority**

14. **The UK needs to be clear about the position it wishes to occupy within future coalitions and operations. Excellence in S&T research and its effective exploitation within specific defence and security specialist areas will be necessary to guarantee the UK an authoritative position amongst its allies and to make the UK a strategic *partner of choice* for emerging nations.** Cooperation through the alignment of research capabilities, exchanges of information, and programme collaboration, are a natural way for the UK to build trust and partnerships and to leverage the investments and efforts of other nations. Hence, in addition to the obvious benefits of knowledge, world class science can be used as a tool for influence and diplomacy. By contrast, to under-invest in S&T is to be relegated to the role of an *also-ran* in research, and, by implication, in thought leadership. This would send out a clear message of weakness, a lack of desire to lead, and a lack of commitment to existing and potential partners. We are well aware that this line of argument necessarily leads to hard decisions over which disciplines and applications should be the focus of investment, since future budgets would need to be controlled by varying the number of areas to be maintained at world class level rather than "salami slicing" everything. It also raises questions about those fields where we

require to be leading and how far ahead we need to look. The MOD must be specific on both this point and its desire to exploit S&T research to enhance its position and influence internationally.

## Innovative options within a changing world

15. Experience has shown that novel and disruptive S&T developments can be rapidly adopted by population strata and communities and may even become pervasive across societies. The MOD will need to deliver its future capabilities in operations within urban, social, digital, cultural, and ethical environments that are themselves subject to both S&T and social drivers. In addition, it is necessary to accommodate:

- the **pace of change of innovations** and to be aware that the take-up of disruptive new ideas and technologies often occurs by unexpected ways and means;
- the miniaturisation of laboratory science; and
- the global availability of expertise, knowledge, intelligence and know-how.

16. Research is essential to stay ahead of the game and to create and maintain awareness of, and advantage over, threats. Cyber influence is an excellent example of social and technical multidisciplinarity at work and of the urgency with which concepts and innovations may need to be deployed. Such "research through doing" (we are living through the experiments) is critical and yet the level of investment is currently very small.

## Research should not be entirely driven by requirements: it must yield game changing capabilities when called upon.

17. The specification of requirements for future capability is necessarily a large part of MOD's planning. However, this can only cover the "known unknowns". List–based approaches to threats (in Chemical and Biological, for example) may be blindsided by innovations. Operational "customers" understandably tend to focus on short to medium term improvements and, for a variety of reasons, tend, or are forced, to adopt an incremental approach. Their "requirements" are naturally focused on improved capabilities within the current paradigms and a limited number of operational environments. A stark example of this was the inability of significant parts of the Core Equipment Programme (some parts of which are arguably still entrenched in Cold War doctrine and planning) to deliver capability in Iraq and Afghanistan resulting

in a significantly reduced military effectiveness. The risks of relying on requirements alone to drive research and inspire innovation, are captured in this quotation from the US Defense Advanced Research Projects Agency (DARPA)[6]:

***"None of the most important weapons transforming warfare in the 20th century – the airplane, tank, radar, jet engine, helicopter, electronic computer, not even the atomic bomb – owed its initial development to a doctrinal requirement or request of the military"***.

18. To this, DARPA goes on to add unmanned systems, stealth, Global Positioning System (GPS) and Internet technologies.

19. Even thermal imaging, so much a part of military capability world-wide today, was made possible by the fundamental work of MOD scientists at Malvern in the late 1950s against vigorous opposition from the defence community in the absence of a 'clear military requirement'. It was only the determination of a few visionary scientists that enabled the UK to establish a world-leading capability in the 1980s and beyond.

20. The research of ideas and topics driven by opportunity "push" is the one area of S&T spending where there is the opportunity to break out of this incremental cycle and explore new futures, possibly independent of current modes of operation. **We recommend that a significant fraction of the S&T budget should be devoted to exploring ideas and opportunities that may be medium to long term game changers.** This would allow the MOD to develop new capabilities in new domains where the challenges and threats may occur, i.e. virtual, digital, economic, environmental, social, health, cognitive and physical. **A portfolio approach would be necessary for adventurous or high risk research, plus willingness to either fast track, or cull, such alternative themes and topics.**[7]

[6] Chambers, John, ed., The Oxford Companion to American Military History quoting from DARPA Strategic Plan, US DoD, 2005.

[7] Indeed it was the excellence and experience of the S&T knowledge in MOD which allowed UORs to be developed and deliver capability inside a year from request for Operations Telic and Herrick that added critically to UK military effectiveness in theatre.

## Avoiding stakeholder biases and group-think

21. Commercial entities (suppliers) have a legal obligation to act in the best interests of their investors and shareholders. They have no corresponding legal obligation to their customers or their supply chain. Consequently, they cannot guarantee to act in the best interests of the UK. Issues arise when MOD requires support for new strands of S&T in which traditional suppliers, or prime contractors, may have little, or no, expertise. As a result of their obligations to shareholders, their interest lies in maintaining "agreed road maps", Government to industry relationships, guaranteed programmes and long term investment. This has the potential to deliver an unhealthy, "lock in" between MOD and its prime contractors with a consequential stifling of the essential, wider thinking. The logical extension of this would have industry taking on progressively more contracted "research" packages with the possibility that the existing scientific defence R&D community may become marooned, marginalised and, eventually, redundant. Yet already a large amount of research funding is distributed to the large defence primes, precisely because they are the large primes rather than the best minds. Those who are tasked to deliver such research may lack both tension and excellence. This in turn puts an added onus on Defence Science and Technology Laboratory (Dstl), as MOD's in-house supplier of S&T, to ensure that they are getting something useful from MOD's investment. This pendulum clearly needs to reset under the current economic circumstances.

22. In parallel, management and practitioners feeling a responsibility to their institutions, colleagues, aspirations, and disciplines could merely promulgate the research directions of the past. **The money spent on development could easily be a victim of such group thinking and, consequently, we would suggest that MOD review how R&D activities serve each other now and how they should in future. For its responsiveness and capabilities to be genuinely adaptive and agile, MOD should consider adopting a "portfolio" approach to its research and maintaining a wide set of informed S&T research activities.** In any portfolio approach, a significant proportion of the investment should target "high risk high return" activities. MOD should also develop, and demonstrate, an ability to both accelerate promising lines of research and to terminate unpromising lines.

## Leverage and Open Innovation

23. Due to funding constrains, it will never be possible to cover all the bases. Indeed, it is probable that current budgets cannot cover all the known high priority topics. Creating and maintaining in-house capability is expensive, prone to comfort zones, strategic errors and internal process drag (inertia, resistance to change, "not invented here" and "rice bowls"). In many cases,

this will eventually result in redundant knowledge and resource. In our view, it would be far better to identify a very wide set of the key fields of S&T research that can be prosecuted through an **open innovation** approach. This involves the creation of an ecosystem of researchers across current research providers, laboratories, Higher Education Institutes, Small to Medium Sized Enterprises (SMEs) and global corporations. MOD would be a very powerful magnet to attract co-investors, both directly and through other conduits, e.g. the Department of Business Innovation and Skills (BIS), Research Councils, the Technology Strategy Board (TSB), other Government Departments or Agencies, various industrial and commercial interests, and even venture funding. Such investments could be made with the prospect of creating long-term relationships, providing access to routes to exploitation, impact and wealth creation, plus the building of national and international centres of repute, esteem and influence. The objective should be to seed national capabilities within specialist S&T centres of viable size that can be called on in a flexible and adaptable manner. MOD's co-investors should be required to at least match MOD investment and would have the opportunity to gain MOD as a customer. In many cases, potential partners, already have multidisciplinary expertise and platforms, e.g. high performance computing, that would be difficult for MOD to assemble and maintain within its own budgets. In the *internet age,* presumed secrecy and confidentiality are far less important than technical dominance and ability. We believe that MOD should catalyse such world-class centres of expertise and scientific leadership, sharing costs and benefits with aligned world-class universities and companies that aspire to become international leaders in the appropriate fields.

24. While leverage with Engineering and Physical Sciences Research Council (EPSRC) and other research councils may seem desirable, it is also a severe constraint. Academic reviewers do not always understand MOD opportunities and priorities, the long timescales for applications are inhibiting for true innovation, and the project funding is rarely responsive to new technology push (which has low priority when set against current "managed" requirements). Rather, MOD should look beyond the research councils to form strategic relationships with suitable universities, and, if appropriate, pull in research councils once academic-Dstl led proposals for research projects have been formed.

25. Since more and more cutting edge scientific activity is multidisciplinary (including social sciences), interdisciplinary and multifaceted, this approach has the advantage of both gaining access to leading contributors across subject boundaries and being as transparent as possible in terms of

providing benchmarking of excellence and achievements. Similar thinking should be focused on the development of SMEs as participants; not just as suppliers, but at all levels. In our opinion, the current Small Business Research Initiative (SBRI) and the Centre for Defence Enterprise (CDE) operations are not at a level of investment, nor at a level of commitment and quality, to be fully effective and much more thought and development is needed if they are to deliver high impact results. A vital dimension for success must be the effective transition of research achievement into viable military capability – a dimension that is critically lacking at present. As MOD develops its approach to SBRI and CDE in line with Government policy, it has an opportunity that should be vigorously and enthusiastically embraced.

26. Regarding other models to stimulate defence innovation, whilst DARPA is perceived by many in the UK to be expensive and inefficient, it has consistently delivered game changing technology, defence capability and civilian products for the US economy. The reasons for its success go far beyond simply having a large budget and include its deliberate stimulation of high risk but potentially high gain ideas, the early culling of ideas whose promise is not materialising and the provision of sufficient funds to take promising ideas forward to the point of at least some form of demonstration. DARPA acts as an open innovation broker bringing together academic researchers and industry to guarantee the exploitation of promising research. Furthermore, a critical core strategy is to get companies to develop civilian products so that civilian markets can support the technologies required by the military. This reduces defence support costs and, importantly, also generates more tax dollars that can be used to support defence programmes. **We recommend that urgent consideration is given to the identification of those elements of DARPA[8] that could be of greatest benefit to MOD and which could be instigated within the UK, together with some work on how this might be achieved.**

27. Finally, there appears to be a view in some areas that all scientifically trained people employ identical, infallible scientific methods within similar environments, so that the outcome of a piece of scientific work is the same irrespective of whether it is performed by academics, government scientists, industry employees or consultants. This would imply that efficiency and effectiveness are merely a matter of the cost of supply and so research can be procured on a competitive tender basis in much the same way as commodities such as cap badges and belt buckles. Yet science, and especially research, is a creative activity, and it is folly to discount the implicit (unbilled) deliverables brought to the table: the wealth of experience and

[8] The US DoD's Defense Advanced Research Agency (http://www.darpa.mil ) has a FY-2012 budget of some $3Bn; (Basic Research 11%, Applied Research 44%, Advanced Technology Development 42%, T&E support 3%).

knowledge, the tensioned excellence, the scientific and innovation networking, the halo of related research activities, and the curiosity-driven exploration of novel concepts and ideas.

# The Cost of Doing Less

28. The default response to declining budgets, salami slicing, is of limited value when applied to S&T programmes and is positively damaging when applied to upstream research. This point has been accepted by the present Government (and its predecessor) who recognise S&T investment as an intrinsic part of the Nation's growth strategy as the UK seeks an economic recovery. At a time when very hard decisions are being made across all public spending, the Government continues, via HM Treasury and BIS, to invest both capital and budget into strategic S&T research themes. In S&T, it is better to be clear about what research needs to be done and why and to fund it appropriately, i.e. to have a strategic plan for success.

29. **The research funded by the MOD should draw gearing from this national investment from BIS to help address defence needs and to support the building of S&T capability for its own requirements.** In this way, it can contribute to the strengthening of UK S&T for wider benefit in the medium and long term. Experience shows that, with MOD S&T capability suitably integrated to a broader national S&T effort, there will be near-term advantages that can be realised by accelerating new knowledge and S&T via Urgent Operational Requirements (UORs), and then on into core capabilities. For example, MOD research on flight control laws enabled the development and implementation of novel helicopter manoeuvres to increase survivability from surface-to-air missile attack. We have a right to expect some such serendipity, but only if we have invested *widely and wisely* in research, and we have an innovative ecosystem of R&D to call upon. However, to have such a network available, it must be fed.

30. More starkly, the full cost of not investing, or doing less, is borne across the whole public sector. Where MOD capabilities become less current, less efficient, or less effective, the consequent underperformance usually results in the prolonging of operations, missed opportunities, increased loss of life and physical and mental health problems (not only for the military but the wider communities). This, in turn, leads inevitably to expensive long-term remediation and support.

31. The 2009 Haddon-Cave report into the crash of Nimrod XV230 highlighted the importance of holding decision makers to account when serious failures to protect military personnel have occurred. While there is a political acceptance of the risk in undertaking conflicts with this must come the moral willingness to pay to provide protection and S&T research is an essential part of this. For example, Osprey body armour, Panama improvised explosives device (IED) detectors and the heavily armoured Mastiff personnel carrier

have saved many military lives[9] and their short order development in the UOR programme was heavily reliant on previous S&T programmes. The Department for Transport (employing a "willingness to pay" model recommended by the HM Treasury appraisal and evaluation "Green Book" guidelines) estimated the full cost to the UK per road fatality in 2011 at £1.69M[10]. Similarly, notwithstanding the human cost to family and friends, without defence S&T spend over the past decades, Operation Herrick alone would have cost an additional £8.5Bn in pensions, benefits and healthcare costs for bereaved families.

[9] The estimation of the numbers saved uses the data of IED direct hits to Mastiff vehicles, the number of damaged plates scrapped from Osprey body armour and the number of IEDs detected by Taslisman to produce a number. Whilst operation strategies may change depending on the available capability, this estimation is based on events which could without the deployment of the correct new capability have resulted in fatalities.

[10] Department of Transport, "Reported Road Casualties in Great Britain: 2011 Annual Report", http://assets.dft.gov.uk/statistics/releases/road-accidents-and-safety-annual-report-2011/rrcgb2011-02.pdf.

# Concluding Remarks and Initial Recommendations

DSAC commends the complementary arguments set out in this paper to the MOD. And we offer the following recommendations:

**Recommendation 1:** The collective arguments of this paper suggest a repositioning of S&T research, from the current largely neutered activity, effectively corralled at the early stages of requirements-driven supply chains, to becoming a strategic, influential and essential activity in its own right, mitigating future risks within uncertain futures and being agile in exploiting opportunities whether foreseen or not.

**Recommendation 2:** MOD should consider adopting a “wide and wise” portfolio approach to its research requirements, with a significant portion of activity being responsive to opportunities, or “push”, whilst the majority supports the evolving requirements agenda, or “pull”, as now. We believe that the MOD should further develop excellence by accelerating promising research lines whilst culling others.

**Recommendation 3:** MOD research requires a balance of inputs and interests, with large industry, SMEs, academia and Dstl playing the correct part: the current distribution is neither justified nor optimal.

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**Recommendation 5:** All of this requires the formulation of a clear *research vision* that should be owned, championed, and led from the top; together with a well-defined research mission to develop essential expertise and resources. Then others can confidently align their aspirations, plans, R&D, business activities and financial investment with those of the MOD, and the nation can be assured that the UK will indeed have access to game-changing technologies, addressing “unknown unknowns”, under uncertain futures.

# *APPENDIX A: Terms of Reference and Working Party Membership*

A-1. **Study Terms of Reference**

The study was requested by Minister for Defence Equipment Support and Technology and sponsored by Director DST Strategy. The purpose of the study was to provide a DSAC perspective on research spending with particular emphasis on future needs. This was to inform the Minister and senior MOD officials of DSAC's view and justification of the appropriate level of spending on research.

**Anticipated impact of the study**

A clearer understanding of what research is, why it is done, and how much it costs.

**MOD milestones or decision points that affect the timing of the study**

The study will inform internal MOD work preparing for the 2015 Strategic Defence and Security Review.

**Study Delivery**

DSAC will undertake this study in two phases:

- Phase 1 - addressing the question 'why S&T research is essential to MOD?'
- Phase 2 - addressing the questions 'how much should be spent and on what?'

This document presents DSAC's Phase 1 response.

A-2. **DSAC Study Team**

- Mr John Ames
- Prof Peter Grindrod
- Prof Douglas Paul
- Prof Ian Poll
- Prof Phil Sutton

The team wishes to acknowledge the contributions made by Prof Gareth D Padfield to the activities of this study and to early stage drafts of this report APPENDIX B: Background Information

# *APPENDIX B: Background Information*

**National Security Through Technology: Technology, Equipment, and Support for UK Defence and Security White Paper**

**Presented to Parliament by the Secretary of State for Defence, February 2012**

B-1. The White Paper emphasises the critical importance of technology to protecting the UK's operational advantage and freedom of action. To quote:

''*Given the critical role that science & technology plays in supporting our immediate needs and programmes, we will need to manage carefully the balance between this and addressing our future capability needs. We also need to ensure our own technical capability, infrastructure, and research organisations are carefully prioritised to retain our ability to be an intelligent customer, develop specific solutions, and maintain credibility with our allies*.''

B-2. Balance and prioritisation of research are key in times of limited resources, when the goals of operational advantage and freedom of action are strictly relative concepts, begging the question - what kind of operational advantage and how much freedom of action are really required? Different answers to this question lead to different routes to achievement, but we suggest that S&T research forms a metaphorical front line here, a defence capability in its own right, determining what can and cannot be achieved.

B-3. The White Paper acknowledges the challenges posed by an uncertain future in prioritising S&T resources, but states clearly that investment in defence-related and security-related science & technology research must focus on six critical outcomes:

- support to current defence and security operations (12%)
- plan for future capabilities that will be needed in the longer term (39%)
- cost reduction and more future proof systems (16%)
- support to critical science & technology capabilities/facilities (12%)
- provide timely and effective advice to Ministers and Government (13%)
- particular focus on the human and sociological aspects of capability (8%)

B-4. The percentage of the CSA S&T research budget spent on each activity in 2012 (total £420M) is included in parenthesis, derived from the Hansard[11]. These priority areas provide the framework of government thinking and planning on Defence and Security S&T, and for this DSAC study.

[11] Extract provided to the 20th September 2012 DSAC Council meeting and attached as Annex B to the meeting minutes.

# *APPENDIX C: Definition of Research and Development*

### Definition of Research and Development

C-1. What is research? Two commonly used structures to define research and development (R&D) can be found in the Frascati Manual[12], an internationally recognised methodology for collecting and using R&D statistics, and the Technology Readiness Level (TRL) construct[13], developed by NASA to differentiate research and development activity. Figure 1 shows an approximate alignment of the Frascati and TRL descriptions. Important aspects of this taxonomy are that:

- basic research is focussed on discovery "without any particular applications in view";
- applied research is to acquire new knowledge "towards a specific practical aim"; and
- development draws on existing knowledge directed to "produce, install or improve."

C-2. The DSAC study team agree with these broad definitions but are also aware that there are no clear dividing lines, especially when research advances rapidly through the TRLs.

[12] "*Frascati Manual*", Proposed Standard Practice for Surveys on Research and Experimental Development, 2002.

[13] "*Technology Readiness Assessment (TRA) Guidance*". United States Department of Defense, April 2011.

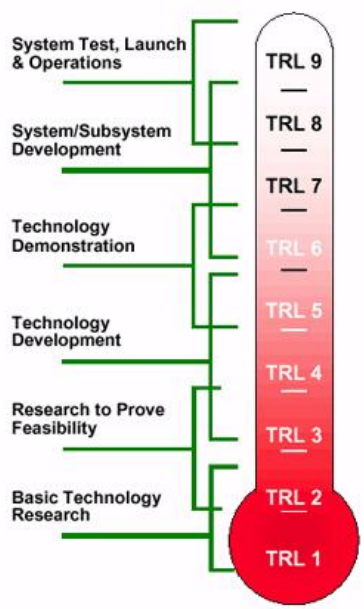
| Frascati Definitions of R&D | NASA TRL Construct for R&D |
|---|---|
| **Experimental development** is systematic work, drawing on existing knowledge gained from research and/or practical experience, directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.<br><br>**Applied research** is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.<br><br>**Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. |  |

**Fig. 1 Distinguishing Research and Development - Alignment of Frascati and TRL**

C-3. Generally speaking, the higher the TRL, the more expensive is the activity, as it draws in more resources for integration, prototype developments and realising production standards. It is also well recognised that the process of pulling the results of basic research through the applied channels and particularly into development is very challenging. The mid-TRL range is often described as a 'valley of death' or 'challenge basin', a place where many innovative ideas fail to attract early adoption or gain commercial exploitation. Concept immaturity and weak financial arguments are often part of this; but there is also a significant intellectual challenge involved in seeing and developing routes through the valley that clearly reduce risk. In defence research these processes normally require close collaboration between researchers and industry. Exploitation can also depend critically on ownership of the outputs from basic research. Without a basic research programme, MOD does not own any such outputs and relies on technology watchers to spot relevant activity; this carries a very high risk as analysis of research outputs is itself a specialist activity. We argue strongly that MOD, with its emphasis on applied research, and increasingly on

capability 'deltas', probably misses many opportunities and, critically, are unlikely to realise this loss until years in the future.

C-4. As we continue, the aligned Frascati-TRL descriptions serve as the basis for the narrative of this Report and we explore how MOD's research (and development) activity fits into these structures and addresses the exploitation challenges. It is noted that, according to DASA's Defence statistics 2012 report[14], MOD spend a (net) total of £1.7Bn on R&D, with 32% of that on research.

[14] UK Defence Statistics 2012, DASA, December 2012