Our ref: MH16-4898

Government of South Australia

The Hon. Jack Snelling M.P.

15 November, 2016

Mr G. Burns
Independent Review into
Extreme Weather Event

c/- Ms R. Ambler
Executive Director, Cabinet Office
Department of the Premier and Cabinet
G.P.O. Box 2343
ADELAIDE S.A. 5000

Dear Mr Burns

I write to as part of the independent review you are leading into the extreme weather event experienced by South Australia from 28 September to 5 October, 2016.

As you may be aware, on 28 September, 2016, the Flinders Medical Centre (F.M.C.) lost normal power supply and operated on its standby power systems for over three hours. After one hour and 45 minutes, there was a failure of one of the five generators for the site, causing loss of emergency power to a number of areas for one and a half hours, until the main power was restored to the site. I was advised this resulted in activation of F.M.C.'s business continuity plan to ensure continuity of care for patients.

Following this incident, SA Health commissioned Aurecon, a Professional Service Contractor (Engineering), to undertake a comprehensive and independent post-incident review of the performance of the F.M.C. emergency stand-by power system.

I received the report today, and am now referring to you to consider as part of the broader independent review you are undertaking.

I have made an undertaking that the report will be made public. I therefore request that you release the report at the same time as you release the recommendations of your broader review.

Please contact Ms Cat Blaikie, Senior Ministerial Adviser in my office at catherine.blaikie@sa.gov.au or by telephone on 8463 6285, if you would like further information.

Yours sincerely

Jack Snelling

Jack Snelling M.P.
Minister for Health

encl. Flinders Medical Centre Standby Power Electrical Systems Post-incident Review - SA Health

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SOUTH AUSTRALIA

aurecon

Flinders Medical Centre

Standby Power Electrical Systems Post-incident Review

SA Health

1 November 2016

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Bringing ideas to life

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1 Executive summary

Aurecon has been commissioned by SA Health to carry out an independent post-incident review of the performance of Flinders Medical Centre (FMC) emergency standby power systems following the state-wide electrical outages experienced on Wednesday 28 September 2016.

During this outage, FMC lost normal supply and operated on its standby power systems for over three hours. However, after one hour 45 minutes, there was a failure of one of the five generators for the site, causing loss of emergency power to a number of areas for one and a half hours, until the main power was restored to the site.

The direct cause of this loss of standby power was related to the failure of the diesel fuel system of one generator, most likely caused by human error in wrongly leaving a control switch off, but with contributing cause related to the lack of alarms to notify maintenance staff of an impending shutdown due to a low fuel situation. To restart the generator, fuel needed to be added to the day tank, but once the generator shut down, power was not available to operate the fuel pumps. Although maintenance staff attempted to improvise solutions during the event, this was hampered by overall conditions and lack of equipment for such a situation.

Recommendations to upgrade technical and administrative systems to mitigate the risk of this reoccurring have been made in the body of the report and summarized in the conclusion, and we have seen that some are already in progress.

Measures have been identified that will improve the ability of maintenance staff to respond to future emergency power loss events.

As part of this review, the overall main power system's reliability, in design, condition, maintenance and operation has also been assessed.

In Aurecon's opinion, the FMC main emergency standby power system's design meets the requirements of the relevant standards detailed in this report, and is comparable to equivalent hospitals of a similar age in Australia.

It is noted that over the last 10 years, several major projects renewed and improved the power supply infrastructure at FMC. As has been occurring over the life of the FMC, including the current Transforming Health programme, any new developments or refurbishment of elements of the infrastructure or areas of the hospital should consider opportunities to further increase system redundancy and reliability.

The emergency standby power system's network is largely in good condition, operational and reliable. Those parts of the system that have not been upgraded in the last 10 years will need to be reviewed and plans put in place to renew.

The review has identified some other improvements that, although not related to the events of 28 September 2016, would further mitigate the risk of power failures.

During the review, we also formed a view on the general performance and capability of the FMC maintenance staff. The key staff have many years of experience on the site and strong knowledge and commitment to the hospital's operations, and are capable of reliably providing power supply to the facility.

It should be emphasised that the highlighting in this review of possible risks has been in the spirit of learning from failures to improve capability and future performance, and that overall FMC has a robust contemporary emergency electrical system.

2 Purpose and scope of review

2.1 Project brief

The following brief was provided by SA Health to Aurecon for this review:

Project overview

A comprehensive and independent post-incident review of the performance of Flinders Medical Centre (FMC) emergency standby power systems, processes and controls (both planned and actual), following the state-wide electrical outages experienced on Wednesday 28 September 2016.

Project purpose

To ensure we understand the causes of any emergency standby power electrical system failures at FMC in order to identify any improvements that can be made, and to reassure clinicians and the community that FMC has a robust contemporary emergency electrical system.

'Learn from failures to improve capability and future performance'

Project background

The recent total state-wide loss of power incident had a significant impact on SA Health service sites and presented associated extreme risks.

The post-incident review is structured around the SA Government Common Incident Management Framework, which identifies 10 agreed functions and responsibilities of incident management, including:

- **Command and control** – Control of the response to the emergency including incident command centre and incident management teams
- **Safety** – Ensure a safe working environment and safe systems of work
- **Communication** – Ensure effective liaison, communication and cooperation with all involved
- **Intelligence** – Continually assess the situation, identify risks and share information with all involved
- **Planning** – Develop and share plans and strategies that meet the requirements of all persons and agencies responding to the emergency (Incident Action Plan)
- **Operations** – Implement and monitor an Incident Action Plan
- **Logistics** – Ensure the effective allocation and use of available resources
- **Public information** – Ensure the public is adequately informed and warned so as to enhance community resilience
- **Investigation** – Facilitate the investigation of the emergency and review of response activities
- **Recovery** – Ensure transition from response to recovery, including the coordinated handover to the state recovery arrangements

Project objectives

A robust Root Cause Analysis investigation and report of the emergency power system failures at Flinders Medical Centre that identifies:

- What actually happened
- What issues were identified
- What will we do to make it better

Project scope

This review will include consideration of:

- The appropriateness of the architecture of the existing standby power system network relative to contemporary health industry best practice
- Standby power system network components condition, plant reliability and performance assessment
- Identification and description of any failure incidents identified, including photographic depiction
- The site's response to the failure incident
- Root cause analysis of any failure incident
- Identification of contributing factors to the failure incident
  - Physical
    - System and plant design including (BMS and controls)
    - Failure of plant and equipment, including ancillary systems to generator manufacturer's requirements
      - Airside including system pressure drop
      - Generator exhaust
      - Bulk fuel system including fuel quality, polishing (if provided)
    - Main emergency power distribution systems up to local distribution boards
  - Organisational
    - Availability of accurate and as installed/as built records
    - Operating systems and testing processes
    - Maintenance activities including frequency and constraints
    - Training
  - Individual factors
- Identify key single points of failure and determine mitigating/remediation strategies related to the identified causes of the failure incident
- Report any other significant risks related to standby power that may be identified by stakeholders during the investigation
- A review of the testing regime for generators
- Recommendations and, where appropriate, estimated cost of implementation for future action

Personnel involved

- SA Health Infrastructure

- SA Local Hospital Network (SALHN) Strategic Asset Manager
- SALHN Risk Manager
- Facilities Management (FM) Contractor (Spotless)
- DPTI - Subject Matter Expert

Project timeframe

Priority deliverable (3 weeks)

2.2 Scope of investigations carried out

The investigations carried out in preparation of this report included:

- Review of documentation describing the FMC emergency power systems (documents provided by SA Health by means of portable hard disk download from the hospitals documentation system – 5 GB of data, 5000 files), and including system single line diagrams, switchboard shop drawings, generator, Automatic Transfer System (ATS) and other ancillary equipment operating and maintenance manuals, fuel system documentation, BMS, alarm and associated communications systems documentation.
- Review of maintenance records, covering the last annual service and recent monthly services, including generator, fuel systems, electrical main switchboards and ATS, and general electrical maintenance – all documents provided by SA Health.
- Interviews with SA Health staff and contractors, including Strategic Asset Manager, FM Contractor (review of report provided from earlier meeting), FMC COO.
- Site investigation of key items of plant, and areas identified from the documentation and interviews that may represent causes for the incidents, or risks to future operations. This included three separate site visits and involved physical inspection of all generators and all essential power main switchboards. Given the time available, we were not able to comprehensively audit the site to confirm accuracy of all documentation provided, or confirm all information provided from interviews. However, enough information was collected to confidently present the contents of this report. Where there may be risk or doubt, we have recommended further investigations. Site investigations were limited to visual, non-invasive inspections, without specific testing or commissioning activities.
- The investigation focused on the specific incidents identified from the 28 September events, to identify causes and strategies for mitigation and remediation. Where other risks to security of overall power supply to the FMC were identified incidental to our investigations, which were not related to the specific incident (including those raised from stakeholder interviews), these have been addressed as far as possible within the report.
- The investigation and report focuses on the overall power supply to the FMC, and does not consider in detail local application of emergency power to specific areas and equipment within the facility, and is therefore not necessarily a comprehensive coverage of all possible risks to power supply reliability at all areas of FMC.

Note that this report relies on information provided, and will necessarily be limited by the time available. Refer also to notes in Appendix B.

3 The appropriateness of the architecture of the existing standby power system network

3.1 Flinders Medical Centre context

Flinders Medical Centre (FMC), an approximately 593 bed specialist referral public teaching hospital in Adelaide, South Australia, is part of the Southern Adelaide Local Health Network, and is situated in the Adelaide foothills approximately 12 kilometres from the city centre.

Since opening in 1976, FMC has earned an international reputation as one of Australia's finest public teaching hospitals and as a centre for research excellence.

The hospital is collocated with the Flinders University School of Medicine, the Flinders Centre for Innovation in Cancer (FCIC) and the approximate 130 bed Flinders Private Hospital. (The FCIC and Flinders Private Hospital facilities are not included in this review as their power infrastructure is separate from the FMC). FMC has close links with other health providers in southern Adelaide.

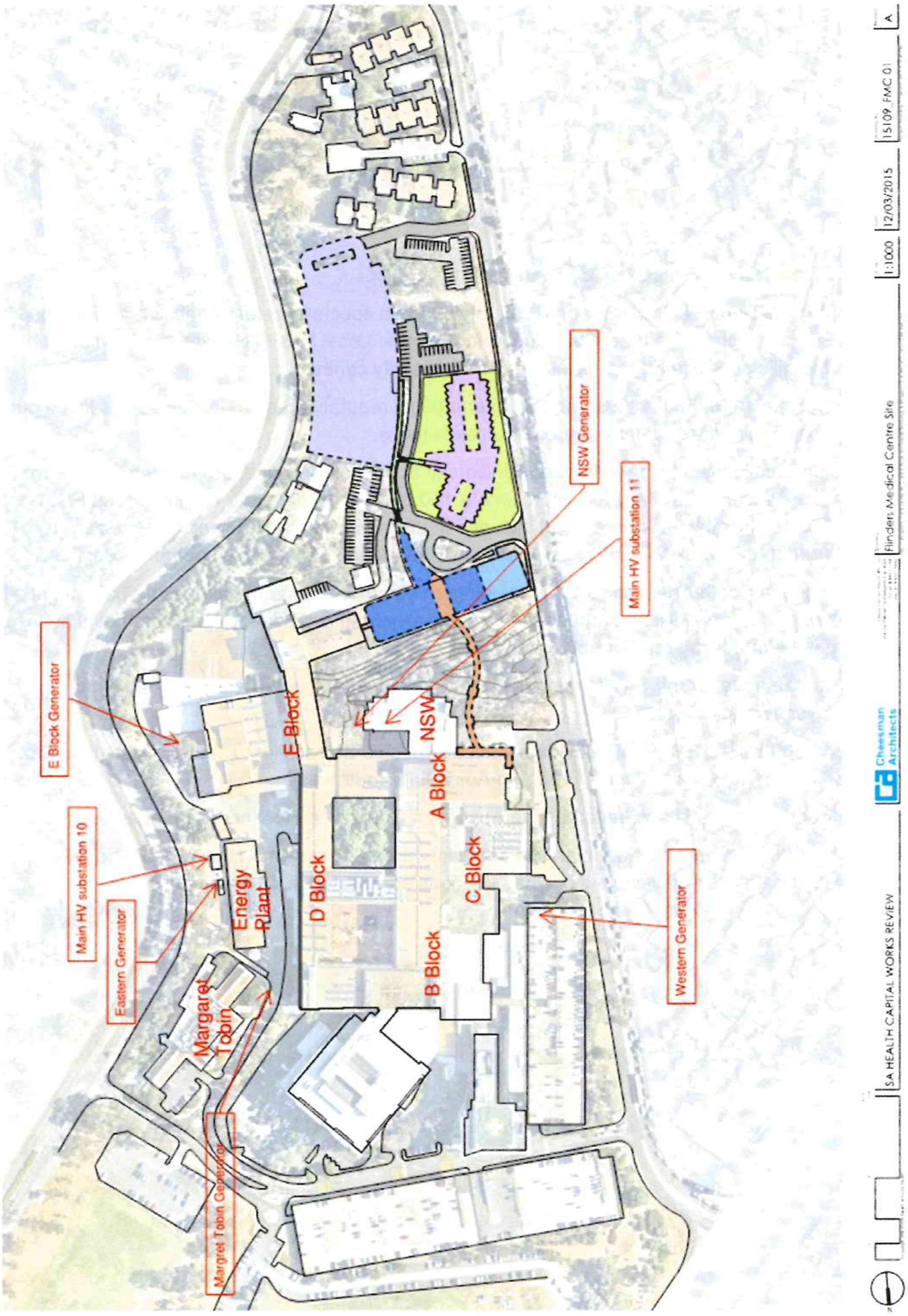
FMC is unique in South Australia (SA) in providing an extensive range of services for patients of all ages. It is one of two major trauma centres in SA. An around-the-clock emergency retrieval service brings patients to FMC by road or helicopter.

FMC is also the base for the South Australian Eye Bank and the South Australian and Northern Territory Liver Transplant Unit.

More than 3500 skilled FMC staff provide services to people across Australia, from Darwin in the Northern Territory to Mount Gambier in South Australia's south east.

Flinders Medical Centre is accredited by the Australian Council on Healthcare Standards.

Refer to the site plan below for an overview of the key areas discussed in this report, and to Appendix C for a more detailed view of what functions are located in which areas:



FMC site plan

3.2 FMC emergency power systems

The power infrastructure at FMC provides three main levels of power supply. Refer to diagram below for a simplified view of the system. Detailed technical drawings and reports are available for further review if required.

- Primary High Voltage (HV) – this is a dedicated SA Power Networks (SAPN) 11 kV underground feeder from Seacombe substation. This supply and associated substation within FMC were constructed in 2008/9.
- Backup HV – this is a shared SAPN 11 kV feeder from Tonsley Park substation. It has available capacity to support full operation of FMC. The incoming feeder cables were replaced in 2000, and the associated substation within FMC was constructed in 2008/9. The FMC power system is arranged to automatically switch from the primary to the backup HV supply on loss of the primary supply.
- Generators. There are 5 generators at FMC (plus one for FCIC). Generators supply essential circuits only, consequently, when operating on generator there is some impact on hospital operations:
  - "Eastern" (or "main") generator supplies emergency power to the majority of the hospital. The essential supply is derived from Transformer 1 if it has power, or from the generator, and distributed to back up the main supply serving blocks A, B, C (except theatres), D, E (except certain critical engineering plant). Located externally adjacent to the main plant building and installed in 2008/9.
  - "Western" generator supplies emergency power to the operating theatres, Post-anaesthesia Care Unit (PACU) and associated areas in C block. Located on the roof of the car park and installed in 2010.
  - "E Block" generator supplies emergency power to certain engineering services including critical water supply plant, and has capacity and provisions in place for future backup supply to other areas. Located externally adjacent to E block and installed in 2006.
  - "New South Wing" generator supplies emergency power to this new wing (Women's health). Located externally and installed 2008/9.
  - "Margaret Tobin" generator supplies emergency power to the mental health facility, installed outside the facility in 2005.
  - A new generator is planned as part of the current Transforming Health project to supply emergency power to the new Rehabilitation and Older Persons Mental Health facilities.

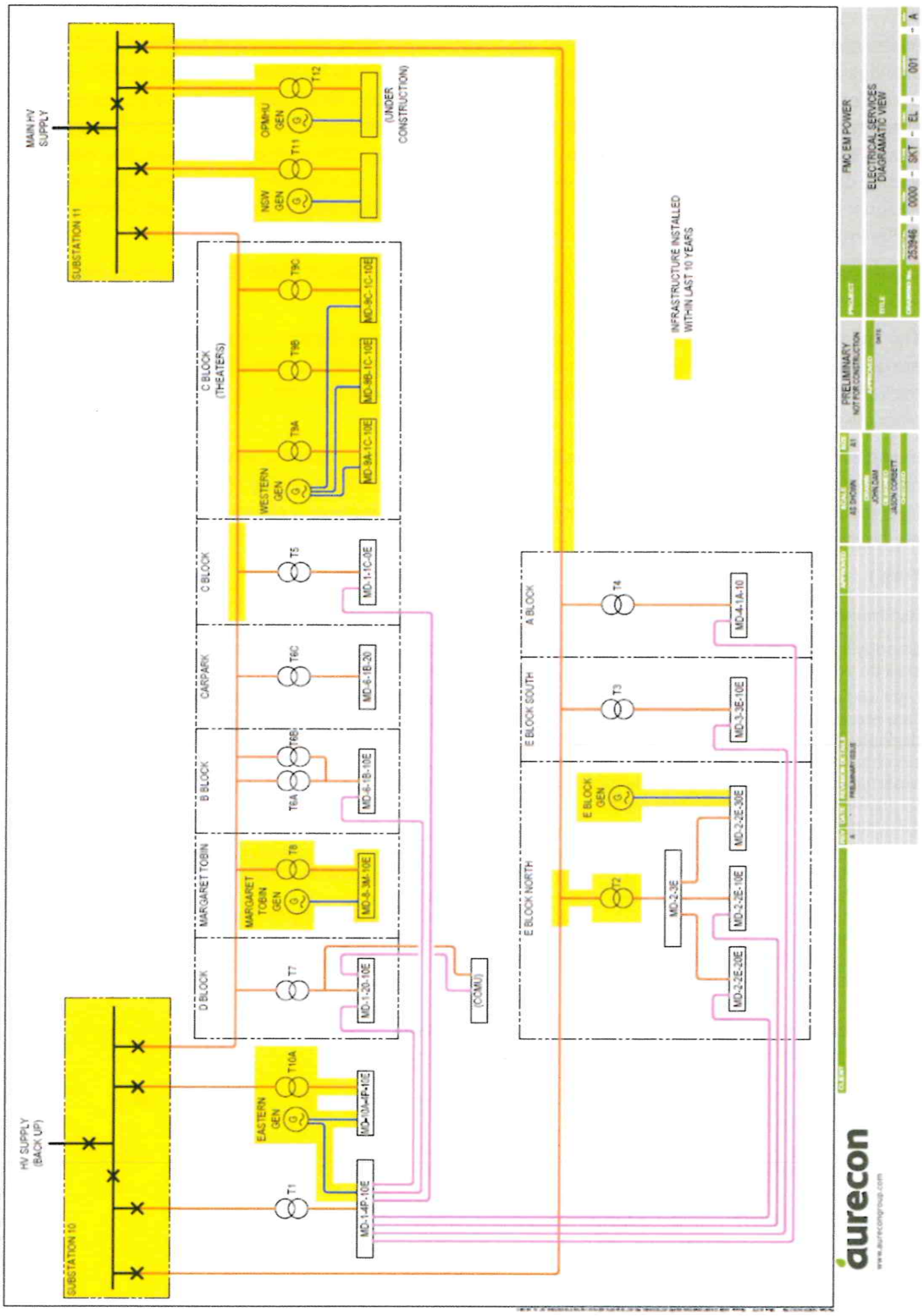
These main power sources are connected to different areas of FMC as shown on the diagram.

As a fourth level of backup, should there be a local failure of power, or general failure of all the first three levels, then local emergency provisions localised throughout the facility are also available, including:

- Battery-backed emergency lighting
- Battery-backed medical equipment
- UPS systems including for the operating theatres, and areas of ED and ICU

The connection of the internal HV network to 11 substations with switchgear and transformers supplying different blocks of the facility is mainly via a flexible arrangement of ring mains as shown in the diagram below. This can be configured in a variety of ways to allow potential supply to local substations from two different HV sources or different feeder pathways. This reduces the risk of local faults or maintenance activities on the HV system affecting power supply to particular areas. It is normally configured with supply from the primary HV network supplying approximately half of the FMC through one feeder network, and half through another.

The connection and switching between normal and essential power supplies to various areas of FMC is at essential main distribution boards (MD) at each substation.



FMC emergency power systems (simplified)

3.3 Current hospital standards

Australasian Health Facility Guidelines (AHFG) Part E – Building Services and Environmental Design provides a preliminary overview of engineering services issues to be taken into consideration in the design of health facilities. Technical performance specifications for engineering services are provided in additional reference documents published on the AHFG website, and includes reference to NSW Health Engineering Services Guidelines GL2016_020 26-Aug-2016 and Western Australia Health Facility Guidelines for Engineering Services 2006. In addition, SA Health requires that planners and designers for South Australian facilities should use the Victorian Department of Health Design Guidelines as the primary reference for technical performance specification.

These standards all reference the key Australian Standard "AS/NZS 3009:1998 Electrical Installations – Emergency power supplies in hospitals".

The key recommendations in these referenced documents with regard to emergency power systems are generally consistent and are summarised below, with an outline of the current status of the relevant facilities at FMC. (Recommendations in Table 1 below are from the Victorian Standard unless otherwise noted).

In addition, these standards provide recommendations on which specific services in the facility should be supplied with emergency power from generators, or from UPS supplies. The decisions to be made from these recommendations require consultation with end users and clinical risk assessments and are beyond the scope of this report.

Table 1 Review of relevant standards

Recommendation in referenced standards	Current FMC provisions
Standby lighting and power systems to AS 3009 shall be provided in critical care areas.	Standby lighting and power systems are provided throughout the hospital.
Light and general purpose power outlets in critical care areas shall have dedicated submains originating from the main switchboard. The switchboard and submains shall be configured to ensure continuous availability of electrical supply by means of an essential section on the switchboard.	Separate essential and non-essential submains and distribution boards are provided.
Two dedicated submains circuits shall be provided for each critical care area. At least one of the circuits shall be connected to the emergency generator supply where installed. Critical care submains cables are not required to be fire rated. Protection against mechanical damage shall be provided.	Separate essential (generator backed up) and non-essential submains and distribution boards are provided. Submains are generally fire rated, and are mechanically protected.
The following factors shall be considered when dual high voltage electrical supplies are to be used without providing emergency generators:	As follows.
Do high voltage supply feeders originate from two independent network circuits?	Yes, from Tonsley and Seacombe substations.
Are high voltage supply feeders reticulated through two separate geographical routes?	Yes, within the site (SAPN infrastructure not reviewed as part of this report).
Does the standby feeder have full capacity available all the time?	Yes.
Are the high voltage supply feeders reticulated overhead or underground?	Underground.
Is an automatic bus tie permitted by the Supply Authority?	Yes. Arrangements are in place for automatic changeover of alternate supplies, and for reconfiguration of

Recommendation in referenced standards	Current FMC provisions
	internal HV reticulation to overcome local faults.
Are either of the HV feeders likely to be interrupted due to weather conditions, vehicle crashes or vandalism?	SAPN infrastructure not reviewed as part of this report, but it would appear that the local HV supply from the SAPN substation is underground and well protected.
Emergency generators are recommended to be installed to ensure continuity of essential electrical supply in critical areas, when suitable dual supply high voltage feeders are generally not available.	Generators provided, even though suitable dual high voltage feeders are available.
Where the facility has a post disaster function or requires chilled water/cooling services for sustaining human life or critical service, this shall be achieved by providing sufficient electrical generation capacity to start and run chillers, chilled water pumps, critical air conditioning necessary for the continued operation of all critical areas and services.	Separate air conditioning plants for theatres 1 to 8, 10 and 12, PACU, procedure room and Day of Surgery Admission (DOSA) are provided and are on generator supply.
For hospitals where life-sustaining procedures are undertaken and no emergency generator is installed, a quick connection facility is recommended to be provided enabling connection of a mobile generator to the essential (emergency) section of the main switchboard	Connections for temporary generators are possible. Some provisions could be improved to make this easier to achieve – see recommendations in section 6 below.
Regardless of whether the hospital has permanent diesel generating plant installed, provision of a quick connection facility (i.e. 'power lock' connection or busbar cable connection facility) for linking the loads identified under standby power to a temporary (mobile) generator set should be considered (NSW Guideline).	Connections for temporary generators are possible. Some provisions could be improved to make this easier to achieve – see recommendations in section 6 below.
A minimum of 24 hours of fuel storage capacity at full load is required. Larger storage capacity may be provided based on justifiable clinical needs or local factors (NSW guideline).	Yes – refer to information in 5.2.1 below.
Western Australia Health Facility Guidelines for Engineering Services 2006 has, for hospitals that will continue to offer invasive surgery or emergency medical services during failure of normal utility services, options for electricity supply arrangements, including a 2 x 100% capacity normal supply and a 1 x 100% of essential supply.	FMC electrical system supply arrangement is a 2 x 100% capacity normal supply and a 1 x 100% of essential supply, with the two separate HV supplies each able to supply the whole facility, and the generator systems able to supply all the emergency circuits.

3.4 Conclusion

The FMC main emergency power systems' architecture in Aurecon's opinion meets the requirements of the relevant standards including AS3009, and is comparable to equivalent hospitals in Australia of a similar age.

Major teaching/emergency hospitals recently constructed have adopted some different overall architecture, with multiple parallel high voltage generator sets in an n+1 redundant arrangement, dual supplies to critical areas with local ATS and load shedding. This has some technical reliability advantages, but is only possible because of their large scale and "single build" nature e.g. Sunshine Coast University Hospital, Gold Coast University Hospital, Sydney's Royal North Shore Hospital. It would not be possible without a major rebuild of the electrical infrastructure including a hospital shutdown to change the fundamental architecture at FMC in that regard.

It is noted as described above that over the last 10 years, several major projects renewed and improved the power supply infrastructure at FMC. As has been occurring over the life of the FMC, including the current Transforming Health programme, any new developments or refurbishment of elements of the infrastructure or areas of the hospital should consider further opportunities to increase system redundancy and reliability.

Application of additional local power security measures to address local impacts from loss of power requires review and consultation of individual clinical situations, and is outside the scope of this report, but it is recommended that such reviews be carried out.

4 Standby power system network components condition, plant reliability and performance assessment

As indicated previously and shown on the simplified diagram in Section 3.2, key main components of the electrical infrastructure have been installed within the last 10 years, and are in very good condition, reliable and performing as required. This has been demonstrated by operational history, performance in previous events, and maintenance records. This includes the two main incoming substations, all the generators, approximately 50% of the transformers and local HV switchgear.

The other elements are of various ages, some dating back to the original 1975 construction. These have been well maintained. They include the other 50% of transformers, some of the HV local switchgear, and the older essential main distribution boards. It is noted that the replacement or refurbishment of this critical plant is complex, as works would need to be planned to avoid impacting the continuous operation of critical facilities of FMC, and should also consider the condition and capacity of downstream, local distribution systems within the facility.

The downstream distribution systems represent a limitation on the amount of emergency power that can be supplied to any particular area. As demand for essential power circuits grow as more essential equipment and services are required, this restriction will need to be addressed at the local distribution level, to allow the generator capacity to be delivered where required.

It is noted that some planning in this regard has been carried out as part of earlier projects.

> **Recommendation: The electrical Master Plan for the site should be updated to include planning for the scheduled replacement or refurbishment of those parts of the infrastructure that have not been renewed in the last 10 years. This planning to consider other upgrades or plans for the FMC overall.**

A specific review of the generator systems' maintenance records, monthly and annual tests, was undertaken. From the records and from observation of the generators on site, it appears maintenance is being carried out appropriately. Annual generator tests include load bank testing by means of temporarily installed load banks. Testing of changeover mechanisms from normal to emergency power is simulated as far as possible without causing an actual loss of power to the operational hospital. Measures to improve testing mechanisms to mitigate risk of failures should be included in the Master Plan update.

During the review, we also formed a view on the general performance and capability of the FMC maintenance staff. The key staff have many years of experience on the site and strong knowledge and commitment to the hospital's operations, and are capable of reliably providing power supply to the facility. Ensuring that this capability is maintained over the long term, with suitable succession planning and investment in human resources, will be important to maintaining the reliability of FMC operations.

There are some specific details of the instrumentation and alarm systems design that impact on reliability and have contributed to the failure event of 28 September, and there are some installation details that impact on maintainability and ability to respond to emergencies. These are discussed in more detail in the review of these events in Section 5.

5 Events of 28 September 2016

5.1 Sequence of events

The sequence of key events relating to the power failure at FMC on 28 September was, as reported to us by FMC staff and from available alarm records, as follows:

- 15:43 hrs – total loss of SAPN power as a consequence of a state-wide power failure
- FMC infrastructure responded as designed – primary HV supply switched to backup supply, and when detected as unavailable, all emergency generation systems started and supplied the essential power systems. FMC operating on essential power (normal power circuits not available)
- FMC organisation mobilised and continued to take critical actions to manage the impacts of power failure on hospital operations (not subject of this report)
- FMC maintenance staff responded to site control centre and checked and monitored emergency power systems, and responded to localised issues caused by loss of the normal power supplies
- Generator maintenance contractor was contacted to come to site as a backup measure to ensure generator operation. Due to traffic issues also associated with the state-wide power failure, contractor was significantly delayed in reaching site (approximately 18:00 hrs)
- 17:30 hrs (approximately) Eastern (main) generator shut down – areas served without essential or normal power (Blocks A, B, C (except theatres), D, E (except certain critical engineering plant)). Refer to Appendix C for some details of services provided in these areas. Other generators continued to operate as normal.
- FMC maintenance staff responded to main generator to determine cause of fault and attempt to restart the generator. See further discussion in this section.
- 19:06 hrs primary HV supply restored from SAPN. Power systems returned automatically to normal supply operation and power restored to FMC. FMC maintenance staff had been communicating with SAPN Network Operations Centre, and it is understood that SAPN prioritised restoration of this supply.
- 21:00 hrs (approximately) Main generator issues resolved and generator tested and available for service (not operating as normal power available).
- 23:00 hrs (approximately) All fuel systems topped up in case of further supply failures
- Some time before 07:00 hrs on 29 September, backup HV supply restored from SAPN. Power supply systems to FMC then back to normal.

In summary,

- FMC without normal power from 15:43 to 19:06 hrs (3 hours 23 minutes) due to state-wide power failure
- Parts of FMC (Blocks A, B, C (except theatres), D, E (except certain critical engineering plant)) without normal or emergency power from approximately 17:30 to 19:06 hrs (approximately one hour 36 minutes) due to failure of main generator

5.2 Analysis of the failure

The direct cause of the main generator shutdown related to the fuel system.

5.2.1 Description of generator fuel system

The main generator fuel system consists of:

- Day tank within the packaged generator enclosure, 750 L capacity
- External underground main fuel tank (bulk tank) adjacent to generator enclosure, 6000 L capacity
- Dual fuel pumps under the day tank, which pump fuel from underground tank
- Control system for generator, which includes fuel control system. Elements of the control system are located within the generator enclosure, and other elements within the P (energy plant) building, approximately 5 minutes' walk away
- The fuel control system is set up so that the transfer pump starts when the day tank is 50% full, and remains operating until the tank is 100% full. Should the day tank fall to 40% full, a low level alarm is raised. This is approximately one hour of generator operation and would allow sufficient fuel in the day tank for continuous operation while maintenance staff respond to the alarm and ensure fuel supply to the day tank. Should the day tank reach 5% full, a day tank empty alarm is generated and the generator shuts down. This is to prevent damage to the generator that may make it difficult to restart once fuel is available. The settings of these controls reported here are based on the generator O&M manuals, and should be checked on site as part of generator maintenance. The alarms generated from the fuel control system are:
  - Day tank overfull
  - Day tank low
  - Day tank empty
  - Pump 1 failed
  - Pump 2 failed
  - Bulk tank low
  - Bulk tank empty
- These alarms are not currently connected to the site-wide BMS alarm system for the main generator (they are connected for Western, Margaret Tobin and partially for NSW generator).
- Note generator fuel consumption at full load is 326 L/hr. Actual operation is not at full load. Therefore a full day tank should operate the generator for at least two hours, estimated at three hours based on actual loads, and the bulk tank should operate the generator for 18 hours, estimated at more than 24 hours based on actual loads

5.2.2 Analysis of generator shut down

The cause of the generator shutdown is analysed as follows, based on events reported by FMC staff, and based on our analysis of the systems documentation and visual inspections:

1. Generator operation consumed fuel from the day tank until a sensor, as part of the control system, detected a critically low fuel level in the tank and automatically shut down the generator.
2. It was reported that the pumps did not operate to bring fuel from underground tank to the day tank because the control system Auto Off Manual switch was turned "Off". This prevents the pumps from running. This switch is available for testing and maintenance of the control system. It should always be left in "Auto" for normal operation. No other reason for failure of the fuel supply to the generator is apparent to us from information received.

3. How this switch was left in the off position is not known. Possibilities include:
    a. At the last monthly service of the generator on 23 September, the generator maintenance contractor would have used this switch to test the operation of the fuel system. The testing was recorded in the maintenance records. The generator maintenance contractor has provided a detailed report on that maintenance, and it is their "true and best recollection of the events" that they left the switch in the auto position as per their procedures.
    b. During the main power failure event, FMC maintenance staff checked the operation of the generator systems. It is possible that during this check the switch was left off in error. There is no evidence to indicate that this happened.
    c. The switch is within the generator enclosure, which is locked, with keys kept at various locations. There is no apparent reason why or evidence that anyone accessed the generator enclosure at any other time between the monthly service and the event, although it is possible.
4. In any case, it could be considered that the basic cause of the failure is not necessarily this human error. Other measures should be in place to prevent this error from leading to generator shutdown, or to allow for a more rapid recovery from such a shutdown. It is also noted that there are other possible faults which, although not apparent in this case, could have occurred, with a similar impact. The fuel control system itself consists of electronic modules, cabling and sensors that could develop faults stopping the pumps from operating.
5. To mitigate the risk of fuel control system failure (whether from human error or otherwise) alarms generated from the fuel control system need to be reliable and be transmitted reliably to maintenance staff. This did not happen during these events. If alarms had been activated, maintenance staff would easily have been able to correct the switch position and no shutdown would have occurred. By reliably transmitted, we mean via the BMS critical alarm system, which raises alarms at the manned control centre as a high priority on the BMS screen, and also sends pager messages to key maintenance duty staff. It is also important that during an emergency event, the volume of alarms generated does not swamp the operators with too much information, where critical alarms can be lost.

    Recommendation: A detailed review of the fuel control and BMS systems (for all generators) be carried out and actions taken to:

    - **Ensure that the fuel alarm system is operational and properly calibrated, and ensure that the alarms are connected to the BMS. Ensure that the BMS transmits these alarms effectively to the maintenance staff.**
    - **Ensure that the BMS system during an emergency event manages the volume and priority of alarms appropriately to allow effective staff response.**
    - **If this review demonstrates risk of fuel control systems not adequately reporting alarms, consider an independent day tank level switch to be installed in each generator fuel tank, directly connected to the BMS.**
    - **Consider the feasibility of adding a "fuel system not in auto" or "fuel system fault/fail-safe watchdog" or "pre-alarm identifying that the generator is about to shut down without intervention" feature to current systems – subject to details of each individual generator system.**
6. To further mitigate these risks, although the existing administrative controls of generator maintenance and testing are of a typical standard, given the events, additional administrative controls could be implemented. It is also noted from the latest generator test report that the generator day tank was left at 50% full at the end of the last monthly maintenance.

    Recommendation: Add to generator test procedure a checklist at the end of testing, which includes checking (independent of maintenance contractor) that all systems are back to normal positions and includes a requirement to leave the day tank full where there is a bulk tank/day tank arrangement.

5.2.3 Cause of delays to restarting generator

The consequences of the generator shutdown were exacerbated by delays in being able to restart the generator. The causes of this delay were as follows:

1. To restart the generator, fuel needed to be added to the day tanks, but once the generator shut down, power was not available to operate the fuel pumps. Although maintenance staff attempted to improvise solutions during the event, this was hampered by lack of pre-prepared plans and equipment for such a situation, as well as the overall conditions they were working in (see Paragraph 2 below). A portable manual backup system would mitigate against this and a number of other possible failure scenarios related to the fuel systems.

   Recommendation: A portable manual fuel pump and portable fuel drum be made available on site to manually transfer fuel to day tanks. Emergency procedures be prepared to describe how this is to be done, including listing potential source of accessible fuel (other generator tanks, motor vehicles, offsite sources).

2. The overall conditions in which the maintenance staff were responding to the generator shutdown event could be improved to improve their ability to effectively diagnose and rectify faults.

   Recommendation: Improvements to installation to be implemented as follows:

   - **Lighting within the generator enclosure and immediately adjacent to be emergency battery backed type.**
   - **Improvements to the spatial layout within the main generator enclosure should be investigated, including allowance for the control panel door to open 180° (only 90° currently), moving the fuel pumps to a more accessible location, and ensuring clear access to the day tank for manual filling if required.**
   - **Improvements to communications facilities between critical areas, including fixed phone line connections between the main control room, main generator control panel in the P (energy) Building, and the generator enclosure, and allowing link to offsite specialist advice.**
   - **Where generator maintenance requires operations outdoors (not applicable to main generator but applicable to others), a shelter over the relevant area should be provided to allow safe working during wet or hot weather.**
   - **Written emergency procedures to be prepared covering credible failure scenarios with step by step checklists and recommended actions.**

6 Other risks identified

Although not relevant to the particular events of 28 September, the following other risks to power supply reliability were identified during our review:

1. There are other scenarios where a complete generator failure may occur. Generator power should be available at all times in case a mains failure occurs. To allow for this, a connection point should be available where a temporary generator can be placed in a safe and convenient location and connected electrically in place of the failed generator. For each of the current generators, there is the possibility to do this, but for the main generator, the preferred connection location at outgoing circuits of the related generator switchboard does not allow for full power to be connected, and an alternate connection point at the generator is not easily connected.

   Recommendation: Review all generator locations for arrangements for temporary generator installation, including design of modifications as required for electrical connections and spatial requirements at installation locations, to be documented in an emergency procedure.

2. Another single point of failure for the main generator essential power distribution is the central control system that operates the changeover contacts at each supplies essential main distribution board. Were this system to fail, the generator power would not be able to be connected to the relevant areas.

   Recommendation: Review control system for the main generator normal/essential changeover system and ensure that it has effective backup/manual or redundant operations, and suitable testing facilities. The Essential board that supplies the main generator power to blocks A, B, C (except theatres), D, E (except certain critical engineering plant) (MD-1-4P-10E) is a potential single point of failure of a significant portion of the emergency power system and, as part of the Master Plan, an update should be considered as a priority.

3. Another potential point of failure for generators is the starting system. Although these can be repaired relatively quickly, due to the critical nature and lack of backup to the generator, dual redundant starter systems should be considered.

   Recommendation: Generator dual redundant starter systems should be considered.

4. In carrying out this review, we note that although there is a considerable amount of documentation on the systems available on FMC's data base, due to the nature of the changes to the facilities over many years, these documents are not necessarily consistent and up to date. The single line diagrams displayed in many of the plant rooms are not necessarily current. It would assist in troubleshooting in an emergency and reviews such as this if these documents were updated – refer to Table 3 System summary in Appendix A for the relevant drawings.

   Recommendation: As part of the electrical master plan update recommended above, a complete and consistent set of single line diagrams describing the electrical

distribution network be prepared. Relevant diagrams to be laminated and displayed in the main substations. Labelling to all main electrical equipment be reviewed and updated in accordance with the final documents.

5. Physical installation to some of the generators could be improved. Where possible, improvements could be carried out to reduce these risks:

    a. The generators are located with either no or limited physical protection from the public and unauthorised access. Even though the enclosures are locked they are susceptible to vandalism and damage that could inhibit their operation. The generators have external emergency stop buttons (as required by code). With a low level of physical security there is a risk of unauthorised shutdown. Consider the addition of fencing or use of CCTV or security systems such as intruder alarms/reed switches on the generator enclosure doors and "door left open" alarm may assist in managing these risks.

    b. The Margaret Tobin generator is located adjacent to a road with no protection against vehicle damage.

    c. The generators are located adjacent to or below deciduous trees with a risk of foliage and branches falling onto the generator enclosure.

    d. No fire suppression equipment positioned within the generator enclosures. It is typical to include portable appliances.

    Recommendation: Review generator installations details as noted in report and implement physical improvements where possible.

6. Controls and switchgear for the main generator are located in the main plant building without physical segregation from other plant areas. This may result in water damage should there be a catastrophic failure of water pipework or equipment. Switches may be accidentally operated or damaged by other activities taking place in the plant room. Since the plant room is quite open, often with many operators and subcontractors in attendance, it is possible that unauthorised operations could take place. Solid wall barriers around the locations should be considered.

    Recommendation: Provide walls around critical electrical infrastructure within the main plant area to provide security and protection from catastrophic water system failures.

7 Conclusion and Recommendations

From the review carried out, Aurecon concludes that

1. In Aurecon's opinion, the FMC main emergency power systems' architecture meets the requirements of the relevant standards, and is comparable to equivalent hospitals in Australia of a similar age.
2. It is noted that over the last 10 years, several major projects renewed and improved the power supply infrastructure at FMC. As has been occurring over the life of the FMC, including the current Transforming Health programme, any new developments or refurbishment of elements of the infrastructure or areas of the hospital should consider opportunities to increase system redundancy and reliability.
3. The standby power system network is largely in good condition, operational and reliable. Those parts of the system that have not been upgraded in the last 10 years will need to be reviewed and plans put in place to renew.
4. The direct cause of the loss of essential power on 28 September was related to the generator fuel system, and most likely caused by human error in wrongly leaving a switch off, but it could be considered that a contributing cause is deficiencies in alarm systems to notify the low fuel situation.
5. Other improvements can be made to improve the ability of maintenance staff to address emergency situations.
6. The review has also identified some other improvements that, although not related to the events of 28 September, would further mitigate the risk of power failures.

It should be emphasised that the emphasis in this review of possible risks has been in the spirit of learning from failures to improve capability and future performance, and that overall FMC has a robust contemporary emergency electrical system.

The recommendations of this report are summarised as follows. It is noted from interviews and site inspections, that some of these recommendations are already in the process of implementation.

Table 2 Summary of Recommendations

	Recommendation	Status	Preliminary Budget Cost
1.	The electrical master plan for the site should be updated to include planning for the scheduled replacement or refurbishment of those parts of the infrastructure that have not been renewed in the last 10 years. This planning to consider other upgrades or plans for the FMC overall.		$100k for engineering investigations. Ultimate works cost subject to outcomes.
2.	A detailed review of the fuel control and BMS systems (for all generators) be carried out and actions taken to: - Ensure that the fuel alarm system is operational and properly calibrated, and ensure that the alarms are connected to the	In progress through maintenance.	$20k

	Recommendation	Status	Preliminary Budget Cost
	BMS. Ensure that the BMS transmits these alarms effectively to the maintenance staff. - Ensure that the BMS system during an emergency event manages the volume and priority of alarms appropriately to allow effective staff response. - If this review demonstrates risk of fuel control systems not adequately reporting alarms, consider an independent day tank level switch to be installed in each generator fuel tank, directly connected to the BMS. - Consider the feasibility of adding a "fuel system not in auto" or "fuel system fault/fail safe watchdog" or "pre-alarm identifying that the generator is about to shut down without intervention" feature to current systems – subject to details of each individual generator system.		
3.	Add to generator test procedure a checklist at the end of testing which includes checking that all systems are back to normal positions and includes a requirement to leave the day tank full where there is a bulk tank/day tank arrangement.	In progress through maintenance.	-
4.	Improvements to installation to be implemented as follows: - Lighting within the generator enclosure and immediately adjacent to be emergency battery-backed type. - Improvements to the spatial layout within the main generator. enclosure should be investigated, including allowance for the control panel door to open 180° (only 90° currently); moving the fuel pumps to a more accessible location, and ensuring clear access to the day tank for manual filling if required. - Improvements to communications facilities between critical areas, including fixed phone line connections between the main control room, main generator control panel in the P (energy) Building, and the generator enclosure, and allowing link to offsite specialist advice. - Where generator maintenance requires operations outdoors (not applicable to main generator, but applicable to others), a shelter over the relevant area should be provided to allow safe work during wet or hot weather. - Written emergency procedures to be prepared covering credible failure scenarios with step by step checklists and recommended actions.	In progress through maintenance	$40k
5.	Review all generator locations for arrangements for temporary generator installation, including design of modifications as required for electrical connections and spatial requirements at installation locations, to be documented in an emergency procedure.		$10k for engineering works. Ultimate works cost subject to outcomes
6.	Review control system for the main generator normal/essential changeover system and ensure that it has effective backup/manual or redundant operations, and suitable testing facilities. The Essential board that supplies the main generator power to Blocks A, B, C (except theatres), D, E (except certain critical engineering plant) (MD-1-4P-10E), is a potential single point of failure of a significant portion of the emergency power system and as part of the Master Plan update should be considered as a priority.		$10k for engineering investigations. Ultimate works cost subject to outcomes
7.	Recommendation: Generator dual redundant starter systems should be considered.		$50k
8.	As part of the electrical master plan update recommended above, a complete and consistent set of single line diagrams describing the	Partially addressed as	Incl. in above

	Recommendation	Status	Preliminary Budget Cost
	electrical distribution network be prepared. Relevant diagrams to be laminated and displayed in the main substations. Labelling to all main electrical equipment be reviewed and updated in accordance with the final documents.	part of this review	
9.	Review generator installations details as noted in report and implement physical improvements where possible.		$20k
10.	Provide walls around critical electrical infrastructure within the main plant area to provide security and protection from catastrophic water system failures.		$100k

Appendix A
System summary

Table 3 System Summary

The following table is provided as a useful summary of the key infrastructure and reference to the related Single Line diagrams used in the technical analysis

Substation	Transformer	Main Board	Essential Board	Drawing	Generator	Note
10 (Building P)	TF10A	MD-10A-4P-10	MD-10A-4P-10E	E010	Eastern	Supplies Plant air, vacuum plant
1 (Building P)	TF1	MD-1-4P-10	MD-1-4P-10E	E011 (and *E14 for old version)	Eastern	Supplies plant and distribution to other areas. Includes supply to generator control.
			MD-1-1A-10E (MD-4-1A-10E?)	E011 and *E05		Block A em supply – see below.
			MD-1-1B-10E (MD-6-1B-10E?)	E011 and *E04		Block B em supply – see below.
			MD-1-1C-10E	E011 and *E07		Block C em supply – see below.
			MD-1-1D-10E	E011 and *E02		Block D em supply – see below.
			MD-1-2E-20E (MD-2-2E-20E?)	E011 and *E10		Block E em supply – see below.
			MD-1-2E-10E (MD-2-2E-10E?)	E011 and *E06		Block E em supply – see below.
			MD-1-3E-10E (MD-3-3E-10E)	E011 and *E03		Block E em supply – see below
2 (E block North)	T2	MD-2-3E		E104		
			MD-2-2E-30E	E104	E building	EM only board supplying essential hydraulic and fire plant.
		MD-2-2E-10	MD-2-2E-10E	*E06	Eastern via	Note provision made for supply from E Building

Substation	Transformer	Main Board	Essential Board	Drawing	Generator	Note
					MD-1-4P-10E	generator, but not connected – see dwg 06/0044/1,2,3,4.
		MD-2-2E-20	MD-2-2E-20E	*E10	Eastern via MD-1-4P-10E	Note provision made for supply from E building generator, but not connected – see dwg 06/0044/1,2,3,4.
		MD-2-3E-40	MD-2-3E-40E			CSSD.
3 (E Block South)	T3	MD-3-3E-10	MD-3-3E-10E	*E03	Eastern via MD-1-4P-10E	Note provision made for supply from E building generator, but not connected – see dwg 06/0044/1,2,3,4.
4 (A Block)	T4	MD-4-1A-10	MD-4-1A-10E	*E05	Eastern via MD-1-4P-10E	
11 (New South Wing)	T11	MD-11-1NSW	MD-11-1NSWE	E478	New South Wing	
9 (C Block)	TF9A	MD-9A-1C-10	MD-9A-1C-10E	E006 and E521	Western	Theatres, incl. UPS system and HVAC plant for chillers.
	TF9B	MD-9B-1C-20	MD-9B-1C-20E	E007 and E520	Western	
	TF9C	MD-9C-1C-30	MD-9C-1C-30E	E008	Western	
5 (C Block)	T5	MD-5-1C-10	MD-1-1C-10E	*E07	Eastern via MD-1-4P-10E	
6 (B Block)	T6C	MD-6-1B-20	NA	*E15	NA	Car park and retail.

Substation	Transformer	Main Board	Essential Board	Drawing	Generator	Note
	T6A and B in parallel	MD-6-1B-10	MD-6-1B-10E	*E04	Eastern via MD-1-4P-10E	
8 (Margaret Tobin)	T8	MD-8-3M-10	MD-8-3M-10	BE switchcraft 05/0270/1	Margaret Tobin	Mental health.
7 (D Block)	T7	MD-7-2D-10	MD-1-20-10E	*E02	Eastern via MD-1-4P-10E	
		MD-7-2D-10A	MD-7-2D-10A?	*E02 and CW job no A6692 dwg E8	Eastern via MD-1-4P-10E and MD-7-2D-10	Critical Care Medicine Unit.
12 (OPMHU)	12	MSB-12-3V-01			OPMHU	Under construction in current development – supplies new OPMHU Rehab, Car park.
(FCIC)					FCIC	FCIC is in separate HV system and separate elec distribution

Notes

1. Switchboard naming: MD - supply from sub no – location of board, floor and block – sequence number 10, 20, 30 etc
2. Drawing number *Exx refers to drawings in “Electrical Master Plan” prepared by Bassett Consulting Engineers, September 2000
3. Drawing number Exx refers to drawing in 2009 Infrastructure upgrade projects documentation
4. In addition, the drawings in report “Flinders Medical Centre Redevelopment Briefing” prepared by Bassett Consulting Engineers, October 2006, that describe the board locations and zoning (30018378-XE01,2,3,4,5,6, where X is floor number, should be updated
5. Green shading is relatively new (less than 10 years)

Appendix B
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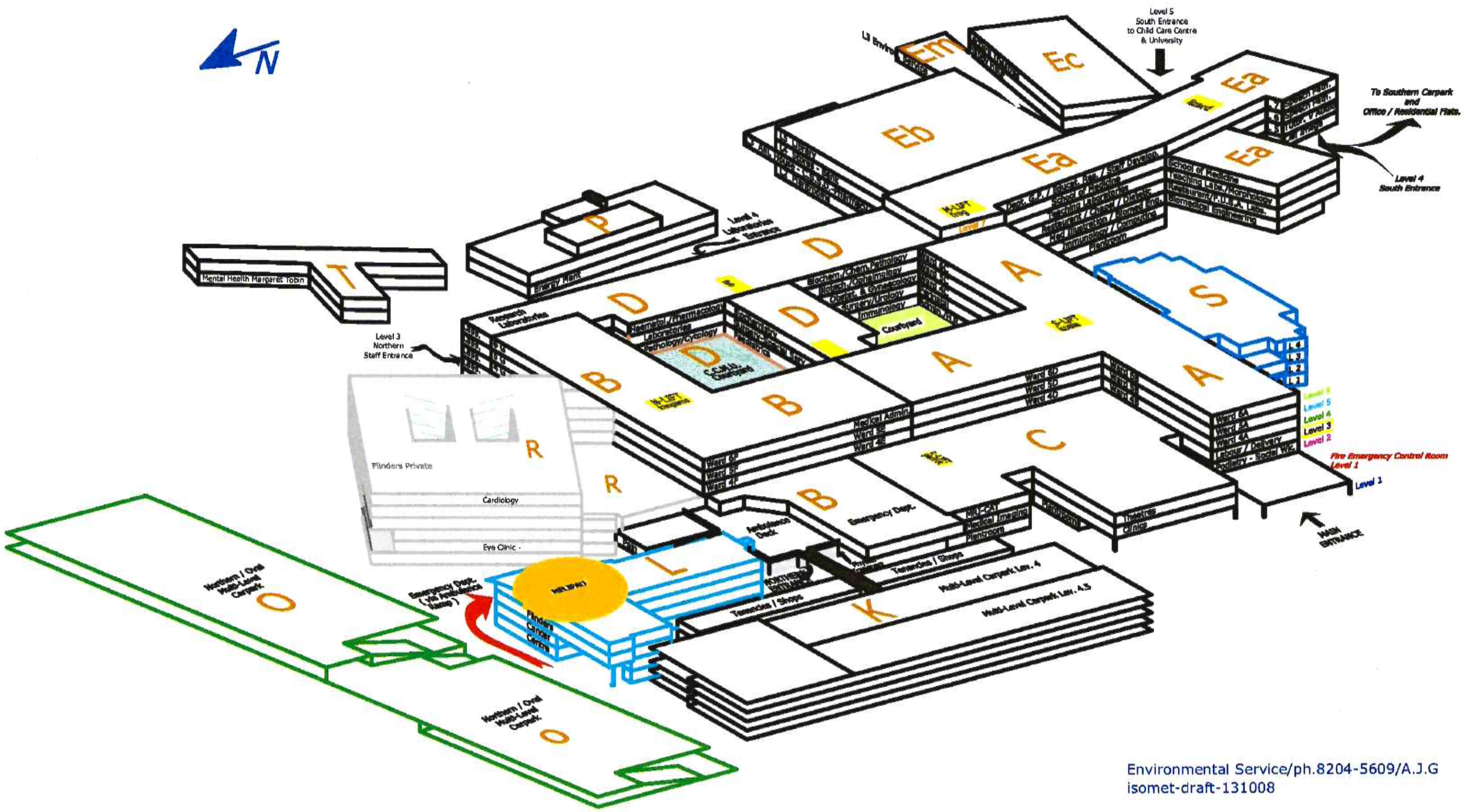
Appendix C
FMC site diagram

FLINDERS MEDICAL CENTRE -



Environmental Service/ph.8204-5609/A.J.G
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