The Power Failure at Karolinska University Hospital, Huddinge 7 April 2007

Observer Studies

Kamedo Report 93

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THE NATIONAL BOARD OF HEALTH AND WELFARE

Kamedo (the Swedish Disaster Medicine Study Organisation) has existed since 1964. The committee started its activities under the auspices of the Swedish Research Delegation for Defence Medicine. In 1974 Kamedo was transferred to FOA (the Swedish Defence Research Establishment), now called FOI (the Swedish Defence Research Agency). Kamedo has been affiliated with the National Board of Health and Welfare since 1988.

The main task of Kamedo is to send expert observers to places in the world affected by large-scale accidents or disasters. The observers are sent to disaster areas at short notice and collect relevant information by contacting key individuals, principally on a colleague-to-colleague basis. The information they obtain may only be used for documentation purposes. There are four main areas which are studied first and foremost: the medical, psychological, organisational and social aspects of disasters.

Results from the studies are published in Kamedo reports. Since 1979 (report 34) they have a summary in English, which are presented on the Kamedo website. Several reports have also been translated in full into English. The aspiration is that all reports will be translated into English. (http://www.socialstyrelsen.se/Amnesord/krisberedskap/specnavigation/Sakomraden/KAMEDO/).

The general guidelines for Kamedo activities are set by an internal steering group at the National Board of Health and Welfare and a reference group with representatives from some of the National Board of Health and Welfare centres for research and development within the area of emergency preparedness, the joint authority needs assessment group for international actions, Crisis Management Research and Training (Crismart), the Swedish Civil Contingencies Agency (formerly the Swedish Emergency Management Agency), the Red Cross and one of the previous scientific secretaries.

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Foreword

A sudden and large-scale power failure occurred at Karolinska University Hospital, Huddinge, on Easter Saturday, 7 April 2007. An earth fault in a high-voltage cable between two switchgear units knocked out 70 per cent of the hospital's electricity network. The power failure lasted just under one and a half hours, but it took considerably longer before activities returned to normal. No one was injured, but Kamedo has chosen to study this incident as there are many lessons to be learnt both from the technical point of view and in relation to clinical activity. If the power failure had occurred on a weekday of full activity, the consequences might have been very serious.

The hospital reported the incident to the National Board of Health and Welfare as a lex Maria case and details from the case forms parts of the material on which this report is based. The lex Maria is primarily intended to safeguard the safety and health of patients in healthcare and to prevent similar incidents by disseminating information about high-risk incidents and systemic errors in healthcare. Lars Asteborg, biomedical engineer, who was the person who dealt with the lex Maria case, contributed factual data to the report. Many supplementary interviews were conducted with key individuals in the preparation of this Kamedo report.

The principal author of the report is the biomedical engineer Lars-Göran Angantyr, who for many years worked at the National Board of Health and Welfare's Department of Supervision in Malmö as an expert in the area of medical devices. A co-author is Eskil Häggström, a consultant with Rejlers Ingenjörer AB, who advises the Swedish Emergency Management Agency and was previously for many years a consultant to the National Board of Health and Welfare in SSIK (program for acute-care hospital functional reliability – reserve power, water supply, heating). Other co-authors are Per Kulling, who at present is seconded national expert (SNE) in the Health Threats Unit of the EU's Directorate General for Health and Consumers (DG SANCO) in Luxembourg, who previously worked at the National Board of Health and Welfare and for many years was involved in Kamedo work. The authors are themselves responsible for contents and conclusions. The National Board of Health and Welfare does not draw its own conclusions in the document.

The report is targeted at individuals who are involved in medical and psychosocial care in major accidents and disasters, at training managers and emergency planning coordinators in county councils and municipalities, as well as government agencies, committees and associations with an interest in disaster management. The report is also of interest to those responsible for building systems, IT systems and medical devices.

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Acronyms and abbreviations

DUC	Dataundercentraler (building automation system controllers)
RD&E	Research, development and education
IT	Information technology
ICU	Intensive Care Unit
KBM	Krisberedskapsmyndigheten, the Swedish Emergency Management Agency (SEMA)
Lex Maria	Regulations requiring health care providers to investigate and report serious adverse events, or risk of serious adverse events, to the National Board of Health and Welfare, to institute preventive actions and to inform the patients
MIDS	Biomedical engineering information data system (Medicintekniska informationsdatasystem)
MTA	Department of Biomedical Engineering (Medicinteknisk avdelning)
PACS	Picture archiving and communications system
SEK	SEK Swedish Electrical Standard, formerly Swedish Electrical Commission
SLL	Stockholm County Council (Stockholms läns landsting)
SSIK	Program for acute-care hospital functional reliability (reserve power, water supply, heating)
TiB	Official on call
TDK	Telecomms/computer/wiring (tele/data/kablage)
UPS	Uninterruptible power supply

Keywords

Lessons learned
Gas supply
Infrastructure
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Disaster
Emergency management
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Safe Hospitals
SSIK
Safety of healthcare
Power failure

Contents

Summary and lessons learnt

Summary

The Power Failure on 7 April 2007 at Karolinska University Hospital, Huddinge

A sudden and extensive power failure occurred at Karolinska University Hospital in Huddinge on Easter Saturday, 7 April 2007, at 12.13 pm. An earth fault in a high-voltage cable connecting two substations in the hospital knocked out 70 percent of its electric power supply. The fault automatically tripped circuit breakers in switchgear and the connection between the substations was broken. The substation that supplied power to most of the hospital was consequently not live. The second substation was still connected to the external power network and was able to supply the hospital's main building with electric power throughout. The main building contains emergency rooms, radiology, a pharmacy, shops, a café, areas for visitors and the hospital's control centre. The power failure lasted one hour and 22 minutes, but it took a long time for activities to return to normal.

The power failure meant that many patients were at great risk, particularly in the intensive care unit and other departments where critically ill patients were being cared for. However, no patient was harmed, which is principally due to the fact that the power failure occurred at the weekend – in the middle of the day – when no major surgical procedures were under way and that no major operations had been performed on the days leading up to the long weekend. Resolute action on the part of management and staff also contributed to the favourable outcome. The managers ordered staff from the morning shift to stay on while replacement staff were arriving, leading to extra staff being available to monitor worried and care-demanding patients.

The power failure meant that many items of medical equipment critical to patient safety did not work. Rooms lacking daylight and with no emergency lighting were completed blacked out. The patients' signalling system to summon assistance stopped working. It was not possible to open medicine cabinets, changing rooms and other rooms with combination locks. The staff had to call security to open a medicine cabinet, and in another department staff smashed a window in order to gain access to necessary medication. Nearly all the lifts stopped and food supplies were delayed.

The pressure in the central pipe system for respiratory air fell after the compressors stopped working despite one of the three compressors having a power supply. This was due to faulty design of the control of the compressors and their cooling system. Staff had to connect reserve gas cylinders instead. When these ran out there was no possibility of getting hold of new cylinders. In the Department of Surgery it was not possible to connect cylinders of respiratory air. This meant that the staff could not use surgical and secretion aspirators.

Preparations for two urgent operations were discontinued and the patients were sent back to their wards. In addition, the staff had to discontinue two dialysis sessions early.

The power failure meant that all IT systems for administration and health care-support ceased to function. It was particularly critical to patient safety that the patient record system TakeCare, the patient monitoring system Clinisoft in the intensive care unit and the operative planning system Orbit were put out of action.

Karolinska University Hospital in Solna and Huddinge, St Erik's Eye Hospital, Södertälje Hospital, healthcare centres, geriatric and psychiatric hospitals and departments, municipal and private care throughout Stockholm County Council (SLL) use the patient record system TakeCare. TakeCare is also used at Visby Hospital, at healthcare centres and in municipal care in the municipality of Gotland. It was not possible to use the patient record system for 2.5 – 3 hours.

The backup systems, which the departments were instructed to use to cope with interruptions to the central patient record system TakeCare, were only exceptionally used. In addition, battery capacity in the local computers used for this purpose was insufficient, as TakeCare was out of action for a long time.

Great difficulties arose in establishing contact with the control centre at the hospital during the power failure, since the control centre was quickly flooded with incoming automatic alarms and phone calls. Those responsible did not utilise the hospital's disaster plan to deal with the situation. The deputy hospital director, two of the hospital's medical directors and the head of the emergency room monitored developments instead. They took a decision early on that all incoming ambulances should be diverted to the hospital in Solna and that a mobile standby generator should be collected from Solna. They informed other hospitals; the official on call (TiB) in Stockholm County Council was later contacted by the SOS-Alarm emergency call centre.

The duty technician in the control centre called in service staff with the necessary electrical skills who could locate the fault and restore the power supply in the hospital.

The hospital's generator set failed to start, which was entirely correct since the fault occurred in the hospital's electrical installation. There was voltage from outside in the public mains supply throughout. A smaller part of the hospital was therefore not affected, including the main building with emergency rooms, radiology and the control centre. If reserve power had been generated and connected in this situation, a conflict between reserve power and ordinary power from outside might have caused even greater problems.

Service engineers disconnected the high-voltage cable with the earth fault and replaced it with a new one within a few days following the incident. The cable was put into service on 23 April.

Lessons learned

1. The disaster plan for a hospital must describe the procedures to be followed in the event of serious incidents, including those occurring within the hospital, that cause disruption to the hospital's supplies and infrastructure. Those responsible need to, at least, adopt the lowest alert status, which is staff status, at an early stage. It is better to scale up the organisation at an early stage and then adapt it to the extent of the incident. If this is not done, there is a risk of the organisation never having time to get control of the situation if the incident proves to be extensive.
2. Disaster plans and disaster exercises must also include disruptions within the hospital arising from, for instance, power failures, disruptions to the water supply and gas supply as well as fires.
3. The management must base action plans and instructions for action to be taken in crisis situations on risk assessments.
4. It is made easier if the term ”official on call“ (”tjänsteman i beredskap” – TiB) is used throughout the country for this function, as described in the National Board of Health Welfare Regulations and general guidelines on peacetime disaster medicine preparedness and planning for heightened preparedness (Socialstyrelsens föreskrifter och allmänna råd om fredstida katastrofmedicinsk beredskap och planläggning inför höjd beredskap) [1].
5. The control centre at a hospital must be manned by personnel who have the knowledge and authority required to locate faults. They must also be able to carry out necessary switching operations in the electrical system so that they can restore the power supply – when this is technically possible.
6. When owners or operations managers use external contractors it is important that responsibilities are made clear in the contracts that are drawn up. This is particularly important when several parties are involved.
7. It is inappropriate for the secondary server in an IT system, which is to take over operation automatically if the primary server stops, to be in the same building complex as the primary server.
8. It is not realistic to believe that reserve power will always be generated if the ordinary power supply fails. There must therefore be preparedness to deal with situations in which there are prolonged power failures both in the mains supply and in the hospital’s own reserve power generation. Rooms for intensive care only permit power failures lasting less than 0.5 seconds. If there is also computer equipment, the requirement may be for the power supply to be completely free of disruption, variations or failures. To dispense with uninterruptible power supply (UPS) for important equipment in an intensive care unit is, apart from being a great risk, not permitted according to SEK Swedish Electrical Standard SS

437 10 02/T1 Electrical Installations in Buildings – Section 710: Medical Locations (SEK Svensk Elstandard SS 437 10 02/T1Elinstallationer i byggnader – avsnitt 710: Medicinska utrymmen) [2].

9. It is advantageous to limit the number of locations for UPS units in order to ensure that those responsible for test-running and maintenance of them do this in a correct manner. It may also be suitable if the organisation responsible for management of the facilities also has operational responsibility. The probability of those responsible checking and maintaining the UPS units in an acceptable manner is then increased.
10. Assessment of whether the hospital is to install UPS must be based by those responsible on risk assessment, with the aim of attaining optimum patient safety. When new energy-demanding equipment is installed it is important to review the capacity of existing UPS units and to revise risk assessments made previously.
11. Established routines must exist for regular checking of UPS units and internal batteries in equipment to make sure that they have the intended capacity when a power supply failure occurs.
12. If access to electric power has to be restricted, there is relevant prioritisation of buildings and/or activities where those responsible can read off which objects primarily need to receive the available electric power. This priority list must be available at the control centre.

    The same type of priority-setting must also exist for the common IT systems that the IT function uses. Based on this prioritisation, servers with the most important IT systems can be kept in operation for longer if the UPS units only need to supply power to them. Servers with other less important systems can be turned off. The priority list must be available to an IT technician with operational responsibility.
13. It is important to mark all electrical outlets clearly and consistently so that there is no doubt over what kind of load they are intended for.
14. In severe disruptions in operation personnel must quickly receive information concerning the cause of the problems and be informed as soon as possible when these might be remedied. If the normal information channels are not working due to the disruption, there must be alternative routes by which staff can be reached. It is particularly important that the organisations that are able to remedy the breakdowns receive quick and adequate information.
15. To ensure access to the information that is crucial to the care of a patient, for example current medication, it is important that there are alternative sources of such information, for example notes kept manually.
16. The hygiene requirements in the health service mean that no one among the staff wears a wristwatch, which means that the electric clocks in the rooms are relied upon instead. When these clocks stop or clearly go wrong, people lose their sense of time.

17. If combination locks and/or card readers are used to keep medicine cabinets and similar rooms locked and inaccessible to unauthorised persons, there must be provision for entering the rooms even if there is a power failure.
18. There must be provisions for connecting spare gas cylinders for respiratory air in a surgical unit where surgical and suction pumps and other equipment powered by the pressure in the respiratory air system are used. There must be spare gas cylinders close to the connection point. It must be possible to obtain new gas cylinders at any time of the day or night.
19. If those responsible had followed the recommendations in the National Board of Health and Welfare publication The Robust Hospital (Det robusta sjukhuset) [3] only a very brief power cut – a blink – would have occurred instead of the prolonged power failure that ensued.

Introduction

Power failures of varying duration occur with some regularity in society. As part of its emergency preparedness activity, the National Board of Health and Welfare has for many years pressed for the general hospitals with emergency care facilities to have reserve power. The National Board of Health and Welfare has done this as part of its SSIK activity (program for acute-care hospital functional reliability – reserve power, water supply, heating). The objective for the National Board of Health and Welfare's SSIK work is to support the authorities responsible for medical care in their efforts to bring about appropriate and reliable hospitals with the necessary backup facilities. An important aspect is the build-up of knowledge and feedback of experience for safety and endurance in functions. In the electrical area this has meant, in purely practical terms, that the National Board of Health and Welfare has firstly offered the county councils consultancy support in the investigation, planning and implementation of the expansion of reserve power and secondly has given the county councils certain financial grants. A large part of the overview of knowledge The Robust Hospital (Det robusta sjukhuset) [3], published by the National Board of Health and Welfare in 2002 is devoted to reserve power. This publication has been revised, and the 2008 edition of The Robust Hospital (Det robusta sjukhuset) [4] has now been published. Experience from this report makes up a significant part of the material. The Swedish Emergency Management Agency took over the SSIK activity with effect from 2007, but they run it in largely unchanged form and in close collaboration with the National Board of Health and Welfare.

A large number of power failures have occurred at general hospitals with emergency care facilities every year, lasting for variable periods of time and with consequences of varying seriousness. The power failure at Karolinska University Hospital in Huddinge, which is the subject of this report, resulted in medical care being seriously disrupted for several hours, but did not have any serious consequences for the patients despite this. However, the consequences could have been far more serious if the power failure had occurred during a very intensive week day. Since there are many lessons to be learnt from this incident, with regard to both the technical systems and clinical activity, Kamedo has chosen to study this incident.

The hospital reported the incident to the National Board of Health and Welfare as a lex Maria case, and this information forms parts of the material on which this report is based. Many interviews have subsequently been conducted with key individuals during the production of the Kamedo report, and several reports have been obtained to supplement the material. It is apparent from the hospital's final report on the lex Maria case that a number of risks to patient safety have been identified and that work is in hand to eliminate these risks.

The areas Kamedo has studied are the technical systems and the clinical activities affected by the power failure. The concluding chapter discusses factors of significance in improving patient safety when serious disruptions occur internally in hospitals. The health care provider is, for instance, responsible for issuing instructions and ensuring that there are management systems to ensure quality in each activity. The management system has to contain routines for safe use and handling of products, supply systems and information systems.

Several power failures have occurred since Easter 2007 at Swedish general hospitals with emergency care facilities, for instance at Blekinge Hospital in Karlskrona, Malmö University Hospital (MAS), Sahlgrenska Hospital in Göteborg, Norrland University Hospital in Umeå, Lund University Hospital, Lindesberg Hospital and Mälarsjukhuset Hospital in Eskilstuna.

The arrangement of the report follows the common template presented as an annex to Kamedo report 92 Evacuation of Swedes from Lebanon 2006 [5] and developed under the Swedish Emergency Management Agency's network for observer activity.

In this report we use the name Karolinska instead of Karolinska University Hospital.

General Information Regarding Technical Facilities, Products and Systems

General Information Regarding Electrical Installations

Normal power or non-prioritised power refers to power supply from the public mains which is not replaced by reserve power in the event of a power failure. Normal power or non-prioritised power is used for objects that do not require continuous supply, and is known as non-essential load.

Reserve power or prioritised power relates to power supply with a different power source. If an interruption occurs in the external delivery of electricity, the supply is maintained using generator sets. A generator set of this kind usually consists of an electric generator powered by a diesel motor. A generator set starts automatically if the supply from the public mains is interrupted. There is an interruption to the power supply lasting 15–30 seconds before the generator set has time to start and supply current. Reserve power is used for objects that require a continuous supply, known as essential load.

Uninterruptible power supply, UPS, is used for objects that do not tolerate any disruption at all to the power supply. UPS's consist of battery systems that take over the load without interruption. Objects that require uninterrupted power are referred to as critical load.

Reserve Power Installations

To cope with interruptions to the power supply, the general hospitals with emergency care facilities need to have their own reserve power equivalent to 100 per cent or more of maximum power consumption. When choosing the degree of cover for reserve power it is important also to take account of future increased dependence on electricity.

Reserve power capacity is put to best use if the hospitals run all permanently installed units in joint operation in a common way.

The generator units should be designed and arranged so that they can be operated continuously during prolonged power failures. Sufficiently large oil tanks are also necessary to ensure a prolonged capacity. The fuel in the full tanks needs to last for at least one week at full load.

The hospitals' reserve power capacity can be advantageously expanded by mobile generator sets to be attached at connection points at important low-voltage switchgear. With mobile sets and connection points there are also options for reserve power supply in the case of both planned interruptions and damage on the high-voltage side.

If the mobile generator sets are to work, it is important that the whole chain, the technical and organisational aspects and all routines, is described and tested.

Power outlets that supply reserve power when the electricity supply from the external mains stops must be clearly marked so that the generator sets are not loaded with non-essential load.

UPS (Uninterruptible Power Supply)

For certain primary systems and functions, such as telecom systems, switch functions etc. in switchgear, IT systems such as computers, servers and network units and surgical lighting and other important medical equipment there is uninterruptible power based on battery systems.

A UPS unit in principle consists of three parts

- a rectifier that converts 400/230 V alternating current (50 Hz) from the mains to direct current (battery charger)
- a battery for the storage of electric energy
- an inverter that converts the direct current to 400/230 V alternating current (50 Hz).

The battery is maintenance charged continuously so that it has full capacity if the mains voltage should fail. The battery takes over the load automatically in the event of a power failure without there being any disruption of the outgoing voltage.

The time for which the batteries in UPS's can take over the electricity supply to connected equipment is relatively short, usually 15–30 minutes. In addition, the time is completely dependent on the connected load. This means that the battery capacity and the load must be checked when connecting new objects (or removing existing objects) in order to be able to decide on possible running time in the event of a power failure.

More and more equipment is being supplied with UPS power. UPS is very often included as part of an item of equipment, either built in or else a separate component recommended by the equipment supplier.

Power outlets that supply UPS power must be clearly marked so that only critical load is connected.

Authors' Comments

The Swedish Emergency Management Agency publication The Robust Hospital (Det robusta sjukhuset) 2008 edition [4] describes the most appropriate ways to design and operate electrical installations to create safe and robust functions in a healthcare system that is constantly changing and has increasing requirements for a supply of electricity.

In the health care system UPS units are principally used for building systems, medical devices and IT systems. This means that different organisations often have responsibility for operation and maintenance. It is advantageous to limit the number of locations for UPS units in order to ensure that those responsible for test-running and maintenance of them do this in a correct manner. It may also be suitable if the organisation responsible for management of the facilities also has operational *responsibility. The likelihood of them checking and maintaining the UPS units in an acceptable and consistent manner is then increased.*

Handbook 450, edition 1 Electrical Installations in Medical Locations (Handbok 450, utgåva 1 Elinstallationer i medicinska utrymmen) [6] contains both standard SS 437 10 02, 4th edition with the additional standard T1 [2] as well as clarifying comments to simplify application of the standard. The standard describes various power supply systems, protection requirements in various patient settings, wiring systems, marking of the electrical system etc. The handbook is published by SEK (Swedish Electrical Standards), which is the Swedish standardisation organisation for electrical standards. The handbook can be advantageously used as a basis in planning electrical installations in hospitals.

Medical devices

The definition of a medical device is contained in the Medical Devices Act (1993:584) [7]. The Act is what is known as a framework law and covers all devices that serve a medical purpose.

Extract from Section 2 of the Medical Devices Act (1993:584) [7]

…

A medical device in this Act signifies a product which, in accordance with the manufacturer's instructions, is to be used, separately or in combination with something else, in order to, in humans, solely or principally

1. detect, prevent, monitor, treat or alleviate a disease
2. detect, monitor, treat, alleviate or compensate for injury or a disability
3. examine, modify or replace the anatomy or a physiological process
4. control fertilisation

If the device achieves its principally intended action by pharmacological, immunological or metabolic means, however, it is not a medical device within the meaning of this Act.

…

Development in the field of medical technology is making very great demands on the ability of the users to understand and apply the technology. These requirements are particularly great with regard to understanding what happens if the technology does not work as expected and what measures they must take to prevent or reduce any harm that may be caused to patients, staff or those around. The health care provider has the ultimate responsibility for there being routines that ensure that the staff use the correct product and that they have the right skills for their duties. The care provider may transfer responsibility to the directors of departments in the organisation.

Extract from Chapter 3 Management systems and routines in the National Board of Health and Welfare Regulations (SOSFS 2008:1) on the Use of Medical Devices in the Healthcare System. These regulations apply with effect from 12 February 2008 [8]

…

Section 4 The care provider shall issue instructions and ensure that there are routines in the management system for

1. how each activity is to be organised to make possible safe use and handling of medical devices
2. when a director of department is to be given a remit to take responsibility for the areas and tasks stated in Chapter 3 Sections 6-7 and Chapter 4 5–6 §§

Section 5 The care provider may give a director of department a remit to take responsibility for all or some of the areas and tasks in an operation for which some other director of department is responsible.

The tasks which a care provider has allocated to an operational manager shall be documented.

…

If the normal power supply is interrupted, certain medical equipment will continue to work with the aid of internal batteries or if it is connected to reserve power or UPS power. All power outlets must be clearly marked so that it is possible for the user to choose the appropriate level of safety for the equipment concerned.

Development in recent years has meant that medical devices and IT systems are linked and made to work together to provide a basis for diagnosis, monitoring or treatment of patients. Communication takes place via computer networks between server systems, databases and/or storage media. Such systems are known as Medical Information Data Systems (MIDS). The sharing of responsibility and roles of responsibility between information technology departments (IT departments), biomedical engineering departments, suppliers and system users must be documented and clear to all parties.

Medical Gas Installations

The hospitals handle medical gases (respiratory air, respiratory oxygen and nitrous oxide) in fixed gas installations that supply the gases to the various parts of the hospital through fixed pipe systems. The division of responsibility with regard to these fixed gas installations must be clear, as many different parties may be operating in the area. It is common for the manager of the facilities to be responsible for operation, i.e. for the supply and delivery of gases, the pipe system including pressure monitors, valves and outlets and for the ordering and delivery of gas in cylinders. A pharmacologist or pharmacist is responsible for the quality of the gases in the system, since medical gases are medicinal products, and the user is responsible for the connected equipment. This person can hand over technical maintenance and service to the hospital's biomedical engineering department or equivalent, or to an external service provider.

Authors' Comments

Spri (Swedish Institute for Health Services Development) Recommendations 6.1 edition 5 Medical gas installations (råd 6.1 utgåva 5 Medicinska gasanläggningar) [9] were previously the recommendations applicable to central gas installations produced in-house in Sweden. HB 370 Safety Standard for Medical Gas Installations [10], issued by the Swedish Standards Institute (SIS) superseded these recommendations on 11 September 2002.

Information Systems – IT Systems

The healthcare system is heavily dependent on IT systems that work smoothly. All kinds of data relating to care and treatment of patients are registered using computers. Computerised patient records, system for the planning of surgical procedures, archiving systems for X-rays and other imaging systems are examples of IT systems that are of primary significance to patient safety. Further examples are laboratory systems, systems for sending referrals and referral results and for sending prescriptions to pharmacies. The hospitals use IT systems to record financial and administrative circumstances that apply both to patients and to the hospital's own organisation and staff.

All these IT systems are normally run on centrally located servers and distributed across the hospital via networks. Communication with the outside world takes place through various external networks and the Internet. Hospitals usually use their own networks – intranets – for internal communication. In addition to these overarching IT systems there may be local networks and servers for special applications.

Networks usually consist of copper or glass fibre cables. To reduce the risk of interruptions in sensitive networks, these are constructed with several redundant connections, separated geographically. If possible the hospital can use other networks when the primary ones do not work.

Local wireless networks also occur, for example in the use of portable computers for patient records within a ward.

Servers and communication units in networks are normally supplied with power with UPS units that are connected to the distribution network for essential load.

Hazard (Threats and Vulnerability)

The power supply in Sweden is relatively reliable and of good quality. The high security of supply and the fact that electricity is usable for so many systems and functions has made society heavily dependent on electricity.

Rapid technological development in the health service has meant that virtually all functions in healthcare are almost completely dependent on a power supply that works. This is a trend which, in all probability, will continue.

Undeveloped responsibilities for installation, maintenance and operation of both generator sets and uninterruptible power supply may entail maintenance problems, poorer quality of electricity and risks severe disruption to the power supply occurring.

Sectorised organisation, with increased degree of specialisation, may entail lower preparedness for unexpected situations. Experience shows that the risks of incorrect decisions or delayed action are increased when many different parties have to work together to locate faults and rectify problems that have arisen.

Heating, water and sanitation, ventilation, medical gases, lifts, communication systems, central clock systems, access control and alarm systems, fire alarms etc. are facilities-related systems that are all dependent on electricity.

Internally in hospitals a large number of different electrical faults may arise, such as cable faults, blown fuses, tripped switches etc. Because of this it is important to build the electrical installations with alternative routes for the power supply, so that enable switching over the electrical system either manually or automatically.

If a fault occurs in the internal electricity network the start-up of generator sets may lead to a worsening of the situation if the faulty part of the installation has not been disconnected first.

If power outlets that supply reserve power or UPS power are not clearly marked there is a risk of someone connecting other less essential load and increasing the power consumption more than anticipated. For UPS power this additionally leads to a shorter running time.

If UPS units are not regularly maintained and adapted as new items of equipment or systems are connected, there is a risk that the intended capacity of the UPS's will be insufficient. This risk is particularly great if UPS's are in installations, equipment or systems that one operational unit uses but which is maintained by another operational unit.

All medical care uses medical equipment and systems. If the power supply does not work, problems arise in the operational unit, threatening patient safety.

Rapidly increasing dependence on information technology (IT) at all levels and in all operational units entails a new kind of vulnerability.

Particular mention should be made of the risks that arise when medical equipment and computer networks are combined.

For security reasons primary and secondary servers for important IT systems are often placed in different rooms. This may, however, if the secondary servers are located in the same building complex as the primary servers, lead to severe disruption and loss of data, for example in the event of fire.

The pressure in the respiratory air system normally powers surgical and secretion suction pumps. If this pressure falls or completely disappears, there is a serious risk to the patients in surgical procedures. In addition, it may be that when the pressure in the respiratory air system falls the pressure is automatically down-regulated in the oxygen system by pressure switches present in some wards, for example in neonatal wards. This in turn means that in some places the oxygen supply is lost when the respiratory air runs out.

Background

The Situation Prior to the Incident

Activities

Karolinska University Hospital, Solna and Huddinge, is one of the largest hospitals in Europe. The two sites of Karolinska University Hospital have a total of around 1,600 beds, around 101,000 care episodes per year and receive around 1.4 million outpatient visits annually. Turnover in 2006 totalled SEK 10.8 billion and the number of employees is around 15,000,

Buildings

Karolinska Huddinge comprises a number of buildings with a total floor area of 430,000 m^2. The hospital has 1,600 rooms, 850 beds, 24 operating theatres and 89 lifts. Annual consumption of electricity in 2004 was 42,145 MWh, which is equivalent to the electricity consumption of 2,000 detached houses with normal electric heating.

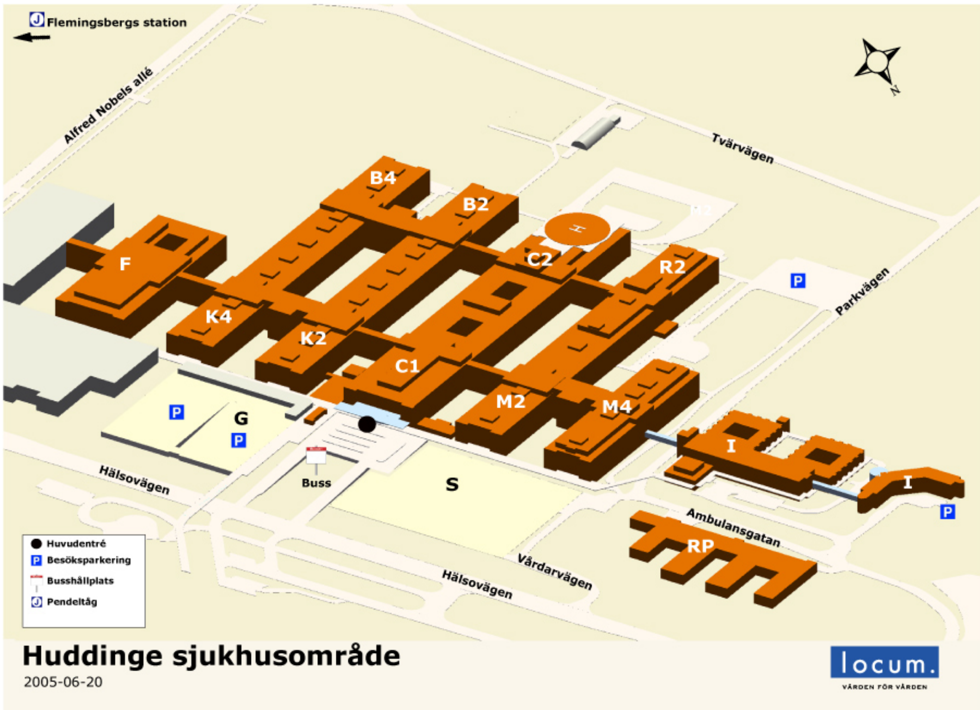

Figure 1. Karolinska Huddinge with symbols representing the various areas of the buildings

Illustration: Locum AB

The table in Annex 1 lists all the buildings and departments and units. The table also shows which buildings and departments and units were affected by the power failure on 7 April 2007.

Responsibilities and Agreements that Apply to Buildings and Facilities

Stockholm County Council and Landstingsfastigheter Stockholm own the buildings in Huddinge where Karolinska University Hospital is a tenant. The County Council has delegated the responsibility of management of its facilities to Locum AB. Landstingsfastigheter Stockholm has contracted out the running of the properties and their fixed installations to Dalkia Facilities Management. The staff, who among other things man the control centre at the hospital, are employed by Dalkia.

Facilities Manager – Locum AB

Locum AB (Locum Ltd, referred to in the text as Locum) is wholly owned by the Stockholm County Council holding company Landstingshuset i Stockholm AB. Locum is one the largest facilities management companies in Sweden, with a property stock of around 2.2 million square metres of premises in the county of Stockholm. Healthcare dominates among the tenants in the county.

The owner has the statutory responsibility for an electrical installation. This responsibility can be delegated. Stockholm County Council is the owner, and under facilities management contracts Locum has become the owner of the electrical installations. This applies to the fixed installation as far as the wall outlets, as well as necessary equipment for the running of the facilities, such as ventilation and lifts.

Contractor – Dalkia Facilities Management

Dalkia has a presence in some forty countries and employs nearly 50,000 people. In Sweden its operations are run by the subsidiaries Dalkia Facilities Management (referred to in the text simply as Dalkia) and Dalkia Industripartner, with total turnover of around SEK 1.5 billion. Dalkia is a leading supplier of property-related and industry-related supported services and energy services on the Swedish market.

Operating Contract between Facilities Manager and Contractor

There is an operating contract between Locum and Dalkia. The contract stipulates that Dalkia has delegating responsibility to look after Locum’s facilities and keep them in such condition that they provide the necessary safety for people, animals and property.

The Tenant’s Responsibilities

The tenant owns several technical systems in the properties whose function depends on a stable supply of electricity. The tenant is responsible for all equipment being connected to and supplied from the fixed electrical installation.

Important systems for patient safety owned by the tenant are the medical gas installation, including compressors for the production of respiratory air, equipment for uninterruptible power supply (UPS) and IT systems for patient records, patient monitoring and messaging.

Authors' Comments

When the owners appoint contractors it is important that the allocation of responsibility becomes clear in the contracts they draw up. Someone has to take the overall responsibility so that there are no uncertainties regarding who is responsible for what. This is particularly important when several parties are involved in different ways.

The Electrical Installation at Karolinska Huddinge at the Time of the Power Failure

The electrical installation at Karolinska Huddinge largely dates from the early 1970s, when the hospital was built. The present-day generator sets were installed ahead of the turn of the millennium, at the end of 1999, when one of the two substations (S0) also was built. The second substation (A1) was built in 2002. Both substations are equipped with modern technology.

The electric power system consists of two substations, seven transformer stations and reserve power installation with seven diesel generator sets and a distribution network. In addition there are UPS units in many places.

Normal Power

High voltage (22 kV) from the external mains is taken in via one of the substations. The substations for safety reasons are located at different places in the hospital area and linked by a cable joint (two parallel high-voltage cables). The station which at present is not connected to the external mains is supplied by this cable. The cable thus constitutes a safety feature as failures of the external supply of electricity to one substation can be replaced from the other through this connection. The cable was installed before the turn of the millennium in 1999.

In buildings C1, C2, F, G, I, K and M (see Figure 1) in the hospital area there are transformer stations with switchgear and transformers that convert 22 kV to the working voltage the buildings and their installations need.

For a description of the installation, see Annex 2 Description of the electrical installation, Overview Diagram 22 kV and Station Location, Overview.

On 7 April 2007 substation S0 was connected to the external mains. Substation A1 also received voltage through the link between the substations.

Reserve Power

The seven generator sets are located in fire-proof rooms in a separate building around 500 metres from the hospital, see Annex 2. Four sets are in one room and three in another one. There is space in the second room for a fourth set if the need should increase. The seven sets have a combined capacity of 12,775 kVA (10,220 kW) and can supply the whole of Karolinska Huddinge in the event of a mains failure, that is to say if there is a failure of the external electricity supply. The hospital's maximum power requirement at present is around 7,800 kW. This means that the generator sets have around 30 percent higher capacity than present-day needs.

The generator sets supply 22 kV to the switchgear in the two substations.

The installation is automated and starts up in the event of a mains failure.

UPS (Uninterruptible Power Supply)

Uninterruptible power supply, UPS, is installed for various functions at Karolinska Huddinge There are UPS’s in the central services unit and in the building automation system controllers for secure supply of electricity to control and alarm systems in the electrical installation and to the facilities' fixed installations.

In computer room K3 at Karolinska Huddinge there were two UPS’s at the time of the power failure which each supplied a number of servers and items of communication equipment. UPS’s for computer servers are normally designed to make up for a maximum of 30 minutes of power failure. The UPS’s in the computer rooms did not have sufficient capacity to be able to be redundant for each other. The electric power for the computer rooms was designed to supply the two UPS’s, which had capacity to run a number of servers for around 30 minutes in case of a power failure. However, more and more data servers had been installed in the computer room for future IT systems without decommissioning older systems. The running time of the UPS’s was therefore reduced.

Data switches in the computer network out in the hospital were therefore required for the communication between the servers in the computer rooms and the workstations in the departments to work. These are located telecoms/data/cable (TDC) rooms. UPS’s were present at the time of the power failure in some of these TDC rooms. The UPS’s supplied both the data switches and the workstations in affected departments with power.

The patient record system TakeCare (see below under Information systems – IT systems) was on one of the servers in computer room K3 at Karolinska Huddinge. This server had duplicate power modules for safety reasons. However, one UPS fed both power modules, which means that the safety feature covered faults in the power modules but not the server directly.

In the Department of Surgery there were UPS’s for supplying surgical lamps and other critical equipment.

When the new intensive care unit was planned, a decision was taken not to install UPS generally as the power supply was considered to be secure with existing reserve power solutions. In addition, those responsible in the intensive care unit felt that there was a guarantee from the facilities manager that the reserve power would be running within a maximum of 15 minutes in the event of a power failure.

Authors' Comments

Assessment of whether to install UPS must be based on risk assessments, with the aim of attaining optimum patient safety by those responsible. When installing new energy-demanding equipment it is important to review the capacity of existing UPS's and to revise risk assessments made previously.

To dispense with uninterruptible power supply (UPS) for important equipment in an intensive care unit is, apart from being a great risk, not permitted according to Swedish Electrical Standard SS 437 10 02/T1 Electrical Installations in Medical Locations [2]; a power failure lasting as little as 15 minutes can lead to situations that are very difficult to handle in an intensive care unit.

If there are UPS's there must also be routines for regular checking of the capacity and function of the batteries.

Distribution Networks

In the buildings at Karolinska Huddinge there is one distribution network for 230 V/400 V for non-essential load and one for essential load. But as the generator sets have capacity to meet the hospital's maximum needs with a 30 percent margin – the two distribution networks have been connected together in the switchgear. However, the networks can be separated in an emergency with limited access to electric power.

The power outlets for 230 V that are only fed with normal power if the non-essential load and essential load networks are separated in the switchgear are marked by white signs for non-essential load. The outlets fed with reserve power in the event of a power failure have green signs for essential load. The wording on the signs indicates the cable connection concerned in a local electrical cabinet. The outlets supplied with UPS power are marked by brown signs. Even if the hospital's generator sets have capacity to supply the whole hospital, there is therefore a need to note whether the outlets have signs for non-essential load or essential load when connecting important equipment. Emergencies may, in spite of everything, arise when the network for non-essential load is not live.

Authors' Comments

It is important to mark all outlets clearly and consistently so that there is no doubt over what kind of load they are intended for. Non-essential load, essential load or critical load. See the recommendations in The Robust Hospital, edition 2008 [4] and SEK Handbook 450 Electrical Installations in Medical Locations [6].

Information Systems – IT systems

IT Forum at Karolinska Solna and Huddinge at the time of the incident was a virtual organisation which consisted of four departments: the department for customer responsibility and system care, the department for IT operation and infrastructure, the department for innovation and medical informatics and a staff department.

There are around 180 IT systems or applications that the departments of the IT Forum manage wholly or partially at Karolinska Solna and Huddinge. In addition to these systems known to IT Forum there a number of other local IT applications.

All the IT systems judged to be critical to the operation are duplicated as well as being separated geographically for the maximum possible safety.

Within Karolinska there were totally eight computer rooms, of which four were located in Solna and four in Huddinge. There were servers and communication equipment in these computer rooms. The items of equipment in the computer rooms in each hospital were connected by fibre networks. They used the Stockholm County Council data network, SLL-net, for data communication between the hospitals and other external users.

The electronic patient record system in the Stockholm County Council area, TakeCare, is the largest central record system in Sweden; see Annex 3 The patient record system TakeCare, Overview. The primary installation was on a server in computer room K3 in Huddinge, which meant that TakeCare was normally run on this. The secondary installation was on a server prepared for the purpose in one of Huddinge's other computer rooms. It was to be used if the primary server was inoperative. Transfer of operation to the redundant server is done manually to ensure and maintain control of system during the move. Users of TakeCare have differing authorisation to write and/or only read patient data according to established rules based firstly on secrecy requirements and secondly on the need for care concerned.

The patient record system TakeCare is used at Karolinska University Hospital Solna and Huddinge, St Erik's Eye Hospital, Södertälje Hospital, healthcare centres, geriatric and psychiatric hospitals and departments, municipal and private care throughout Healthcare Provision, Stockholm County. TakeCare is also used at Visby Hospital, as well as at healthcare centres and in municipal care on the island of Gotland.

The patient record system TakeCare contains patient data for around 1.6 million individuals.

Authors' Comments

In view of the scope of the patient record system TakeCare, it is risky for the redundant server to be in a different computer room in the same hospital. In the event of a prolonged power failure without reserve power or for example in the case of a major fire, there is a risk of both computer rooms being affected. The transfer must additionally be done manually, which means that competent IT personnel must be in place quickly.

Medical Devices and Systems

At Karolinska Solna and Huddinge the hospital director has transferred responsibility for the use and handling of medical devices to the directors of departments in accordance with Section 3 of the National Board of Health and Welfare Regulations and Guidelines on the use and own manufacture of medical devices (Föreskrifter och allmänna råd om användning och egentillverkning av medicintekniska produkter) [11].

The director of department of the Biomedical Engineering Department (MTA) is responsible for establishing routines for the handling and in-house production of medical devices and for dealing with non-conformances when adverse events occur with medical devices. In addition, the director of department of MTA has to assist other directors of department and the procurement function on issues concerned with standards, routines and choices relating to medical devices.

The director of department of MTA is responsible for a gas committee being set up in accordance with Swedish Pharmaceuticals Standard and SIS HB 370 Safety Standard for Medical Gas Installations [10]. The remit of the gas committee is to coordinate, follow up and develop the handling of medical gases in the hospital.

The director of department of MTA is responsible for monitoring, collating and forwarding information from authorities on medical devices to the directors of department concerned. The intensive care units at Karolinska Huddinge and Solna use a computerised record system, Clinisoft. This is linked to the medical monitoring equipment and automatically produces real-time and trend curves for each connected patient. On the basis of this data staff can see whether a patient's condition is deteriorating early on and countermeasures can therefore be initiated more quickly. The servers for Clinisoft are located in computer rooms K3 and R3 at Karolinska Huddinge and have an uninterruptible power supply, UPS. The estimated running time in the event of a power failure is 15 minutes.

Authors' Comments

Since Clinisoft is of direct significance to patient safety it is risky to only have redundancy in another computer room in the same hospital. In the event of a prolonged power failure without reserve power or, for example, a major fire, there is a risk of both computer rooms being affected.

Medical Gas Installation, Central Production of Respiratory Air

Oxygen and nitrous oxide are contained in large tanks at Karolinska Huddinge and are distributed to the various buildings through two parallel pipe systems. A third pipe system distributes the respiratory air to units throughout the hospital as part of the common installation for medical gases. A small number of places in the hospital use nitrous oxide, while almost all units use oxygen.

Three compressors produce respiratory air. One compressor has the capacity to supply the normal consumption of the whole hospital.

To ensure the production of respiratory air, two of the compressors are supplied with electric power from the switchgear in Building G and the third compressor from the switchgear in Building C.

There are pressure switches or pressure monitors at strategic points in the building that sense whether the set pressure in the pipe system is right. If the pressure deviates from the set value, an alarm is sent to the control centre as well as locally to the affected department.

There are pressure switches in the Department of Surgery, Emergency, Radiology, Obstetrics and Neonatology. There are pressure monitors in the intensive care units and in all medical wards.

The facilities owner is responsible for the pressure switches and pressure monitors being designed for the stated flows; the facilities owners Stockholm County Council and Langstingsfastigheter Stockholm have delegated this responsibility to the facilities manager Locum. At each pressure switch, or pressure monitor, written instructions describing the procedure to be followed when connecting a gas cylinder are to be in place. The operating contractor Dalkia is responsible for checking the pressure switches and pressure monitors regularly according to the instructions contained in SIS's HB 370 Safety Standard for Medical Gas Installations [10].

Authors' Comments

The head of unit concerned is responsible for appointing staff who are to be responsible for the routines relating to the pressure switch and pressure monitor and for staff receiving adequate training in connecting reserve gas cylinders. As well as having specialist knowledge relating to gas technology and medical devices, the director of department must also assess the capacity of the reserve gas cylinders.

The difference between a pressure switch (also known as a group regulator) and a pressure monitor is that the pressure switch has a regulating function for the outgoing gas pressure. This function means that the pressure in the gas lines after the pressure switch has a particular mutual relationship. The pressure in the respiratory air system is normally set highest, followed by oxygen, and the nitrous oxide has the lowest pressure. Depending on their activity, the departments use this regulating function in slightly differing ways. In a neonatal unit the pressure in the respiratory air for use in incubators is allowed to regulate the oxygen pressure. In another unit the oxygen may be allowed to regulate the nitrous oxide. A pressure monitor does not have this regulating function.

Affected Units at Karolinska Huddinge

Some of the affected departments at Karolinska Huddinge have contributed information on their activities, such as numbers of beds and other relevant information. See also Figure 1 for the location of the departments in the various parts of the buildings.

Department of Emergency

The Department of Emergency consists of the emergency room in Building C1 and two emergency units in Building K4 with a total of 71 beds. The emergency units have had UPS's for the past six years for the power supply to very important medical equipment.

Department of Anaesthesiology and Intensive Care

This department consists of the Anaesthesiology Unit, the Postoperative Recovery Ward, the Research, Development and Education Unit, Intensive Care Units, the Pain Unit and administrative offices. The department is responsible for all Department of Surgery premises.

Anaesthesiology and Surgery, as well as the Postoperative Recovery Ward and the Research, Development and Education Unit are housed in Buildings B4 and K4. The Intensive Care Unit is in Building B, the Pain Unit in B4 and the administrative offices in B3 and K3.

Paediatric Department, Neonatology Unit

The Neonatology Unit in Building K has a total of 24 beds, of which ten are emergency/ICU beds including two beds for ventilator treatment. The unit cares for full-term and premature infants with acute lung diseases, circulatory disorders, obstetric asphyxia, life-threatening infections, metabolic crisis conditions, dialysis etc.

Department of Renal Medicine

This department has 26 in-patient beds and is housed in building M. It has around 3,000 patients for continuous monitoring and treatment and around 80 patients receiving regular haemodialysis.

Fourteen patients normally undergo haemodialysis on Saturday mornings.

Preparedness

The Electrical Installation

There are two transformers in the two network stations in the main buildings C1 and C2. See Annex 2 and Figure 1. One transformer is supplied from substation SO and the other from A1. If one of the substations becomes dead automatic change-over takes place to the transformer which receives current from the other substation. This means that this transformer takes over the whole load, and out in the departments staff only notice a brief blink. With this 'smart coupling'; it is possible to maintain the supply of electricity in the event of a mains failure that affects one of the substations. The main buildings C1 and C2 contain, among other things, the Department of Emergency and the Department of Radiology. It was planned that this technology would be introduced for the whole hospital, but it has not yet been fully installed. The other network stations also had two transformers, but these are only supplied with power from one of the substations. Nor was there any automatic switch-over arrangement in the network stations.

Authors' Comments

If those responsible had followed the recommendations in the National Board of Health and Welfare publication The Robust Hospital (Det robusta sjukhuset) only a very brief power cut – a blink – would have arisen instead of the prolonged power failure that occurred.

Preparedness of the Operating Contractor

Staff from the operating contractor Dalkia manned the control centre at the time of the incident with one person 24 hours a day. There was no requirement for this person to have the skills and authorisation to carry out switch-overs in the electrical installation. The attendance time for emergency prioritised maintenance was, according to the operating contract between Locum and Dalkia valid at the time of the power failure, no more than 20 minutes during normal working hours and no more than 30 minutes at other times before specialist staff started taking action. These attendance times applied to actions where there was an immediate danger to life and property. It was not explicitly stated that this applied to the electrical installation, but there were examples in the contract of situations that require priority maintenance, such as fire alarms and when people have become trapped in lifts.

If problems arise with UPS's in the computer rooms an alarm is sent to the control centre. The staff at the control centre check the problem and if necessary contact the contractor concerned. The latter takes remedial action. IT Forum receives information on the incident and action taken on the first following weekday. Dalkia does not have any up-to-date information on the capacity and condition of the UPS's.

Authors' Comments

If there had been personnel with the skills required for work in a high-voltage environment and if there had been clear operating routines in the control centre at the time of the power failure, it would probably not have lasted longer than around 15 minutes. These skills exist in the control centre at Karolinska Solna, and every week they conduct a small-scale exercise so that staff will be prepared if anything happens.

Preparedness of IT Forum

IT Forum has a preparedness organisation to receive reports around the clock and if necessary take remedial action to deal with problems with common critical IT systems. Outside of office hours IT staff are on standby at home, known as First-line On-call, according to an established schedule. All users phone First-line On-call in the event of problems with the common IT systems. The First-line On-call person in turn contacts the technical staff who are on standby in the preparedness line. There are preparedness lines for different IT systems (NT, Novell, Unix, Domino and EDI).

An alarm is also given automatically by SMS text message to the mobile phones of responsible IT technicians from a large number of applications for system monitoring. However, these alarms depend on their being a supply of current to both servers and network equipment.

There is a special agreement for the patient record system TakeCare where the commitments of IT Forum are stated among other things in requirements for availability. It is established here that TakeCare ”… has to be available 24 hours a day at client level with a maximum deviation equivalent to 0.3% of the total time in the month…”.

IT Forum has a contract with a supplier for annual checks on UPS installations for the IT systems.

Preparedness of the Department of Biomedical Engineering (MTA)

The Department of Biomedical Engineering (MTA) only has preparedness during normal work hours to receive reports and remediate faults in X-ray equipment and connected IT systems. The Department of Biomedical Engineering radiology unit in Huddinge consists of five biomedical engineers and technicians and three IT systems administrators.

The person who is on standby at the time of an incident receives reports of faults and coordinates action. This may mean that he calls in other Biomedical Engineering staff or contacts the supplier to remediate the problem. All radiology staff can use the standby service for all kinds of faults up to 10 pm, after which they are only allowed to report more serious faults.

Preparedness in the Event of Loss of Centrally Distributed Medical Gases

In an emergency situation, with falling pressure in the medical gas installation, it is possible to connect reserve gas cylinders to the pressure switches or pressure monitors in the departments. The connection has to be made by staff in affected departments.

In the Department of Surgery, the Emergency Room and Radiology there are pressure switches for oxygen and nitrous oxide (although nitrous oxide is no longer used in these departments). In these pressure switches it is possible to connect gas cylinders to the oxygen system. On the other hand, there is no provision in the Department of Surgery for connecting reserve gas cylinders to the respiratory air system. In the Delivery Unit there are pressure switches for respiratory air, oxygen and nitrous oxide. In the Neonatology Unit there are pressure switches for respiratory air and oxygen. In these units it is possible to connect reserve gas cylinders to both respiratory air and oxygen. In the Intensive Care Unit (ICU) and in the medical wards there are pressure monitors for respiratory air and oxygen. Here too reserve gas cylinders can be connected to both respiratory air and oxygen. The Delivery Unit and the Department of Dentistry are now alone in using nitrous oxide. The prospects of connecting reserve gases thus differ between different units in the hospital. It may be mentioned by way of example that in ICU there are two 50 litre gas cylinders containing oxygen and two 50 litre gas cylinders containing respiratory air in reserve. If the cylinders run out the internal transport organisation can fetch more during daytime on workdays.

Authors' Comments

Differing ways of monitoring and regulating the gas pressure in the central gas installation pose a risk of staff becoming uncertain how to proceed when they have to connect the reserve gas cylinder.

Provisions must be made for connecting reserve gas cylinders for respiratory air in the Department of Surgery. If access to respiratory gas ceases, the department's secretion and operative suction pumps cannot be operated, which entails a substantial risk to patients.

Karolinska University Hospital Disaster Plan

The 2007 disaster plan for Karolinska University Hospital describes three levels of alert beyond normal status: staff status, reinforcement status and disaster status. The SOS-Alarm emergency line alerts the official on call at Stockholm County Council in the event of accidents where the number of people involved is, or can be estimated to be, more than ten.

> *"Staff status is ordered in the event of an alarm concerning an incident or threat where the extent is unclear and the available capacity of medical resources can be expected to be insufficient. In staff status increased alert for emergency action is reached within the framework of available resources. The medical director and head of staff in the disaster management groups are contacted/summoned following a decision by the second on-call surgeon Karolinska Huddinge/first on-call surgeon Karolinska Solna through the switchboard. In Solna the first on-call surgeon calls contacts the second on-call surgeon before a decision is taken regarding heightened alert status. The summoned medical director and head of staff take over responsibility for the hospital's planning."*
>
> (Extract from the disaster plan, *katastrofmedicinsk planering (Local disaster medicine planning),* Karolinska University Hospital Solna and Huddinge, page 9).

It is also stated in the disaster plan that in the event of an alarm received by the Emergency Room of a serious incident in the hospital that may require major medical input, the Emergency Room must alert SOS-Alarm. The situation is then managed according to the Emergency Room's internal disaster plan and action timetable. This management of the situation also includes deciding what alert status to announce.

There is no information in the disaster plan regarding action in the event of a power failure. No exercises have been held at Karolinska Huddinge for staff on what to do if the supply of electricity in the hospital is lost.

Power failure exercises had, however, been conducted twice at Karolinska Solna during the last 18 months before the power failure.

Relevant parts of the Karolinska University Hospital disaster plan can be found in Annex 4**.**

Authors' Comments

It is important that the disaster plan also describes the procedure in serious incidents that entail disruption of the hospital's power supply and infrastructure. The hospital is thus not only to apply the plan in the event of incidents resulting in many people arriving at the hospital.

The Information Department

The Information Department at Karolinska has a press service manned on weekdays from 8 am to 8 pm, in addition to which the press officer and director of information can be reached on their mobiles or home phone lines.

The normal information channel to the hospital is the intranet. If it is not possible to use this due to disruption to the computer systems, a multifax function can be used. With this around 1,400 fax machines can be reached at the same time in the organisation. It is also possible to send out SMS messages via mobile phones at the same time as they are being sent to the hospital management and the directors of departments.

If a prolonged power failure knocks out all internal information channels it is possible to broadcast messages on Radio Stockholm.

Preparedness of Clinical Units in the Event of Power Failure

In each department at Karolinska Solna and Huddinge there should be an especially reserved computer on which a backup copy of the notes in the patient record system TakeCare on the department's patients is taken every day. The computer is supplied with uninterruptible power from UPS. In this way notes that have been made in patient journals up to and including the previous 24 hours will always be available, even if the central records system does not work.

In some departments staff keep all notes on paper made at the time of admission in a binder file. They can use these if the computer-based patient record is not available.

For all patients in the emergency departments there are record extracts on paper containing information on current prescriptions and the doctors' supporting notes from the time of admission.

Some medical equipment for life-maintaining measures and for monitoring also has built-in batteries that automatically take over the power supply in the event of a power failure.

Since the turn of the millennium all anaesthetic equipment in the Postoperative Recovery Unit has been provided with pocket torches.

The digital picture archive in the Department of Radiology, PACS, is on two redundant services in different computer rooms at Karolinska Huddinge.

Course of Events

At 12.13 pm on Easter Saturday 7 April 2007 an earth fault occurred in one of the two parallel cables constituting the cable link between the two substations S0 and A1. The fault arose in a splice made previously in one of the cables. A relay protection blew and the whole substation A1 lost its power supply. There was no automatic switching unit for this fault. See Block Diagram 22 kV in Annex 2.

The power failure affected buildings B, F, I, K, M, R, S and G. The failure did not affect buildings C1, C2 and RP, see Figure 1.

The power failure lasted for 1 hour and 22 minutes.

Detailed description of course of events

Time	Event	Comment
12.13	Common alarm from the two substations A1 and S0 are registered on the control computer in the control centre. Around 2,300 other alarms were received at the same time.	The whole of Karolinska Huddinge apart from buildings C1 and C2 were without electricity.
12.15	Information to the duty engineer in the control centre by phone from the central kitchen concerning the power failure. There after the phones were blocked by incoming calls. The engineer did not see any direct fault on the control centre's control panel.	The building (C) that houses the control centre did not become electrically dead.
12.20	The duty engineer phones operating staff on standby (one person) and other off-duty staff. An attempt is made to solve the problem over the phone, but fails.	
12.23	Hospital staff start knocking on and kicking the doors to the control centre. The duty engineer informs them that fault-tracing is in progress.	
12.25	The duty technician runs to switchgear C1 and substation A1 (these are closest to the control centre). He finds that the busbars of both switchgear units are live.	
12.30	Operating staff who have been phoned contact the duty technician to find out about the situation. They decide not take any action until operating staff arrive. The staff also inform Dalkia’s control centre supervisors and the supervisors call in further staff.	The deputy hospital director informs Locum's service manager of the power failure.
12.30 – 13.20	Dalkia’s deputy head of department informs Dalkia management according to the internal routine. As the power failure had already become known there was no time to phone everyone on the list before they heard for themselves. Locum's management is informed. Locum initiates the transfer of mobile generator sett from Karolinska Solna to Karolinska Huddinge.	The media make contact.
13.20	Operating staff who have been phoned arrive at	

	Karolinska Huddinge.	
13.25	Operating staff restore the electric power supply to buildings K and B.	Comprises surgery, intensive care, neonatology, obstetrics, medical wards.
13.32	Operating staff connect alternative supply route. The control centre supervisor arrives.	
13.35	Operating staff restore the electric power supply to the whole hospital.	
13.40	An earth-fault alarm in a circuit-breaker in substation S0 is discovered.	
13.50	Checking and resetting of relay protection of alarms in other stations.	
14.30	Operating staff initiate fault-tracing and discover fault in internal high-voltage cable. Resetting of other technical installations is initiated and is expected to go on for several days.	

Authors' Comments

The long down time can be mainly explained by inadequate skills among service staff present and an alarm indicating system that was outdated and difficult to read.

The first attempts to find the cause of all the alarms were made by phone between the duty service technician and staff who were on standby at home eight minutes after the first alarm.

Damage

A small gash had inadvertently been made in the insulation material in one of the two parallel cables in the cable joint connecting the hospital's two substations when the technicians spliced the two cables together. The splice was located 60–70 metres from one end of the cable. Over the year this gash was slowly hollowed out so that the insulation to earth deteriorated. The deteriorated insulation now caused a leakage current from one of the phase conductors to the surrounding earth conductor shield and what is known as an earth fault occurred. The voltage between phase conductor and earth is 22,000V. See photograph of cable splice below, Figure 2.

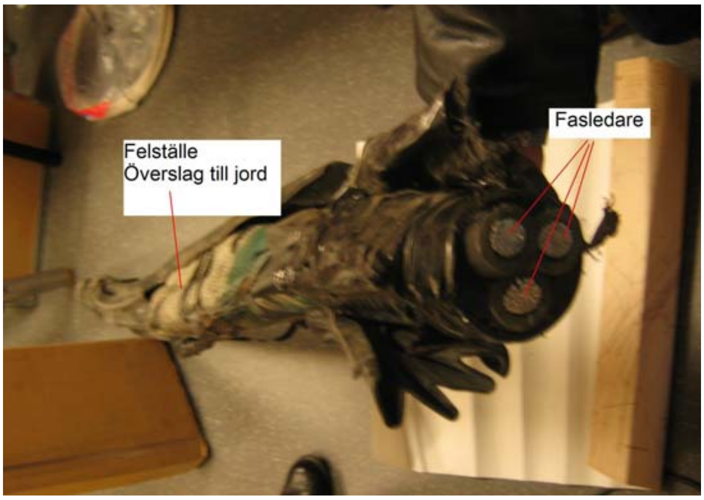

Figure 2. Photograph of the piece of the cable the technicians had spliced. The insulation has been partially removed.
Photo: Eskil Häggström

The greatest damage caused by the power failure were all the secondary disruptions that arose in the medical care activities. This disruption posed risks to patient safety to varying degrees. Medical equipment stopped, the pressure in the respiratory air system fell, staff were unable to open medicines cabinets, lifts stopped working, rooms without daylight were plunged into darkness, some communication systems ceased to work and so on. All the IT systems, including the patient record system TakeCare, stopped either immediately or after a brief time. The chapter headed Disruption describes these disruptions in more detail.

A hard disk in the monitoring centre in an intensive care unit was corrupted as a result of the power failure.

Unsuitable design of and electrical power supply to the electronic unit that controls the peripheral equipment of the air compressors meant that the production of respiratory air could not be maintained despite one of the compressors having current throughout the power failure.

The UPS’s in the computer room did not have capacity to supply the servers with power throughout the time the power failure lasted.

Poor internal batteries in certain medical devices meant that they did not have the expected running time.

No harm was caused to patients or staff.

Authors’ Comments

UPS’s for computer systems are usually designed to cope with power failures lasting 15–30 minutes. This means that they would not have managed to keep the servers running the whole time the power failure lasted.

The electric power in the computer rooms in Karolinska Huddinge was designed according to the needs that existed when they were built. Several new systems have since been installed, while only a few have been closed down, which means that the power supply is now overloaded. In addition, the phase load is uneven.

Some switches and similar items in the computer networks of the hospital's various buildings lacked UPS power. The UPS units in the computer rooms were thus not sufficient to maintain operation in the computer network.

Disruption

Building-related Systems

Alarms from switchgear, distribution boxes, battery rooms, UPS's and so on are registered in the control centre. The control centre received a total of around 2,300 alarms. The following systems, units and functions set off alarms

- fire warning system
- assault alarm system
- access control system
- patient signalling system
- pressure switches for respiratory air
- low-temperature freezers
- refrigerators
- de-ionising units
- the central clock installation

Since the power failure was relatively lengthy, most of the UPS's did not manage to supply the building automation system controllers in the various installation parts of the facilities. This led to the control programs for various facilities systems disappearing.

The battery installation that serves the central clock installation discharged so that all the clocks ran slow.

During the power failure the respiratory air system emptied, which meant that the pressure switches and pressure monitors out in the hospital started to set off an alarm. The reserve gas cylinders were emptied during the power failure.

The fire alarm computer indicated constant alarm during the power failure. After the power supply returned technicians were able to acknowledge and reset all these alarms.

When the power supply returned a number of fault reports arrived relating to tripped circuit breakers serving various building systems and items of equipment.

Information and IT Systems

The IT Operation and Infrastructure Department in IT Forum received approximately 40 reports of disruption to IT systems as a direct or indirect consequence of the power failure. The power failure to a greater or lesser degree affected all three computer rooms at Karolinska Huddinge. Computer room K3 contains the IT systems that are of direct significance to patient safety. The effects of the power failure are described below.

In this computer room (K3) around 75 servers went down and the communication equipment stopped working. Some servers in the room were automatically switched over to UPS operation. But as the power failure lasted so long, the two UPS's that were already overloaded were unable to supply the servers with power for longer than 7 and 20 minutes respectively. Other systems were automatically switched over to redundant servers in another computer room which the power failure did not affect to the same extent.

The IT systems that directly affected medical care were:

- The patient record system TakeCare, down time (time when the system was out of action) 12.30–15.00.
- The blood donor system Prosang, down time 12.45–13.30.
- The X-ray referral and results system RIS, down time 12.30–12.45.
- The messaging system Amtrix, which among other things sends referrals and referral results via the patient record system TakeCare, down time 12.30–15.15.

The patient records system TakeCare was out of action for around 2.5 hours, which was due to it not being possible to automatically transfer the system to a redundant server in another computer room. IT Forum instead considered carrying out a manual transfer, but this was not done because it was understood in the prevailing situation that the mains voltage would soon be restored. For TakeCare the power failure meant that approximately 35 records were locked or damaged and needed to be repaired. The locking also meant that staff could not read the medication records and the admission record (acute cases register) in the Department of Emergency (both Solna and Huddinge). The interruption to the Amtrix messaging system was also prolonged as staff had to re-start it manually. The down-time meant that referrals and results that had been sent were not delivered to their recipients.

Among other IT systems that stopped when the servers went down, mention can be made of Orbit operation planning, e-prescriptions, ordering of stock items, the hospitals' intranet, external web applications, web hosting etc.

The telephone switchboard worked but quickly became overloaded.

Authors' Comments

To ensure access to data that is absolutely necessary for the care of a patient it is important that there are alternative sources of information, such as manually kept notes of important data. Another alternative may be another server outside the hospital area with a separate power supply.

IT Forum ought to have received information early on that a power failure had occurred. That would have explained all the incident reports that flowed into IT Firstline On-call.

It is important that the secondary server for important IT systems and similar systems is not located in the same building complex as the primary server.

Medical Devices and Systems

A hard disk for the central unit in patient monitoring in ICU failed.

Poor internal batteries in medical equipment, such as ventilators, infusion pumps, portable monitoring equipment etc. meant that these did not work as long as the manufacturer had specified.

Authors' Comments

It is important that the staff regularly check UPS's and internal batteries in equipment, to make sure that they have the intended capacity in all situations.

There need to be power outlets in the ceiling pendants that supply UPS power to very important medical equipment.

Clinical Departments

General Disruptions

In common for all the clinical departments and units in the buildings affected by the power failure that rooms without daylight were plunged into darkness, combination locks on doors and medicines cabinets could not be opened by staff and card readers for doors did not work. Medical equipment that did not have internal batteries ceased to function. The patients were unable to use the signalling system to call for assistance, and lifts and wall-mounted clocks stopped. The pressure in the central system for respiratory air fell, which meant that ventilators and suction pumps failed to work. Where there were UPS's for medical equipment the staff was able to maintain some activity for a further 10–30 minutes, the UPS batteries then ran out, and these functions too came to a halt.

The computerised patient record system TakeCare stopped working when the battery power in the UPS's to the server in the computer room ran out. Contact with the patient record system for some TakeCare users was lost immediately as there was an insufficient number of UPS's in the computer network at the hospital. This also applied to Karolinska Solna, as well as all external users of TakeCare such as St Erik's Eye Hospital, Södertälje Hospital, healthcare centres, geriatric and psychiatric hospitals and departments, municipal and private care throughout Healthcare Provision, Stockholm County, Visby Hospital, healthcare centres and municipal care in the Municipality of Gotland. Nor was it possible to send referrals or results of tests and examinations as this function forms part of TakeCare.

The power failure thus meant that staff were unable to either read or register information concerning patients and their medication for two to three hours in large parts of Healthcare Provision, Stockholm County and on the island of Gotland.

The computerised operative planning system Orbit was out of action, affecting all departments in which surgical procedures were performed.

Further Disruption Affecting Certain Departments

Department of Emergency, Karolinska Solna

When the patient record system TakeCare failed to work, it meant that in the emergency room there was no access to the acute-cases register which is a module in TakeCare. It contains information on which patients have been admitted to the emergency room and most of the acute and previous documentation concerning them.

It was not possible to obtain test results for laboratory samples taken and sent.

In the emergency wards there was no access to important information about the patients such as history, hypersensitivities, laboratory results, contact details of family members and care planning. Information on prescribed medication was, however, available.

Information to the department as to the reason for the problems with the patient record system TakeCare was delayed. Nor was any information received on how long the power failure was expected to last, and IT managers instead referred to a forthcoming press release. This uncertainty contributed to a delay in the transition to manual routines.

Department of Emergency, Karolinska Huddinge

The emergency room, which is located in Building C1, had a supply of power throughout but when the computerised patient record system TakeCare did not work the data communication between the hospital's laboratories and radiology departments failed.

Staff from the intensive care unit and the neonatology unit of the Paediatric Department came to the emergency room to borrow batteries for their ventilators.

At 14.00 Radiology announced that it could now perform CT scans and skeletal X-rays, but that only preliminary results could be given and no comparisons. The chemical laboratory announced that it could perform urgent analyses and send the results by fax or tube post.

In the emergency ward a member of security staff helped in gaining entry to the medicines room as the combination lock could not be opened. By way of the information about the patients available on paper there was access to prescriptions for medication and certain other patient details. This meant that it was possible to continue with current medication despite the patient record system not working.

Only the emergency lighting was on, which caused great uncertainty among staff and patients. The alarm to security staff in the department did not work.

Ambulance arrivals were closed 13.00 following consultation with the medical director. The ambulances were re-directed to Karolinska Solna. Ambulance Arrivals was re-opened at 16.00 after information had been received that the Department of Surgery had started work again. At the same time access was obtained to the patient record system TakeCare, but it was not possible to make printouts of labels. It took until 19.00 for this function to start up. At 17.10 Radiology announced that it had resumed activity.

Departments of Anaesthesiology and Intensive Care, Karolinska Huddinge

When the power failure occurred it was expected at the department that reserve power would start up. A quick internal check showed that the power failure had affected all activities in the department. The second-line on-call physician in the intensive care unit contacted the director of department early on. An attempt was then made to contact the control centre by phone, but it was engaged. The hospital switchboard did not answer. The attempts to contact the control centre were continued.

After around ten minutes without power the director of the department made contact with the on-duty medical director. The latter stated that the deputy hospital director was making the necessary internal and external technical contacts. The on-duty medical director returned after around ten minutes and stated that the facilities management company Locum and the service contractor Dalkia were in the process of locating the fault. He did not give any definite prediction as to when power might return.

Intensive Care Unit

The unit was fully occupied with eight patients, six of whom were on ventilators. These ventilators had built-in batteries for brief power failures, but two ventilators did not work at all.

The infusion pumps automatically went over to battery operation.

The patient information system Clinisoft stopped working, which meant that important information on the condition and treatment of patients was not available. Infusions in progress could continue, but staff did not have a basis for correct treatment with other medication. The patients therefore did not receive any medicines unless a doctor or nurse knew for certain what type of medicine was to be given and when. When TakeCare, but not Clinisoft, started working, staff were able to draw up more complete paper records for medicines. However, they had to do this manually from the screen, since no printers were working.

Department of Surgery

Staff discontinued the setting-up of two imminent operations and the patients were sent back to the wards. This was made difficult by the fact that the lifts were only working in Building C.

It was also noted that neither surgical suction pumps nor secretion suction pumps could have been used if an operation had been performed during the power failure since the gas pressure in the respiratory air system operates the aspirators. When the gas pressure disappeared and there was no possibility of connecting reserve gas locally in the Department of Surgery, these aspirators could not be used.

Postoperative Care Unit

The staff sent a patient to the medical ward without complete optimisation of pain relief having been achieved. They did this to free up resources for urgent needs and to be prepared in case the power failure proved to be prolonged. The situation for the only patient remaining in post-op was stable.

The pressure switch for the central supply of respiratory air did not work since there was no battery in it. As a consequence of this no alarm went off when the respiratory air pressure began to fall.

Paediatric Department, Neonatology, Karolinska Huddinge

At the time of the power failure five patients were treated with pressure-assisted breathing, two on a ventilator and three with positive pressure and oxygen by CPAP (Continuous Positive Airway Pressure). After a while monitoring equipment and infusion pumps stopped working. After about 25 minutes of power failure staff observed that the pressure in the wall outlets for respiratory air was starting to fall.

The internal pager system stopped working.

The Department points out that neither the section nor the department management were informed during the time the power failure was in progress. It was not until the power returned that information was received regarding what had happened.

Department of Endocrinology, Metabolism and Diabetes, Karolinska Huddinge

The power failure only caused certain problems when it proved impossible to access the medication records in the patient record system TakeCare.

Department of Cardiology, Karolinska Huddinge

The patient record system TakeCare worked for around 10 minutes before going down. In accordance with the prevailing routine, admission notes had been made with a list of medication on paper. The staff therefore knew what medication the patients were on. No patient was severely ill, nor was anyone affected by problems in conjunction with the power failure.

Department of Infectious Diseases, Karolinska Huddinge

No patient was harmed due to the power failure, but the clinic points out that the failure entailed risks to patients and caused disruption to and problems in the unit. As the patient record system did not work, this meant that the staff could not read the lists of medication. Some medical equipment did not work.

It was impossible to transport patients confined to bed to other floors because the lifts to the 6th floor were not working. Food transport was delayed.

Department of Clinical Chemistry, Karolinska Huddinge

The power failure did not affect the power supply to the rooms and laboratory instruments of Clinical Chemistry as this unit is in Building C1.

On the other hand, when the internal network was put out of action all laboratory function was paralysed. Most orders within Huddinge Hospital are made via the patient record system TakeCare. This meant a substantial reduction of efficiency and a risk of quality deficiencies.

Clinical Chemistry in Huddinge provides a service to the whole clinic, which means that the power failure also affected urgent activities in the chemical laboratories at Karolinska Solna, Södersjukhuset (Stockholm South General Hospital), Södertälje Hospital, Danderyd Hospital and Norrtälje Hospital.

Department of Clinical Microbiology and Virology, Karolinska Huddinge

When the power failure affected activities, an attempt was first made to establish contact with the control centre by phone, but it was not possible to get through. An action plan was then sought to find out how to carry on with activities if power did not return during the day.

The staff were unable to register urgent tests as data communication within the hospital cases, nor could they receive orders or provide test results during the period of the power failure. They were unable to perform analyses as the instruments were without power, nor could they complete analyses that had started, despite some instruments being supplied with UPS. These have an operating time of 20 minutes, and the power failure lasted longer.

There was concern that the blood culturing apparatus would not work when the power returned. However, when the power returned after about 1.5 hours it was found that these worked without any problems.

No patient samples or test results were adversely affected. Test results were, however, delayed. Negative test results from blood cultures for about 50 patients were delayed by two days.

The department notes that an action plan is necessary in order to be better equipped to deal with a similar situation in the future. In addition, greater capacity is required in the UPS's that supply blood culturing apparatus and other equipment.

Department of Obstetrics and Gynaecology, Karolinska Huddinge

No patient was harmed as a result of the power failure, but the failure posed risks to the patients as it knocked out electronic foetal monitoring. When it is not working staff are unable to detect asphyxia, if there is an uncertain diagnosis there is a risk of Caesarean sections being performed unnecessarily.

The central foetal monitoring by CTG did not work during the power failure. The paediatric emergency trolley was taken out of use, the heated cots worked for a while on internal batteries and the drop counters were automatically switched over to battery operation. The internal batteries supplied the CTG machines with power in the care rooms for about ten minutes.

Fire doors were closed and various alarms were set off.

The six to seven patients who came to the outpatient clinic could not be assessed by staff during the just less than two hours that the power failure lasted.

Five patients were in the gynaecological emergency unit. None of these was in need of immediate care. Neither ultrasound equipment nor examination lamps worked, nor did the patient record system.

The on-duty doctors in the department found it most noteworthy that no information was received about what had happened, nor was any indication given as to when it was expected that the power would return. After a long wait on the phone the doctors managed to make contact with the control centre, and all they were told was that technicians were attending to the problem.

Department of Respiratory Medicine and Allergy, Karolinska Huddinge

When the power failure occurred it proved necessary to prescribe medication without having access to the medication list in the patient record system TakeCare. It also meant that patients did not receive their medication in time. The signalling system the patients use to summon help did not work. Staff therefore had to go round to the patients continuously to see whether they needed help. This became a greater burden during the following night as the signalling system did not start to work until the following day.

Department of Renal Medicine, Karolinska Huddinge

The dialysis machines have internal batteries and worked during the power failure, but the water treatment system (RO system) and the distribution of dialysis concentrate ceased.

Most of the morning's dialysis patients only had a short time left in their treatments and the staff were able to finish these without any major drama. However, in the case of two patients the dialysis had to be interrupted when there was up to an hour of treatment still to go. The staff had to resume the treatments at a later time. Blood and filters were discarded.

Radiology Department, Karolinska Huddinge

The power failure did not affect the Radiology Department directly, as the department is located in Building C. There was lighting in the premises and all the radiology equipment worked. The radiology computer room was operational throughout and was able to take over the PACS function – the digital pictures archive – from the server in the computer room that was put out of action. Certain problems arose in the transfer of PACS with the consequence that pictures could not be saved to the archive for a period. Staff were, however, able to run the X-ray machines and examine the pictures directly at the equipment.

Disruption also occurred in RIS (Radiology Information System) and the patient record system TakeCare with the consequence that manual routines had to be used to book patients and for the management of referrals. It was, however, possible to carry out examinations and make X-ray diagnoses during the period of the power failure.

Department of Transplant Surgery, Karolinska Huddinge

Staff had to postpone a kidney transplant for 3–4 hours. The absence of the patient record system TakeCare did not cause any major medical problems during this period. There was no lighting in the medicines room during the power failure.

Authors' Comments

The clinics did not receive information regarding the cause of the power failure, nor were they told when the power supply was anticipated to return. This lack of information created problems for patient care. Nor was it made known that staff alert status had been initiated.

It is important to be able to connect reserve gas locally in all units and that there are gas cylinders in reserve for compressed air and respiratory oxygen.

The head of biomedical engineering at Karolinska had for several years pointed out that the fixed gas network needed to be upgraded. He has also pointed out that the intensive care unit not being supplied with UPS power represents a patient risk.

There must be established routines for regular checking of internal batteries in medical and other equipment and in pressure switches.

The security systems become like a prison as no combination locks worked. It is important that there are manual alternatives such as ordinary keys to open doors, medicines cabinets and so on.

The hygiene requirements mean that no one wears a watch. Staff therefore relied entirely on electric clocks and thus lost their perception of time.

Factors of significance for the fact that, in spite of everything, no patients were harmed:

- *Only urgent activities were taking place on the eve of a holiday.*
- *There were sufficient staff (morning staff still present and afternoon staff on the way in), so that someone was able to take overall responsibility, coordinate activity, redistribute staff and investigate what was working and what was not and so on.*
- *No patient had severe pulmonary dysfunction. These patients do not tolerate manual ventilation.*
- *If two major operations, for example liver transplants, had been in progress, the risks of fatal outcome would have been high since the suction pumps, for instance, were not working.*
- *The power failure took place during daytime and the intensive care unit has windows, so that there was the benefit of daylight. There was a relatively plentiful number of staff.*
- *Parts of the hospital were not affected, for example certain lifts worked, which meant that it was possible to transport patients.*

Responses – the Acute Stage

Information Efforts

The duty press service in the Information Department was contacted at the home of someone at the hospital shortly after the power failure had occurred. At the same time the director of information was contacted by the second-line on-call physician. Following close contacts with the medical director it was understood that most of the hospital was without power.

The normal information channels within the hospital – intranet and fax – could not be used, and contact had to be made with the second-line on-call physician and medical director by phone.

The hospital maintained regular contact with the press and issued a press release.

As the power failure occurred on Easter Saturday, activity at the hospital was scaled down. The hospital did not undertake any internally targeted information efforts during the two public holidays following the incident.

Staff at the hospital thus did not receive any information from the information department concerning the power failure.

Authors' Comments

It is important that the staff receive information quickly when serious disruptions occur at the hospital. If the normal information channels are not working, there must be other routes by which to pass on information. Phones and mobile phones worked at the hospital, and it was thus possible to disseminate information in this way to the directors of departments and to the hospital management. The Information Department ought to have issued summary information during the first few days following the incident. Willingness to create new, or revise existing, safety routines is greatest when people have a serious incident fresh in the memory.

Building-related Systems

The on-duty service technician in the control centre immediately called in the service technician who was on standby. The service technician also called in other personnel he was able to reach so that they could help in searching for the cause of all the error alarms. Attempts were made to find the cause of the power failure by telephone, but this proved unsuccessful. A service engineer was on the scene within an hour and immediately carried out switching operations so that power returned to the parts of the hospital that were without electricity. This was done in consultation with Locum's electrical safety officer.

An immediate start was made on fault-tracing, and when it was found that there was a cable fault the company Mätbussen AB was contacted. They were on the scene at 16.50 the same day and established that there was an earth fault somewhere in one of the cables, but the precise location could not be indicated. A decision was therefore taken to call in another mobile measuring unit with better technical resources after the Easter holiday weekend. In the resumed investigation it was found that the fault was in a splice between the two cables that constituted one cable in the cable joint the substations. See Figure 2.

Locum decided immediately that the defective cable should be replaced throughout its length, 350 metres. This entailed a substantial amount of earthworks, including excavation. The new cable was tested and installed on 20 April, and entered service on Monday 23 April.

Once the voltage had been restored it was possible to acknowledge and rest most of the alarms registered in the control centre during the power failure.

One of the three air compresses was not affected by the power failure. However, it only worked for a short time as the pump that provided the compressor with coolant did not have a power supply. This was due to faulty design of the control system in the compressor installation. This state of affairs had previously been observed by Dalkia and described in an incident report in August 2006 which had been submitted to Locum.

Authors' Comments

If the staff in the control centre had had sufficient skills to carry out all urgent measures, the power failure would probably been brief. It is important that these skills are present at the control centre 24 hours a day, since this will otherwise only give a false sense of security.

At Karolinska Solna this expertise has been present in the control centre for a number of years.

It is notable that this control of the air compressor installation had not been dealt with.

Information and IT systems

When the power supply returned IT Forum's Unix group was able to re-start the Amtrix messaging system. All messages arriving at the server – referrals and referral results – were sent without disruption to their recipients.

IT Forum's affected departments gradually re-started other IT systems which had stopped when the servers went down, and all systems were back in operation by 7 pm the same evening.

Around 1.5 hours after power was restored, the patient record system TakeCare was back in operation. IT Forum's TakeCare Administration repaired the patient records that had been damaged when the servers stopped. Around 30 records were restored and could be used again on Tuesday 11 April. On Saturday 16 April – nine days after the power failure – all records were in working order again.

Medical Devices and Systems

A hard disk for the central unit in patient monitoring in ICU was replaced.

The Biomedical Engineering Department checked internal batteries in medical equipment and replaced the ones that no longer met the specifications for running time.

Authors' Comments

The cooperation between the IT Department and the Biomedical Engineering Department must be well developed as the activities overlap.

Clinical Departments

The Department of Emergency, Karolinska Solna

The disaster management group was activated early on. The director of department arrived at the hospital within 30 minutes and was then in regular contact with his counterpart at Huddinge Hospital during the time the power failure lasted.

The director of department continuously informed staff how the incident was developing, in part by writing up-to-date information on a whiteboard.

In the emergency room there was a backup copy of TakeCare. Using this it was possible, after a time, to print previously recorded data from the emergency register, but it was not possible to enter new data.

Staff could receive and send new laboratory samples for analysis, referrals and results had to be sent by fax.

Authors' Comments

It is important to continuously inform staff that there are secure information channels even when the computer systems are down.

The Department of Emergency, Karolinska Huddinge

The alert level staff status in the disaster plan was never announced at Karolinska Huddinge.

The director of department in the Emergency Department was contacted at 13.00 and arrived at the hospital around 30 minutes later. Two medical directors were contacted early on and quickly became active, as did the deputy emergency planning coordinator, who in turn received support from the emergency planning coordinator by phone. The latter was on holiday elsewhere.

The directors of department of the emergency departments at Solna and Huddinge decided in consultation to close ambulance admissions in Huddinge at 13.00. The director of the Emergency Department in Huddinge contacted the dispatch centre SOS-Alarm. SOS-Alarm ordered re-directing of ambulances in Stockholm so that none were sent to Huddinge.

Ambulance admissions could be opened again at 16.00 after it had been announced that the Department of Surgery had started working. At the same time staff gained access to the patient record system TakeCare, but they were unable to print labels. Not until 19.00 was this function resumed. At 17.10 Radiology announced that it had resumed activity.

Preparations were made to enable patients to be received from other departments at the hospital, as it was learnt that only Radiology and the Emergency Room had not been affected by the power failure. However, examinations in Radiology were not working.

It may be noted that the Emergency Room had a functioning CT scanner throughout and could have received a multitrauma.

There were old admission records on paper in the management of the acute patients, which meant that the absence of the patient record system TakeCare did not become a problem.

Authors' Comments

Staff status ought to be have triggered as soon as the extent of the incident became apparent. Disaster planning applies to just as great an extent to internal disruptions and should be used. It is also important to adopt staff status early.

Duty officers in Stockholm County Council are responsible for decisions to redirect ambulances. (Official on call – TiB – is the statutory equivalent to duty officer)

Departments of Anaesthesiology and Intensive Care, Karolinska Huddinge

The Intensive Care Unit

Resolute intervention and good preparedness for extreme situations as well as partially functioning battery backup made the situation manageable. Those responsible ordered staff from the morning shift to stay on.

Preparations were made so that transportation to other hospitals could be accomplished if the power failure continued for a prolonged period.

The intensive care ambulance was summoned and was on standby outside the hospital.

The central intensive care unit at Karolinska Solna was prepared to take two to three patients on ventilators if necessary.

Staff had to ventilate the six patients, who could not manage without ventilators, with mask and bag-valve. Those responsible called in extra staff to assist. Battery-driven transport ventilators were gradually connected. When the pressure in the outlets to the central system for respiratory air dropped, reserve gas cylinders were connected.

New infusion pumps were collected from the Anaesthesiology Department when the batteries in the infusion pumps which had automatically changed over to battery operations ran out.

The staff had to use the department's only battery-driven saturation meter. They took blood pressure manually and battery-driven monitoring equipment intended for transport was connected to the most unstable patients.

The staff introduced entered documentation into a temporary paper record when TakeCare and Clinisoft stopped working.

Authors' Comments

The power failure occurred at a time of change-over of staff and there was therefore a plentiful supply of staff. There is a good supply of duty lines, which guarantees high staffing levels.

Someone has to take functional responsibility and take an overall view which must include both the technical systems and direct patient care.

There must be routines – based on risk assessments – to maintain patient safety in different crisis situations.

The intensive care nurses coped with the situation tolerably well without TakeCare, but the incident nevertheless represented a significant risk. It is therefore important that there is some form of back-up system for the computerised system.

The fact that it went so well has had a self-confidence boosting effect among staff.

We need to remember, however, that the fortunate outcome of this incident was largely due to the favourable time when the power failure occurred. It was daytime, a weekend and no major operations had been performed on the two preceding days.

Department of Surgery

Operating Theatre 7 for emergency caesareans was given battery-driven monitoring equipment. The anaesthesiology nurses were transferred to the intensive care unit to assist with respiratory support etc.

Paediatric Department, Neonatology, Karolinska Huddinge

Staff had to manually ventilate the five patients who were being treated on ventilators or by positive pressure and oxygen by nasal CPAP during the power failure.

Department of Cardiology, Karolinska Huddinge

Staff in the Department of Cardiology intensive care unit (HIA) moved all the patients out to the patients' canteen and monitored them there.

The spare key to the medicine cabinet was locked in the cabinet. The staff therefore had to break a pane of glass to gain access to the medicines.

Department of Clinical Chemistry, Karolinska Huddinge

All ordering, quality assessment and communication of laboratory results had to be done verbally on the phone or through personal contacts. This signified a substantial loss of efficiency. The power failure led to working overtime in all the laboratories, but staff did not report any serious quality deficiencies due to the loss of power.

Department of Clinical Microbiology/Virology, Karolinska Huddinge

Staff had to reset the analyses when power had returned, which meant, for instance, that the maternity ward had to wait for more than three hours for test results. Around 100 blood culture bottles had to be checked once more in accordance with the applicable recommendations as the power failure had lasted more than one hour.

Obstetrics and Gynaecology, Karolinska Huddinge

During the power failure staff had to use wooden funnels and battery-operated foetal doppler monitors.

Patients in rooms without daylight were given torches and information about the power failure. Staff prepared transfers of patients so that those who might give birth in the next hour were placed in rooms with daylight.

Department of Respiratory Medicine and Allergy, Karolinska Huddinge

When the signalling system, which the patients use to call for assistance, did not work until the following day, this problem was solved for an isolated patient by being allowed to phone the department desk.

Department of Renal Medicine, Karolinska Huddinge

Two patients whose dialysis was interrupted by the power failure were forced to stay in the department as the lifts were not working.

Department of Radiology

The X-ray machines were run without connection to the PACS picture archive, the staff instead reviewed the pictures directly at the equipment.

When all the systems were running again, all the picture material that had been produced during the period of the power failure was archived and the patient information in the RIS (Radiology Information System) was updated.

Stockholm County Council Central Disaster Management

SOS-Alarm alerted the duty officer in Stockholm County Council (SLL) 52 minutes after the power failure had occurred. The information provided stated that a transformer at the hospital had gone on fire but that the fire had been put out. The emergency room could not take any patients and SOS-Alarm reported that they were directing the ambulances to Karolinska Solna and Söder Hospital.

One hour and 14 minutes after the power supply had been restored the duty officer received detailed and now correct information from SOS-Alarm about the power failure. It was clear from the report that no patients had been harmed and that there was no need to transfer patients to other hospitals. The Emergency Room was working again and ambulances could be sent back to Karolinska Huddinge.

The duty official informed the county council head of security and the county council director.

Authors' Comments

It is important when serious incidents occur in a hospital that those responsible inform the duty officer at the county council at any early stage, in case of the need to re-direct ambulances and so on.

The National Board of Health and Welfare Regulations and general guidelines on peacetime disaster medicine preparedness and planning for heightened preparedness (Socialstyrelsens föreskrifter och allmänna råd om fredstida katastrofmedicinsk beredskap och planläggning inför höjd beredskap) uses the term official on call (TiB) [1]. Stockholm County Council uses the term duty officer (jourhavande tjänsteman) for the same function.

Recovery and Development

Information Efforts

All the hospital's directors of department, including the medical director, were informed by Locum at a meeting held on Tuesday 10 April 2007.

Locum's Chief Executive Officer, together with the hospital's Executive Vice President, informed the county council management on Wednesday 11 April 2007.

The county executive board's production committee was informed about what had happened on Monday 16 April 2007.

Restoration of Building Systems and other Equipment

The power failure meant that many technical functions for the monitoring and control of the electrical installation were put out of action or disrupted. Several technicians restored, using hand terminals, the control programs in the electrical installation once the power supply was re-established. This work was completed on Thursday 12 April, i.e. five days after the power failure. It may be mentioned by way of example that the ventilation in Building F2 was not operational until Wednesday 11 April.

Built-in batteries in patient signalling system and assault alarm systems, which ran out during the power failure, were replaced.

Service technicians re-started the deionisation and reverse osmosis installations. In order to do this they needed to acknowledge and restore fault alarms on every installation.

Every clock in the central time system in the hospital was adjusted manually. This was carried out by several technicians.

Further Measures

The facilities manager, Locum, has clarified routines and instructions for the staff of the service contractors Dalkia in the control centre.

Since the power failure Dalkia has raised the skills levels of duty service personnel, so that they are competent to carry out any switching operations in an urgent situation. Instructions on how to proceed are also to be found in the control centre. Dalkia now trains its staff once a week in various stimulated situations with a power failure.

Assessment of the Electrical Installation

Representatives of Locum and Dalkia met on Tuesday 10 April. They discussed the status of the electrical installation at the meeting, and expressed the view that no changes needed to be made in relation to switching. Alternative supply routes existed if a further fault occurred.

On Thursday 12 April an investigation group was formed with the remit of investigating firstly the course of events more closely and secondly the actions of the service contractor on the basis of the applicable contract, and of drawing up an action plan with the aim of minimising the impact of similar incidents in the future.

Both the Dalkia service manager and Locum's electrical safety manager attended a meeting prompted by the incident which was held on Tuesday 17 April. The Swedish National Electrical Safety Board and the National Board of Health and Welfare's experts judged on a site visit that a report to the Swedish National Electrical Safety Board would not be necessary since there was no electrical safety fault in the installation. The agencies' representatives were in agreement regarding their assessment that it was not possible to predict or prevent the fault that had occurred. It was also judged that the service contractor's actions had been correct on the basis of regulations and guidelines. The Swedish National Electrical Safety Board chose to record the incident as a service note.

Authors' Comments

There is measuring equipment today that can detect partial discharges in cable joints that generally presage a power failure. Damaged parts of the insulation system can be detected by continuous monitoring of partial discharges before major damage, for example breakdowns, occur in a cable joint.

Ongoing and Planned Measures

Extensive risk and vulnerability assessment is in progress in Locum, and a first sub-report was submitted to the county council management in June 2007. This work covered strategic buildings.

The scenario underlying the analysis is how a prolonged power failure affects the technical supply of reserve power, telecoms, data, water and heating.

Locum has since long started an overhaul of the electric power system at Karolinska Huddinge with the aim of modernising the installation. Because of the changed operational requirements and needs an electrical engineering upgrade of the existing power and control system is required. The project as a whole is aimed at replacing older switchgear and improving the control and monitoring system.

The project budget is just over SEK 75 million, and the overall timetable indicates that the project is to be completed during the spring of 2009. The electrical installation will then fully comply with the 2008 edition of The Robust Hospital (Det robusta sjukhuset) [4].

Locum started on the project planning work in the autumn of 2007.

Locum has been inspecting the whole building stock for electrical audits, at intervals and in stages, in accordance with electrical legislation. The results of the electrical audits are collated in action lists. In those cases where action has been proposed it has also been implemented.

In addition, checks are regularly made on the electrical distribution system such as checks on the condition of switches and thermography, by which faults and overheating in switchgear and control centres are detected by thermal imagers.

A completely new pipe system for the distribution of oxygen was built in the autumn of 2007 as the old one was no longer functional and leak tight. When this has been completed, the distribution system will need the requirements laid down in HB 370 Safety Standard for Medical Gas Installations[10]. Locum is expected to take over responsibility for the medical gas installation at the hospital in 2009.

Landstingsfastigheter and Locum entered into a contract with a supplier of UPS equipment in the autumn of 2007. Under this contract all vital installations and equipment will be supplied with electric power from batteries in UPS units, which receive maintenance charge from the essential load network. The contract will also cover surgical and intensive care units, radiology and computer rooms. A total of 32 UPS units will be installed. All the units will provide a minimum battery time of 15 minutes, surgical lighting for 180 minutes, emergency lighting for 60 minutes and computer room operation for 40 minutes.

A full service contract has been signed with the supplier. Locum will take over responsibility for the UPS units when they have been installed and approved.

Production of Respiratory Air

The hospital's gas committee discussed the report on the pressure drop in the respiratory air system when the power failure occurred at its meeting held on 24 May 2007. The committee received information to the effect that Locum and Dalkia are working on the matter and that they intended to have changed the control of the air compressors and their peripheral equipment by the end of 2007.

New Procurement of Service Contract

Locum has made a new procurement of the service contract. Dalkia has received a renewed contract effective from 1 April 2008. According to the new service contract, the service centre has to be manned by two people 24 hours a day and there must be staff on site with the necessary knowledge to intervene in the electrical installation. In addition there must be staff on standby. The contract also lays down requirements for training in the management of situations in which mains power is lost.

Information and IT systems

Computer networks, server rooms and the distribution of systems within Karolinska have been examined and some action has been taken. The administration of the computer rooms is to be organised more clearly and the number of computer rooms is to be reduced. The Stockholm County Council computer network (SLL-net) was previously used as the only link between Karolinska Huddinge and Karolinska Solna. There are now two fibre pairs, geographically separated, as primary and secondary connections, and SLL-net represents the third connection path between the hospitals. There is new UPS equipment for the computer networks and for the computer rooms in i Karolinska Huddinge. Karolinska and SLL-net are joined by four redundant connections.

The TakeCare patient record system and other databases are located on servers in computer rooms in Huddinge and Solna. The systems can be made redundant thanks to the fixed fibre connections. In addition an improved monitoring system for computer networks and server environments has been introduced.

Work has been under way for some time to segment the computer network into several virtual computer networks. This means that, in addition to the open computer network, it will have a number of isolated computer networks for certain user groups or for certain types of equipment. This work is being done in cooperation with the Department of Biomedical Engineering.

Medical Devices and Systems

There are plans to purchase mobile UPS units for the Department of Anaesthesiology and Intensive Care for diathermy equipment, laparoscopy systems and possibly also for blood warmers.

The surgical aspirators of the Department of Surgery are modified so that some of them can be connected to the outlets for respiratory oxygen as a safety measure if the pressure in the respiratory air system disappears. In addition a number of electrically operated aspirators have been purchased.

The Disaster Plan

The disaster plan will be recast for Karolinska University Hospital. The plan is to contain routines for action to be taken in the event of internal serious disruption, such as interruptions to the electricity and water supply, breaks in connections with care-supporting IT systems and hospital fires. The local disaster groups will be supplemented by specialist know-how in these areas.

Exercises will be performed for disaster management and activities in various scenarios with simulated power failures of varying scope and in various parts of the organisation.

Discussion

The Time of the Power Failure

The power failure on 7 April 2007 at Karolinska University Hospital in Huddinge occurred on Easter Saturday, i.e. during a major public holiday. It was favourable from the point of view that it was the third day in a row of only emergency activity. The time in the middle of the day was also a positive factor in the course of events. When the power failure occurred, a change-over of staff was taking place, which meant that those responsible could order staff, whose shift had finished, to stay on and help with the situation at hand. In addition, all rooms with windows benefited from daylight. The good weather that prevailed in the area on the day was another circumstance that led to the emergency room not being burdened with road-traffic accident cases.

These highly favourable circumstances must be borne in mind when considering that no patient was harmed despite the power failure occurring in a large general hospital with emergency care facilities and lasting for almost 1.5 hours.

The timing was not, on the other hand, favourable with regard to quickly establishing the reason for all the fault alarms that were registered in the service centre during a short time. The manning was minimal and no service personnel with full electrical competence were on duty at the hospital. If the failure had occurred in daytime on a weekday action would have been taken much more quickly. It is likely that the electric power supply would then have been restored within 15–20 minutes.

Some parts of the organisation have pointed out that the self-confidence of staff has been boosted by the fact that they managed to cope with such a serious situation without any patient suffering harm. The favourable outcome should not, however, been taken to signify that emergency planning and organisation were so good that they do not need to be improved. On the contrary, it is important to use the experience from the incidence in the continued efforts to raise quality and safety. It is valuable if the experience is also available to others.

Management Issues

Management Involvement

Successful safety work is conditional on management being involved in the work to the extent necessary. The management has to establish clear limits of responsibility for the supply and information systems which the hospital uses and which are essential to the organisation.

This is expressed in the National Board of Health and Welfare Regulations and Guidelines on Management Systems for Quality and Patient Safety in Healthcare (Socialstyrelsens föreskrifter om allmänna råd om ledningssystem för kvalitet och patientsäkerhet i hälso- och sjukvården) [12] as follows: The care provider shall issue instructions for and ensure that the management system is appropriate with regard to organisation, routines etc. in order to ensure quality in operation. The management system shall contain routines for safe use and handling of products, supply systems and information systems.

The word “products” inludes not just medical devices but also other products that may be of significance to enable health and medical care to be undertaken in a safe and effective manner, for example alarm systems, central clocks and lock systems. There is a special regulation for medical devices that governs the responsibility of the care provider for routines to be created for safe use and handling.

“Supply systems” signifies the electrical installation including reserve power, UPS units and distribution networks for heating, water, wastewater, ventilation and lifts, communication systems, installations for medical gases etc.

“Information systems” includes all IT and communication systems that can affect the care and treatment of the patients in any way, for example patient record systems, picture archives, messaging systems and all IT systems that are connected to medical devices. These also include telephone systems, internal computer networks, pagers and other communication systems.

It is particularly important to identify all conceivable risks when many different parties have to work together to trace faults and remediate problems that have arisen. If contractors are to take action, it is crucial to safety that the contracts are clear and comprehensive, and that there are clear routines for collaboration across organisational boundaries.

When the power failure occurred it was not stated in Dalkia’s instructions that they were to inform IT Forum's First-line On-call Unit, which IT Forum has highlighted as a deficiency. It is probably correct that a service contractor should not be responsible for informing the hospital's various internal organisations, as this may create uncertainty over roles of responsibility and the giving of orders. On the other hand, there must be internal routines at the hospital that guarantee that everyone concerned receives information as quickly as is required by the problem that has arisen.

IT Forum could have clarified the reason for all the fault reports in the IT systems earlier if had immediately been told that a large power failure had occurred at Karolinska Huddinge. It is also likely that the action taken could be made more effective if the IT Forum technicians had known of the cause and extent of the disruption early on.

The form of collaboration between IT departments, or the equivalent, and departments of biomedical engineering, or the equivalent, must be clear and organised since these units often have overlapping activities.

In a crisis situation, in which resources of various kinds are in limited supply, there must be guidelines for setting priorities. If access to electric power is limited, for example if not all the generator sets can produce power, there must be a classification of buildings or activities. Service managers must from this classification be able to establish which objects are to primarily receive the electric power that is available. The managers responsible cannot leave decisions on establishing such priorities to a service contractor. Responsibility for this classification can only rest at the top level of management, that is to say with the care provider.

The same conditions and requirements apply to administrative information systems and to care information systems. Managers responsible for IT operations cannot themselves take decisions on what information systems (computer programs/databases) they can close down first and which ones have to be kept in operation for as long as possible. There must thus be an up-to-date prioritisation list of the information systems installed on common servers. If the operations managers in IT activity do not have such a list there is a risk of IT systems being closed down without full knowledge of the effects for patient safety.

Risk assessments are the basis for creating safe and effective routines for action in disruptions of various kinds. This is particularly important when both internal and external parties have to work together. Staff must regularly practise these routines under conditions that are as realistic as possible, since there is otherwise a risk of the planned measures not being implemented in the intended way. The publication Incident analysis and risk analysis – Handbook for patient safety work (Händelseanalys och riskanalys – Handbok för patientsäkerhetsarbete) [13] is to be recommended in the investigation of adverse events that have occurred and conduct risk analyses in new or changed activities.

The Disaster Plan

The 2007 disaster plan for Karolinska University Hospital, see Annex 4, describes three levels of alert beyond normal status: staff status, reinforcement status and disaster status. Normal status is the level that always exists in Stockholm County Council. The SOS-Alarm emergency line alerts the duty officer in the county council in the event of accidents where the number of people involved is, or can be estimated to be, more than ten.

Those responsible have to order staff status in the event of an alarm concerning an incident or threat the extent of which is unknown and where these available capacity is expected to be insufficient. In staff status increased alert for urgent action is reached within the framework of available resources.

It is also stated in the disaster plan that in the event of an alarm regarding a serious incident within the hospital that may require major medical input coming in to the emergency room, the emergency room must alert SOS-Alarm.

A power failure on the scale considered here should have been regarded as a serious incident within the hospital. Staff status ought therefore to have been triggered as soon as the extent of the power failure became apparent. This is important as someone with an overall view must take functional responsibility, including both the technical systems and direct patient care. It is possible that in spite of everything this overview was gained by the deputy hospital director monitoring the situation while two medical directors and the head of the emergency room were making their way to the hospital to judge the situation on the spot.

In serious incidents in a hospital it is important that those responsible inform the official on call (TiB) at the county council at an early stage. A decision to redirect ambulances would therefore have been taken by the duty officer (equivalent to official on call) in Stockholm County Council.

Experience in recent years provides reason for revising the activity plans to respond to serious internal incidents and disruptions. Power failures have occurred at several hospitals around the country, resulting in evident risks to patients. These power failures have in some cases knocked out computer networks and important information systems. In other cases reserve power has not started as intended. Such situations entail risks of hospitals not being able to carry out planned care and treatment. The situation also puts staff under great strain if they do not have any action plans to follow. The power failure in the case discussed here revealed some factors which should be included in a disaster plan. The focus in disaster plans to date has been on dealing effectively with many injured or infected people and patients following external or internal serious incidents and disasters. On the other hand, the managements have not observed measures in response to serious disruptions to the hospital's internal functions to the same extent, to which more space should be given in disaster plans.

The remit in the disaster plan that IT Forum should guide the medical director organisation and the disasters committee when major IT incidents occur is ineffective unless IT Forum has received information on the underlying causes of the disruption to IT. It is stated in the disaster plan that the IT Forum emergency planning line should be contacted in all forms of raising of the hospital’s state of alert in order to find out about the situation and abut emergency planning in IT operations.

Operating Issues

Construction of the Electrical Installation

The 2008 edition of The Robust Hospital (Det robusta sjukhuset) [4], published by the Swedish Emergency Management Agency, passes on knowledge, experience and information on the functional and operational reliability of installations and systems in health and medical care. It primarily deals with building-related issues, including safety across traditional discipline boundaries with a link to both medical care and the organisational culture. If the results are to be good and cost-effective, reliability and issues related to robustness must be considered in the early planning of new or changed activities, functions and technical systems.

Security of supply for electric power makes up a substantial portion of the book. There are proposals here on how an electrical installation needs to be designed and executed to attain the best possible reliability and cost-effectiveness.

The National Board of Health and Welfare published the first edition of The Robust Hospital (Det robusta sjukhuset) [3] in 2002. This book has since been recommended as part of the material on which the planning of new construction or reconstruction of electrical installations in Swedish health and medical care is to be based.

Reserve Power

The current view is that a reserve power installation needs to be designed so that it can meet the entire power needs of a hospital at peak load. This is due in part to the fact that hospital production is largely based on equipment that requires a power supply. A situation in which there are separate outlets for reserve power and normal power may lead to important equipment being connected to outlets for normal power, despite the outlets being marked. This creates uncertainty and unnecessary stress for healthcare professionals who are already under great strain.

The common moving of departments and units, with different requirements for electric power supply, in hospitals also indicates a need to expand reserve power. With full-cover reserve power there is no need for important activities to be without reserve power or for them to change location. The recommendation for new installations in the 2008 edition of The Robust Hospital (Det robusta sjukhuset) [4] is that outgoing groups from the low-voltage side of switchgear to objects that can be considered to be less important are provided with remote-controlled circuit breakers which can be activated in a crisis situation. This makes it unnecessary to draw duplicate electric power lines to the same place.

The reserve power at Karolinska Huddinge did not start up on 7 April 2007, when the earth fault suddenly occurred in the internal wiring system. This was entirely in accordance with the programming in the control system for reserve power. The control system sensed that there was still voltage in the external network in the substation which at the time was providing the hospital with electric power. Nor did the power failure affect main building C. When faults occur in the internal network there is a great risk of the situation becoming even worse if the generator sets start up and supply electric power before the faulty part of the installation has been identified and disconnected.

Before an alternative supply route is connected past a faulty part of the installation, specialist staff must check this on site. There is otherwise a risk of other damage or problems occurring.

Uninterruptible Power Supply – UPS

Activities in most rooms in the departments of surgery and intensive care, laboratories and some radiology departments require a continuous supply of power. They cannot tolerate interruptions to the power supply lasting longer than 0.5 seconds. Some computerised equipment requires electric power with no interruptions at all. This is stated in standard SS 437 10 02, which can be read in Handbook 450, edition 1 Electrical Installations in Medical Locations (Handbok 450, utgåva 1 Elinstallationer i medicinska utrymmen) [6]. A reserve power installation can take effect within 15 seconds, and it is barely possible to achieve a shorter time.

UPS had not been installed in the intensive care unit at Karolinska Huddinge. An intensive care unit today is dependent on a large number of pieces of medical equipment that require a continuous supply of electricity. It is not sufficient to rely on reserve power. It is necessary to use uninterruptible power supply, UPS to meet these requirements.

The battery capacity in the UPS's in computer room K3 at Karolinska Huddinge did not have the expected capacity, largely because they were overloaded. More and more servers had been installed in the computer rooms for additional systems, without older systems having been taken out of operation. The electric power supply was not adequate for more or larger UPS units. The available electric power in the computer room was not designed for such a large load. In addition the phases were unevenly loaded.

If IT systems, such as the patient record system TakeCare, the monitoring system Clinisoft and the messaging systems, are to work in the event of a power failure the computer networks must work. These contain data switches and other equipment that require electrical power supply. All units in the computer networks must have the same operating reliability as the servers.

If responsibility for a UPS unit is transferred to someone other than the person who is responsible for the equipment connected to the UPS, there must be a clear contract that defines the responsibilities and obligations of the parties. When power consumption increases due to more connected items of equipment, the person responsible for the UPS must receive information to this effect in order to be able to notify a new running time or adjust the capacity of the UPS.

Marking of Electrical Outlets

It is important to mark electrical outlets in a clear and uniform manner. The colours and symbols to be used are indicated in standard SS 437 10 02/T1 [2]. In hospitals with reserve power capacity to supply the whole hospital the distribution networks for non-essential load and essential load may be linked together in switchgear. It must, however, be possible in an emergency to separate the networks, and therefore non-essential load and essential load must be clearly marked.

In new electrical installations with full reserve capacity it is possible to, from the outset, construct the distribution network so that certain outgoing groups from the switchgear are allowed to supply installations or permanently connected equipment which is considered less important for patient safety. The other groups supply all other electrical outlets. This means that these electrical outlets have to have signs for essential load.

The best technical solution is for all electrical outlets to be provided with a device that continuously shows whether the outlet is non-live.

Medical Devices

The care provider is responsible for there being routines in the care provider's management system for the use and handling of medical devices. The care provider can ask directors of departments to draw up these routines. If they do not do so there may be confusion as to who is responsible for example for installation, use, training, prescribing, checking and maintenance of the medical equipment. The tasks which the care provider has allocated to a director of department must be documented. This is stipulated in the National Board of Health and Welfare Regulations on the Use of Medical Devices in Health and Medical Care [8]. When the pressure in the respiratory air system disappeared it was found that there was not satisfactory knowledge of how to connect reserve gas cylinders in all the departments.

Information Systems – IT Systems

The legislation on IT in health and social care has deficiencies, but is due to be revised in accordance with the National IT strategy for health and social care (Nationell IT-strategi för vård och omsorg) [14], in which Action Area 1 relates to harmonising laws and regulations due to the increased use of IT. A priority issue in this context is to clarify supervisory responsibility for the transfer of information between medical devices and healthcare IT systems.

The information systems within health care contain many technical systems. Computer networks for both medical and administrative systems, electrical installations and medical equipment are examples of areas that are often maintained by various internal parties or external contractors. There must therefore be clear overall management so that the players work together in such a way that patient safety is given top priority.

If serious disruptions occur, for example power failures, there must be routines for quickly informing IT managers so that they can take measures to secure IT function. The IT department or equivalent must have a smooth-running duty system so that staff with the right skills can quickly take the necessary action.

The management of IT activity at Karolinska University Hospital Solna and Huddinge at the time of the power failure in question consisted of a virtual organisation called the IT Forum. There was no clear head or director of the organisation. The four departments of which it was made up each had their own heads who worked together in the framework of IT Forum. With this form of organisation there is a risk of the hospital management not having a collective picture of IT activity and its needs and requirements. The sections of IT Forum have discussed the requirement of prioritisation between the various IT systems. If a shortage of resources arises with regard to the electrical power supply, this may mean that certain IT systems have to be shut down. They have not received any clear messages about prioritisation of the systems from the care provider, which may be due to the unclear form of organisation.

Other Installations

Combination locks and code readers

Combination locks, sometimes combined with card readers, are increasingly used in locks for rooms that are not accessible for the public. The benefits of such lock systems must be weighed up against the risks. Future problems can be avoided or reduced by consistently making use of risk assessments in introducing new methods and techniques. If combination locks are installed for medicine cabinets or other sensitive areas there must be alternative methods for entering the premises even if the power supply is lost. This means firstly that it must be possible to use technology independent of electricity, normally keys, and secondly that staff are well acquainted with the technology. The safety system may otherwise entail risks to patients who need medicine or whom staff have to move.

The hospital's electric clocks

The hygiene requirements in the health service mean that staff is not allowed to wear wristwatches. They have to rely on the electric clocks positioned throughout the hospital. When these clocks stop it is easy to lose sense of time. These clocks therefore need to be provided with batteries so that they keep going. But if there is no routine at the same time for regularly checking and if necessary replacing the batteries a false sense of security can easily be created.

Responsibility for developing maintenance routines of this kind primarily rests with the care provider, according to the National Board of Health and Welfare Regulations and Guidelines on Management Systems for Quality and Patient Safety in Healthcare (Socialstyrelsens föreskrifter om allmänna råd om ledningssystem för kvalitet och patientsäkerhet i hälso- och sjukvården) [12].

Lifts

There are a large number of lifts at Karolinska Huddinge which are intended for the transportation of patients and staff. In addition, there are lifts for emergency transportation of patients and for other purposes. When the power failure occurred on 7 April 2007 only the lifts in Buildings C1 and C2 worked. For departments and units that normally do not use these lifts it would have been an advantage if those responsible had sent out information concerning lifts that were working in the hospital. The intranet was not working, and some other channel would have been needed to reach out with this information.

Equipment with built-in batteries

Batteries built into equipment must be regularly checked and maintained. If this is not done, these battery systems create a false sense of security. The batteries are usually charged when the equipment is connected to the mains. The manufacturer has to state the running time with fully charged batteries in the technical specifications for the equipment. The charging status of the batteries needs to be checked regularly, and maintenance work means, as a minimum, replacing the batteries after the running time stated by the manufacturer.

Chapter 1 Section 2 of the National Board of Health and Welfare's Regulations on the Use of Medical Devices in Health and Medical Care [8] states that the scope also extends to the maintenance of medical devices. There is a need to bring in medical device expertise in order to assess the need for maintenance. The manufacturer's instructions must be followed in checking a medical device before putting it to use.

Medical gas installations

The centrally produced respiratory air is of the greatest significance to patient safety. Staff use it, as well as respiratory air for ventilator patients, as a propellant in ejector aspirators in surgical and secretion aspirator. If these do not work in an operation great difficulties are faced in keeping surgical wounds free of blood and other fluids. Secretion aspirators are used to keep the respiratory tract of patients clear, and they can be found in medical wards throughout the hospital.

The medical gas installation contains pressure switches or pressure monitors positioned at strategic points around the hospital. When the pressure in the various gas lines passes certain pre-set values an alarm is triggered. Reserve gas which is contained in gas cylinders can then be connected locally in the departments. Knowledge and practice are needed in order to do this. There must be clear routines, and staff must practise handling the reserve gas cylinders. Responsibility for this rests with the director of department concerned. In addition it must be possible to order more reserve gas cylinders when the existing ones have been emptied. Staff must be able to do this every day, at any time of the day or night. It may be noted here that knowledge of how reserve gas cylinders are connected and changed varied among staff in the departments at Karolinska Huddinge.

When the control of the compressors for the production of respiratory air was designed, the intention was to make it extra safe by using duplicate power supplies. However, a mistake was made in the design, which the operating contractor's staff noted and described in a non-conformance report. The mistake meant that none of the compressors worked despite there being a supply of electricity to one of them. The cooling system for this compressor was, however, supplied with electricity from a mains station that was affected by the power failure. Such design flaws can be avoided if a risk assessment is carried out on the complete installation before it enters service. It was also proposed in the non-conformance report drawn up in 2006 that a risk assessment ought to be made.

The operating contractor handed over the non-conformance report mentioned above to the facilities manager together with a number of other reports. However, the installation belonged to the tenant, and nothing was done until after the power failure. The Gas Committee took up the matter in May 2007 and measures were then taken to make the control safer.

This incident highlights again the problems that can arise when many different parties are involved. If responsibility is not clear to all parties concerned or when routines for working together do not work, there is always a risk of matters not being dealt with.

The medical gas installation has been supplemented by new components over the years, and some reconstruction has taken place. This means that staff have different pressure monitoring systems to learn, which does not result in optimum safety.

A new pipe system for the distribution of oxygen throughout the hospital is now being completed.

Operations Centre – Skills

The Operations Centre was manned by staff from Dalkia in accordance with the contract drawn up with Locum. The requirement was one person on duty at the operations centre at weekends and no explicit requirement for skills was written into the contract. Skilled staff were to start action to remediate serious faults or disruption within 30 minutes during weekends. The duty service technician contacted the supervisor and other staff within a few minutes after the first alarm for help. Attempts were made to establish the cause of the power failure by telephone, without success.

If the right expertise had been in place in the operations centre when the power failure occurred the fault would probably have been identified and the electrical power supply would have been restored more quickly. It is difficult to say how quickly this could have been done. Even if the duty technician had from the position in the control centre been able to see what the fault was, it would nevertheless have been impossible to remediate it unless more people had been immediately available. In the situation that arose the person responsible was unable to leave the control centre unmanned for the length of time required to investigate the cause of the common alarm from switchgear located far away from the control centre. The service technician who was on standby had to come to the hospital first. At best, the length of the power failure could have been limited to around 15–20 minutes.

It is possible that the power supply could have been restored more quickly with a more modern control and alarm centre. The cause of the power failure could be been established in more detail from the alarm and control panel in the control centre. On the other hand, switching operations in the electrical installation should not be done without first making sure that there are no other obstacles in the installation.

To cope with situations in which there are serious disruptions to the supply of electricity, ventilation etc., the hospital must man the control centre with at least two people. The requirement will then be for at least one of these to have sufficient knowledge to perform switching operations, shutting-down operations or to take action to restore important supply functions. It is also important to carry out regular exercises with the staff in the control centre. These requirements have long been met by Karolinska Solna and must also be met by all hospitals.

Expert action must also be taken within the agreed time for other types of serious disruptions to the supply and building systems, not just in the event of power failures.

Medical Care Activity-related Issues

Medical care activity was only disrupted to a limited extent since the power failure occurred at the weekend, when only a few planned operations were scheduled and no emergency surgery was in progress. The patients who were due to undergo surgical procedures had to return to the medical wards and could be operated on later. In addition, no major operations had been performed in the last few days preceding the long weekend. No critically ill patients who were in need of advanced ventilatory support were being cared for in the intensive care unit. If complicated operations had been under way and very seriously ill patients had been cared for in the intensive care unit the consequences of the power failure might have been very serious.

The power failure occurred at a time when there were many staff who could manually ventilate the patients who were on ventilators. Staff had to discontinue dialysis that was in progress and in the cardiac intensive care unit all the patients who were in need of monitoring were moved to the unit's canteen. In addition, there was a relatively good supply of duty lines, which guaranteed high staff density, making it possible early on to designate staff who could take more overall responsibility for the situation. The fact that it went so well has had a self-confidence boosting effect among staff. The intensive care nurses coped passably with the situation this time without access to the information on medication in the patient record system, but this was a factor of uncertainty. Once again this must not be taken to mean that the organisation cannot and should not be improved, during this incident many fortunate factors worked together to contribute to nothing more serious occurring.

It is important that there is some form of reserve system for the computerised record system. In the intensive care unit there was a routine of always having the most critical information available on paper directly alongside the patient as backup if the computerised record did not work. Only one department at Karolinska Huddinge has reported having a special computer with a backup copy of the previous day's notes in the patient record system TakeCare. It has not become apparent from the details supplied by the clinics whether they have had functioning routines in place for taking backup copies of the patient record every day. On the other hand, the patient record system TakeCare was out of service for so long that the batteries in these computers would not have had capacity to run the computers until the system was back in operation.

Information Issues

Staff must quickly receive information when serious disruptions that affect normal work occur. This is a responsibility that rests at all levels of management. When extensive and general disruption occurs, the Information Department must reach out with information concerning what has happened and what is being done to remedy the situation that has arisen. If there is information about when the situation may return to normal, this must be passed on quickly. If such information exists, decisions can be taken locally in departments on what measures will be necessary, for example whether a major operation must be interrupted or whether a chemical analysis must be re-done because the power failure is expected to last for a prolonged period. It has been emphasised in the reports from the clinics after the power failure and in later interviews that the lack of information created great uncertainty over how to act. If adequate information concerning the expected development of the incident is not available, this may result in unsuitable or incorrect decisions being taken on care and treatment. It has also been pointed out that it would have been good if the departments had been informed that the lifts in Building C were working.

The Information Department naturally has a key role to play in this context. Its task to provide information internally in various crisis situations cannot be emphasised enough. The routines for dissemination of information must be clear, and there must be alternative information channels even if there is a total power failure or if the local intranet crashes.

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Annexes

1. Karolinska University Hospital Huddinge, Building – departments
2. Description of the 22 kV electrical installation at the time of the power failure, Block Diagram 22 kV and Station Location, Overview
3. The patient record system TakeCare, Overview
4. Extract from the Disaster Plan 2007, Karolinska University Hospital *(not included in the English translation)*
5. The National Board of Health and Welfare's decision in the Lex Maria case concerning the power failure at Karolinska University Hospital Huddinge on 7 April 2007
   (not included in the English translation)

Karolinska University Hospital, Huddinge

Building	Departments (starting from the lowest floor)	Power failure
B2–B4	Intensive care unit ICU, surgery, paediatric medicine, ophthalmology, ear, nose and throat, oral surgery, transplantation department, geriatrics, gastroenterology clinic, social workers, research, sterile centre, changing	Yes
F2	Laboratory medicine, pathology, virology, EG dept, microbiology, immunology, dept of biomedical engineering, changing, supplies	Yes
G1–G2	Car park	Yes
I1–I6	Infectious Diseases Clinic, changing	Yes
K2–K4	Anaesthesiology, intensive care unit ICU, surgery, post-op, delivery, admissions/emergency room, obstetrics and gynaecology, urology, renal medicine, transplant surgery, orthopaedics, gastroenterology, IBD unit, respiratory medicine, endocrinology, training unit, changing, stockroom	Yes
K32	ICU administration	Yes
M2–M4	Psychiatry, cardiology, intensive care units, research, haematology, endocrinology, thoracic surgery, respiratory allergy, dialysis unit, administration, changing, supplies, stockroom, standby hospital	Yes
R2	Physiotherapy, oncology, neurology, rheumatology, rehabilitation, medicine, geriatrics, changing, shelter	Yes
S1–S4	Kitchen, heating, supply functions	Yes
C1–C2	Outpatient clinics, radiology, neurophysiology, clinical chemistry, pharmacology, hospital physics, hospital main entrance with service functions, café, orthopaedic workshop, department of biomedical engineering, administration, hospital management, disaster centre, changing, supplies	No
RPA	Forensic psychiatry	No

Annex 2

The electrical installation at Karolinska Huddinge at the time of the power failure, April 2007

This annex contains:

- Description of the installation's 22 kV network
- Block diagram of 22 kV network
- Station location, Overview

Description of the installation

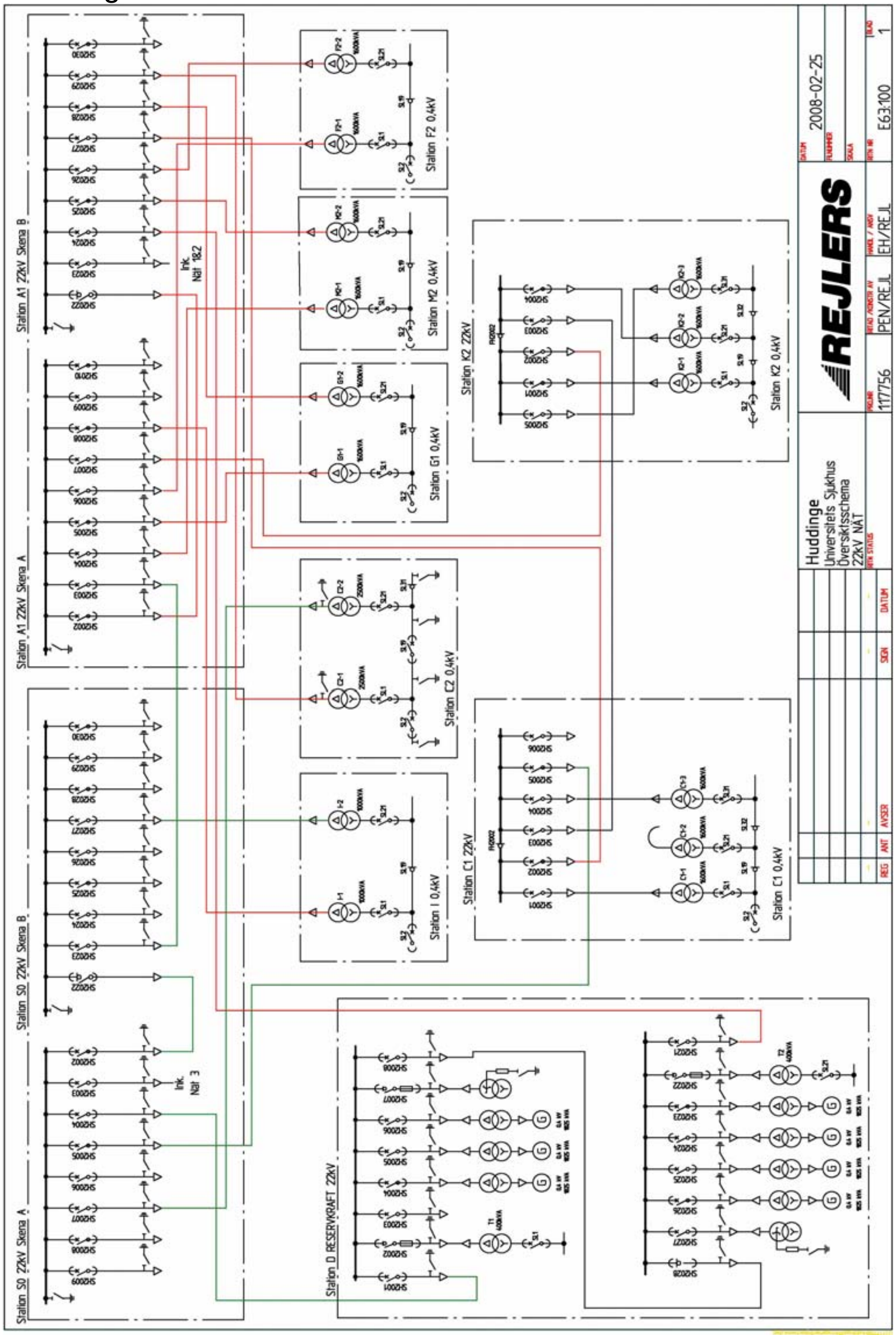
The substations SO and A1 are fed with 22 kV from the public mains supply from the Flemingsberg station. The cable links are directed along different routes to the hospital's substations. One incoming network to substation S0 is connected to busbar A (compartment SH 2003) and the other incoming network to station A1 is connected to busbar B (SH 2023). The substations are also connected to the reserve power installation by cable links. From each substation 22 kV is fed out to the different transformer stations by cable link with radial feed. The substations are joined together by a cable link.

Substation SO is located in a separate building adjoining the hospital. Substation A1 is located in one of the hospital's supply buildings.

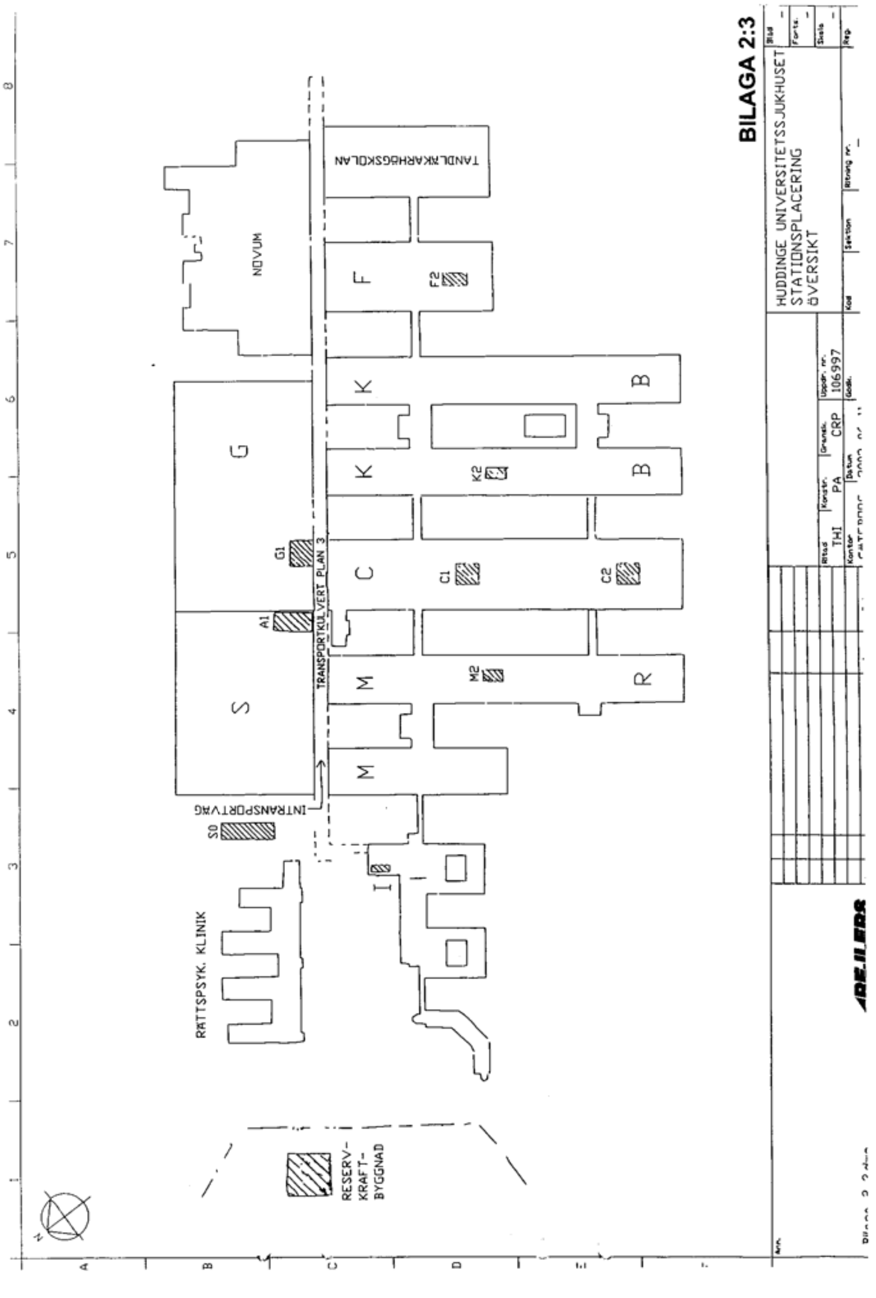
All the switches in the switchgear are miniature circuit breakers and are located on trucks, which means that switches can be pulled out and replaced without the switchgear needing to be made non-live. The switchgear units have built-in fixed earth couplers. The substations are equipped with arc monitors that initiate the tripping of all switches in both the A and B busbars.

In Buildings C1, C2, F, G, I, K and M there are substations in which the voltage 22 kV is transformed down to 400 V and 230 V for further distribution to the various parts of the hospital. The transformer stations in Buildings C1 and C2 are fed with 22 kV from both the substations SO (busbar A) and A1 (busbar B). The transformer station in Building K2 is fed by substation A1 (busbar A) and SO (busbar A) via the switchgear in transformer station C1. Transformer station I is fed by SO (busbar B) and A1 (busbar A). The other transformer stations are only fed from substation A1.

Block diagram of 22 kV network.



Station location, Overview.



Annex 3

The patient record system TakeCare, Overview