House of Commons

Defence Committee

Developing Threats to Electronic Infrastructure

Written Evidence

COMMITTEE IN CONFIDENCE

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Written evidence from officers of the International Electrotechnical Commission (IEC) Subcommittee 77C

The authors of this letter are officers of the International Electrotechnical Commission (IEC) Subcommittee 77C and have been leading the effort within the IEC to develop standards and other publications to protect the civil infrastructures of the world against man-made attacks from different types of "EMP". This work began in 1989 and has focused on two particular "EMP" threats: the high-altitude electromagnetic pulse (HEMP) produced by nuclear detonations in space and Intentional Electromagnetic Interference (IEMI) produced by electromagnetic weapons used by criminals or terrorists. In addition a few of the IEC publications deal with low-frequency HEMP environments that are very similar to the environments created by space weather or more particularly geomagnetic storms, which are natural, but severe threats to the power infrastructure.

The title and scope of IEC SC 77C are:

High Power Transient Phenomena
"Standardisation in the field of EMC to protect civilian equipment, systems and installations from threats by man-made high power transient phenomena including the EM fields produced by nuclear detonations at high altitude. Note - high power conditions are achieved when the peak incident EM field exceeds 100 V/m."

This committee produces international civil standards and technical reports on protection and test methodologies against high power transients. They are available for use by any country wishing to protect its civil systems against such transients. At the present time the IEC SC 77C is supported by 18 'P' or participating (voting) member countries (including China, Germany, Republic of Korea, Russian Federation, UK, USA) and 16 'O' or observing member countries. As with all IEC standards, they are voluntary until they are adopted by national or regional standards organizations or when they are referenced in contractual documents.

The publication set encompasses 20 documents, which is in fact the most complete set of high power electromagnetic standards available for defining the threats and designing protection measures and test methods to ensure that the protection elements perform according to their specifications. The most recent of these publications deal mainly with IEMI aspects, and these were published over the past five years. Many of the older publications deal specifically with HEMP, and some deal generally with the protection methods available for high-level EM fields at frequencies above 10 MHz, which covers both HEMP and IEMI.

It is important to note that the publications of IEC SC 77C are basic standards that need to be applied to specific products and industries. In recent years the publications of IEC SC 77C have been adapted to the needs of the telecommunications industry by the International Telecommunication Union (ITU-T Recommendations K.78, and K.81) and to the needs of the international power industry in Cigré (WG C4.206 where work is underway).

In order to aid the Defence Committee, we have attached in an annex, the complete list of publications prepared by IEC SC 77C.

26 September 2011

Annex

Publications Dealing with the Protection of Civil Equipment and Systems from the Effects of HEMP and HPEM (IEMI) – Issued by the International Electrotechnical Commission (IEC) SC 77C

IEC/TR 61000-1-3 Ed. 1.0 (2002-06): Electromagnetic compatibility (EMC) – Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems. **Basic EMC publication**

IEC/TR 61000-1-5 Ed. 1.0 (2004-11): Electromagnetic compatibility (EMC) – Part 1-5 : High power electromagnetic (HPEM) effects on civil systems. **Basic EMC publication**

IEC 61000-2-9 Ed. 1.0 (1996-02): Electromagnetic compatibility (EMC) – Part 2: Environment – Section 9: Description of HEMP environment – Radiated disturbance. **Basic EMC publication**

IEC 61000-2-10 Ed. 1.0 (1998-11): Electromagnetic compatibility (EMC) – Part 2-10 :Description of HEMP environment – Conducted disturbance. **Basic EMC publication**

IEC 61000-2-11 Ed. 1.0 (1999-10): Electromagnetic compatibility (EMC) – Part 2-11: Environment - Classification of HEMP environments. **Basic EMC publication**

IEC 61000-2-13 Ed. 1.0 (2005-03): Electromagnetic compatibility (EMC) – Part 2-13 : High-power electromagnetic (HPEM) environments – Radiated and conducted. **Basic EMC publication**

IEC 61000-4-23 Ed. 1.0 (2000-10): Electromagnetic compatibility (EMC) – Part 4-23: Testing and measurement techniques – Test methods for protective devices for HEMP and other radiated disturbances. **Basic EMC publication**

IEC 61000-4-24 Ed. 1.0 (1997-02): Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 24: Test methods for protective devices for HEMP conducted disturbance. **Basic EMC Publication**

IEC 61000-4-25 Ed. 1.0 (2001-11): Electromagnetic compatibility (EMC) – Part 4-25: Testing and measurement techniques – HEMP immunity test methods for equipment and systems. **Basic EMC publication**

IEC/TR 61000-4-32 Ed. 1.0 (2002-10): Electromagnetic compatibility (EMC) – Part 4-32: Testing and measurement techniques – HEMP simulator compendium. **Basic EMC publication**

IEC 61000-4-33 Ed. 1.0 (2005-09): Electromagnetic compatibility (EMC) – Part 4-33: Testing and measurement techniques – Measurement methods for high power transient parameters. **Basic EMC publication**

IEC/TR 61000-4-35 Ed. 1.0 (2009-07): Electromagnetic compatibility (EMC) – Part 4-35: Testing and measurement techniques – High power electromagnetic (HPEM) simulator compendium. **Basic EMC publication**

IEC/TR 61000-5-3 Ed. 1.0 (1999-07): Electromagnetic compatibility (EMC) – Part 5-3: Installation and mitigation guidelines – HEMP protection concepts. **Basic EMC publication**

IEC/TS 61000-5-4 Ed. 1.0 (1996-08): Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 4: Immunity to HEMP – Specification for protective devices against HEMP radiated disturbance. **Basic EMC Publication**

IEC 61000-5-5 Ed. 1.0 (1996-02): Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 5: Specification of protective devices for HEMP conducted disturbance. **Basic EMC Publication**

IEC/TR 61000-5-6 Ed. 1.0 (2002-06): Electromagnetic compatibility (EMC) – Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences. **Basic EMC publication**

IEC 61000-5-7 Ed. 1.0 (2001-01): Electromagnetic compatibility (EMC) – Part 5-7: Installation and mitigation guidelines – Degrees of protection by enclosures against electromagnetic disturbances (EM code). **Basic EMC publication**

IEC/TS 61000-5-8 Ed. 1.0 (2009-08): Electromagnetic compatibility (EMC) – Part 5-8: Installation and mitigation guidelines – HEMP protection methods for the distributed infrastructure. **Basic EMC publication**

IEC/TS 61000-5-9 Ed. 1.0 (2009-07): Electromagnetic compatibility (EMC) – Part 5-9: Installation and mitigation guidelines – System-level susceptibility assessments for HEMP and HPEM. **Basic EMC publication**

IEC 61000-6-6 Ed. 1.0 (2003-04): Electromagnetic compatibility (EMC) – Part 6-6: Generic standards – HEMP immunity for indoor equipment. **Basic EMC publication**

EIS 002

Written evidence from the Royal College of Physicians

The Royal College of Physicians (RCP) plays a leading role in the delivery of high quality patient care by setting standards of medical practice and promoting clinical excellence. We provide physicians in the United Kingdom and overseas with education, training and support throughout their careers. As an independent body representing over 25,000 fellows and members worldwide, we advise and work with government, the public, patients and other professions to improve health and healthcare.

Introduction

1. The Royal College of Physicians (RCP) welcomes the House of Commons Defence Select Committee's inquiry into Developing threats to electronic infrastructure. We value the opportunity to provide comment.

Comments

2. We believe that it would be appropriate to consider the effect of electromagnetic pulse (EMP) on patients with implantable cardiac devices.

October 2011

EIS 003

Written evidence from Peter Taylor, Ethos Consultancy

I am a writer with a recently developed interest in spaceweather impacts. I am sure that you will receive many detailed submissions in answer to your inquiry which will contain much of the relevant science – I add here some comments which may be of assistance in your assessment of this material.

My own interest was sparked firstly by analysis of ice-core records. This kind of material in unlikely to come your way as it is a difficult area. I have not had the time to evaluate the material fully, nor provide you with a reliable guide to the data – but from what I have seen, it is possible to assess the frequency of 'Carrington' type events – I will call them 'megaflares', as they leave a chemical imprint in the ice-core record. The general conclusion is that such events may have a frequency in the range of 1:200 to 1:500 years. Perhaps you would be able to instigate a more detailed analysis.

As you will know the last such event was in 1859.

Given the large potential impact of such an event on modern infrastructure, this is a very high risk, and doubtless why you are now devoting your time to the issue. Of course, this phenomenon is well-known within the science community, and you might usefully ask someone why the issue is only now being addressed.

I, myself, only came across a detailed investigation on publication of the US National Academy of Science report in late 2008, along with the Congressional hearing.

My main points are:

- that report showed that the long-distance electric grid could be disabled to such an extent that repairs might take 3-4 years (optimistically)
- it was not clear to what extent the electronic infrastructure of satellites and terrestrial computer systems and data storage was robust to such an event
- it was not clear what strength of solar EMP was required to disable vehicles with electronic ignition
- it was not clear whether this damage would be confined to the northern hemisphere or would be worldwide

It would be of great value if your inquiry could establish:

- the likely frequency of such megaflares and their relation to the sunspot cycle

From what I have read, megaflares are not restricted to high points in the solar cycle.

This is important because there has been much recent misunderstanding regarding the high-point of the next solar cycle. In 2006, NASA's team was predicting a 2012 peak in a very high cycle. That prediction has had to be revised each year since as the solar cycle is behaving unpredictably. Firstly, this cycle (number 24) is obviously now much lower than the previous one. Secondly, it may peak later in 2013, or it may already be at its peak – this is not discernible from the data, and past patterns are not well known. The Carrington event was not associated with the peak nor a particular high cycle strength.

Thus – a megaflare could occur at any time. The cycle is already producing X-class flares and its behaviour is not predictable ('normal' within the instrumental record). This makes your work of the utmost urgency.

I would like to see you focus on emergency preparations:

- the NAS report identified water and food distribution as critically impacted – this is due to the short (3 day) supply food chains and centralised distribution; and with regard to water – the dependency upon the electrical grid for pumping supplies
- Cities would be without light and water and within three days supermarket shelves would be emptied
- There is a question whether any transport would be operating as well as a complete lack of communications via radio, TV, telephone and press.

In my view, the public need to be briefed on emergency measures:

- there need to be *regional* food and water supply centres
- there needs to be a fleet of public service vehicles that are hardened to EMP (as are military fighting vehicles).
- each household should be advised to carry one month's supply of non-perishable food (with guidance on what to purchase) and bottled water
- each household should purchase a gas-bottle emergency system for cooking

These measures would go some way to mitigating panic and disorder following an emergency and long-term loss of power supplies.

Finally – there are lessons from Fukushima for all industrial plant where safety relies upon electrical systems. In the case of nuclear plant, failure of the electrical grid causes an immediate shut-down but the plant will then be reliant upon its diesel generators. Each nuclear plant should carry at least three month's supply of diesel. Failure to supply diesel will result in melt-down of the reactor core with extreme consequences for a crowded island such as Britain. Additionally, nuclear waste tanks at Sellafield have about 100x the potential release of a single nuclear reactor – and they also require 24/7 power supplies for cooling.

I find it quite extra-ordinary that the scientific and engineering community have constructed an infra-structure that is so vulnerable to a perfectly natural and rather regular event. As the NAS report makes clear, a Carrington event could incapacitate power supplies for several years...something from which civilisation would not readily recover. Your work is thus of the utmost importance.

I do hope you will be able to give some thought as to what constitutes a robust power-grid, transport and communications system – whether, for example, smaller scale and decentralised supply systems would be less vulnerable.

October 2011

Written evidence from National Grid

Key Messages

- Severe Geomagnetic Disturbances (GMD) resulting in Geomagnetically Induced Currents (GIC) in high voltage transmission systems are a category of what is known as High Impact Low Frequency (HILF) events.
- Severe GMD events can be as a result of natural causes from solar activity and space weather or artificial causes such as High Altitude Electromagnetic Pulse (HEMP) from a nuclear detonation or other man made activity such as Intentional Electromagnetic Interference (IEMI).
- Space weather is the term for changes in the sun-earth environment analogous to the atmosphere and terrestrial weather. While the weather on earth is well understood, space weather forecasting is in its infancy.
- The effects of space weather on transmission systems has been known for some time and National Grid is a world leading transmission operator in understanding the effects and developing operational mitigation actions.
- HEMP is a more recent perceived risk raised particularly in the US and has resulted in the Shield Act legislation being progressed.
- HEMP effects are not well understood, there is almost no experience to estimate the effects but it is probable that they will be unforeseen, extreme and affect much more than transmission systems. For this reason mitigation policy for HEMP is extremely difficult to develop.

The extent of any threat posed to UK electronic infrastructure by electromagnetic pulse (EMP) events caused by space weather events, nuclear weapons detonated at high altitude or other EMP weapons

1. National Grid is fully aware of the threat of disturbance to the Electricity Transmission System from the effects of space weather and take this very seriously.
2. National Grid first realised the seriousness of the problem after the Solar Storm of March 1989, during which two transformers were damaged by overheating.
3. As a result of discussions with DECC at the Space Weather: Energy Partners Meeting on 21 September 2010, National Grid raised the level of its Worst Case Planning Scenario from a storm of size 500 nT/min to 5000 nT/min.
4. National Grid's operating procedures propose to deal with the effects of severe Geomagnetic disturbance (GMD) by operational mitigation strategies, as outlined in National Grid BP1832. This includes daily monitoring of the space environment, principally using information provided by NOAA and NASA.
5. We also work with key partners to understand threats. This includes the British Geological Survey, Met Office, SUNBURST, EURISGIC, University of Manchester and

NASA, and National Grid maintains regular contact with NERC (UK), NERC (US) and the Solar Shield project.

6. As a result of concern in the US, National Grid has considered the threat from a high altitude nuclear device and the corresponding electromagnetic pulse (HEMP). If such an event were to occur, significant damage could occur to both the Electricity and Gas Transmission Systems.

7. The United States Congress commissioned a report, Commission to Assess the Threat to the United States from EMP Attack, to assess the threat from EMP. It concluded that 'It is not practical to try to protect the entire electrical power system or even all high-value components from an EMP event….Widespread collapse of the electrical power system in the area affected by EMP is virtually inevitable after a broad geographic EMP attack.[1] Also, 'Industry is responsible for assuring system reliability, efficiency and cost effectiveness…. Government is responsible for protecting the society and its infrastructure, including the electric power system.[2]

8. HEMP produces a short lived (nanoseconds) E1 phase, an intermediate (milliseconds) E2 phase similar to a widespread lightning storm, and a longer lived (tens of seconds) E3 phase. All are capable of disrupting or damaging the Transmission Network over a distance encompassing the whole UK.

9. Supervisory Control and Data Acquisition Systems (SCADA) are susceptible to the E1 pulse. Control systems, Protection systems and System State Monitoring equipment can either malfunction or be irreparably damaged by the pulse. Combined with concomitant disruption to communication systems this could leave control engineers effectively blind and unable to act.

10. The E3 pulse is similar to a severe Geomagnetic Storm, except that the quasi-DC currents that flow are many times greater, of the order of 100s to 100s of Amps. This disruption would be an order of magnitude greater than National Grid has planned for.

11. Research to investigate options to harden the UK system, rather than relying on operational procedures as is appropriate for solar events, would be needed to mitigate this threat. But given the size of the undertaking, and the subsequent cost of procurement and installation, this is beyond the resources of any one commercial organization, or group of organizations, and would need to be pursued at national level.

The extent to which space weather is forecasted and the effectiveness of early warning systems that may be in place

12. According to the director of NOAA's Space Weather Prediction Center 'Space weather forecasting is still in its infancy.[3] An expert at the Met Office likened the current state of

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[1] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 45

[2] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 53

[3] http://science.nasa.gov/science-news/science-at-nasa/2010/04jun_swef/

Space Weather forecasting to terrestrial weather forecasting techniques a hundred years ago.[4]

13. Space Weather forecasting requires information gathered by spacecraft and satellites: principally the two STEREO spacecraft, SOHO, GOES, and ACE.

14. ACE is particularly important as it sits at the L1 point, a million miles from Earth, and is able to detect the polarity of incoming Coronal Mass Ejections (CMEs). ACE was launched in 1997 for an operational mission of 3 years. It is now well beyond its original operational life, although it has fuel capacity to take it to 2024. Crucially, it is a single point of failure in our ability to forecast Space Weather.

15. CMEs can take from 18 hours to 3 days to reach Earth. Forecasting models are used to decide on their trajectory and timing. NASA issue forecasts of arrival time giving a six hour window. However these forecasts are frequently inaccurate, with the actual arrival being many hours early or over a day late.

16. Models for what happens once the CME starts to interact with the Earth's magnetosphere are far less advanced. There are models that describe the interaction in high Polar regions. These models can predict fluctuations in the magnetic field at ground level with 50% accuracy. However, the models run ~300 times slower than real time, so are not useful for practical forecasting.

17. There are currently no models that can predict the effect of a CME at the latitudes occupied by the UK.

18. National Grid relies on rough estimates of the size of the CME impact issued by NOAA at the time the CME is ejected from the sun; the size and polarity of the magnetic field disturbance at the ACE spacecraft, with a lead time of 25-45 minutes; modelling of generic scenarios using the BGS/NG modelling tool.

The potential impact of such events for both civilian and military infrastructure

19. Geomagnetic disturbances from naturally occurring Solar Storms cause quasi-DC Geomagnetic currents to flow in long transmission lines, and to pass through neutral earthing connections in Supergrid transformers (SGTs). The size of these currents depends on the exact dynamics of the CME interaction with the magnetosphere, the position of the jet stream above the UK and the geological makeup of the rock beneath the surface of the UK.

20. Direct current, superimposed on top of the AC current that transformers are designed for, can cause the core of the transformer to saturate, and this in turn leads to flux leaking out using routes such as transformer bolts. This then leads to overheating and potentially catastrophic damage to the transformer.

21. Evidence for transformer damage comes from: the UK experience of 1989, when, anecdotally, two transformers overheated after being exposed to GIC of ~30 A; the failure of a transformer at Salem, USA during the same storm; and failures of six transformers in South Africa in the 12 months after the Halloween storm of 2003.

[4] Personal communication from Mark Gibbs, Met Office

22. Based on the most severe event that National Grid plans for, a storm of 5000 nT/min, 10 times greater than the 1989 storm, National Grid expects that, without mitigation strategies, its worst case scenario is of the order of 9 transformer failures in England and Wales, the location of these transformers being at the edge of the network. This number of failures is within the capacity of National Grid's spares policy (even before the recent review of that policy).

23. If all transformers at a node are damaged then, depending on the location of the node within the network, this could result in a local area being disconnected until replacement transformers could be installed. Replacing a transformer can take two or more months depending on the availability and location of spares. In this extreme event scenario National Grid estimates that the probability there would be a disconnection event is 62% for England and Wales, and 91% for GB as a whole.

24. The number of nodes expected to fail is 0.9 in England and Wales and 1.1 in Scotland. There are 4 locations in England and Wales where the failure is most likely to occur, and 3 in Scotland. None of these locations has a high population density.

25. Because of their design and heavier loading National Grid believes that Generator Transformers are at more risk than SGTs. National Grid is working with DECC and the Generator Operators to include generator transformers in its modelling and mitigation plans.

26. A secondary effect is the creation of harmonics in the saturated core of the transformer. These propagate out and can cause malfunction of protective relay equipment, switching out hardware needed for stabilisation of the network. It was this type of event that caused the blackout of the Hydro-Quebec system in 1989, and the blackout of Malmo, Sweden, in 2003.

27. The effect of E1 and E3 pulses from HEMP would be considerably more extreme. For these effects we have no practical experience to fall back on,[5] although the Commission to Assess the Threat to the United States from EMP Attack did conduct a number of experiments on E1 and its effect on SCADA. They concluded that 'Large-scale load losses in excess of 10% are likely at EMP threat levels,[6] and that 'widespread collapse of the electrical power system…..is virtually inevitable.[7]

28. Although National Grid recognizes the threat from other sources of deliberate EMP generation, given the localised nature of the effects we do not believe that the consequences would be severe. For instance, if a localised EMP pulse were able to penetrate the National Control Centre, the system is capable of being run from alternative locations without loss of load.

Ways of mitigating electromagnetic pulse events, either targeted or naturally occurring

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[5] Metatech Report Meta-R-320, The Early-Time (E1) High_Altitude Electromagnetic Pulse (HEMP) and Its Impact on the US Power Grid

[6] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 36

[7] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 45

29. For GMD caused by naturally occurring Space Weather events, National Grid has a set of operational strategies to mitigate the effects. These include routine daily monitoring of the space environment. In the event of a serious storm being likely National Grid would operate an all-in policy, where all available lines and all transformers would be brought into service (reducing load on individual units), power transfers between regions would be reduced, increased reactive power would be instructed to help stabilise voltage swings, and all generators would be instructed to generate. In addition, a simultaneous tap change on transformers could be instructed to lower system voltage, which reduces the risk to transformers.

30. In the event that the storm was so large (a superstorm) that it exceeded National Grid's worst planned-for scenario, then, in conjunction with Government, National Grid would consider a controlled shut-down of the network. National Grid has a well developed Black Start Policy. Training exercises are regularly held on Black Start, and generating units are at all times scheduled for Black Start capability.

31. National Grid is developing in conjunction with BGS a tool for monitoring of GIC current flows based on real-time magnetometer data. This tool will also be able to be used as an analytical tool for assessing various possible scenarios.

32. National Grid has recently reviewed its spares policy and has increased the number of spare transformers that it holds.

33. As explained in the National Grid consultation document *Operating the Electricity Transmission Network in 2020*, managing the Transmission System with much higher penetration of intermittent generation will require greater resiliency and higher reserve requirements. The effect of this will be to harden the system and make it less susceptible to the effect of GMD.

34. National Grid is actively considering the introduction of series capacitance on the long lines connecting England and Scotland. These are capable of blocking the flow of GICs.

35. National Grid has considered the use of devices for providing permanent or switchable resistance to ground. It may be that the design characteristics of UK transformers make them unsuitable for such devices so further work is needed to assess the efficacy of such measures. At present National Grid is not planning to install these devices to counter the effects of GIC. In the event of HEMP, and an E3 pulse it is not clear that switchable devices would work, as the control mechanisms would be affected by the earlier E1 pulse.

36. With regard to HEMP, National Grid agrees with the Commission to Assess the Threat to the United States from EMP Attack that 'it is not practical to try to protect the entire electrical power system or even all high-value components from an EMP event,[8] and that 'the key to minimizing catastrophic impacts from loss of electrical power is rapid restoration.[9]

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[8] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 45

[9] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 47

37. Rapid restoration of communication systems is vital. The recommendations of the US report suggest that in the US responsibility for this falls on the Department of Homeland Security.

38. Again, from the US report: 'To better understand EMP-related system response and recovery issues, conduct in-depth research and development on system vulnerabilities. The objective is to identify cost effective and necessary modifications and additions in order to further achieve the overall system performance. Specifically there should be government-sponsored research and development of components and processes to identify and develop new consequential and cost effective approaches and activities.[10]

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[10] Report of the Commission to Assess the Threat to the United States from EMP Attack: Critical National Infrastructures, P. 55

Written evidence from Research Councils UK

Bulleted summary

- Major space weather events have been recorded in the past but had relatively minor societal impact. Equivalent events today could be dangerous due to our greater reliance on technology.
- Examples of the hazards and risks associated with space weather include: damage to space-based infrastructure (satellites) by energetic particles and radiation; disturbance of the ionosphere degrading communication and navigation signals (including GPS) with particular impacts on aviation and shipping; blackouts and damage to electricity distribution grids extending over long distances caused by geomagnetically induced currents.
- Our ability to predict space weather and the severity of particular events is currently limited. The US Space Weather Prediction Center is the major agency providing space weather services. The UK has the potential to contribute further via research and capability supported by the UK Research Councils, services provided by the Met Office and via the European Space Situational Awareness Programme.
- Warning and prediction of space weather events is one of the most important ways of mitigating impacts. In addition, a variety of engineering and other approaches exist and are being developed to mitigate impacts of space weather across the range of infrastructure it affects.
- The UK has over 100 years' leadership in the science underpinning our understanding of space weather. This continues today with UK Research Councils as significant funders of research and capability relevant to understanding, forecasting and mitigating the impacts of space weather.

Introduction

1. Research Councils UK is a strategic partnership set up to champion research supported by the seven UK Research Councils. RCUK was established in 2002 to enable the Councils to work together more effectively to enhance the overall impact and effectiveness of their research, training and innovation activities, contributing to the delivery of the Government's objectives for science and innovation. Further details are available at www.rcuk.ac.uk.

2. This evidence is submitted by RCUK on behalf of the Research Councils listed below and represents their independent views. It does not include, or necessarily reflect the views of the Knowledge and Innovation Group in the Department for Business, Innovation and Skills (BIS).

   Natural Environment Research Council (NERC)[1]
   Science and Technology Facilities Research Council (STFC)

3. This evidence focuses on the threat posed by space weather to civilian infrastructure. Further information of relevance to this inquiry can be found in several relevant POSTnotes[2] and evidence for the House of Commons Science and Technology Committee inquiry into Scientific Advice and Evidence in Emergencies.[3]

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[1] Views were sought from experts based at NERC's centres: British Antarctic Survey and British Geological Survey.
[2] http://www.parliament.uk/business/publications/research/post/physics/
[3] Science and Technology Committee, Third Report of Session 2010-12, *Scientific Advice and Evidence in Emergencies*, HC 498 http://www.parliament.uk/business/committees/committees-a-z/commons-select/science-and-technology-committee/inquiries/scientific-advice-in-emergencies/

Question 1. The extent of any threat posed to UK electronic infrastructure by electromagnetic pulse (EMP) events caused by space weather events, nuclear weapons detonated at high altitude or other EMP weapons

4. Space weather creates conditions potentially hazardous to assets in space and on the ground, detrimental to a range of the services they provide.

5. Space weather is underpinned by solar activity. The sun is a continuous source of electromagnetic radiation over a wide spectrum and of charged particles that stream through space forming the solar wind with embedded solar magnetic fields. Solar flares, radio bursts, solar energetic particle (SEP) events and coronal mass ejections (CME) are examples of impulsive solar release events where electromagnetic energy, particles and solar magnetic fields are ejected at high speed from the sun. CME's are one of the most important types of space weather disturbances. The frequency of impulsive release events is modulated by the solar activity cycle of around 11 years commonly characterised by sunspot numbers with the next solar maximum currently estimated to be in 2013. Threats occur throughout the solar cycle, however, and levels of cosmic radiation are highest during solar minima.

Threat to space based infrastructure

6. Solar release events can result in high energy charged particles which penetrate the Earth's magnetic field directly, and cause magnetic storms which rapidly increase the number of high energy charged particles trapped in the Van Allen radiation belts. These particles threaten satellite operations by accelerating cumulative damage to the solar arrays providing power and by their effects on electronic systems. High energy particles can penetrate chips in digital electronic systems causing Single Event Effects (SEE), flipping memory and changing the state of software. Modern developments in microelectronics are leading to equipment with increasing chip density and increased vulnerability to SEEs.[4] Electrons in the radiation belts can penetrate satellites and cause build-up of charge in insulating materials. Discharges can permanently damage electronic components or generate false signals to which the satellite may respond.

Upper atmosphere and ground level derived threat

7. At the Earth, solar ultraviolet and X-ray emissions are absorbed in the atmosphere creating the ionosphere, which affects the transmission of radio waves and supports the flow of electric currents which generate magnetic fields. When a CME encounters the Earth's magnetic field it can cause a severe magnetic storm lasting from a few hours up to several days. The rapidly changing magnetic fields during magnetic storms induce electric fields in the solid Earth and oceans. These can drive Geomagnetically Induced Currents (GIC) through earthed conductors, including electrical power grids and pipelines.

8. Some SEP events, through the production of neutrons from collisions in the atmosphere, lead to increases in radiation at ground level and with higher intensity at aircraft altitudes. The risk is higher in the polar regions where there is less protection from the Earth's magnetic field. SEP events result in increased

[4] Dyer, C.S., Lei, F., Clucas, S.N., Smart, D.F, & Shea, M.A., 2003. Solar particle enhancements of single event effect rates at aircraft altitudes, IEEE Trans. Nucl. Sci., vol. 50, No. 6, pp. 2038-2045.

radiation dose to aircrew, electronic upsets in aircraft avionics and disruption to air traffic communications on polar routes.

Question 2. The likelihood that a viable EMP weapon can or will be used by either state or non-state actors

9. Nil response.

Question 3. The extent to which space weather is forecasted and the effectiveness of early warning systems that may be in place

10. The UK has a long and successful heritage in relevant solar observations and there are a number of UK-led instruments on major international space missions. However, forecasting space weather is very difficult and is still at an early stage often considered comparable to weather forecasting in the 1960s.

11. Disturbances such as CMEs take 15-72 hours to travel from the sun to Earth. Particularly key to the prediction of Earth-impacting CMEs are the UK-led Heliospheric Imagers flying aboard the twin NASA STEREO[5] spacecraft, which have been developed by the Rutherford Appleton Laboratory and the University of Birmingham. These UK instruments are the only systems able to image Earth-impacting CMEs, from out of the Sun-Earth line, enabling tracking of CMEs from the Sun to the Earth. This pioneering work is central to current research into CME arrivals at Earth and is funded by STFC and the UK Space Agency.

12. Despite this technology, it is only possible to provide a reliable warning of the extent of impact of the CME within an hour or so, as we need to measure the direction of the interplanetary magnetic field as it passes the Earth. More research to understand the basic physics and to develop better models is required to improve the reliability of forecasts.

13. The US Space Weather Prediction Center (SWPC), part of the National Oceanic and Atmospheric Administration (NOAA) is currently the major agency providing space weather services. The UK Met Office has agreed to a request from the NOAA to ‘mirror’ the services provided by SWPC recognising the Met Office’s strengths in reliable 24/7 operational service delivery.

14. The European Space Agency’s (ESA) Space Situational Awareness (SSA) Programme[6] objectives are to support Europe’s independent utilisation of, and access to, space through accurate information about the space environment, with particular regard to hazards including space weather, posed to infrastructure in orbit and on the ground.

15. NERC strategy is focussed around seven science themes,[7] one of which, Natural Hazards, recognises the importance of space weather.[8]

16. The NERC funded British Antarctic Survey (BAS) has worked with a consortium of UK insurance companies to forecast periods of high risk to satellites. BAS now leads an international project called SPACECAST to develop European modelling and forecasting capabilities in order to protect satellites on orbit from high energy

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[5] http://www.nasa.gov/mission_pages/stereo/main/index.html
[6] http://www.esa.int/esaMI/SSA/SEMYTICKP6G_0.html
[7] http://www.nerc.ac.uk/research/themes/
[8] http://www.nerc.ac.uk/research/issues/naturalhazards/

particle radiation. This is a research project that will also deliver an initial forecasting capability from March 2012 onwards via a public web site, and issue warnings and alerts for stakeholders who sign up to the service. The forecasting will be provided on a best efforts basis and will lay the foundation for an operational service. The project is funded by the EU under Framework 7 and involves 7 European partners and 4 collaborations with the USA. SPACECAST is funded for three years up until the end of February 2014.

17. The NERC funded British Geological Survey (BGS) has developed a suite of space weather monitoring and forecasting services over a number of years following work for the ESA and Scottish Power. For example, BGS has access to real-time data from the UK and many other magnetic observatories around the world and is able to estimate measures of geomagnetic disturbance in near real time. BGS has worked closely with Met Office in the Natural Hazards Partnership (NHP). Since March 2011 BGS has been delivering daily magnetic activity forecasts and real time data, indicating UK and global magnetic activity conditions, for inclusion in a pilot daily hazards report issued by the Met Office as part of NHP activities.

18. Another important ground based technology of relevance is the LOw Frequency Array (LOFAR), [9] a multi-purpose sensor array whose main application is astronomy at low frequencies (10-250 MHz). LOFAR supports UK and international efforts to demonstrate interplanetary scintillation as a complementary method to monitor CMEs and other heliospheric transients, thereby improving resilience of the global space weather monitoring capability, particularly if space based technologies were to fail. The first LOFAR station to be built in the UK was opened at STFC's Chilbolton Observatory in September 2010.[10]

19. Appendix 1[11] provides an audit of potential UK based space weather assets including those supported by NERC and STFC, prepared recently (November 2009) as an input to ESA's SSA programme. It can be seen as one measure of the UK's 'preparedness' to predict, monitor and analyse the effects of space weather, or the UK's 'National Capability' in respect to space weather and solar storms. The extent of the UK commitment to the SSA programme, via UKSA, will need to be determined as part of the wider UK strategy for engagement with ESA.

Question 4. The potential impact of such events for both civilian and military infrastructure;

20. The largest space weather event on record occurred in 1859. A number of reports have examined the impacts of a similar event today,[12] with the US National Research Council giving an estimate of $1-2 trillion for the wider societal and economic costs of a severe geomagnetic storm scenario.[13] The Lloyds and RAL[14] Space Weather Report explores the threat to business and included input from BGS.[15] The Space Environment Impacts Expert Group (SEIEG) chaired by

[9] http://www.lofar.org/astronomy/solar-ksp/solar-physics-and-space-weather
[10] http://www.lofar-uk.org/index.html
[11] Appendix 1 - UK space weather assets as published by ESA in tender 2010.pdf
[12] http://www.nerc.com/files/HILF.pdf
[13] http://www.nap.edu.catalog/12507.html
[14] Based at STFC's Rutherford Appleton Laboratory, RAL Space is at the forefront of UK Space Research - http://www.stfc.ac.uk/ralspace/default.aspx
[15] http://www.lloyds.com/News-and-Insight/360-Risk-Insight/Research-and-Reports/Space/Space-Weather

member of staff from STFC and including BAS and BGS representation has helped the Civil Contingencies Unit of the Cabinet Office to evaluate potential impacts of space weather.

21. There are more than 600 satellites in orbit providing essential services including TV, banking, internet, remote sensing, navigation, and security. During a space weather event the Van Allen radiation belts can intensify 10,000 fold or more resulting in satellite charging and damage to electronic components. Solar energetic particle events can also reduce solar array power and satellite lifetime. Three satellites in the radiation belts were damaged in one event in 1994, leading to serious loss of service, and satellite losses occurred in 1997, 1998 and 2003 during the last solar cycle. Many other satellites have been damaged or lost over the years but it is not clear if those losses were due to space weather. Past experience shows that the highest space weather risk to satellites will occur two years after the peak in the sunspot cycle, sometime in 2015.

Impact on positioning, navigation and timing services

22. An important space-based infrastructure is positioning, navigation and timing (PNT) services delivered by Global Navigation Satellite Systems, predominantly the US Global Positioning System (GPS). Navigational applications of GPS are now commonplace and the use of GPS-derived time has become integral in areas as diverse as scientific monitoring, telecommunications, and financial transactions and services. Implications of loss of PNT services caused by space weather have been highlighted in a report by the Royal Academy of Engineering.[16] PNT services may be degraded by direct effects of space weather on satellite infrastructure.
23. Disturbance to the ionosphere may also impact PNT services. On the ground, GPS receivers rely on receiving radio signals from the GPS satellites. During magnetic storms the ionospheric density profile changes, affecting the propagation time of the radio signals, which leads to positional errors. Magnetic storms can also result in loss of signal lock by receivers. In addition, solar radio bursts can overwhelm GPS satellite signals leading to loss of service for periods of several hours.[17]

Impact on aviation and shipping

24. Disturbance of the ionosphere can have particular impacts on aviation and shipping. SEP events can lead to loss of high frequency communications in the polar-regions for 24 hours or more requiring aircraft on polar routes to be re-routed, adding considerably to the flight costs. Solar flares can also produce communications blackouts for a few hours. A space weather event disrupted trans-Atlantic aviation in 2005. See also paragraph 28.

Impact on power supply

25. GICs pose a threat to electricity distribution grids extending over long distances which can cause blackouts and damage. Permanent damage to transformers caused by GICs is a major concern. Transformers are costly, not available as 'off-the-shelf' items, and replacing one is a major exercise. The consequences of a

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[16] Royal Academy of Engineering (2011). Global Navigation Space Systems: reliance and vulnerabilities, ISBN 1-903496-62-4. (http://www.raeng.org.uk/gnss)

[17] Cerruti, A. P., P. M. Kintner Jr., D. E. Gary, A. J. Mannucci, R. F. Meyer, P. Doherty, and A. J. Coster 2008. Effect of intense December 2006 solar radio bursts on GPS receivers, Space Weather, 6, S10D07, (doi:10.1029/2007SW000375)

prolonged loss of electrical power are potentially catastrophic as the infrastructures and services that modern developed societies rely on are entirely dependent on electricity. Examples include heating, lighting, refrigeration, communications, pumping of fuel, water and sewage.

26. It has been estimated that if a magnetic storm that occurred in May 1921 was repeated today then 130 million people in the US would lose their electricity and more than 350 transformers would be at risk of permanent damage.[18] A large space weather event caused power blackouts across North-Eastern Canada in March 1989. Quebec was blacked out for 9 hours, millions of people without electricity. During the same storm a large step-up transformer at the Salem Nuclear Power Plant in New Jersey was damaged.

Question 5. Ways of mitigating electromagnetic pulse events, either targeted or naturally occurring

27. Warning and prediction of space weather events is one of the most important ways of mitigating effects. Essential systems can then be put into a safe mode, but this may not always ensure survival.

28. There are a number of mitigating possibilities to help protect satellites in the aftermath of an EMP or severe space weather event. Scientific research at the BAS on natural radiation belts has shown that various types of electromagnetic waves can remove energetic charged particles so that they are deposited down into the atmosphere. Once in the atmosphere they are quickly absorbed. A potential mitigation process is to increase the rate of scattering and particle loss by these waves. This might be done by:

- Injecting very low frequency and extremely low frequency waves into space from ground based transmitters;
- Transmitting very low frequency waves from satellites in orbit;
- Releasing chemicals from rockets which generate waves in space by natural wave-particle interactions.

29. These ideas are at the research stage and are led by the USA. The UK has considerable expertise in wave-particle interactions through its research on space weather and radiation belts at BAS.

30. Satellite operators attempt to mitigate the effects of space weather by hardening chips against radiation and by using multiple circuits so that a malfunctioning circuit can be outvoted by ones that are operating correctly. However, during the so-called Halloween magnetic storm in October/November 2003 more than 47 satellites reported anomalies and one scientific satellite was a total loss.

31. The use of dual-frequency receivers can help overcome the effect of magnetic storms on the propagation time of the radio signals from GPS satellites to GPS receivers.

32. Aircrew on long-haul flights are classified as radiation workers by the European Union and frequent flyers are also at risk.[19] The only mitigation strategies to reduce exposure during a radiation event are to fly at lower altitude to increase atmospheric shielding or re-route to lower latitudes.

[18] US National Academy of Sciences, 2008. Severe Space Weather Events - Understanding Societal and Economic Impacts, Workshop Report. ISBN: 0-309-12770-X. (http://www.nap.edu/catalog/12507.html)
[19] Hapgood, M.A. & Thomson, A.W.P. 2010. Space weather: its impact on Earth and implications for business. Lloyds 360° Risk Insight Briefing.

33. ISIS pulsed neutron and muon source at Rutherford Appleton Laboratory[20] is in the build phase of Chipir,[21] a new experimental facility which will study how microchips' operations are severely disrupted by cosmic radiation, one of the first dedicated resource of its kind outside the US. Chipir will be world leading with unique capabilities for screening microchips with neutrons and will enable the development of more resilient electronic systems. The project received funding in March 2011[22] from the UK Large Facilities Capital Fund.[23]

34. Possible mitigation strategies to reduce the threat to electrical power distribution systems include fitting blocking capacitors to the earth connections of transformers and management of the distribution of load throughout a grid system to protect the components most at risk. Risk assessments require the identification of a 'reasonable worst case' that a system should be designed to be resilient to, or for which an adaptation strategy should be developed. The statistical distribution of extreme events is required, but for a number of the space weather effects the available data are limited. This is not the case for magnetic disturbances as magnetic observatories have been in operation for more than 160 years. Analyses on data from European magnetic observatories to estimate the size of major geomagnetic storms using extreme statistics methods have been carried out.[24]

35. NERC/BGS and STFC/RAL Space were co-sponsors of a workshop on Geomagnetically Induced Currents in National Power Grids held at Lancaster University on 30-31 March 2011. This workshop was led by Lancaster University using impact funding from EPSRC. It brought together UK and international experts from science, industry and government to discuss the space weather threat to power grids and was a welcome opportunity to exchange ideas and develop links between experts from different communities.

36. In partnership with National Grid, BGS has developed a range of scenarios and modelled the effects on a simplified representation of the UK high voltage grid to identify transformer 'hot spot' locations. National Grid has, in parallel, been considering the engineering and supply consequences of these scenarios. BGS has been commissioned by National Grid to provide a geomagnetic hazard monitoring and analysis service and is working with National Grid to improve models of the high voltage system, to enable more accurate assessments of space weather impacts on the UK grid system. BGS is also a partner in the EU Framework 7 project EURISGIC, carrying out research into the generation and impacts of Geomagnetically Induced Currents on power distribution networks.

37. The adoption of optical cables for most telephone and internet communications makes them largely immune to space weather effects. Transoceanic cables have electronic systems to amplify signals which introduce a potential but relatively minor vulnerability. The ability of relatively recent and rapidly developing wireless technologies including mobile phones, wireless internet and device controllers to reject interference from radio bursts has not yet been established by exposure to significant events as their widespread adoption has been recent and during a quiet period in solar activity.

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[20] http://www.isis.stfc.ac.uk/
[21] http://www.isis.stfc.ac.uk/instruments/Chipir/ - including detailed technical specifications
[22] http://www.isis.stfc.ac.uk/news/2011/speech-by-david-willetts-minister-for-science-at-isis11743.html
[23] http://www.rcuk.ac.uk/research/Infrastructure/Pages/CapitalFund.aspx

[24] Thomson, A.W.P.; Gaunt, C.T.; Cilliers, P.; Wild, J.A.; Opperman, B.; McKinnell, L.-A.; Kotze, P.; Ngwira, C.M.; Lotz, S.I.. 2010. Present day challenges in understanding the geomagnetic hazard to national power grids. Advances in Space Research, 45 (9). 1182-1190. (doi: 10.1016/j.asr.2009.11.023)

Question 6. The resources available in respect of research and development in this field;

38. The UK has over 100 years' leadership in the science underpinning our understanding of space weather. This continues today with the UK Research Councils, in particular NERC and STFC, acting as the significant funders of relevant research programmes.[25] Research Council commitment is broadly split between ground-based and space-based studies with NERC funding Earth orientated solar terrestrial physics and STFC funding space based activities. There are many inter-relationships between the various areas of research. UK scientists are world leaders at combining data from ground-based and space-based studies.

39. SEIEG provides a forum for developing research plans and the Met Office, which is one of the founder members of SEIEG, is playing an important part in work being carried out by the World Meteorological Organisation (WMO) on space weather.

40. The following are examples of significant recent Research Council activity:

- STFC is currently finalising negotiations with the EU Commission for a 5M Euro FP7 project to establish an advanced data system to facilitate scientists' access to databases essential for research across all aspects of space weather. The project, which involves 22 partners from the UK, the rest of Europe and from the US, will be led by a team in RAL Space.
- STFC is leading preparation of a bid for up to 10M Euro FP7 funding to coordinate and improve the networks of European ground-based sensors that provide measurements critical to space weather research. If successful, this bid will enable instrument groups in the UK and the rest of Europe to provide high-quality ground-based measurements that are an essential complement to space-based measurements, such as those being developed by ESA. This mix of ground-based and space-based measurements is critical to advancing the quality of space weather forecasts.
- STFC/RAL Space was a key part of the organising team for Space Weather and Society workshop that took place at NASA Ames Research Centre in California over the weekend of 15/16 October 2011. This workshop aimed to establish a plan for linking space weather expertise with societal and economic needs. STFC provided the key international input to complement internal US expertise in the organising team. The UK attendees included representatives from STFC, NERC, industry and Government.
- NERC are developing significant collaborations with research groups across Europe and the USA on space weather (e.g. via three Framework 7 projects at the British Antarctic Survey and through another involving the British Geological Survey). It is also developing an integrated approach where BAS and BGS are co-operating to develop computer models to forecast space weather which utilise a variety of ground and space based data.
- A UK-US workshop on space weather research coordination in Boulder, Colorado on 11-14 October was sponsored by the FCO Global Partnership programme. The workshop involved experts from STFC, NERC, the universities and Met Office, plus their counterparts from the US, and will

[25] From 2008 responsibility for ground based research transferred from STFC to NERC and amounted to approximately £2.7M per annum. The space-based research programme funded by STFC currently amounts to approximately £1M per annum, but is difficult to accurately define given the many crossovers. These figures do not include spend on post-launch support or new mission development (e.g. ESA's Cosmic Vision Solar Orbiter mission) and this aspect is now managed by the UK Space Agency.

result in a roadmap for future collaboration on science to advance the mitigation and forecasting of adverse space weather.

- See also responses to Q3 including reference to assets.
- Also with reference to Q3 (paragraph 11), the STEREO Heliospheric Imager data are being made available to the public through a project known as Solar Stormwatch,[26] and this has enabled thousands of people worldwide to identify and track CMEs. This is a successful and on-going pilot study for crowd-sourcing techniques, mobilising effort that cannot be duplicated otherwise, and it is consistent with a UN approach for crowd-sourcing as a tool for hazard mitigation and which is being applied to a number of disaster planning scenarios.

Question 7. Contingencies in place to react to a large-scale loss of UK electronic infrastructure, and the role of the military in such an event

41. Nil response.

Question 8. The broader security of UK electronic and space infrastructure, particularly satellites and satellite navigation systems and the risk posed by space debris

42. Nil response.

October 2011

[26] http://www.solarstormwatch.com/

United Kingdom

Asset name	Owner	Operator	Type of asset	Brief description of the asset
Merlin Radiation Detector	QinetiQ	QinetiQ	Sensor(s)	Small space environment monitor capable of being fitted to various spacecraft to provide wide-ranging environmental information.
Real-time space weather data	STFC	STFC	Data	Access to real time data from the NASA STEREO mission via the SSTD ground station
Real-time space weather data	STFC	STFC	Data	Access to real time data from the NASA/NOAA ACE mission via the SSTD ground station
Skynet 5 comms facilities	Paradigm	Paradigm	Other	extensive ground infrastructure for networking comms with ability to serve overseas sites and link to all UKK SSA related facilities
Ionosonde in Slough, Falklands, South Georgia			Sensor(s)	
GPS station network			Sensor(s)	
SAMNET magnetometer network		Lancaster university	Sensor(s)	stations in: UK, Faroe islands, Iceland & Russia
Magnetometers		BGS	Sensor(s)	Located at Eskdalemuir, Hartland, Lerwick
EISCAT (UK support)		STFC/RAL	Expertise	Supports and coordinates UK related EISCAT activities
Ionospheric modelling		Leicester U, Lancaster U.	Expertise	
IRIS: imaging riometer		Univ Lancaster	Sensor(s)	located in Finland.
CUTLASS (Co-operative UK Twin Located Auroral Sounding System)		Univ Leicester	Sensor(s)	HF radars at Þykkvibær, Iceland, and Hankasalmi, Finland. Part of global international Super Dual Auroral Radar (SuperDARN). Group also has several scientific instruments located in the arctic. The CUTLASS data are made available in real time via web site. SuperDARN cross polar cap potential maps for the northern hemisphere, to which the CUTLASS data contribute, are also available in real time from APL web site.
Expertise in solar s/c instrumentation		University College London/MSSL	Expertise	Flown relevant instrumentation on SOHO, Yohkoh, Hinode + others
Expertise in solar s/c instrumentation		STFC/RAL	Expertise	Flown relevant instrumentation on SOHO, STEREO + others
EGSO		Hosted at UCL/MSSL	Service	GRID test-bed aimed towards simplifying access to heterogeneous solar data. Currently operating at pilot.
SOARS: Spaceweather Operational Airlines Risks Service		University College London/MSSL	Service	Pilot service, part of the ESA space weather applications pilot project & member of SWENET
Solarmetrics		commercial	Expertise	startup geared towards providing space weather information and services to airlines
CEDEX radiation monitor		Univ Surrrey	Sensor(s)	
Expertise in space plasma s/c instrumentation		University College London/MSSL	Expertise	Flown relevant instrumentation on e.g. Cluster
Incoherent radar Malvern			Sensor(s)	
DIFS: Daily Ionospheric Forecasting Service	Bae Systems	Bae Systems (UK)	Service	Nowcast and forecast HF and SATCOM signal propagation conditions
BINCASTS: Index Nowcast and Forecast	BGS	BGS (UK)	Service	Indices now and forecast
SWIMIC: Solar Wind Monitoring and Induction Modelling for GIC	BGS	BGS (UK)	Service	Nowcast and forecast GIC in Scottish power grid
SOARS: Spaceweather Operational Airlines Risks Service	MSSL/UCL	MSSL/UCL (UK)	Service	Service for airlines focussing on radiation and communication issues
GEOSHAFT	QinetiQ	QinetiQ (UK)	Service	Radiation hazard nowcast and alert at GEO
STIF	STFC/RAL	RAL (UK)	Service	ionospheric propagation parameters for European region
ASAP	Univ Bradford	Univ Bradford (UK)	Service	Forecast solar flare activity
EDAM	QinetiQ	QinetiQ	Service	3D electron density model
HOTRAY		British Antarctic Survey	Software	Ray tracing code for calculating the path, amplification and absorption of electromagnetic and electrostatic waves in hot magnetised plasmas. Potential applications to Galileo signals
PADIE		British Antarctic Survey	Software	Computer code for calculating pitch angle and energy diffusion rates for wave-particle interactions in connection with radiation belts. Potential applications to space weather modelling
BAS dynamic global radiation belt model		British Antarctic Survey	Software	Computer code for dynamic modelling of the Earth's radiation belts in 3d. Potential applications to space weather modelling

Global magnetic field models (e.g. scientific, International Geomagnetic Reference Field and World Magnetic Model)		British Geological Survey	Expertise	Leadership role in International Geomagnetic Reference Field
UK regional magnetic field model		British Geological Survey	Service	
Magnetic index forecast codes		British Geological Survey	Service	Includes services that contribute to SWENET
GIC analysis code for UK		British Geological Survey	Software	
Atmospheric radiation model		QinetiQ	Expertise	
Synthetic Aperture Trans-Ionospheric Radio Propagation Simulator (SAR-TIRPS)		QinetiQ	Software	
Kinetic modelling of coronal mass ejections		STFC/RAL	Expertise	
Integration of UCL GCMs with lower atmosphere GCMs		UK Met Office	Expertise	
Terrestrial thermosphere/ionosphere models		University College London	Software	CMAT2 goes from 15km to 500km plus plasmasphere and high-latitude connection into the magnetosphere
Thermosphere/ionosphere models for other planets, eg Mars, Jupiter		University College London	Software	
MIDAS ionospheric tomography/data assimilation software for ionospheric specification		University of Bath	Software	
Automated Solar Activity Prediction Tool		University of Bradford	Service	Used for detection and classification of sunspot groups, and solar flare prediction. It is online and near real time. http://spaceweather.inf.brad.ac.uk/ Contributes to SWENET
SHARE radar - now called the Halley SuperDARN radar. Measurements of winds, tides and waves in the mesosphere and ionosphere. Part of global international Super Dual Auroral Radar		British Antarctic Survey	Sensor(s)	Operated by BAS from 1988 to 2008. Will resume operations at Halley 6 in Jan 2012.
New Falkland Islands radar - to start about 2010		British Antarctic Survey	Sensor(s)	
Meteor radar at Rothera		British Antarctic Survey	Sensor(s)	
Imaging riometer, being moved to Halley 6		British Antarctic Survey	Sensor(s)	
AARDDVARK network of radio receivers for measuring electron precipitation		British Antarctic Survey	Sensor(s)	
Search coil magnetometer, Halley 6		British Antarctic Survey	Sensor(s)	
Pulsation magnetometer, Halley5, will move to Halley 6.		British Antarctic Survey	Sensor(s)	
VELOX at Halley, for whistler detection and substorms		British Antarctic Survey	Sensor(s)	
Low power magnetometer network, poleward of Halley		British Antarctic Survey	Sensor(s)	
AIRIS riometer in Norway/ALOMAR		Lancaster University	Sensor(s)	
Ny-Alesund imaging Riometer		Lancaster University	Sensor(s)	In collaboration with China (PRIC)
Rainbow all-sky camera network in Iceland and Faroes		Lancaster University	Sensor(s)	during darkness and clear sky
Ionosonde at Tromsø		QinetiQ	Sensor(s)	Real-time data goes to SWPC Boulder
GPS receivers		QinetiQ	Sensor(s)	
CREDANCE monitor to fly with NASA Living with a Star Space Environment Testbed.		QinetiQ	Sensor(s)	Will monitor accumulated dose, energetic protons, heavy ion LET spectra, electron fluxes and charging currents. Approx launch date 2012.
EMU monitor to fly on Galileo.		QinetiQ	Sensor(s)	Similar capabilities to CREDANCE but additional proton channels.
QDOS aircraft radiation monitor		QinetiQ	Sensor(s)	To fly regularly on high latitude flights.
Ionosondes at Chilton and Port Stanley		STFC/RAL	Sensor(s)	Real-time data supports DIAS system and hence SWENET services. Real-time data goes to SWPC Boulder and hence to end users including MOD
Ground station: 12m S-band uplink/downlink antenna system 2.4m S-band downlink antenna system 4.5m S-band/X-band downlink antenna system		STFC/RAL	OT	Past space weather use: STEREO beacon mode (now too far away); ACE real-time solar wind (superseded by DLR service in Sep 2009)

Heliospheric Imager on NASA STEREO spacecraft		STFC/RAL	Sensor(s)	
Fabry-Perot measurements of thermosphere winds and temperatures in Svalbard and Scandinavia		University College London	Sensor(s)	during darkness and clear sky
Scanning Doppler Imager (SCANDI) measurements of thermosphere winds and temperatures		University College London	Sensor(s)	during darkness and clear sky
GPS receivers		University of Bath	Sensor(s)	
LEO beacon receivers		University of Bath	Sensor(s)	
Meteor radars		University of Bath	Sensor(s)	
Meridian chain of GPS scintillation receivers, jointly run with Bath: operational: Tromsø, Trondheim, Nottingham, Dourbes, Lagos (Nigeria) to be deployed: Kiruna, Lerwick, Aberdeen, Shrewsbury, Cyprus, northern Nigeria		University of Nottingham	Sensor(s)	
Magnetic field		Imperial College	Sensor(s)	Cluster, Rosetta, Ulysses, Cosmic Visions, cubesat
Thermal electrons (<1 eV to 30 keV)		MSSL	Expertise	Cluster, CRRES, Cassini, Cosmic Visions, miniaturisation studies
EUV spectroscopy		MSSL	Expertise	Hinode
Radiation dose		QinetiQ	Expertise	Shuttle, Concorde, Giove, …
High-res space cameras		STFC/RAL	Expertise	STEREO (HI, EUVI, COR), SDO (AIA, HMI), SMEI, GOES
EUV spectroscopy		STFC/RAL	Expertise	SOHO
Medium energy (30 keV -1 MeV) particle detectors		STFC/RAL	Expertise	Cluster, Cosmic Visions
Radiation dose		Surrey	Expertise	Giove
CRRES satellite wave and particle database			Data	
World Data Centre for Geomagnetism			Service	
CHIANTI			Expertise	Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas
ADAS			Expertise	Atomic Data and Analysis Structure
GAIA-VXO			Service	Global Auroral Imaging Access
UK Solar System Data Centre			Service	data & models for solar and STP studies World Data Centre C1 for STP
PROMPT ionospheric database			Data	Developed as UK input for COST-271
Solar archives			Service	Data from SOHO, STEREO and TRACE
CSDSweb			Service	Magnetospheric near-realtime conditions using Cluster
STPDF			Software	Data access system for STP/space weather data. Key data access component of ESA's SEDAT system
Clustran			Software	Library for coordinate transformations. Used in ESA's SEDAT system.
Database of Fabry-Perot measurements of thermospheric winds and temperatures			Data	30 years data, mostly over Scandinavia but also occasionally elsewhere.
Daily Ionospheric Forecasting Service		BAE SYSTEMS Advanced Technology Centre	Service	contributes to SWENET
Commercial applications of geomagnetic data and science, e.g. for oil and gas exploration and recovery and in navigation		British Geological Survey	Service	
Geomagnetic hazard modelling and analysis, e.g. for power system operators		British Geological Survey	Expertise	Includes services that contribute to SWENET
AuroraWatch UK		Lancaster University	Service	Over 25000 subscribers
Space weather Operational Airline Risks Service		MSSL	Service	contributes to SWENET
Spacecraft Hazard And Anomaly Forecasting Tool		QinetiQ	Software	contributes to SWENET
EDAM533 real time HF propagation prediction service		QinetiQ	Service	web service that provides HF propagation information based on the EDAM real time ionosphere. Access if controlled.
Space-based auroral imagers, primarily at UV but also possibly at X-ray wavelengths		University of Leicester	Sensor(s), Expertise	Derived from systems on XMM and Swift
TRIO-CINEMA - 3 cubesat mission with US and Korea.		Imperial College London	Sensor(s)	Imperial College to supply magnetometer. Launch early 2012. http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2009/2_Science/4_Glaser-CINEMA.pdf
Proton, electron fluxes, ion LET spectra, total dose, charging currents		QinetiQ	Sensor(s)	GIOVE-A plus other Galileo GPS
Particle fluxes, aircrew ambient dose equivalent		QinetiQ	Expertise	Various regular airflights
Solar wind physics		Imperial College London	Expertise	

Written evidence from HM Government

This paper sets out the Government evidence to the House of Commons Defence Committee inquiry on Developing Threats to Electronic Infrastructure. It has been prepared by the Ministry of Defence in consultation with officials from other Government Departments and the National Security Council (Threats, Hazards, Resilience and Contingencies).

Summary

The electromagnetic pulse (EMP) effect of a nuclear weapon detonated at ground level would be limited but one detonated at high altitude would generate a widespread effect. A limited number of States are considered to be capable of detonating a nuclear device at high altitude.

Non-nuclear EMP devices have a much more localised effect, and we continue to track the threat posed by such devices whether employed by state or non-states.

Space weather has the potential to generate EMP like effects. The UK has access to space weather data through close military and civilian links with the US allowing warnings to be issued of extreme events.

Space Weather and EMP have the potential to impact a range of civil infrastructure including: power networks; satellite services; aviation; digital control systems; and, wireless and mobile communications.

A three pronged approach is taken to mitigate the effects of EMP: prior warning is given, either through forecasting or the collection of intelligence, which enables appropriate action to take place, for example switching off vulnerable satellite systems; infrastructure is hardened where appropriate, this is especially the case for critical military infrastructure; and we prepare for these events although the Government’s approach to civil resilience management is to plan for the consequences of potential civil emergencies no matter what the cause. Contingencies are in place to react to large scale loss of electronic infrastructure with the restoration of the National Grid being a priority.

The UK has significant research resources available. The civil sector focuses on the effects of space weather whereas the military sector covers both space weather and its possible EMP effects.

Written Evidence

Q1. The extent of any threat posed to UK electronic infrastructure by electromagnetic pulse (EMP) events caused by space weather events, nuclear weapons detonated at high altitude or other EMP weapons.

1.1 The Government considers risks to national security, such as an EMP event, on the basis of the likelihood of the event as well as its potential impact. This is to ensure that investment in security and resilience remains proportionate to the risk. Risks of civil emergencies,[1] both malicious and non-malicious, affecting the UK mainland over the next five years are assessed in an annual classified National Risk Assessment (NRA), while areas of global risks to UK national security are weighed over a five and 20 year horizon in the National Security Risk Assessment (NSRA), first published in 2010 under the Government's National Security Strategy (NSS).[2]

1.2 The impact of EMP events caused by nuclear devices would be very severe but the likelihood is currently considered to be low. Non-nuclear EMP devices exist and the risks are being kept under review but are not currently considered to be sufficient to warrant recognition as a national security risk. Severe space weather, which might cause geomagnetic storms impacting the Earth's magnetosphere, has been the subject of extensive research over the past year. The likelihood of a severe space weather event is assessed to be moderate to high over the next five years, with the potential to cause damage to electrically conducting systems such as power grids, pipelines, and signalling circuits.

Q2. The likelihood that a viable EMP weapon can or will be used by either state or non-state actors.

2.1 A nuclear weapon (whether state or a terrorist improvised device) activated at ground level would cause a direct EMP but its range of effect would be of limited extent, and arguably less significant than the blast, thermal radiation, and fallout from any such device.

2.2 To generate more widespread damage from EMP, a nuclear warhead would have to be detonated at high altitude to generate the EMP from the interaction between the radiation from the weapon and the outer layers of the atmosphere. This could only be achieved by launching a device by missile to an altitude of several tens of kilometres. A limited number of States possess this capability.

2.3 The use of such a nuclear device against the UK would be considered to be a nuclear attack and an act of aggression. The EMP would also be likely to cause damage to a number of other nations beyond the target country, leading to the possibility of a collective response.

2.4 No non-State actors can currently produce an improvised nuclear device and none are likely to be able to make a sufficiently robust warhead for missile delivery in the foreseeable future.

2.5 State development of non-nuclear EMP devices would require advanced engineering, although cruder devices with limited ranges of effects may be

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[1] Emergency is defined by the Civil Contingencies Act 2004 as an event or situation that threatens serious damage to human welfare in a place in the UK, an event or situation which threatens serious damage to the environment of a place in the UK, or war or terrorism which threatens serious damage to the security of the UK. It must also be a threat or hazard of sufficient scale and nature that it is likely to seriously obstruct a Category 1 responder in the performance of its functions, or require the Category 1 responder to exercise its function and undertake a special mobilisation.

[2] Cabinet Office, *A Strong Britain in an Age of Uncertainty: The National Security Strategy*, Cm 7953, October 2010

achievable by non-States. There is evidence of the proliferation of such technology, which may lead to its acquisition by countries and/or non-state actors of concern to the UK in future years.

Q3. The extent to which space weather is forecasted and the effectiveness of early warning systems that may be in place.

3.1 The US National Oceanographic and Atmospheric Administration (NOAA) Space Weather Prediction Centre (SWPC) is the global centre for space weather services into the civilian community and is the dominant source of data and predictions for the UK. The US Air Force Weather Agency (AFWA), provides prediction services to UK military operations. UK infrastructure operators receive warnings via subscription services with NOAA or AFWA.

3.2 The Meteorological Office is currently developing a space weather prediction capability in partnership with NOAA and a number of UK organisations including British Geological Survey (BGS). Future space weather collaboration is also under discussion between the Met Office and AFWA. The European Space Agency (ESA) Space Situational Awareness (SSA) programme is defining ESA's requirements for space weather services. The global space weather community is dependent on a small number of solar environment observation satellites, many of which were launched for scientific purposes and not for operational observation to support prediction.

3.3 The MoD UK Space Operations Co-ordination Centre (SpOCC), based at RAF High Wycombe, receives 12-hourly updates from the US Joint Space Operations Centre of any solar activity expected within the next 72 hours. The SpOCC also receives automated alerts from the AFWA. These alerts provide details of any space weather phenomena observed in the previous 24 hour period and any solar activity expected in the next 24 hours. Where the level of solar activity is expected to impact on military operations, warnings are sent to the Permanent Joint Headquarters at Northwood and the Global Operations and Security Control Centre at Corsham. AFWA space weather products are also embedded within routine outputs from the Joint Operational Meteorology and Oceanography Centre at Northwood.

Q4. The potential impact of such events for both civilian and military infrastructure.

4.1 Space weather comprises a range of solar phenomena including solar flares, solar radiation storms, and coronal mass ejections (CME), which are likely to impact upon a wide range of systems including:

a. **Power networks:** Severe geomagnetic storms caused by fast-moving CME, can generate large geomagnetically induced currents (GIC) through long, electrically conducting systems such as power grids, pipelines and signalling circuits. High levels of GIC can permanently damage transmission, distribution, and generation assets in electricity networks potentially leading to power failure.

b. **Satellite Services:** Severe space weather can interrupt satellite services including Global Navigation Satellite Systems, communications, and Earth observation and imaging systems by damaging the space-based hardware, distorting the satellite signal, or increasing the errors in ground-based receivers.

c. **Aviation:** Airlines rely on High Frequency (HF) radio and satellites to maintain communications both of which can be disrupted by space weather. Cosmic rays and energetic particles from solar radiation storms can adversely affect microelectronic components in aircraft. The elevated levels of radiation exposure at flight altitude can be of concern for airline passengers and flight crews.

d. **Digital control systems:** High levels of neutron flux produced by the atmosphere by solar radiation storms can greatly enhance error rates in these components.

e. **Wireless and mobile communications:** The Sun can produce strong bursts of radio noise over a wide range of frequencies that can interfere with wireless systems including mobile phone telecommunication and the internet.

4.2 The Ministry of Defence relies on space based assets to provide:

a. **Satellite Communications (SATCOM).** SATCOM and data networks enable the command and control of deployed forces and the timely exploitation and dissemination of intelligence data.

b. **Positioning Navigation and Timing (PNT)**. Precise PNT solutions derived from the US Global Positioning System (GPS) enable the orchestration of complex military operations while reducing the risk of collateral damage and fratricide.

c. **Earth Observation (EO).** Earth observation capabilities (most of which are derived from allies and commercial providers) provide the necessary strategic indicators and warnings, and intelligence to support operational and tactical planning.

4.3 Defence procurement standards direct that military equipment must have an appropriate hardening against nuclear weapon effects including EMP. This hardening provides a level of protection against space weather effects.

a. **SATCOM** All beyond-line-of-sight communications for the MoD are provided through a Private Finance Initiative (PFI) with Paradigm Secure Communications Ltd. Under the terms of the PFI, the military is afforded access to assured and protected communications; these are derived principally from the Skynet 5 satellite constellation (and its ground infrastructure), which is hardened to withstand a reasonable worst case space weather event and a high altitude nuclear explosion (HANE). The PFI also accounts for the provision of commercial SATCOM for military purposes. While commercial satellites are designed to withstand routine space weather effects, they would be more susceptible to severe space weather than their military-grade equivalents, and their ground stations would be less resilient to artificially-generated EMP effects and GIC caused by space weather.

b. **PNT** Ionospheric disturbances caused by space weather are the single largest contributor to single-frequency GPS errors. However, military receivers use two frequency bands and enhanced signal processing techniques, which make them less susceptible to signal errors caused by EMP effects in the ionosphere.

c. **EO** It is possible that a severe space weather event or HANE could degrade the ability of these satellites to collect and disseminate data in a timely manner.

d. **Military Ground Infrastructure** Much of the military ground infrastructure in the UK is connected to the National Grid, the Public Switching Telephone Network, and other utilities, which may be susceptible to artificially generated EMP or GIC caused by space weather. Critical military infrastructure is designed to operate independently of nationally-provided utilities, with many facilities having back-up power generators and bulk fuel reserves.

4.4 The consequences of an attack by non-nuclear EMP can be temporary or permanent. The effect can be achieved either by the generated electromagnetic energy directly coupling to the victim communication wires, links and/or sensors, or coupling indirectly via metallic structures, cables, or network architectures. Equipment hardened to withstand nuclear generated EMP, may be susceptible to aspects of non-nuclear EMP. Commercial-Off-The-Shelf electronics are known to be vulnerable to non-nuclear and radio-frequency electromagnetic pulse attack.

4.5 The success of a non-nuclear EMP attack is, however, dependent on the level of access to and knowledge of the target as acquired by the attacker. Fixed targets such as land based devices, units, and centres that use IT, electronic and/or computer control systems are considered to be more vulnerable to an attack than moving targets such as air systems.

Q5. Ways of mitigating electromagnetic pulse events, either targeted or naturally occurring.

5.1 DECC and National Grid have been working closely over the past year to gain a better understanding of the potential impacts of a severe space weather event on electricity assets and networks. Scientific advice suggests that most of the risk from severe space weather arises from short lived extreme events that are not well correlated with longer term trends in solar activity. Historical records suggest that the so-called “Carrington event” of 1859 is a reasonable worst case scenario. Evidence indicates this event was about ten times more intense[3] than the most severe recent event that occurred in 1989 and led to a major power system disturbance in Quebec, Canada.

5.2 The main risk the Sun poses to electricity networks is CME. The components of the British electricity system most at risk are the high-voltage transformers that are used to enable power to move from one network voltage to another (e.g. from the

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[3] Although this depends on what effect is being measured.

400kV grid network to a 132kV distribution network). Transformers at the edges of a large network and those on ground/rock with high electrical resistance are particularly susceptible. Transformers connected to transmission networks (including those connecting power stations) are at greater risk than those on distribution networks because the networks couple to the ground over greater distances and provide a lower resistance to the GIC. If damaged, the transformers connected to the transmission system would either need to be replaced or returned to the factory for repair. National Grid has around 800 high-voltage transformers installed and holds a number of strategic spares to cover for individual faults.

5.3 There is substantial redundancy within the design of the grid allowing demand to be met in full unless there are multiple transformers out of service in a particular locality. Failure of substantial number of transformers would complicate the restart of the grid. As the normal demand for very large transformers is small (they have a life of around 50-60 years) such an event could cause substantial delay in restoring full connectivity due to the time taken to manufacture replacement transformers. There has yet to be a recorded case in which damage has been sufficient to cause such a delay in service restoration.

5.4 To date, the most severe damage on National Grid's network was in 1989 when two transformers had to be returned to the manufacturer with damage that was believed to have been caused by the same space weather event that affected the Hydro-Quebec electricity network. Although two transformers were damaged, the redundancy within the design of the system enabled demand to be met in full. Since that time National Grid have taken actions to mitigate the risk to their network against a storm of similar intensity: altering the specification of their transformers, monitoring warnings of potential problems, and developing operational strategies.

5.5 National Grid has instituted a GIC warning system with Metatech and EPRI. Scottish Power have commissioned an independent warning and monitoring system with BGS. These processes enabled warnings to be issued for at least five events including the major 'Halloween' storm in October 2003 that caused some issues in South Africa. This storm was detected in the UK but did not have any detrimental effects. The monitoring part of the current system, which records GICs flowing in selected transformer neutrals, has been integrated into the Smart Asset Management monitoring system and US Solar Shield system. A visual warning and modelling system is currently being developed with BGS with a full GB transmission model.

5.6 On 20 September 2010 the Electric Infrastructure Security Summit (EISS) at Westminster Hall was attended by HMG Officials. This was the first in a series of summits intended to promote cooperation on assessing the risks of space weather and taking appropriate action. National Grid agreed to investigate the implications of various scenarios on the British transmission system and have reported their initial findings to the Energy Emergencies Executive Committee (E3C), where government and industry work together to mitigate threats to gas and electricity supplies. E3C have been tasked with conducting further work across the electricity sector to fully understand the risks posed by severe space weather to generators and distribution network operators. An initial report is expected in early 2012.

5.7 The second EISS in April 2011 in Washington had wider industry attendance and particularly highlighted the severe effect on the US of a Carrington type event as well as EMP. Further work following the Washington Summit has determined which transmission networks or regions are particularly susceptible to geomagnetic disturbance. Increased risk is experienced in highly loaded systems with long high voltage lines over highly resistive geology and old design five limb or single phase transformers. Historically the GB transmission system has had a relatively low failure rate of less than 0.3% per year from 1952 to 2004 (five solar cycles) and random failure modes.

5.8 National Grid continues to review its approach to space weather compared to the US, European, and other transmission systems. The National Grid has six monitoring sites that, along with two on the US National Grid, will provide key inputs to the Electric Power Research Institute SUNBURST collaborative project (which the National Grid has been a member of since 2000), which in turn supports NASA's Solar Shield project. Other collaboration is taking place with the University of Manchester for transformer modelling, the University of Lancaster for space environment modelling, as well as BGS, Rutherford Appleton Laboratories, the EURISGIC project, DECC, E3C, and the Cabinet Office. NERC in the US has been particularly useful as its operational mitigation procedures are similar to National Grid.

5.9 Mitigation arrangements are in place to reduce the threat to military infrastructure. These have been detailed in response to Q4, together with the supporting space weather forecasting arrangements detailed in response to Q3.

Q6. The resources available in respect of research and development in the field.

6.1 The UK has significant civil sector expertise in space weather spread over Research Council institutes, universities, industry, and the Met Office. This includes:

a. provision of targeted space weather services for users in the public and private sectors;

b. development and operation of instruments that are the UK contribution to the global space weather monitoring;

c. key roles in European programmes and proposals to improve space weather forecasting (e.g. improved modelling of threats to spacecraft and power grids; improved international coordination and integration of space weather data resources and measurements); and

d. collaboration with US space weather forecasters in the provision of services, the development of advanced modelling and better methods for the detection and tracking of space weather threats.

6.2 A UK-US workshop in October 2010 explored the development of a roadmap for research collaboration to address key gaps in the science needed to deliver accurate space weather forecasts.

6.3 The MoD has expertise on space weather and EMP effects within its Defence Science and Technology Laboratory (Dstl) that is complemented by industry expertise gained through practical hardening and assessments of electronic systems.

Q7. Contingencies in place to react to a large scale loss of UK electronic infrastructure, and the role of the military in such an event.

7.1 Successful management of a major electricity supply emergency requires effective communication and cooperation between industry and government. The wider consequences of an incident could be mitigated by the choices that industry is able to make, and some of the practical aspects of managing an incident could be assisted by the activities of government. *The National Emergency Plan for Downstream Gas and Electricity* (NEP-DG&E) sets out a framework for industry and government to work together to manage a major supply emergency.

7.2 Should a severe space weather event cause sufficient damage to the British electricity system that a prolonged electricity shortage is experienced in a specific region, or, exceptionally, the whole country, electricity rationing may be necessary until such time as repairs are completed or sufficient mobile generation installed. The NEP-DG&E provides an option to implement electricity rationing through existing arrangements contained within the Electricity Supply Emergency Code. This aims to ensure the fair distribution of available electricity regionally/nationally to all consumers whilst protecting supplies to those who require priority treatment, using a process known as “Rota Disconnections”. Electricity distribution network operators maintain lists of priority customers within their networks and in emergencies, as Category 2 Responders under the Civil Contingencies Act 2004, are experienced at working closely with Local Responders to ensure that vulnerable customers are cared for.

7.3 In the unlikely event that a severe space weather event causes a total or partial shutdown of the British transmission system, National Grid as the System Operator, would declare a Black Start. This is the industry procedure to recover from a total or partial shutdown of the transmission system which has caused an extensive loss of supply, and entails isolated power stations being started individually and gradually being reconnected to each other to form an interconnected system again. National Grid run a regular inspection and testing regime of all Black Start stations to ensure that the capability to start-up independently is robust.

7.4 Telecommunications and electrical power generation and distribution infrastructures are mutually dependent. Public, fixed line, telecommunications infrastructures in the UK have arrangements in place that enable them to continue to function for up to five days in the event of the loss of grid-distributed electricity. Telecommunications infrastructures are owned and operated by private sector organisations who are best placed to respond to and recover from a major telecommunications incident.

7.5 Government has worked closely with the owners and operators of telecomms infrastructures through the Electronic Communications Resilience and Response Group to facilitate restoration of services in the event of a major incident affecting networks. The procedures that are in place are subjected to an extensive annual test conducted over several days. This is augmented with more frequent tests of the mustering arrangements for participants.

7.6 Core telecommunications networks are highly resilient when viewed against the planning assumptions from the National Risk Assessment. While the resilience of core networks is largely the concern of the Network Service Provider, since there is a significant incentive to efficiently route traffic, the resilience of access to these networks is largely a concern for the customer. Customers for telecommunications services can undertake a range of measure to enhance resilience.

7.7 The High Integrity Telecommunications System provides a strategic communications network linking Central Government to Strategic Co-ordination Centres, from where the response to civil emergencies are co-ordinated. The network achieves an exceptionally high level of resilience through the use of both military hardened satellite capabilities and terrestrial links.

7.8 Industry has an established procedure in place (the National Emergency Alert for Telecoms) for dealing with emergencies. In both real and exercise scenarios, this procedure has proved to be a highly effective process for ensuring resilience.

7.9 In the case of a national EMP event Defence does not expect to play a significant role in the primary response,[4] for example, restoring the National Grid. Under the provision of Military Aid to the Civil Authorities, MoD may, however, have capacity to augment any civil response, if capabilities are overwhelmed by the scale of the emergency. Defence personnel are likely to be available in the UK, and if requested should be able to provide general duties support to the emergency services and others dealing with the knock-on effects of an EMP event. Such support can be requested by any government department at the strategic level and at the local level this is facilitated through a nationwide network of Joint Regional Liaison Officers who work with local resilience fora and others to enable access to military aid.

Q8. The broader security of UK electronic and space infrastructure, particularly satellites and satellite navigation systems and the risk posed by space debris.

8.1 The Strategic Defence and Security Review of 2010 committed the Government to develop a National Space Security Policy, which would coherently address all aspects, both military and civil, of the UK's dependence on space; assure access to space; help mitigate risks to critical national infrastructure; focus future investment and research on national priorities, opportunities, and sovereign capability requirements; and encourage co-operation with UK industry and with international partners. We expect this policy to be published in 2012.

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[4] Defence may have a small number of specialists who can be deployed.