Power Supplies and Equipment for Military Field Research; lessons from the British Service Dhaulagiri Research Expedition 2016

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Key messages:

- An account of the decision-making process and subsequent performance regarding power supplies and equipment during medical research in an austere environment.
- Descriptions of challenges faced and overcome when operating at extremes of altitude and temperature, with storage and transport logistics.
- Direct military applicability seen when having to source power for equipment during provision of military medical care in remote and inhospitable conditions.

Abstract

Introduction: The British Service Dhaulagiri Research Expedition (BSDMRE) took place from 27th March to 31st May 2016. The expedition involved 129 personnel, with voluntary participation in 9 different study protocols. Studies were conducted in three research camps established at 3600m, 4600m and 5140m and involved taking and storing blood samples, cardiac echocardiography and investigations involving a balance plate. Research in this remote environment requires careful planning in order to provide a robust and resilient power plan. In this paper we aim to report the rationale for the choices we made in terms of power supply, the equipment used and potential military applicability.

Methods: This is a descriptive account from the expedition members involved in planning and conducting the medical research.

Results: Power calculations were used to determine estimates of requirement prior to the expedition. The primary sources used to generate power were internal combustion engine (via petrol fueled electric generators), and solar panels. Having been generated, power was stored using lithium-ion batteries. Special consideration was given to the storage of samples taken in the field, for which electric freezers and dry-shippers were used. All equipment used functioned well during the expedition, with the challenges of altitude, temperature, and transport all overcome due to extensive prior planning.

Conclusions: Power was successfully generated, stored, and delivered during the BSDMRE, allowing extensive medical research to be undertaken. The challenges faced and overcome are directly applicable to delivering military medical care in austere environments, and lessons learned can help with the planning and delivery of future operations, training exercises, or expeditions.

Introduction

The British Service Dhaulagiri Research Expedition (BSDMRE) took place from 27th March to 31st May 2016. The expedition involved 129 personnel, with voluntary participation in 9 different study protocols, investigating adaptation to high altitudes and diagnosis of high altitude illness.(1) Studies were conducted in three research camps established at 3600m, 4600m and 5140m and involved taking and storing blood samples, cardiac echocardiography and investigations involving a balance plate. These studies were carried out in the most remote and inhospitable environmental conditions, with the first research camp 7 days from the nearest settlement with mains electrical supply. Furthermore, due to the nature of the terrain in Nepal any equipment to power the research kit had to be man-packed by Nepalese porters, limiting the weight that could be carried. These constraints are similar to those experienced on expeditionary military deployments, and careful planning in order to provide a robust and resilient power plan is essential.(2) We have previously reported some of the challenges of providing power in these environments and our solutions used on this expedition drew on this experience of supporting previous field studies.(3,4) The aim of this paper is to give an account of these solutions for powering equipment on prolonged field studies, with lessons learned providing assistance for the planning of similar future expeditions.

We will look at methods of calculating estimated power requirements, generation and storage of power, types of storage for samples taken in the field, and specific equipment used on the BSDMRE.

Power requirements

The main considerations with any piece of equipment is the maximum power draw (Watts) and the drain once in consistent use (Amp hours AH).

- X (Battery size in Ah) x Y (Battery Voltage) = Z (Power available in watt hours)
- For a 20Ah, 12V battery the Watt Hours figure is 20(X) x 12(Y) = 240 Wh (Z)

The battery could supply 240 W for one hour, 120W for two hours etc. Running a 12v device from a 12v battery the output becomes more straightforward as in the above example, in theory, a 20 AH battery would run a device drawing 2 Amps for 10 hours.

In practice as the voltage drops below the equipment's requirements it will no longer be able to power it. The following assumption therefore needs to be made;

- Lead acid batteries will deliver approximately 50% of their rated power. (i.e. a 10Ah battery has 5Ah of usable power)
- Li-ion batteries will deliver 80% of their rated power. (i.e. a 10Ah battery has 8Ah of usable power)

This reduced power output is also partly due to the fact that the quoted storage of a battery is at a given temperature (generally a room temperature of 25 deg C is used), and is reduced at lower temperatures – which are of course are to be expected at high altitude.

Using calculations in this way enables an estimate of the requirement for power per day or at times of peak demand. The power requirement of a mains electricity device is generally stated on a plate or similar label, usually on the rear or underside of the device.

The other consideration is the peak power demand of the device. Devices that draw significant power even for an initial period (such as starting a centrifuge) require relatively high power loads.

The last consideration is the voltage required to be delivered to the device. For example most laptops will charge from 16v but not a standard 12v car cigarette lighter. Many medical devices are built with batteries requiring a variety of voltages but other equipment is only designed to work from a mains supply.

Generating Power

The availability of a regular and reliable means of power is a logistical challenge when operating in such environments. Other than for trips of extremely short duration, it is likely that there will need to be a means of generating power, rather than relying purely on stored forms transported with the team. Power in an expeditionary environment is needed to run a number of devices, such as lighting, communications equipment and computers. In a medical research situation, power is often needed for further applications in the form of diagnostic machines, centrifuges and storage containers.

The terrain and exact location of the operating environment will determine to what extent portability of power-generating equipment is of importance, and in a tactical situation further considerations such as noise and visibility will also have to be considered. For this expedition, the extremely remote nature of the research camps meant that all equipment had to be man-carried and as such the weight and size of power generating equipment was a limiting factor. The two energy forms used for power generation were internal combustion engine (ICE) via a petrol-fuelled electric generator, and solar (via high-output solar panels).

ICE generators are generally powered by petrol or diesel, and range from large heavy-duty models often used as a back-up for buildings in emergency situations, to smaller models that are portable but with a corresponding limitation in their power generating capability. Those with diesel engines tend to be more fuel-efficient, reliable, and do not need an ignition system (which could fail, and poses a potential explosion risk) though they also tend to be heavier, emit higher levels of noxious gases (which can be an issue in an enclosed environment), and are not as widely available as petrol-run models. A clear disadvantage of ICE generators in general is that the fuel source is unlikely to be readily available in remote locations, and large volumes of fuel therefore need to be transported for prolonged stays. A further consideration on this expedition was the effect of altitude: internal combustion engines are designed to run at sea-level, and when used at high altitude in thinner air they will perform with reduced efficiency and often prove difficult to start.(5) Solar panels have the obvious advantage of an unlimited energy source when used in the right conditions, but with the potential for this to be diminished in bad weather (though most modern panels will still function to some extent in significant cloud-cover). The majority of panels on the market are composed of silicon, in either a monocrystalline or polycrystalline form. Monocrystalline panels yield higher power outputs, are more space-efficient, and last longer than their polycrystalline counterparts due to a higher purity of silicon; however, they are also more expensive.(6)

Storing Power

As well as using power at the time it is generated, it is also useful to be able to store it, allowing use of devices later when means of power generation may not be available. Lead acid batteries were traditionally the preferred means of storage, though in recent years lithium-ion batteries have overtaken them as the first choice. Although more expensive, lithium-ion batteries are lighter, more efficient, and have less of an impact on the environment.(7) The increased initial cost is also offset by a longer lifespan, as a lithium battery will generally provide four times as many charge cycles in its life-span than its equivalent lead counterpart. Early problems with reports of spontaneous combustion and associated fires with Lithium-cobalt-oxide have been negated by the conversion to Lithium-iron-phosphate. Special consideration and fore planning is still needed if transporting either lead acid or lithium-ion batteries by air freight; airlines may agree to transport sealed lead acid batteries where the acid is in gel form but are likely to be much less amenable to liquid acid batteries even if sealed.

An important consideration on this expedition was performance in extremes of temperature whilst at altitude, with temperatures ranging from >30 deg C during the trek-in to base camp, to -20 deg C overnight in the higher camps: although both lead and lithium batteries will lose capacity in cold environments, lithium batteries are far superior in such conditions.(8) Care was taken throughout the expedition to ensure that the batteries did not come into direct contact with cold ground or surfaces, and were insulated where possible using clothing or equipment bags.

Storage of samples in the field

Multiple blood samples for several studies were collected during this expedition. Some assays can be performed in the field using point-of-care devices but the majority of assays have to be performed back in the UK in specialised laboratories. Blood samples therefore require separation in the field to obtain serum or plasma with subsequent storage as frozen samples. The two methods generally used for storing frozen samples are either a dry-shipper, or a mechanical freezer powered by an external power source.(9)

A dry-shipper is a very effective method of cryopreservation and transportation of biological samples, including serum and plasma blood samples. They consist of a vacuum insulated container of aluminium with a fibre glass neck, which is then filled with liquid nitrogen. This is absorbed and retained by an absorbent material; the cold vapours then dissipate over time, maintaining the cryo-storage between -150 and -190 degrees C. The liquid nitrogen needs to be sourced from a reputable company - this will obviously not be available in remote locations or smaller towns or cities in the developing world. Therefore, significant prior planning is needed to utilise this storage system.

A freezer has the disadvantage of increased weight and needing a continuous power source, although temperature can be more accurately controlled and monitored. The ability to set up and maintain a reliable power source will determine which of the two methods is most appropriate. Furthermore, the use of a freezer means another form of storage is required for transporting biological samples back to the country of origin, either via the use of a dry-shipper or on dry ice.

Equipment used

Usage	Equipment Type	Make/Model
Power Generation	Internal Combustion Engine	- Honda EU10i & EU20i portable petrol generators
	Solar power	- Solarpod™ 120W & 80W solar panels - Powertraveller™ Solargorilla 20V solar panels
Power Storage	Battery packs	- Solarpod™ 960Wh & 240Wh lithium batteries - Powertraveller™ 21000mAH lithium batteries
Safety Equipment	Extension lead with surge protection	- JOJO 13A extension lead
	Residual current device (RCD)	- JOJO 13A 30mA RCD
Sample Storage	Electric freezer	- Engel MT45 Fridge-freezer
	Dry shipper	- MVE Vapor shipper (with Statebourne Cryogenics protective container)

Table 1: Equipment used to facilitate research studies during BDSMRE

During the BSDMRE, equipment in regular use requiring power included: laptop computers, communication equipment, lighting, ultrasound machines, blood pressure monitoring devices, centrifuges and pressure plates.

Power at the research camps was generated using a combination of generators and solar panels. Following consideration, wind was decided not to be used as a potential power source, as the presence of consistently favourable weather conditions needed to harness energy from wind was deemed too unreliable. Generators used were Honda (Honda Power UK, Bracknell, Berks) EU10i and EU20i, which are 4-stroke single-cylinder petrol-fuelled portable generators providing maximum output of 1000W and 2000W and with dry weights of 13kg and 20.7kg respectively.(10) These were chosen having been successfully used on previous similar expeditions.(11) Petrol was sourced in Kathmandu and carried by porters from the road head. Usage of the generators was limited to 2-4hrs/day over the 4-week research period to ensure conservation of fuel. If attached directly to appliances while running, they were done so via surge protectors to ensure no damage to equipment, using 13A extension leads with surge protection, manufactured by JOJO (JOJO Electrical

Services, Ickenham, Middlesex).(12) Despite the high altitude and cold temperatures, there were no issues starting or running the generators, and neither sound or exhaust fumes were excessive (though they were always used in well ventilated areas, Figure 2). We did not need to customise the standard fuel injectors, with the generators working effectively at our maximum altitude of 5140m. If working above this altitude, altering the fuel injectors from their standard settings may have been required.

Solar panels used were 120W and 80W foldable panels from Solarpod™ (Sunbird Solar, Wokingham, UK), using monocrystalline silicon.(13) These worked well, and were able to provide a degree of power even in cloud cover and relatively low-light conditions. To optimise their use, their position was often changed throughout the day to gain maximum sunlight, and care was taken to regularly keep them clean and free of snow. These panels proved robust enough to be left exposed to the elements throughout the expedition.

Both generators and solar panels were used to charge large lithium-iron-phosphate battery packs (240Wh or 960Wh), again supplied by Solarpod™.(13) These batteries are very compact with built in 240v true sine wave inverters, 12v and USB sockets. The 240 model weighs 4.3kg, and has a capacity of 20Ah; the 1k model weighs 15.9kg and has a capacity of 40Ah. The batteries provide 12v DC, which is converted by the integral inverter to 240v AC for use with mains equipment; with modern inverters, any loss incurred in this process is minimal. Although most electrical equipment will tolerate a fairly 'dirty' power supply with poor sine wave (e.g. modified square wave) some specialised scientific equipment can be sensitive to this, hence the importance of a high quality true sine wave inverter on this expedition. Batteries were kept charged daily (from solar when available) and were sufficient to provide charge for all devices needing power at the research camps, despite extremely cold temperatures at night. The high power output of the Solarpod™ 1k model meant that all the medical equipment could be powered through this battery without recourse to the generator. This made conducting research prior to arrival at base camp more straightforward as we did not have to co-ordinate the logistics of bringing medical kit,

generator and fuel to one location.
In addition, Powertraveller™ (Alton, Hants, UK) 20V Solargorilla solar pads were used in conjunction with the small Powergorilla lithium battery packs, providing 21000mAh at a combined weight of 1.4kg.(14) These were primarily used for personal devices, reducing the demand on the generators and solar panels.

As an extra safety precaution, residual current device (RCD) plug-in adaptors were used throughout the expedition when connecting equipment to a power source, protecting against the risk of electrocution or electrical fire in the case of a fault being detected by the RCD. These were 13A 30mA RCDs manufactured by JOJO.(12)

All power generators worked well throughout the expedition, and would be recommended for future use, the Solarpod™ batteries in particular were extremely effective. It was useful to have multiple sources of power generation in case of equipment malfunction, poor weather or limited fuel. There is clear application for a military environment, with the specific equipment to be used dependent on the exact scenario. The Powertraveller™ devices would be appropriate for powering small devices, and could be carried by a medic/MO on foot. The 240 Solarpod unit is small enough to be carried in a bergan and would be effectively incorporated in a Role 1 facility (small, mobile medical units providing basic care and triage), acting as a power source for blood pressure machines/Propaq® units etc. The 1k Solarpod™ unit or Honda portable generators would be useful in a Role 2 environment (larger medical units providing resuscitation +/- basic surgical facilities) where they can be transported by vehicle and utilised for monitoring devices, syringe drivers, computers and lighting. Tactical considerations such as noise caused by generators, and reflection from solar panels may have to be taken into account, possibly reducing their effectiveness.

Blood samples were stored using a mixture of electrically powered freezers and liquid nitrogen in dry-shippers. We have used Engel MT45 (UK Agents MPS Trading, Hellingly, East Sussex, UK) portable fridge freezers on this and a number of previous expeditions.(3,15) The freezer has a minimum storage temperature of -20 deg C and a low power draw of around 2A/h or less in low ambient temperatures. This means the freezer can be run overnight on a charged battery. The freezer needed close monitoring as it has a built-in temperature gauge but no alarm; one lesson identified was that a means of tracking temperature (and alarming with an increase) would have been useful.

Liquid nitrogen dry-shippers were used for samples taken on the trek. There are a huge variety of dry-shippers on the market, of varying capacities. The critical feature is that they all have a limited static hold time (how long they maintain their temperature) primarily limited by their capacity to hold liquid nitrogen. The type of dry-shipper we used (MVE Vapor Shipper, Model: SC 20/12V, United Kingdom) had the advantage of an 85 day hold time for frozen samples. Although incurring a significant weight consideration at 50Kg each, they proved their worth and reliably maintained samples for the required 60 days without any power requirement. Liquid nitrogen was obtained in Kathmandu from BTC Private Limited, Kupondole, Lalitpur, Nepal. Care was needed when opening them and the containers had to be weighed to ensure that sufficient amounts of nitrogen remained; the containers did not need topping up with further liquid nitrogen at any point throughout the entire expedition. For transportation, we used specially made protective cases (Statebourne Cryogenics, Washington, Tyne & Wear, England), to ensure the dry-shippers were not damaged during transportation in such an extreme environment (Fig.1). It was important to ensure the dry-shippers were kept upright at all times, as the static hold time is reduced significantly if they are stored on their side or upside down. A further benefit of the dry-shippers is that that are not subject to the International Air Transport Association (IATA) Dangerous Good Regulations (16) when not containing free liquid nitrogen; therefore, they are exempt under 4.4 special provision, A152.(16) This means they can be flown on civilian air transport as hold luggage. Nonetheless, we took the precaution of obtaining written approval from the airline prior to departure.

It was useful to have two means of cold storage available in case of malfunction of breakdown. The challenges encountered and methods utilised to ensure the successful storage and transport of these samples are similar to those involved in setting up and maintaining a successful cold-chain for the delivery of blood products to Role 1 or 2 facilities in an operational theatre.(17)

Conclusions

Whether in an expeditionary or operational environment, issues regarding maintenance of a reliable cold-chain, and power generation and storage in remote locations will continue to pose a logistical challenge. New technologies, in terms of batteries and solar power will be game-changers in terms of delivering care in remote locations and the lessons learned from the BSDMRE should help others to overcome these challenges in the future.

References

1. Boos CJ, Vincent E, Mellor A, Woods DR, New C, Cruttenden R, et al. The effect of high altitude on central blood pressure and arterial stiffness. J Hum Hypertens. 2017 May 25;10.1038.

2. Command and General Staff School (U.S.), U.S. Army Combined Arms Center. Mountain Warfare - The Need for Specialized Training. Mil Rev. Command and General Staff School; 2004 Sep 1;84(5):94.

3. Mackey J, Mellor A. Lessons learned while undertaking high altitude medical research in the Himalayas. J R Nav Med Serv. 2015;101(2):143–6.

4. Mellor A, Woods D. Physiology studies at high altitude; why and how. J R Army Med Corps. 2014 Jun;160(2):131–4.

5. Taylor CF. The internal-combustion engine in theory and practice. M.I.T. Press; 1985.

6. Dobrzański LA, Wosińska L, Dołżańska B, Drygała A. Comparison of electrical characteristics of silicon solar cells. J Achiev Mater Manuf Eng. 2006;18(12).

7. Armand M, Tarascon J-M. Building better batteries. Nature. 2008 Feb 7;451(7179):652–7.

8. Albright G, Edie J, Al-Hallaj S. A comparison of lead acid to lithium-ion in stationary storage applications. Alternative Energy eMagazine Industry [online serial].

9. Vaught JB. Blood Collection, Shipment, Processing, and Storage. Cancer Epidemiol Prev Biomarkers. 2006;15(9).

10. Honda portable generators [Internet]. [cited 2016 Aug 7]. Available from: http://www.honda.co.uk/industrial/products/generators/portable/overview.html

11. Woods DR, Allen S, Betts TR, Gardiner D, Montgomery H, Morgan JM, et al. High altitude arrhythmias. Cardiology. Karger Publishers; 2008;111(4):239–46.

12. Electrical manufacturers: JOJO [Internet]. [cited 2017 Jun 7]. Available from: http://onecall.farnell.com/b/jojo

13. Solarpod™ by Sunbird Solar [Internet]. [cited 2016 Aug 7]. Available from: http://www.sunbirdsolar.com/

14. Powertraveller™ portable chargers [Internet]. [cited 2016 Aug 7]. Available from: https://www.powertraveller.com/

15. Engel Distributors UK. ENGEL Portable fridge freezers. [Internet]. [cited 2017 Jun 16]. Available from: http://www.engelfridges.co.uk/

16. IATA. Dangerous Goods Regulations (DGR) 2017 [Internet]. [cited 2017 Jun 16]. Available from: http://www.iata.org/publications/dgr/Pages/index.aspx

17. Parker P, Nordmann G, Doughty H. Taking transfusion forward. J R Army Med Corps. British Medical Journal Publishing Group; 2015 Mar;161(1):2–4.

Figures

1. Dry shippers being transported by foot in specially manufactured protective cases (Crown Copyright, 2016).

2. Petrol-fuelled portable generator in use during BSDMRE, powering medical research equipment (Crown Copyright, 2016).


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