TECHNICAL MANUAL

UTILITY SYSTEMS TERRORISM COUNTERMEASURES FOR COMMAND, CONTROL, COMMUNICATIONS, COMPUTER, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE (C4ISR) FACILITIES

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CHAPTER 1
INTRODUCTION

1-1. Purpose

The purpose of this technical manual (TM) is to provide guidance for facility managers and engineers in applying the principles of limited vulnerability design (LVD) to the utility systems for command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) facilities. It will also provide generic guidance to agencies responsible for the planning, design, and installation of such systems in C4ISR facilities. The utility systems for C4ISR facilities include those providing heating, cooling, ventilation, water, sanitation, and electrical service to the mission-critical loads within the facilities as well as their associated control systems

1-2. Scope

The LVD model is a set of principles to apply in designing a C4ISR facility that is compartmentalized and provides multiple service pathways for all utilities to the critical load as protection against an internal terrorist attack intended to interrupt the mission.

a. This TM includes an example facility floor plan, which is the basis for discussion of the application of the LVD principles to the utility systems. The primary focus of this TM is the mechanical and electrical utility systems and their controls.

b. This TM addresses utility system topics only as they are affected by or require different consideration due to the application of the LVD concept. Other aspects of utility system design that are addressed by industry standards, other TMs, or United States Department of Defense (DoD) documents are not repeated in this TM. Similarly, examples include only discussion of those aspects of system design considered relevant to LVD and may not show other features required by industry codes and standards.

1-3. References

Appendix A, References, contains a complete list of the sources cited in this TM. Planning, design, installation, and commissioning of utility systems should always be based on the most current relevant edition of the standards listed as references. Where the recommendations of this TM and the referenced standards differ, the more stringent requirement should be followed.

1-4. Currency

The LVD concept is in part intended to isolate and prevent the spread of chemical, biological, or radiological (CBR) and other agents for which detection and mitigation technology is rapidly evolving. This TM discusses agent detection and mitigation in general but does not recommend specific sensor types or filtration techniques because the technology is expected to advance faster than this TM will be updated. It is also possible that additional detection technology will be developed for threats such as explosives, for which no practical wide-area detection method exists today. Equipment and systems intended for threat detection and response should always be selected from the most current proven technologies.

CHAPTER 2
FUNDAMENTALS OF LIMITED VULNERABILITY DESIGN

2-1. Background

The current approach in combating terrorist attacks on government and private-sector structures has focused primarily on prevention and secondarily on construction. The primary reason for this approach is time considerations. Incorporating minor alterations in a building and security policies is much easier and less costly than completely replacing a structure, and the improvements are immediate. Programs and training initiatives that focus on Anti-terrorism/Force Protection (AT/FP) reflecting this approach are offered by both government and private-sector organizations.

a. Further, existing construction-based approaches to threat resistance are concentrated on external threats and consequently emphasize physical security and perimeter defense measures. Many C4ISR installations incorporate such measures, including CBR filtration of heating, ventilation, and air-conditioning (HVAC) system air intakes and blast-resistant louvers or barriers protecting exhaust air outlets for standby generators.

b. These types of measures, while necessary, have no effect against a threat delivered inside the secured perimeter by an individual who has penetrated security or may even be authorized to be in the space. The intent of the LVD concept, described below, is to redefine the approach to C4ISR facility and utility system construction to permit sustained mission operation following the delivery of such an internal threat.

2-2. Limitations of current practice

Current practice in the design of utility systems for C4ISR facilities incorporates reliability and maintainability considerations but with an emphasis on analyzing the configuration of systems against specified numerical reliability or availability criteria (see paragraph 2-7, Reliability Criteria).

a. Although this analysis emphasizes inherent failures and maintenance downtime; it does not address failure due to external factors such as environment or terrorist threat. The result is typically systems with a high degree of redundancy but little physical segregation or hardening other than that provided at the facility perimeter by traditional security systems.

b. This practice can be contrasted with that of the nuclear industry, where both reliability and security are considered in the design of critical systems. Well-known incidents such as the fire in the cable spreading room at the Browns Ferry plant and the partial uncovering of the reactor core at Three Mile Island Unit 2 have demonstrated the need for both redundant systems and redundant pathways, even for events involving only inherent failures. When the possibility of an intentionally hostile action within the secured perimeter is added, the result is a clear need for a different approach to the design of C4ISR facility utility systems.

2-3. Limited vulnerability design concept

The LVD concept is used to describe a building structure designed to *detect* potential terrorist threats, *isolate* resulting damage, and promote *survival* of personnel affected by an event, while *propagating* continued parallel mission activity. The LVD concept relies on compartmentalizing the construction of the C4ISR facility into multiple zones, each of which is separated from the other zones by barriers adequate to withstand the range of potential threats.

a. This approach is used along with redundancy of mechanical and electrical systems to accomplish two objectives: The first is to limit the effect of an event to the compartment, or zone, in which it occurs, allowing continued mission operation in other zones. The other objective is to prevent an event in any zone of the building from interrupting utility service to the most critical mission, such as a central command center.

b. For example, if a biological agent were introduced into the HVAC system of a structure, sensing and controls capable of detecting the agent would operate the HVAC system to contain the agent within the zone of introduction. If an explosion were to occur within a zone and disable utility service equipment in that zone, the mission in other zones would be unaffected and sources in other zones would continue to provide uninterrupted service to the most critical space.

2-4. Design basis threat

The range of potential threats for application of the LVD concept encompasses generally any weapon or agent that can be hand-carried into the facility by an individual and deployed or released inside the secured perimeter; it also includes any damaging action that can be taken by an individual inside the facility, such as manually discharging a wet sprinkler system over computer equipment.

a. There are many different types of conventional threats such as the ones listed below as well as others not yet defined or developed:

(1) Firearm discharge

(2) Explosion

(3) Fire

(4) Flood

(5) Toxic gas or liquid (chemical)

(6) Infectious agent (biological)

(7) Ionizing radiation source (radiological)

(8) Electromagnetic fields

(9) Software intrusion

b. The design basis threat should be defined specifically for each facility based on a risk and vulnerability assessment that considers mission, geographic location, and other factors.

c. With respect to structural threats such as explosion and fire, this TM is not intended to quantitatively define the threat level or to provide guidance in the design of structures to resist specific threats. It is assumed that other applicable standards will be used to determine the design basis threat for a specific facility and that the structural features separating zones of the facility will be designed to withstand the threat according to those standards. This TM focuses on the design of the utility systems in unaffected zones to detect, respond to, and survive the threat.

2-5. Example C4ISR facility

Figures 2-1 and 2-2 present floor plans of an example C4ISR facility to illustrate the application of LVD concepts to the design of utility systems. This example is not intended to limit either the size or the mission character of potential facilities but simply to assist in explaining the application of design concepts discussed in this TM.

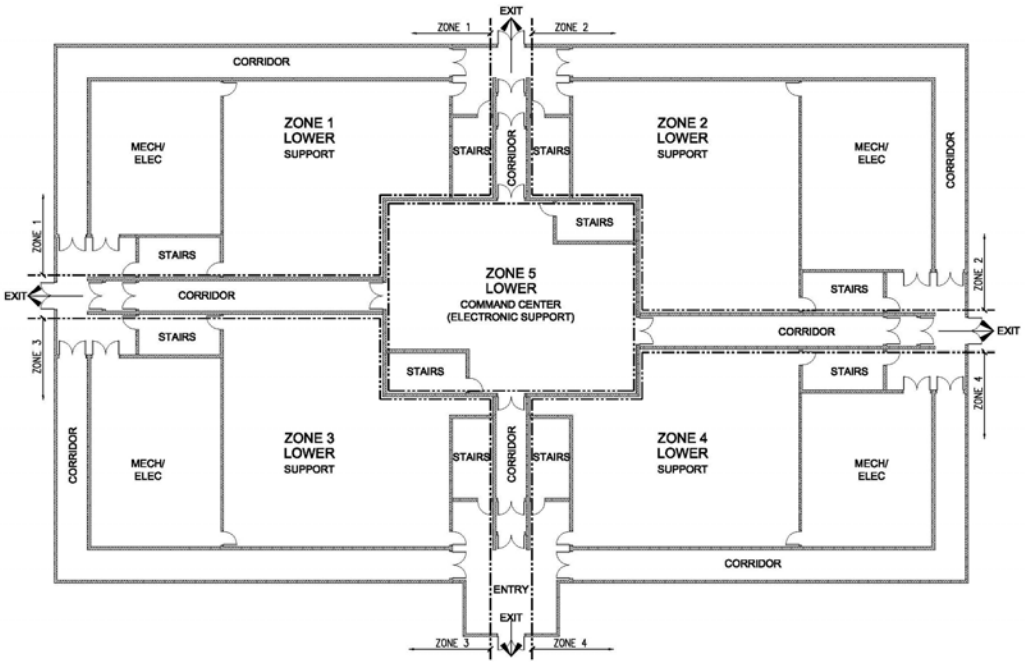


Figure 2-1. Example facility first floor plan

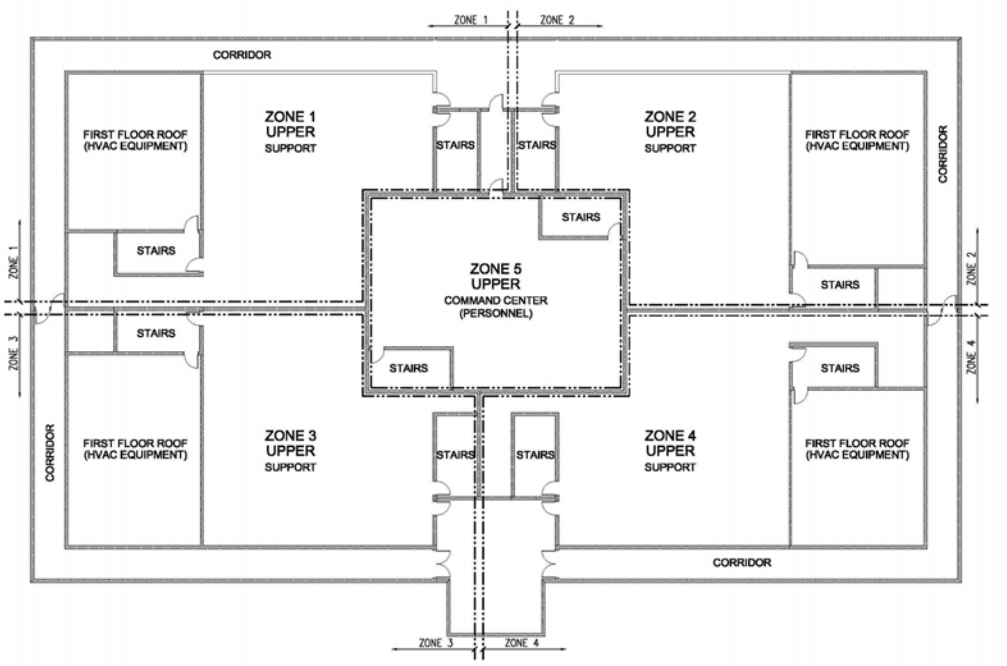


Figure 2-2. Example facility second floor plan

a. The example facility is a two-story structure of approximately 35,000 gross square feet (GSF) of floor plan, divided into five mission zones and containing four classes of secure space, as defined in table 2-1. The outer ring corridor provides a perimeter barrier for the internal space and a means of moving between zones without requiring penetration of internal barriers. This corridor also provides for accessibility and emergency egress as required by building codes. Public access to the building is through an entry checkpoint outside the perimeter of this corridor.

Table 2-1. Example facility space classification

Class	Area	Function	Security Level
0	Entry Checkpoint	Access and Screening	Low
1	Perimeter Corridor	Circulation and Egress	Medium
2	Zones 1 through 4	Mission Support	High
3	Zone 5 (Command Center)	Mission Critical	Highest

b. The peripheral zones (1 through 4) immediately inside the ring corridor contain less critical mission activities and support activities for Zone 5, which is a command center in this example. Each peripheral zone includes mechanical and electrical equipment space for utility service to that zone. Zone 5 represents the most critical space and receives a portion of its utility requirements from each of the peripheral zones.

2-6. Design criteria

The principles of LVD described in this TM are intended to supplement, not replace, existing guidelines for the design of utility systems for C4ISR facilities.

a. The primary references for general design criteria are:

(1) TM 5-601, Supervisory Control and Data Acquisition Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

(2) TM 5-691, Utility Systems Design Requirements for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

(3) TM 5-692-2, Maintenance of Mechanical and Electrical Equipment at Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities – System Design Features.

(4) TM 5-698-1, Reliability/Availability of Electrical & Mechanical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

b. The application of the LVD concept generates the following additional utility system design criteria and assumptions applicable to the example facility:

(1) Mission activities require the entire facility to be self-supporting in the absence of external utilities for a specified mission time. This may dictate substantial internal storage of fuel for boilers and generators and of water for plumbing systems and cooling system makeup. This requirement does not apply to utilities needed only for life safety functions, such as fire protection water.

(2) The mission-critical space (Zone 5) must be supplied by utilities from enough sources to meet the reliability criteria, with segregation of pathways adequate to ensure survival of the required capacity.

(3) The mission-critical space must have fast-acting automatic systems to isolate the connections to a peripheral zone when an event occurs. This will prevent introduction of an agent to the command center through ductwork, draining of the command center chilled water system through ruptured zone piping, and similar impacts.

(4) Activities in the mission support space (Zones 1 through 4) are duplicated, if necessary, by parallel activities in other zones and thus do not require redundant utility services.

(5) There is no need to maintain partial mission activity or survivability within a zone where an event occurs. Systems intended strictly to promote survival of personnel or limitation of damage within a zone are recommended but are considered to be in addition to and not part of the scope of the LVD concept.

2-7. Reliability criteria

In general, the utility systems serving each zone of a facility that incorporates the LVD concept should meet the target reliability, availability, and maintainability (RAM) criteria specified for the mission activity within that zone. RAM criteria and various modeling and analysis methodologies applicable to C4ISR facilities are described in detail in TM 5-698-1. As design proceeds, systems should be modeled and RAM analysis performed in accordance with TM 5-698-1 to verify that all criteria are met.

a. Regardless of the numerical RAM criteria applied, the minimum level of redundancy for utility services from the peripheral zones to the command center should be N+2, where N is the number of sources required to meet the load. This ensures that with one source out of service for maintenance, an event affecting another source will not result in interruption of service to the command center.

b. For the example facility, with four peripheral zones available to supply utilities to the command center, requiring that the command center be able to operate at full mission capacity from two of the four zones (N=2) while providing connections from all four produces an N+2 system. The N+2 mechanical and electrical utility systems described in subsequent chapters of this TM have been analyzed and shown to provide an availability of utilities to the command center of "six nines," or 99.9999 percent, generally considered acceptable for mission-critical spaces. The report of this analysis is provided in appendix C, Reliability Analysis of Example Systems.

2-8. Capacity criteria

The utility systems in each zone should be sized to meet the peak demand of that zone plus the portion of the command center load determined by applying the above reliability criteria to the number of sources. For the example facility, with N+2 redundancy, each zone system would be sized at 100 percent of the zone load plus 50 percent of the command center load as a minimum.

a. Limiting the complexity of the utility systems within the command center zone may dictate higher capacities in the zone sources than dictated by redundancy alone. For example, an electrical system within the command center that uses four 50 percent sources may require more complex switching and controls than one that uses four 100 percent sources. Plan for future growth when sizing equipment.

b. Appendix D, Example of Utility Capacity Calculation, demonstrates how the required capacity is developed for the systems in the example facility.

2-9. Vulnerabilities

The utility systems serving facilities that incorporate the LVD concept have the same vulnerabilities as those in traditional C4ISR facilities, consisting of internal failure and external threat. Internal failure is addressed through proper selection and sizing of equipment and components, selective coordination of protective devices, qualified operators, and an effective maintenance program. External threats are addressed in the traditional manner through hardening, perimeter security, redundancy of sources, and on-site generation.

a. One vulnerability unique to the LVD concept is the potential for common-mode internal failure of multiple sources where they are interconnected at the critical load. The example facility relies on the ability to serve the critical load from any of the four sources to meet the RAM criteria.

b. In order to meet this criteria the facility must have the ability to operate from multiple sources in parallel or to automatically transfer from one to another when a source fails. It should also have the ability to definitively isolate from failed source(s) to prevent the failure from expanding to involve otherwise healthy sources. Lastly, the facility should provide adequate physical segregation within transfer equipment to prevent an internal failure from affecting multiple sources.

2-10. Scalability

Scalability is a desirable design feature of facilities using the LVD concept. This is represented in the building layout of the example facility, in which zone demarcation barriers run vertically and connections for access and egress are limited to the perimeter corridor. The LVD concept can be applied to this type of building configuration with any number of peripheral zones as long as there are at least three utility sources available to meet the N+2 criteria for the most critical zone. Each zone is treated as a separate building from a structural and utility systems standpoint, allowing cost-effective configuration of a larger C4ISR facility using a modular approach of adding identical zones.

a. Caution is warranted in applying reliability criteria as the number of peripheral zones increases. The reliability and availability provided by an N+2 system configuration decreases as N increases because of the larger number of sources required to simultaneously function correctly to meet the load. In a facility designed with eight peripheral zones, an N+2 configuration requiring six sources to serve the command center load would result in a significant decrease in reliability from that provided by the four-zone N+2 configuration discussed above.

b. The systems required to automatically transfer load between sources and isolate failed sources also become more complex as the number of sources increases, resulting in a higher probability of failure within the command center. For these reasons, the number of utility sources required to meet the command center load (N) should be limited to two regardless of the number of peripheral zones in the facility.

CHAPTER 3
ARCHITECTURAL AND STRUCTURAL SYSTEMS

3-1. Architectural and structural systems design criteria

The basic design criteria consist of protecting the command center of the C4ISR facility from an internal attack while limiting the impact of the event on the rest of the building space. The intent is to prevent bomb fragments (projectiles) as well as airborne chemical, biological, and possibly radiological agents from a terrorist attack from spreading throughout the building and to limit their mission impact on the zone in which the event occurs. Therefore, the approach for designing a generic building type such as this (see figures 2-1 and 2-2) is as follows:

a. Divide the building into zones that are sealed off from one another to prevent the spread of any potential contaminants. With each zone being totally self-contained, the damage or infiltration created by a bomb or hazardous agent does not affect an adjacent zone.

b. Locate the command center at the center of the building, with support spaces around it. This buffers this space in the case of a terrorist attack, whether by explosion, ballistics, or CBR agent release.

c. Segregate the mission support spaces into separate zones, each with its own independent mechanical systems, electrical service, toilet facilities, and exit ways (including exit stairways).

d. Connect each zone to other zones via a perimeter corridor for exiting and access functions. These corridors do not need to be separate zones. The perimeter corridor system requires only minimal mechanical and electrical services to meet life safety requirements.

3-2. Applicable building codes and standards

The building should be designed and constructed to meet the codes and standards required by the authority having jurisdiction (AHJ) at the specific location where the building is to be constructed. The building should meet the building codes for seismic construction as required at that locale or as directed by the AHJ.

a. In many cases, specific construction types and materials for exterior construction, and in some cases for interior construction, may be required at a particular location. The building should conform to those individual requirements as necessary. Many bases, posts, and governmental agencies have their own architectural design guidelines, which should be followed as closely as possible in the design of the building.

b. In addition, the building must meet the following codes and standards:

(1) Codes

(a) National Fire Protection Association (NFPA) 70, National Electrical Code (NEC)

(b) Most current approved building code, Uniform Building Code (UBC), International Building Code (IBC), or building code required by the AHJ

(c) NFPA 101, Life Safety Code®

(d) NFPA 13, Installation of Sprinkler Systems

(2) Standards

(a) Unified Facilities Criteria (UFC) 1-200-01 Design: General Building Requirements.

(b)Unified Facilities Criteria (UFC) 4-010-01, DoD Minimum Antiterrorism Standards for Buildings

(c) Unified Facilities Criteria (UFC) 4-010-10, DoD Minimum Antiterrorism Standoff Distances for Buildings

(d) Americans with Disabilities Act (ADA) Standards for Accessible Design

(e) Uniform Federal Accessibility Standards (UFAS)

3-3. Compartmentalization

To compartmentalize the C4ISR facility to prevent the transfer or migration of a fire, an explosion, or an airborne CBR agent, the walls dividing these zones are the first line of defense for the building interior.

a. Therefore, these zone demarcation walls should be constructed as follows:

(1) Extend the zone demarcation walls from the floor to the underside of the structure above.

(2) Construct these walls of blast-resistant materials. (See paragraph 3-5, Materials of Construction, for discussion of those materials.) Seal the walls at all joints, along with all mechanical ductwork, electrical conduit, miscellaneous piping, and other penetrations through these walls, to form a protective barrier.

(3) Use windowless demarcation walls to provide a level of protection against the spread of projectiles from a terrorist attack or other act of sabotage between zones.

(4) Use doors with a blast-resistant rating at all zone demarcation walls.

b. Within each zone, the interior doors, walls, and other structural features may be of standard construction unless directed otherwise by the AHJ. Blast-resistant doors are not required within a zone; the intent is not to require blast-resistant construction throughout the entire building.

3-4. Egress and circulation paths

Egress and circulation paths must take into consideration the Americans with Disabilities Act along with consideration of life safety.

a. C4ISR facilities must meet ADA requirements for accessibility as mandated by the federal government. These requirements include access for persons with disabilities throughout the building and accessible means of egress. The need for accessibility applies not only to persons in wheelchairs but also to people with other disabilities, such as those who use crutches or who have sight, hearing, or mental impairments. The example two-story facility shown in figures 2-1 and 2-2 takes into account the requirements for building accessibility. Note that the compartmentalization of the LVD concept requires accessibility to each zone independently.

b. Life safety is another important aspect of any building and must be taken into account for C4ISR facilities. The example facility shown in figures 2-1 and 2-2 provides a corridor system around the perimeter of the building for access to and egress from all portions of the building spaces. Additionally, corridors are provided to the command center itself for access and egress. These corridors serve as the exit enclosure or exit way for the building and are therefore of fire-rated construction. They are not considered separate zones in the same context as the mission support spaces and the command center. The exit corridors must be provided for life safety purposes; however, they also provide separation in a fire-related event, protection during a terrorist attack, and an additional buffer between mission support spaces to limit potential damage from an event in another space.

c. The example facility shown in figures 2-1 and 2-2 also includes stairways, which are required in multi-story facilities for exiting purposes. The following are considerations regarding stairways:

(1) To maintain the segregation of the LVD concept, each zone should have stairs that are connected to an exterior exit or enclosed exit way leading to an exterior exit from the building. Including a stairway in each zone further limits the spread of contaminants—whether chemical, biological, or radiological—to other parts of the building.

(2) The number of stairways should be determined by the requirements set forth in NFPA 101 or the building code required by the AHJ at that specific location. Those requirements include, but are not limited to, travel distance to the stairways and occupant load of the floor plate.

(3) In the event of an emergency, stairways may also provide an area of refuge for persons in wheelchairs. The size of this refuge area should be determined from the relevant building code or the AHJ.

(4) Personal protective equipment (PPE) and other emergency response provisions such as first aid stations, fire extinguishers, and standpipes should be established individually for each zone.

3-5. Materials of construction

This document is not intended to provide a list of building materials or building systems to use in construction nor to provide equivalent blast requirements of various building materials to use in the application of the LVD concept. There are many DoD documents that provide information about the minimum AT/FP standards for buildings. These documents should be consulted when the design basis threat level for the building has been determined. Only then can the design and engineering professionals design the building to withstand the corresponding event.

a. To determine and specify building material strengths, flammability, and barrier characteristics, it is necessary to consider the design basis threat and the geographic location of the C4ISR facility, which could have a major effect on the construction type and available construction materials.

b. The following guidelines apply to materials for the zone demarcation barriers of a C4ISR facility:

(1) Doors and frames should be of blast-resistant construction. Ratings for blast-resistant doors are to be determined based on the design basis threat for the building.

(2) Glass, when used, should be of laminated construction and used in small amounts. The amount of glass used should be directly correlated to the design basis threat for the building.

CHAPTER 4
MECHANICAL SYSTEMS

4-1. Mechanical design criteria

The intent of the LVD concept, described in paragraph 2-3, Limited Vulnerability Design Concept, is to create a facility that is self-sufficient and capable of surviving a single internal threat event. For mechanical systems, this requires a design that provides the ability to adapt in response to a detected flood, explosion, or CBR event within an area and thereby protects the remaining spaces for the duration of the mission. Paragraph 4-7b(1), Relative Pressurization, discusses these system reactions in detail. The designer should provide means by which service throughout the facility can meet mission RAM criteria. Some recommended methods are system redundancy, multiple utility services, and alternate fuel sources, as discussed in paragraph 4-3, System Reliability.

a. The ability to maintain functionality in the remaining spaces in spite of an event in a single zone is critical. Accordingly, the designer should design the mechanical systems serving those spaces in a manner that mitigates their inherent vulnerabilities to internal threat events. An added benefit of such design considerations is that many of the measures that reduce the vulnerability of facilities also provide enhanced protection against natural and accidental incidents. However, the designer should ensure that any measures taken to reduce the vulnerability of the facility to an internal attack do not inhibit normal operation. The measures must also be capable of immediate, seamless implementation and should follow a regular testing and maintenance schedule.

b. At a minimum, the designer should consider the following basic criteria to ensure self-sufficiency and reliability of mechanical systems in the design of C4ISR facilities.

(1) There should be at least two independent sources for external utilities.

(2) Mechanical systems at a minimum redundancy of N+2 should serve mission-critical zones (such as command centers).

(3) All external critical utilities (such as water or natural gas) should include an internal well, internal storage capacity, or alternate fuel that is sufficient for the established facility mission time. The water source should be sufficient for potable and makeup water uses.

4-2. Applicable codes and standards for mechanical systems

The following codes and standards govern the design of mechanical systems as part of the LVD concept:

a. TM 5-691, Utility Systems Design Requirements for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

b. TM 5-810-1, Mechanical Design: Heating, Ventilating, and Air Conditioning

4-3. System reliability

The overall level of reliability required for the operation of a C4ISR facility is very high. To achieve this, the LVD concept supports the creation of self-supporting peripheral zones serving a central command center. These peripheral zones contain less critical functions, enabling the facility as a whole to accept

the loss of a single peripheral zone to an internal event as long as service to the surviving zones remains intact. For this purpose, the LVD concept incorporates dedicated mechanical systems and utility connections for each zone. The functions of the command center are the most critical to the facility mission. Consequently, the designer should take extra measures to improve the reliability of systems serving it. In accordance with this requirement, the designer should consider the use of system redundancy and alternate fuels, specifically with regard to achieving the minimum required N+2 redundancy for the command center.

a. Redundancy is a proven concept used to increase system reliability, in the LVD concept, the peripheral zones house dedicated mechanical rooms. These rooms contain the main mechanical equipment and hydronic piping mains. They also provide the entry point for all external utilities serving the building. Building operation depends on having adequate backup to all critical systems in the event of a disruption in a single zone. Therefore, redundancy for both external utilities and HVAC systems is required.

(1) Under normal operation, C4ISR facility operation typically relies on public utility systems. These utilities include water, sewer, and natural gas. Given the reliability requirements for the facility, however, dependence on a single source for these utilities is not recommended. The designer should coordinate with other disciplines and local utility providers to ensure that the utilities brought to the site have at least two independent sources.

(a) Each zone should have dedicated taps off these utility mains, with appropriate contaminant sensors, backflow prevention (on water), and shutoff capabilities to protect the main lines. Paragraph 4-5, Automatic Isolation and Backfeed, discusses these devices in more detail.

(b) A dedicated sewer line and storm drain system should also support each zone. The sewer lines should not combine into a common line until outside the facility perimeter. Composting toilets or other means should be available in case sewer service is lost due to an event. Any storm drains serving the command center area should route through the peripheral zone systems. Overflow capability is typically required for a storm drain system design per code and should be adequate for system backup.

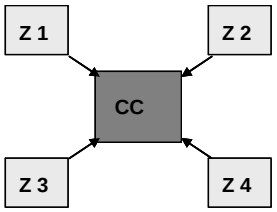
(2) Heating, ventilation, and air-conditioning should also utilize redundancy to increase system reliability. In addition to serving the associated zone, each peripheral mechanical system (wet and dry side) should share an equal portion of the command center load to meet the N+2 redundancy criteria. The designer should size each zone's mechanical systems so that if an event during maintenance were to result in the loss of two of the supporting peripheral zones, the remaining mechanical systems would be able to handle 100 percent of the command center load (see figure 4-1). If the number of peripheral zones exceeds five, to limit the system cross-connections, the designer should select only five of those zones (spread throughout the building) to serve the command center. Similarly, the computer air-conditioning units (CACs) located within the command center should support the load so that two units can be lost without affecting the command center.

b. The requirements for self-sufficiency dictate the provision of internal sources for utilities that are critical to facility operation. Some of these requirements are:

(1) In the case of water, each zone may have an internal well or storage tank. In the case of fuel for boilers and generators, liquid fuel (diesel) is likely to be the most practical to store internally, but compressed natural gas, propane, or other fuels may be considered.

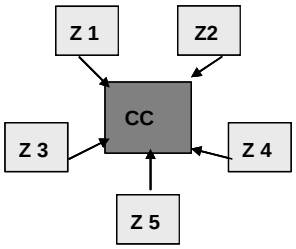
(2) Storage capacity should be based on the defined mission time for each specific facility and may require significant physical space. For example, to provide 3 days of storage for the example facility would require approximately 14,000 gallons of water and approximately 4,600 gallons of diesel fuel for

each of the four peripheral zones. This may dictate adding a below-grade level to the building dedicated to storage tanks.



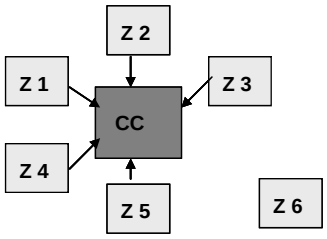
FOUR PERIPHERAL ZONES

ZONE CAPACITY (Contribution Equivalent to 2 Zones down)	NORMAL CONTRIBUTION TO COMMAND CENTER (CC)	ZONE CONTRIBUTION WITH ONE ZONE DOWN
Zone + 50% CC	25%	Zone + 33%CC



FIVE PERIPHERAL ZONES

ZONE CAPACITY (Contribution Equivalent to 2 Zones Down)	NORMAL CONTRIBUTION TO COMMAND CENTER (CC)	ZONE CONTRIBUTION WITH ONE ZONE DOWN
Zone + 33% CC	20%	Zone + 25%CC



SIX PERIPHERAL ZONES

ZONE CAPACITY (Contribution Equivalent to 2 Zones Down)	NORMAL CONTRIBUTION TO COMMAND CENTER (CC)	ZONE CONTRIBUTION WITH ONE ZONE DOWN
Zone + 33% CC	20%	Zone + 25%CC

Figure 4-1. Scaled peripheral zone support of the command center

4-4. Plumbing distribution system configuration

Each peripheral zone requires access to systems served by external utilities. One approach the designer may use involves pressurized loops around the building. Figure 4-2 illustrates this approach, showing the main lines for two external utilities (water and gas) routed in loops around the example facility, inside the secure perimeter. Two independent external sources (labeled W1, W2, G1, and G2 in the figure) serve each loop as discussed in paragraph 4-3a(1), External Utilities. These sources are provided with check valves to prevent backflow. The loops are also equipped with shutoff valves to isolate a portion of the loop should it be damaged. To meet the self-sufficiency criteria, a third source of water (labeled W3 in the figure) is required for each zone. This may be a well or a storage tank but, in either case, should be located within or beneath the zone. These sources should be of sufficient size to provide makeup water to the zone cooling tower (if the required storage tank size is prohibitively large, air-cooled heat rejection should be considered).

a. The designer may choose to provide storage capacity for natural gas as well, but the alternate liquid fuel option may be more feasible. In either case, fuel storage capacity should be provided in each zone. Taps off the main line provide dedicated service to each zone. These taps should have hydro-pneumatic tanks on the lines to replace losses due to leakage. The command center receives domestic water service from taps off the dedicated zone water lines. Design of the domestic hot water system is at the discretion of the designer and is not critical for mission operation.

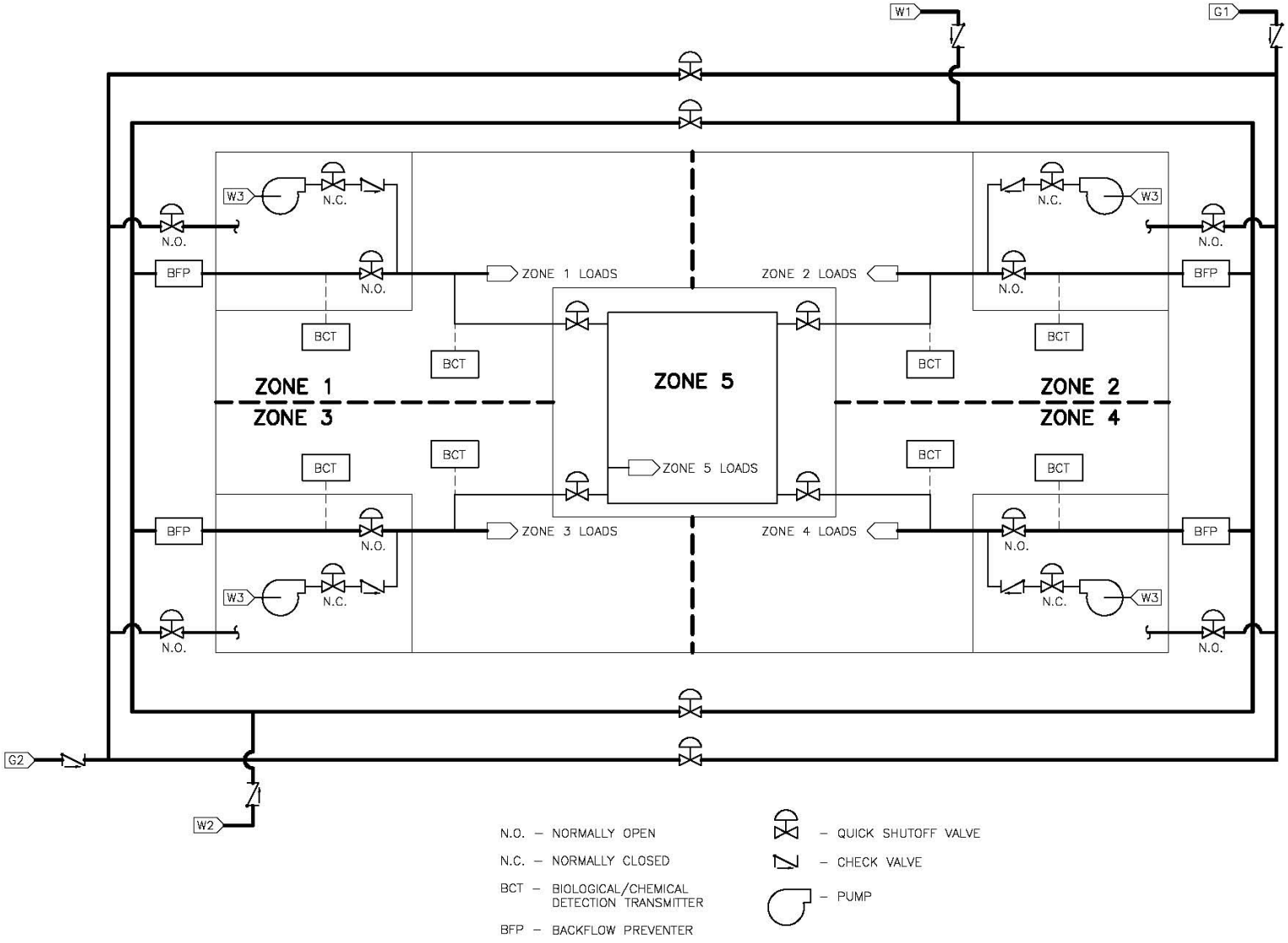


Figure 4-2. Zoned utility connections

b. Locating utility loops inside the secure perimeter should protect the local water and gas mains from potential threats; however, the designer should also consider protecting the building from sewer system tampering. The sewer lines and storm drains for each zone should preferably route to the exterior of the building rather than passing beneath another zone. Potential vulnerabilities in a sewer system include those of explosion and system backflow. In addition to zoning the vent and waste lines, the designer could address these vulnerabilities by including a couple of extra design precautions. Recommended precautions involve oversizing the system vents to reduce the effects of explosion and terminating the vents with goosenecks at the roof level to deter the introduction of foreign substances. Another precaution is to include backwater valves in the sewer lines to prevent CBR contamination of the building through sewer system backflow. Secured cleanouts for water and waste lines should be located inside the building. Vent lines internal to the building and exiting to the building roof are not defensible through mechanical means; protection of these is dependent on limitation of access to the roof.

4-5. Plumbing system – automatic isolation and backfeed

The designer can mitigate the vulnerability of plumbing systems to CBR contamination by employing the redundancy of sources and system segregation techniques discussed previously. The designer should also take additional measures by providing backflow protection, detection, and isolation devices, as follows:

a. Equip zone water lines with a control valve for isolation, coupled with contaminant detection upstream of the valve. Electrically actuated isolation valves, controlled from a central system, automatically close upon detection of a contaminant within the main utility stream. This measure prevents contaminants introduced at the utility level from contaminating everything downstream.

b. Provide additional shutoff and detection devices on the water lines between the peripheral zone and the command center to protect the water from zone-level contamination.

c. Include shutoff valves in the main loop to permit isolation and partial operation of the loop in the event that one side is damaged. These devices should close upon loss of pressure on one side of the loop.

d. Where appropriate, equip utilities with backflow prevention devices. These devices prevent contamination at the zone level from leeching back into the main supply line and rendering it unusable for other zones. Also provide backflow prevention (such as check valves) in the utility source lines to prevent loss of flow from the loop if pressure is lost in a source line.

4-6. Fire protection water and suppression systems

Fire protection water follows the same configuration as domestic water: it is looped beneath the building, with each zone tapped separately from the main line through the appropriate shutoff and backflow prevention. Due to the large volume required, fire protection water typically does not have an internal water tank as backup.

a. This is acceptable because the command center, housing the most critical facility functions, is provided with a clean-agent fire suppression system in lieu of a fire sprinkler system. External water tanks or surface water sources may be considered for backup of the regular fire protection system under special circumstances such as remotely located facilities.

b. The command center fire suppression system is a clean-agent delivery system designed to safeguard both the equipment and occupants within the command center. To minimize the impact on command center operations, the suppression system should be controlled in two stages. This facility is assumed to be staffed on a continuous basis; therefore, the first line of defense in the event of a fire should allow the

staff the opportunity to address the fire with hand-held equipment. Thus, the first control stage for the system should be to alarm only. The second stage should activate the automatic clean-agent fire suppression system to extinguish the fire. The location of the clean-agent tanks and controls for this system should be within the command center secure zone.

4-7. Heating, ventilation, and air-conditioning systems

In addition to providing general space conditioning and occupant comfort, the goal of an HVAC system design generally is "…to achieve isolation of contaminated spaces and provision of safe egress paths or safe refuges for building occupants" (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] Journal, September 2004). C4ISR facilities are unique in that the continuance of the mission is more critical than the survival of building occupants in a zone affected by an event. Nevertheless, the LVD concept endeavors to safeguard personnel to the degree possible while still supporting the mission. The intent is to accomplish this purpose using available proven technologies or strategies, not specialized systems. Some potential strategies are pressurization, filtration, and isolation of systems.

a. Figures 4-3a and 4-3b illustrate the relationship of the zone HVAC systems to their associated zone and to the command center. Figure 4-3c conveys a more detailed schematic of the wet side at the mechanical room. All peripheral zones have similar configurations, as shown in figures 4-3a, b, and c. In this example, each of the four zones can support the zone load plus 50 percent of the command center load as discussed in paragraph 4-3a(2), Heating, Ventilation, and Air-Conditioning.

b. The rooftop makeup air-handling units (MAUs) provide filtered fresh air for the zone air-handling units (AHUs) and the command center. The AHU mixes the space return air with the fresh air to supply air to the zone. A gas-fired boiler (B) provides heating water that warms the air stream while a water-cooled chiller (CH), paired with a roof-mounted cooling tower (CT) and condenser water pump (CWP), provides the means for cooling. CACs provide cooling for the command center, rejecting heat to the chilled water system. Heating water and chilled water pumps (HWP and CHWP) circulate the water to serve the zone-level MAU, AHU, and terminal unit coils. They also feed a pressurized loop within the command center serving the CACs. Roof-mounted exhaust fans (EF) pull exhaust air from the spaces.

(1) Building pressurization may have little effect during a flood or explosion, but it can provide a level of containment and protection in a fire or CBR release event. To compensate effectively for a CBR event, the building pressurization system should have the ability to be dynamic. The HVAC design should positively pressurize the entire C4ISR facility relative to the outdoors. The "level of pressurization should be based on the pressures that need to be overcome, primarily those due to wind and stack effects, but also those induced by system operation. Therefore, each building's pressurization strategy should be designed based on the climate, the building height and the envelope leakage" (ASHRAE Journal, September 2004). A pressure gradient should also exist between zones, resulting in airflow from critical areas to support zones and then to the building exterior. Upon detection of a contaminant, a special controls routine should initiate the shutdown of all supply to and exhaust from the contaminated space. Surrounding zones should increase pressurization with respect to the affected area by adjusting their fan speed to prevent cross-contamination. These adjustments in the mechanical systems should keep the contaminant contained within the zone of origin.

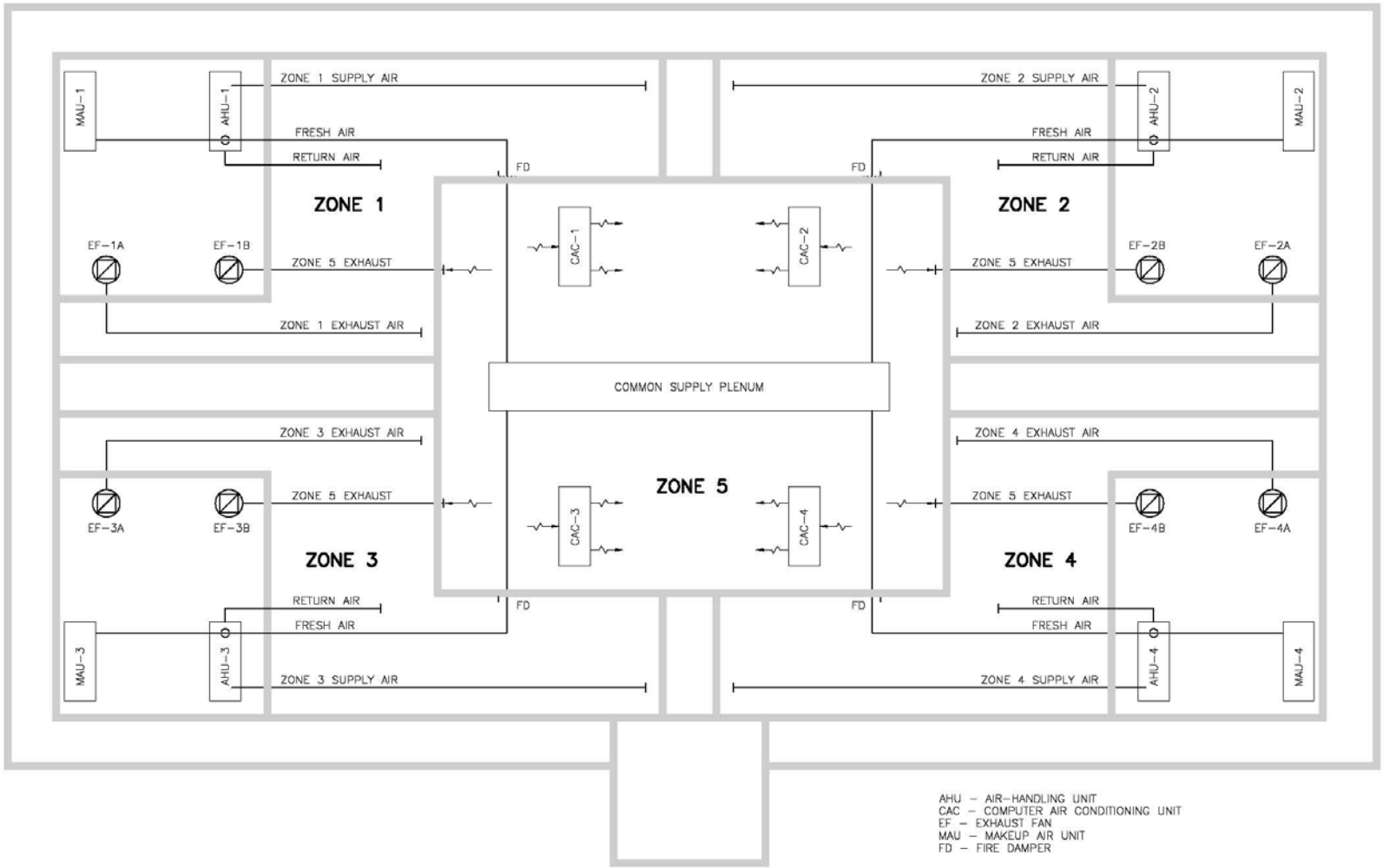


Figure 4-3a . Dry side schematic plan view of HVAC system

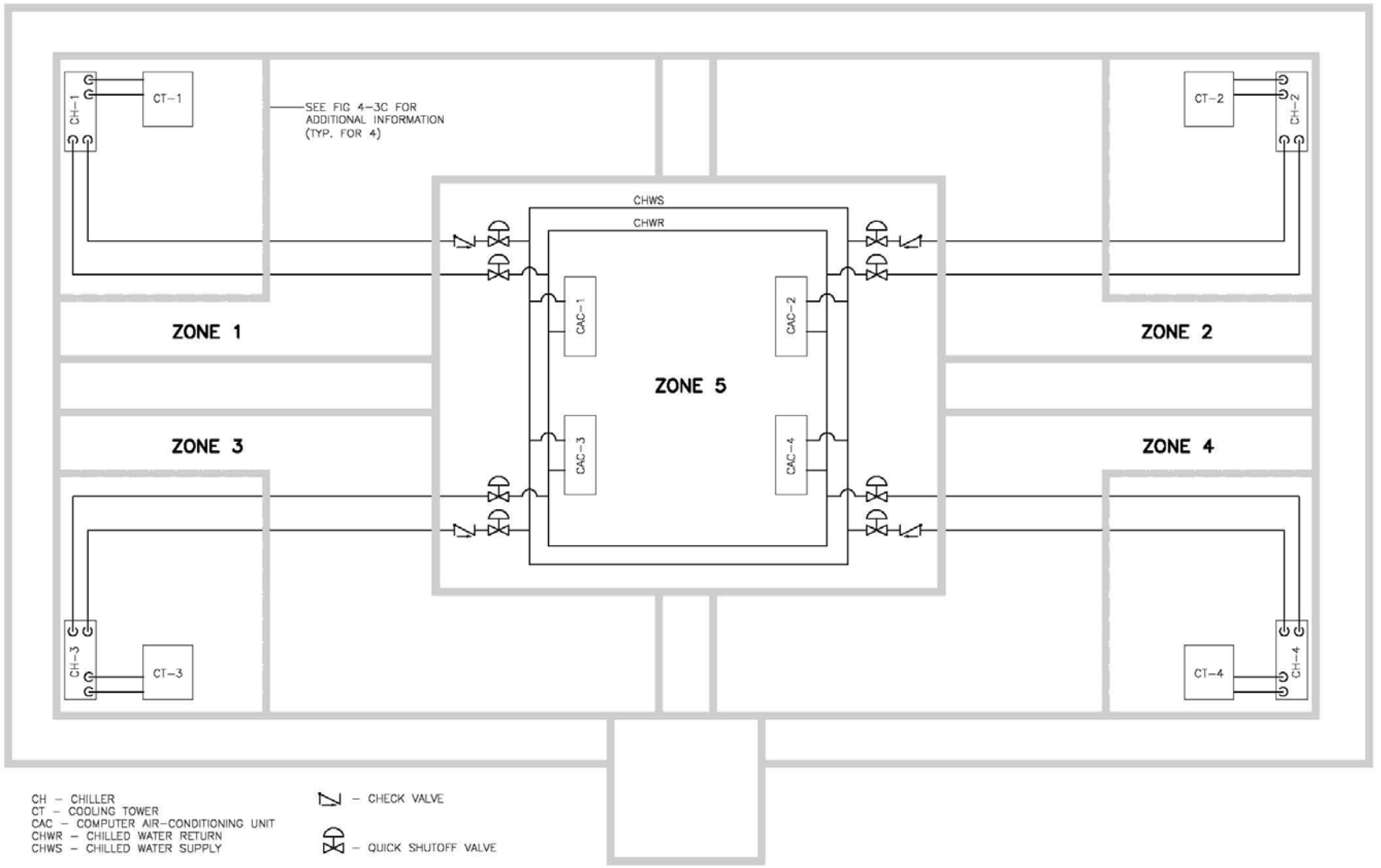


Figure 4-3b. Wet side schematic plan view of HVAC system

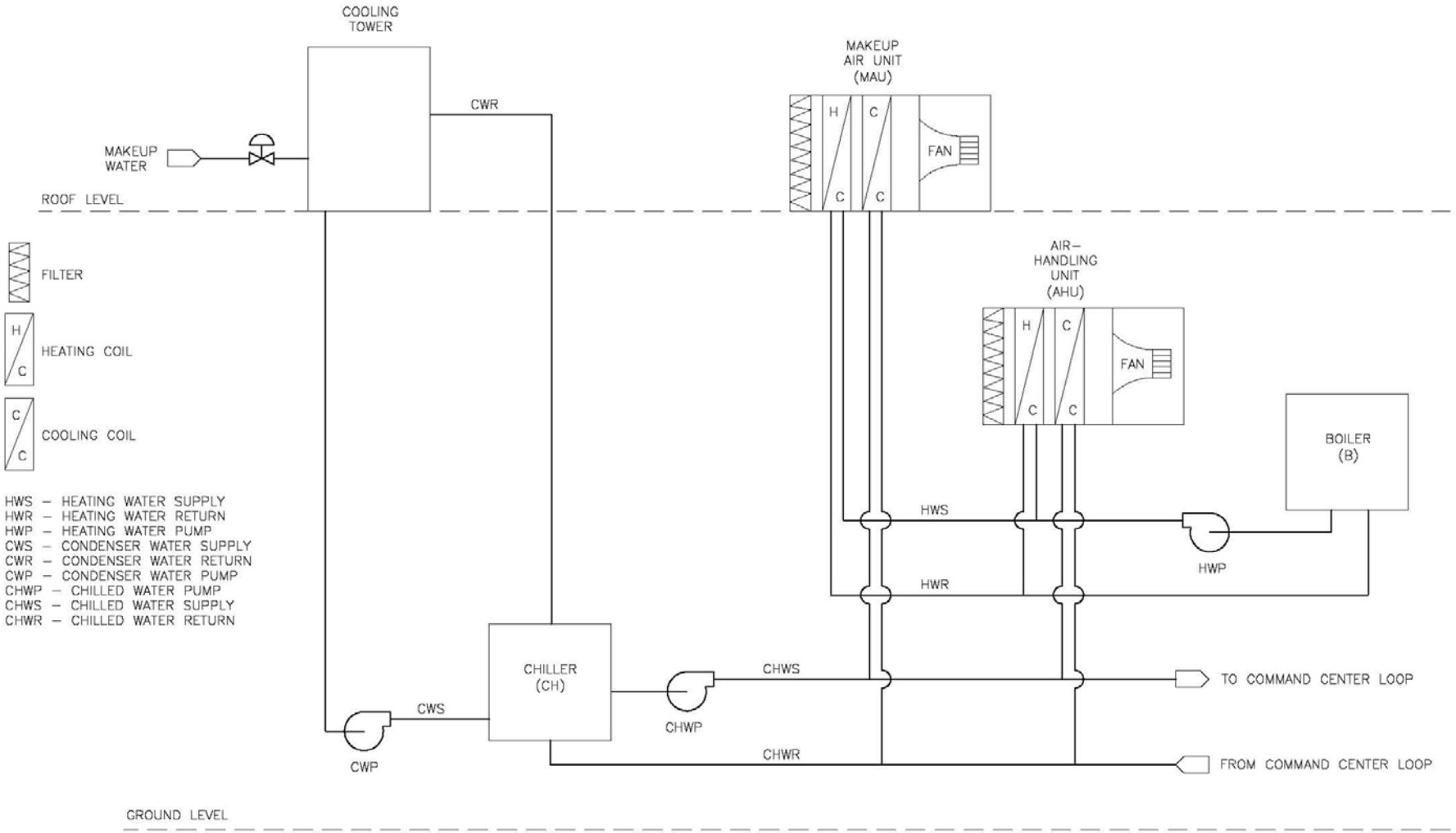


Figure 4-3c. Wet side schematic diagram of a typical mechanical room

(a) Though the mission is the primary concern, the mechanical system should also maximize the potential for egress from a contaminated space. Any event detected in a zone should initiate a response from the mechanical system. The designer should provide the perimeter corridors with air from the nearest peripheral zone system. Central corridors (those providing egress from the command center) and vestibules should be pressurized using conditioned air from the command center. These corridors should always be at higher pressure than the surrounding peripheral zones and perimeter corridors. This allows individuals evacuating a contaminated zone to exit through the common vestibule without risking cross-contamination to other zones. This higher level of pressurization also creates an added layer of zone separation.

(b) Figure 4-4 shows the relative pressurization of the example facility under normal operating conditions. The building is positive to the outdoors, preventing infiltration from an external CBR event. Within the building, the command center, the most critical zone, is positive to the peripheral zones, where pressurization levels are equal relative to one another. The building pressurization would adjust as shown in figure 4-5 upon detection of an event in Zone 2. Shutdown of supply and exhaust should permit the contaminated space (in this case, Zone 2) to slowly move toward equilibrium with the outside through exfiltration. The MAUs and associated AHUs serving adjacent zones would ramp up to provide additional pressurization to their associated zones to prevent contamination. Occupants of Zone 2 could then safely exit the contaminated zone through the adjacent perimeter corridors.

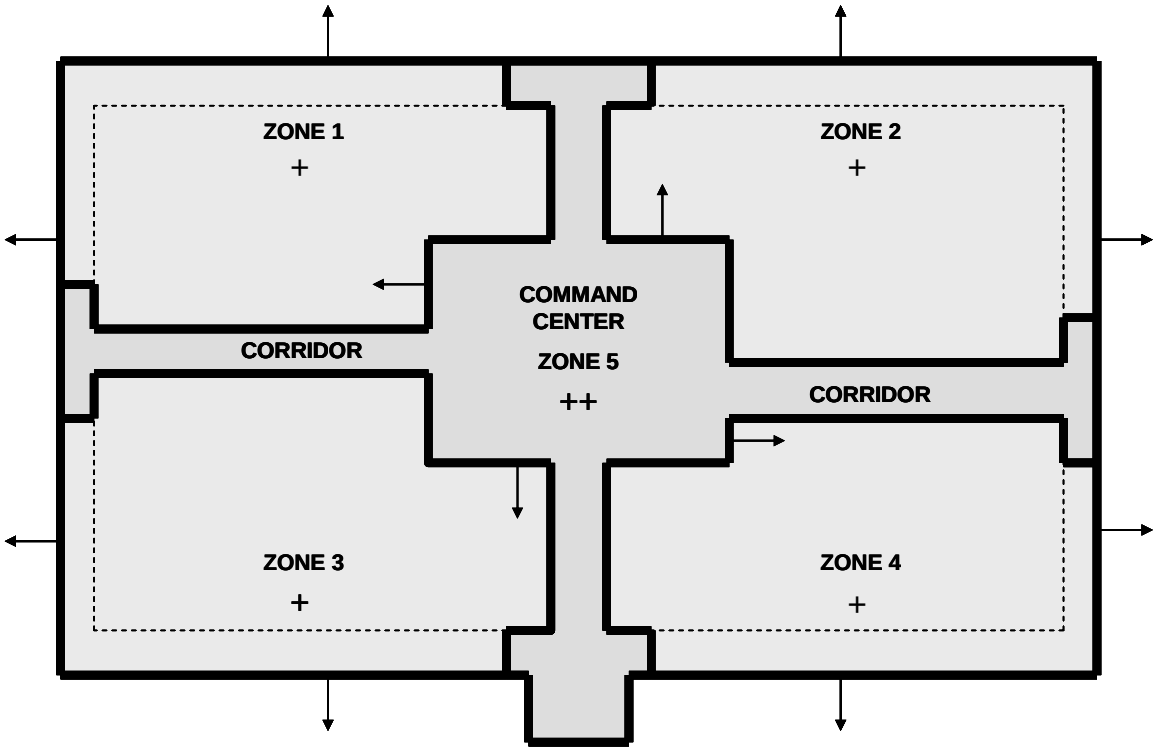


Figure 4-4. Normal pressurization

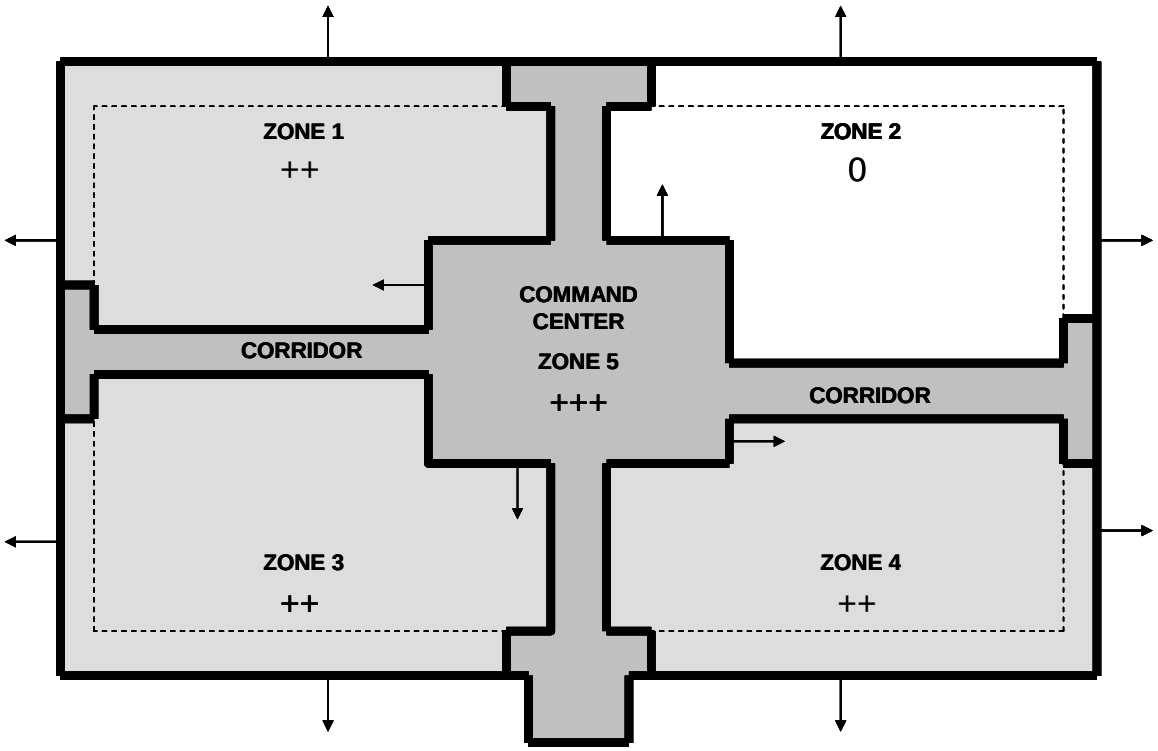


Figure 4-5. Emergency pressurization

(2) The design of mechanical systems for the LVD concept should rely on standard equipment and a segregation strategy rather than specialized systems. With this strategy, the loss of some peripheral zones is acceptable as long as the command center remains operable. Thus, the AHUs serving the zones need only to follow standard commercial design practice for filtration. However, the design of the MAUs should include filtration in accordance with standard guidelines for CBR protection. Use of CBR filtration on the MAUs not only provides an additional level of protection for building occupants, but also expedites cleanup efforts of a contaminated zone. PPE such as gas masks, suits, and gloves should also be available to occupants in the case of a CBR event. The designer may also choose to supplement the filters with ultraviolet light (type C) emitters located within the MAUs to act as a germicide.

(3) Chilled and heating water systems serve the MAU, AHU, CAC, and terminal unit coils in a facility. Provided that they undergo proper maintenance, these systems are less vulnerable to a CBR attack than other systems. However, chilled water is an especially critical system due to the cooling requirements for equipment in the command center. An explosion or similar event is more likely to affect this particular system. Hydronic systems should have quick shutoff devices on the supply and return side of the water loops to prevent loss of water from the command center loop in the event a zone is lost. The supply side should also have a check valve.

(a) These devices should be located within the command center zone. Once these devices shut off a zone, the unaffected zones will continue to support the command center loop. Hydro-pneumatic tanks should be provided in the chilled water lines (just prior to the shutoff valves) in other zones to replace chilled water leak loads. TM-5-691 contains additional discussion of hydronic system vulnerabilities and equipment configuration.

(b) The size and quantity of CACs required to cool the command center depends on the types and amount of electronic equipment, the number of occupants, and the arrangement of the space. For illustra-

tion purposes, four units are shown serving the command center, but the actual number should be determined from load calculations and the N+2 redundancy requirement.

(4) Isolation and control devices used in the control of mechanical systems also should be readily available technologies, not specialized systems. For instance, the controls developed to modulate air-handling systems for building pressurization in a CBR event should be similar to the industry standard strategies and devices for smoke control. Automatic, quick-shutoff, piston- or electrically actuated solenoid control valves for utilities are available in sizes as large as 2 inches in diameter. For larger water pipes up to 8 inches in diameter, electrically actuated, spring-return butterfly valves are available. These devices should operate in less than 10 seconds with fail-safe positioning, typically fail closed. Actuators on time-critical dampers (which must open or close quickly, such as emergency generator exhaust dampers) should be a spring-return type with a safety function.

CHAPTER 5
ELECTRICAL SYSTEMS

5-1. Electrical design criteria

The design of electrical service and distribution systems should be consistent with industry standards such as those produced by the Institute of Electrical and Electronics Engineers (IEEE), NFPA, and the American National Standards Institute (ANSI) as well as applicable DoD guidelines and standards. System designs should make use of utility-grade equipment and components to support reliability and maintainability. While there is no formal standard definition, utility grade is generally distinguished from commercial grade by construction and features that support extended life expectancy, tolerance of adverse environments, and ease of access and disassembly for testing and maintenance. Examples of the difference are shown in table 5-1.

Table 5-1. Features of utility-grade and commercial-grade equipment

Utility Grade	Commercial Grade
Drawout-mounted protective devices with tested surge withstand capability for power system relaying	Surface-mounted relays with no tested withstand ratings
Switchgear complying with Underwriters Laboratories Inc. (UL) Standard 1558 construction standards	Switchboards complying with UL Standard 891 construction standards
Low-voltage power circuit breakers rated to ANSI Standard C37 and UL Standard 1066	Molded-case or insulated-case circuit breakers rated to UL Standard 489

5-2. Applicable electrical codes and standards

The following specific standards are of particular concern in the design of electrical systems to support the LVD concept:

a. TM 5-689, ADP/Computer Electrical Installation and Inspection for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

b. TM 5-690, Grounding and Bonding in Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

c. TM 5-693, Uninterruptible Power Supply Selection, Installation, and Maintenance for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

d. NFPA 70, National Electrical Code (NEC).

e. NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.

f. IEEE Standard 242, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.

g. IEEE Standard 493, Recommended Practice for Design of Reliable Industrial and Commercial Power Systems.

h. IEEE Standard 1100, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.

i. ANSI C37, Standards Collection: Circuit Breakers, Switchgear, Substations, and Fuses.

5-3. Segregation and separation

Segregation and separation of power generation, power distribution, equipment and controls is necessary to provide the ability of the system to reliably and safely function in the event of a catastrophic event.

a. Figure 5-1 shows one possible arrangement of utility service, standby generation, and power distribution for the example facility. In this case, each peripheral zone bus has local standby generation adequate to carry the contingency load on that bus. The load on each bus consists of the demand load of that zone of the building plus a share of the command center demand load. Loss of a single peripheral zone results in a loss of only one of the four feeders to the command center. These feeders should be routed entirely within the zone of origin until they cross the barrier wall into the command center.

(1) Within the command center, it is assumed that physical segregation of utility supplies to protect from explosive threat is not necessary. However, it remains critical to provide adequate segregation internal to equipment to prevent an arcing fault from propagating to affect multiple sources.

(2) Figure 5-1 shows a possible arrangement of transfer equipment when the command center loads are served from a 2N uninterruptible power supply (UPS) and mechanical system. The normally open tie circuits isolate the "A" buses from the "B" buses so that no single component failure can affect both sides.

b. Segregation of controls is also critical. A significant advantage of the distribution scheme shown in figure 5-1 is that independent transfer controls can be provided for the redundant portions of the system. Each service has an automatic bus transfer scheme that starts the generator and transfers the bus on failure of the utility source; there is no need for common controls between services. Similarly, within the command center, the "A" and "B" distribution is provided with separate automatic transfer controls. Redundancy of the electrical system should be selected to match the redundancy of the mechanical and other loads it serves. It may be tempting to increase the degree of redundancy by providing tie circuits between the services or by automating the tie breakers between the "A" and "B" buses within the command center. This would result in higher calculated availability due to more combinations of paths to the load but would require that control systems cross the segregation boundaries established for the distribution. This risks actually lowering availability by complicating the control scheme and introducing the potential for a control system failure to produce common-mode failure of multiple distribution paths.

5-4. Protective device coordination

Electrical systems in all areas of the C4ISR facility should be designed for selective coordination of overcurrent and other modes of protection according to IEEE Standard 242. It is particularly critical that the distribution system within the command center zone be selective to prevent a single internal fault from propagating upstream to the feeders that supply this zone from the peripheral zones. Electrical system reliability calculations verifying compliance with mission requirements generally assume that protective devices are selectively coordinated; failure to design for complete selectivity will result in the actual reliability of the command center service being significantly lower than the calculated values.

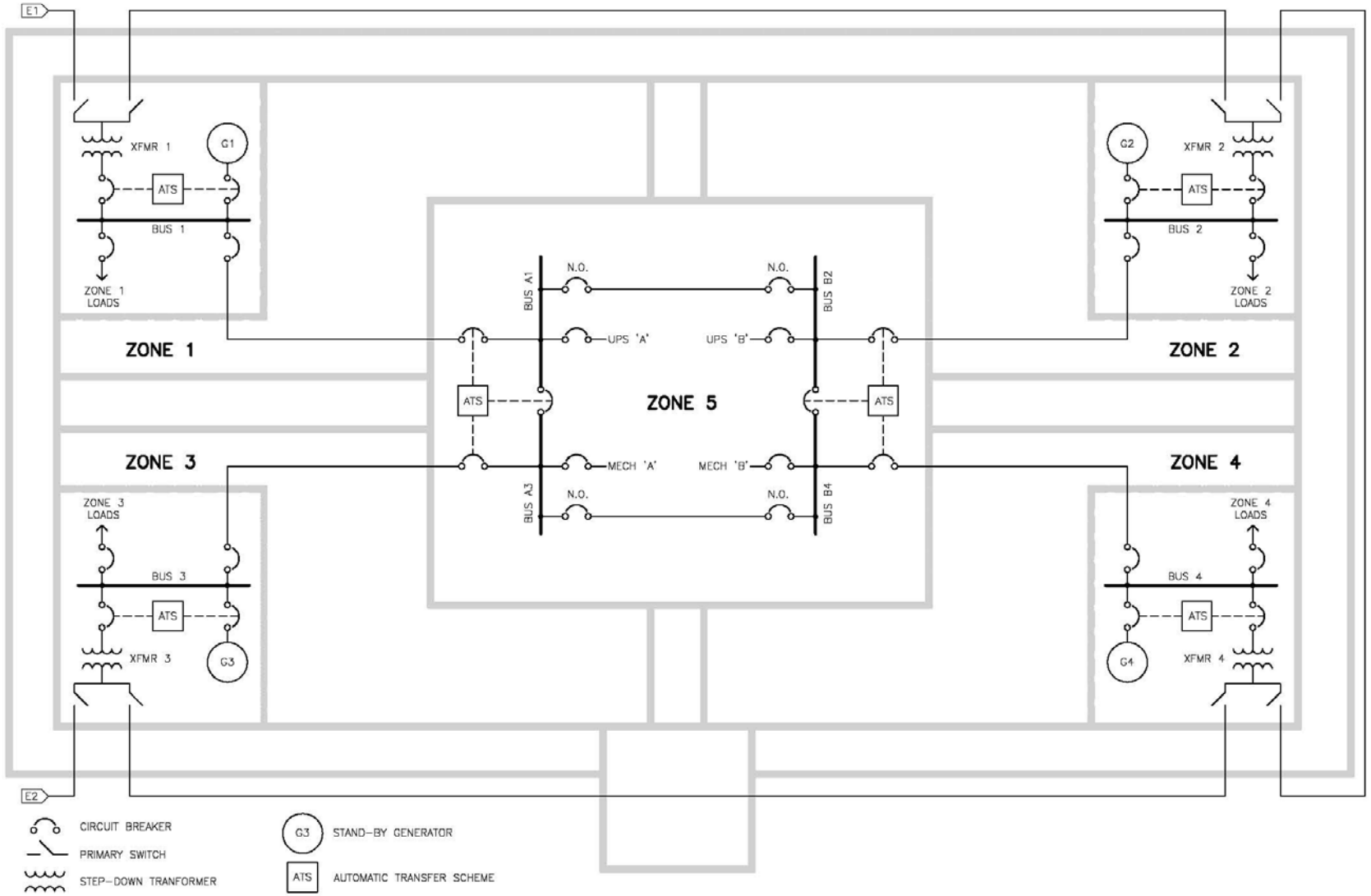


Figure 5-1. Example facility single-line diagram

a. It is assumed that power distribution within the facility will be at 480V or higher due to the large mechanical loads. Such systems, where ground fault protection (GFP) is required, should be designed as 3-phase, 3-wire systems without line-to-neutral loads. This simplifies the GFP schemes and reduces the probability of nuisance tripping. If line-to-neutral loads, such as 277V lighting, must be served, dedicated distribution for them should be provided by separate isolation transformers. This is a particularly valuable design approach for systems such as this, having load transfer downstream of the feeder circuit breakers; if the distribution were a 4-wire system, the large number of neutral tie points would lead to extremely complicated GFP schemes.

b. Within each peripheral zone, feeder circuit breakers must be selectively coordinated with the utility and generator source circuit breakers. This prevents a fault on a feeder within the zone from interrupting service from that zone to the command center. Generator current decrement characteristics must be considered to maintain the selectivity attained for operation from the utility when operating from the higher source impedance of the generator. The number of levels of GFP should correspond to the number of levels of phase overcurrent protection.

c. For the command center service configuration shown, feeder circuit breakers from the main buses to the mechanical and UPS loads must be selectively coordinated with the main circuit breakers on each incoming service. If possible, each main circuit breaker within the command center should also be coordinated with the circuit breaker on the other end of that circuit in the peripheral zone. This prevents a feeder breaker failure within the command center from causing a trip of the supply circuit, which could be misread by the supervisory control and data acquisition (SCADA) controls as an outage and could lead to automatic transfer of the faulted bus to the other supply circuit.

5-5. Grounding and surge protection

Grounding and surge voltage protection of power circuits within the facility is critical to preventing electrical transients, generated naturally or as a threat, from presenting a common-mode failure opportunity for the electrical systems.

a. Control system circuits crossing zone boundaries should use fiber optic cable to eliminate this possibility entirely. Surge protection should be installed in compliance with IEEE Standard 1100, with particular attention to effective grounding.

b. The facility should have a common ground system, designed and constructed in compliance with TM 5-690. It is neither practical nor technically sound to attempt to establish separate ground systems by zone. Rather, attention should be paid to effective bonding and to creating a low-impedance ground grid to minimize potential differences between zones across the full spectrum of surge and noise frequencies. If a single-point grounding system is used, the main ground bar should be located within the command center zone.

5-6. Physical installation

Conduits passing between the peripheral zones and the command center zone should be routed underneath the floor slab whenever possible. This decreases the number of penetrations required in the zone barrier walls, which may reduce their structural strength as well as create vulnerable points for a blast threat. Placing these conduits under the slab improves their survivability in the event that an explosion or fire event damages the interior of the zone but leaves the mechanical and electrical utility space intact. Conduits and other raceways crossing zone boundaries, regardless of routing, should be sealed to prevent the transmission of liquids or gases between zones via the conduit path. Where penetration of zone barrier walls is required, the structural engineer should be consulted for construction details to ensure that the

conduit penetration cannot permit a blast wave to propagate across the boundary. Flanged, cast-in-place conduit sleeves with threaded fittings are recommended as a minimum measure to effectively seal between the wall and the outside of the conduit.

5-7. Standby generation

The capacity of standby generation for each peripheral zone should be determined as discussed in Chapter 2, Fundamentals of Limited Vulnerability Design, for the load of that zone plus the share of command center load allocated to that source under contingency conditions. Due to the constant nature of the electrical and mechanical loads in the command center, and the possibility of extended operation on standby power, engine and generator ratings should be specified on a continuous basis rather than a prime or standby basis.

a. To meet the design criteria of facility operation independent of external utilities, prime movers with fuel storage inside the secured perimeter are required. If the quantity of fuel required for the specified mission time permits, diesel engine generator sets with integral sub-base fuel tanks are a means of both meeting the internal storage requirement and providing redundancy in the fuel supply equivalent to that provided in the generators. If the mission time dictates large quantities of liquid fuel storage, fuel treatment to counter the effects of aging may become necessary. Other prime mover technologies and fuel types may also be considered if proven in standby service.

b. A consideration with respect to the routing of fuel fill and vent lines from internal storage tanks is their potential exposure to fire and explosion as well as the possibility of introducing contaminants through the lines to the tank. Fuel fill lines for tanks serving separate zones should not be grouped at a common fill station. For reliability, gravity flow is recommended from bulk tanks to engines or day tanks.

c. Air supplies used for cooling and combustion air must be protected from unauthorized access and segregated to prevent common-mode threats. The use of rooftop-mounted remote radiators greatly reduces the amount of air that must be circulated through the space housing the engine-generator, which assists with the design of blast-resistant air intakes.

d. In the example facility, it is assumed that a single standby generator is located in each peripheral zone, with a remote radiator mounted on the roof above the mechanical and electrical equipment room. This places the radiator inside the perimeter corridor, where it is relatively well protected from external threats. Air intakes for generator room cooling and combustion air and exhaust of the cooling air must also be within this rooftop area due to the presence of the perimeter corridor. These requirements must be carefully coordinated with those of the mechanical equipment to establish air flow patterns that provide adequate cooling and prevent recirculation of exhaust air into intakes. The use of heat exchangers and either well water or chilled water for engine and engine room cooling can further reduce the air intake size, albeit at the expense of increased chiller and cooling tower size.

CHAPTER 6
CONTROL SYSTEMS

6-1. Controls system design criteria

C4ISR facility systems require the highest possible level of reliability. This is also true of the SCADA systems used to monitor and control the mechanical and electrical systems. In general, the control system layout should mirror the design of the utility systems: if there is an N+2 equipment layout, there should be at least an N+2 control hardware architecture (see paragraph 2-7, Reliability Criteria). All systems should meet the following basic design criteria:

a. The expected lifetime of the hardware and software for the control system should be greater than 15 years.

b. The control system architecture should be designed to achieve maximum reliability.

c. No single failure should be able to disable the command center or multiple peripheral zones.

d. An N+2 design should be implemented to meet the RAM design criteria. In this design, one area can be out of service for known reasons (such as maintenance) and another area can be out of service for unplanned reasons (such as equipment failure or a terrorist event).

e. The costs of cable installation should be taken into account. In other words, communication cables should be used instead of long-distance runs of multiple conductors whenever possible.

f. Peripheral zone systems and equipment should be controllable remotely from the command center and locally at the zone.

g. The control system hardware should be more reliable than the equipment being controlled, such as pumps and motors (high mean time to fail [MTTF]).

h. A single control system failure should affect only one piece of equipment for a limited time duration (low mean time to repair [MTTR]).

i. The use of proprietary hardware, software, and communications should be avoided.

j. Control equipment should be scaled properly, that is, using small systems for small input/output (I/O) counts and large systems for large I/O counts.

6-2. Applicable control systems codes and standards

The following specific standards apply to the design of control systems to support the LVD concept:

a. ANSI/[Instrumentation, Systems, and Automation Society] ISA 84.01, Application of Safety Instrumented Systems for the Process Industries.

b. TM 5-601, Supervisory Control and Data Acquisition Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

6-3. Agent detection

The detection of CBR agents is a fast-developing area of technology. Many government agencies are working on these technologies. Two of the best sources of the latest information are the Technical Support Working Group (TSWG) and the Centers for Disease Control and Prevention (CDC). Their respective websites are www.tswg.gov and www.cdc.gov. No single device or instrument is expected to be capable of detecting all three types of agents. At least three independent agent detection systems are expected to be required as inputs to the facility SCADA system. A promising area of research involves the use of nanotechnology to develop instruments to detect not only the release of a CBR agent but also the specific agent. This is part of a technology group called Micro-Electrical/Mechanical Systems (MEMS) and Micro-Optical Electrical/Mechanical Systems (MOEMS).

a. Some of the most common forms of instrumentation to detect chemical agents are as follows (according to Griffin Davis, MD, MPH, and Gabor Kelen, MD, *[Chemical, Biological, Radiological, Nuclear and Explosives] CBRNE – Chemical Detection Equipment*):

(1) Ion Mobility Spectrometer (IMS) – Ion mobility detection is based on the transit speed of chemical agents. This technology is available in handheld devices, fixed site detectors, and remote agent detectors. IMS is the basis of most chemical agent detectors made today. It can detect agents such as nerve gas, mustard gas, and vesicants (chemicals that cause skin blisters). The military already uses a standalone detector called the M8A1, made by Environmental Technologies Group (ETG). A commercial version of this device is also available that can transmit information remotely, as is required for a C4ISR facility that incorporates the LVD concept.

(2) Infrared Spectrometer (IRS) – Infrared technology looks at the different wavelengths detected in the chemical agent and compares them to the known spectral analysis of each agent. The military uses an M21 Remote Sensing Chemical Agent Alarm (RSCAAL) in the field.

(3) Miniature Automatic Continuous Agent Monitoring System (MINICAMS) – This technology uses gas chromatography with flame photometry and enables more specific detection but takes about 3 to 5 minutes to complete each detection cycle.

(4) Surface Acoustic Wave (SAW) – This technology uses chemically selective coated crystals that change frequency when detecting a chemical agent. This change can be detected by a microcomputer, thus making the device relatively inexpensive. It is commonly used by civilian response units.

b. Some of the most common forms of instrumentation to detect biological agents are as follows (according to [National Institute of Justice] NIJ Guide 101–00):

(1) Wet detection (flow cytometry) instruments – This technology measures cells and particles in a moving fluid as they pass through a testing point. The biological agent can be identified by using laser light scattering, electronics, and computers. Such instruments are made by the Los Alamos National Laboratory and the Becton Dickenson Company.

(2) Bacterial spore detection instruments – This technology is made by the Universal Detection Technology Company and acts as an "anthrax smoke detector." It detects the chemical dipicolinic acid, which is inside any bacterial spore. It is suitable for continuous sampling, with detection occurring within 15 minutes of the attack.

(3) Dry detection (mass spectrometry) instruments – This technology uses mass spectrometry to obtain characteristic information on the structure and molecular weight of the sample. The following are the dry detection instruments of this type:

(a) Chemical Biological Mass Spectrometer (CBMS)

(b) Pyrolysis-Gas Chromatography-Ion Mobility Spectrometer (PY-GC-IMS)

(c) Matrix-Assisted Laser Desorption Ionization-Time of Flight-Mass Spectrometry (MALDI-TOF-MS)

c. For radiological agent detection, both military and commercial detectors are available. Another consideration is the presence of "dirty bombs," which have a different radiological signature than most sources. There are some companies that make detectors for this type of attack.

6-4. Distributed architecture

TM 5-601 discusses a variety of possible control system architectures. All C4ISR facilities should have a distributed architecture, which inherently protects against internal control system failures and their consequences. The protection of individual control components from any external threat is not economically feasible. Therefore, the principal means of protection is the control cabinet itself and its environmental protection rating.

6-5. Reliability

Figure 6-1 shows a control equipment plan for the example C4ISR facility to which the LVD principles have been applied.

a. Zones 1 through 4 each contain not only the zone's mechanical and electrical equipment but also the associated control equipment. Each zone contains a control panel for the mechanical equipment and a panel for the electrical equipment. Typically, these panels are supplied with the equipment. In the example facility, the programmable logic control (PLC) in the electrical panel is replaced by a remote I/O communications module communicating to the PLC in the mechanical panel. Both the mechanical and electrical "programs" reside in the same PLC processor. In addition, the mechanical panel has an operator interface terminal (OIT), housed in the front of the panel, as the means by which an operator can control and monitor the equipment in that zone. With the facility intercommunication system, an operator can also monitor Zones 1 through 4 but not Zone 5, the command center.

b. All peripheral zone PLCs are connected to Ethernet switches by fiber optic communications cables. The Ethernet switches are all housed within Zone 5 and connected in a "self-healing" ring topology, as shown in figure 6-2. The fiber optic cables should be the loose-tube type to avoid damage by shock. In addition, Zone 5 contains the following:

(1) A redundant PLC system

(2) A redundant remote I/O system

(3) Six interconnected Ethernet switches

(4) A human-machine interface (HMI) system for monitoring and controlling all zones in the facility

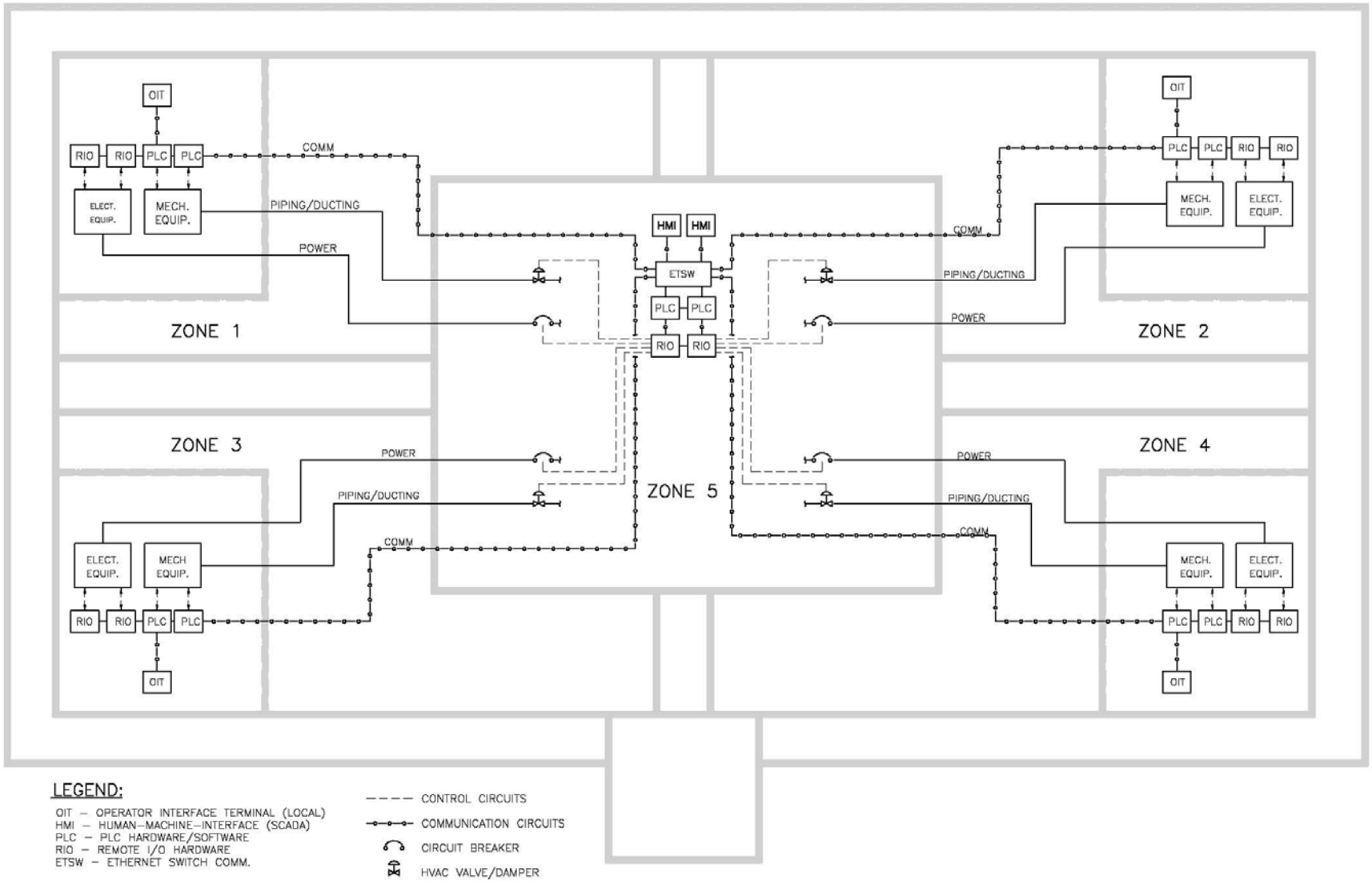


Figure 6-1. SCADA system architecture for the example facility

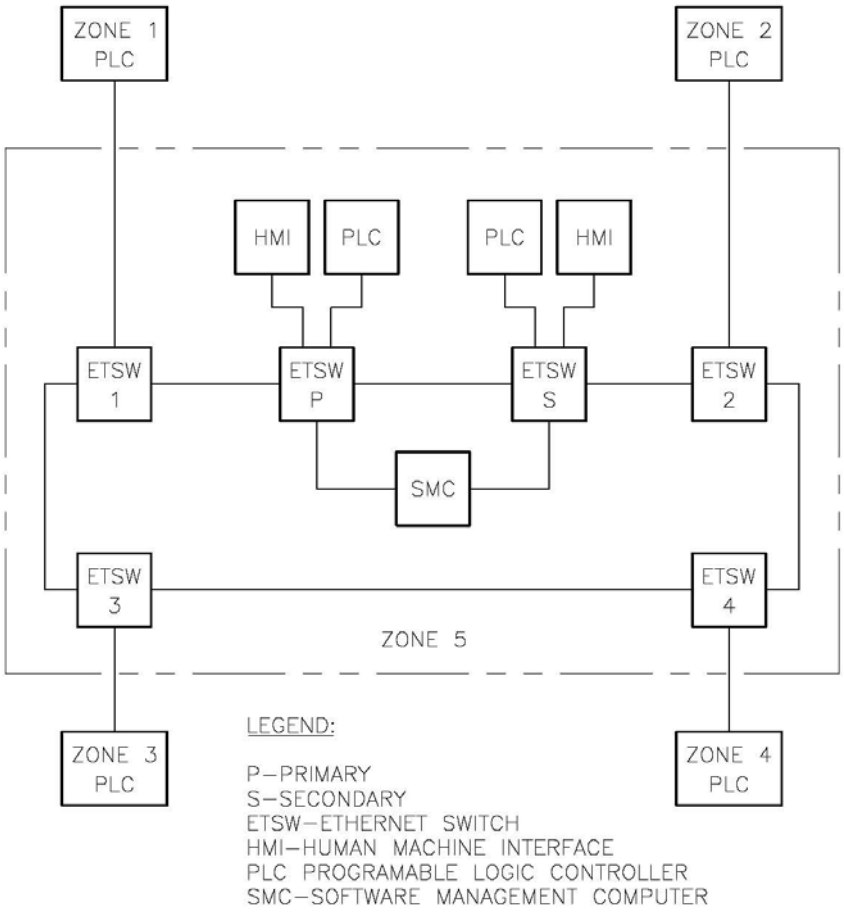


Figure 6-2. Ethernet switches in self-healing ring topology

(5) Each zone's mechanical and electrical isolation equipment (which is controlled by the Zone 5 PLC)

(6) A security computer connected to the communications network

c. The security computer contains specialized, commercially available software that monitors the health of all devices on the network. It also controls access to each PLC, HMI, or OIT to ensure the complete integrity of the control system and not allow unauthorized access to the application or system software. For more information on the security computer and its software, see TM 5-601.

d. There are two possible ways to implement the required redundancy in Zone 5. Figure 6-1 shows the use of PLC equipment with redundant processors and I/O hardware. In this configuration, I/O signals are wired to two different remote I/O racks, which communicate to two PLC processors in separate chassis with their own power supplies and backup communication modules. In this configuration, one PLC is the primary and the other PLC is designated the secondary. These PLCs use the backup communication modules to determine what the status of the PLCs is and which PLC controls the I/O subsystem and communications.

(1) Another option is to use commercially available PLC equipment in which the redundancy is built into the PLC hardware through the use of "two out of three" voting logic. This configuration is a single-chassis PLC system that has redundant power supplies and two or three processors.

(2) The processors communicate to each other through the chassis backplane and execute "two out of three" voting logic to all input and output modules. The system is programmed as if there were only one processor.

6-6. Survivability

With the control equipment plan described in paragraph 6-5, Reliability, the way in which this system would operate can be analyzed.

a. Each zone would have its own detection equipment for CBR agents. The expectation is that the detection equipment would be small devices much like smoke detectors. The interface to the local PLC could range from a simple switch to an analog measurement to a serial communication interface, depending on the sophistication of the device.

(1) The latter interface would not only detect the agent but would identify the agent as well. Once the agent is identified predetermined protocols would take place to minimize the damage. This would be the ultimate goal of any technology involved with agent detection.

(2) As an example, if the Zone 1 PLC detected a CBR event, the OIT of Zones 2, 3, and 4 would show that alarm via each zone's respective PLC. The Zone 5 PLC would react to the alarm by isolating the Zone 1 mechanical and electrical equipment via the valves and breakers located within Zone 5. All other isolation valves and breakers would remain in their normal position so that Zone 5 receives services from Zones 2, 3, and 4. Each unaffected zone system would implement the HVAC pressurization strategy described in paragraph 4-6, Heating, Ventilation, and Air-Conditioning Systems.

b. A very important feature of this design is that Zone 1 does <u>not</u> control the mechanical and electrical isolation equipment between Zone 1 and Zone 5. This logic also follows for the other zones. In the same manner, the Ethernet switches are not located in the outer zones so that the communication network cannot be compromised by an attack.

(1) Figure 6-2 shows the switch interconnections and the self-healing ring. Any single switch failure would not compromise the network but would result in the isolation of only the zone to which that switch is assigned.

(2) The Zone 5 PLC monitors the "heartbeat" (signal) of each of the zone PLCs. Thus, in the event of a CBR attack or an explosion that destroys the Zone 1 PLC, the Zone 5 PLC would know within seconds and would react by isolating Zone 1.

c. In summary, there are six primary ways to initiate isolation of a peripheral zone from Zone 5, the command center:

(1) CBR detection by a zone PLC

(2) Fire or security alarm transmitted to a zone PLC

(3) Loss of communications signal from the zone PLC

(4) Failure of the Ethernet switch to the assigned zone

(5) A hardwired isolation pushbutton for each zone located in Zone 5

(6) A "soft" isolation pushbutton for each zone at the Zone 5 HMI.

6-7. Integration of functions

The example C4ISR facility has services for fire, security, electrical, and HVAC systems. The following describes the interface for each system.

a. The combined fire and security system has a local control panel in each of the peripheral zones, much like the PLC control system. Each panel should send two signals to the zone PLC: an alarm and a panel-in-operation signal. These signals are then sent to the SCADA system in the command center. Paragraph 7-4, Interface to SCADA System, provides further details of this interface.

b. Figure 6-1 shows the electrical system’s interface, which is detailed in paragraph 6-5, Reliability. Each zone PLC controls the electrical system equipment wired to a remote I/O rack.

c. Figure 6-1 shows the HVAC system's interface, which is detailed in paragraph 6-5, Reliability. Each zone PLC controls the HVAC system equipment connected to the PLC in that zone.

CHAPTER 7
FIRE AND SECURITY SYSTEMS

7-1. Fire and security system design criteria

The design of fire and security systems should be consistent with industry standards, such as those produced by NFPA and ANSI as well as applicable DoD guidelines and standards. Because the facility must meet applicable building codes, the AHJ, as defined by NFPA, should be consulted for any local or site-based design criteria.

a. In most cases, the applicable codes or the AHJ will require that a Nationally Recognized Testing Laboratory (NRTL), such as UL, approve the application of the equipment used to implement fire and security systems.

b. Integration of these functions with the SCADA system is typically not possible because the types of control equipment recommended by TM 5-601 for SCADA systems are not approved for fire and security applications. These functions usually require a separate system or systems.

7-2. General considerations

In the case of both fire and security, the system architecture should reflect the treatment of each peripheral zone as an independent building. The distributed processing systems used should provide for independent monitoring, alarm reporting, and alarm annunciation in each zone. As with the SCADA system, the command center should have a central operator station so that personnel there have full access to information from the zones. The security protocol of the mission and the life safety requirements of the architectural design of each zone dictate the detailed requirements for these systems within each zone; therefore, these requirements are not discussed here.

7-3. System layout

Figure 7-1 presents the architecture of a combined fire and security system for the example facility. Each zone has a fire and security field panel (FSFP) that provides complete local processing of monitoring, alarm and annunciation functions, operation of alarm-indicating appliances, and interface to zone HVAC systems.

a. Fire and security command consoles (FSCCs) are located at the public entry, which is assumed to have a staffed security station, and in the command center.

b. The network used to interconnect the FSFPs and FSCCs is typically proprietary to the equipment used. As shown in figure 7-1, the network should be redundant and provided with a means to isolate the segments within each zone in the event of a network fault, thus allowing the balance of the system to communicate freely.

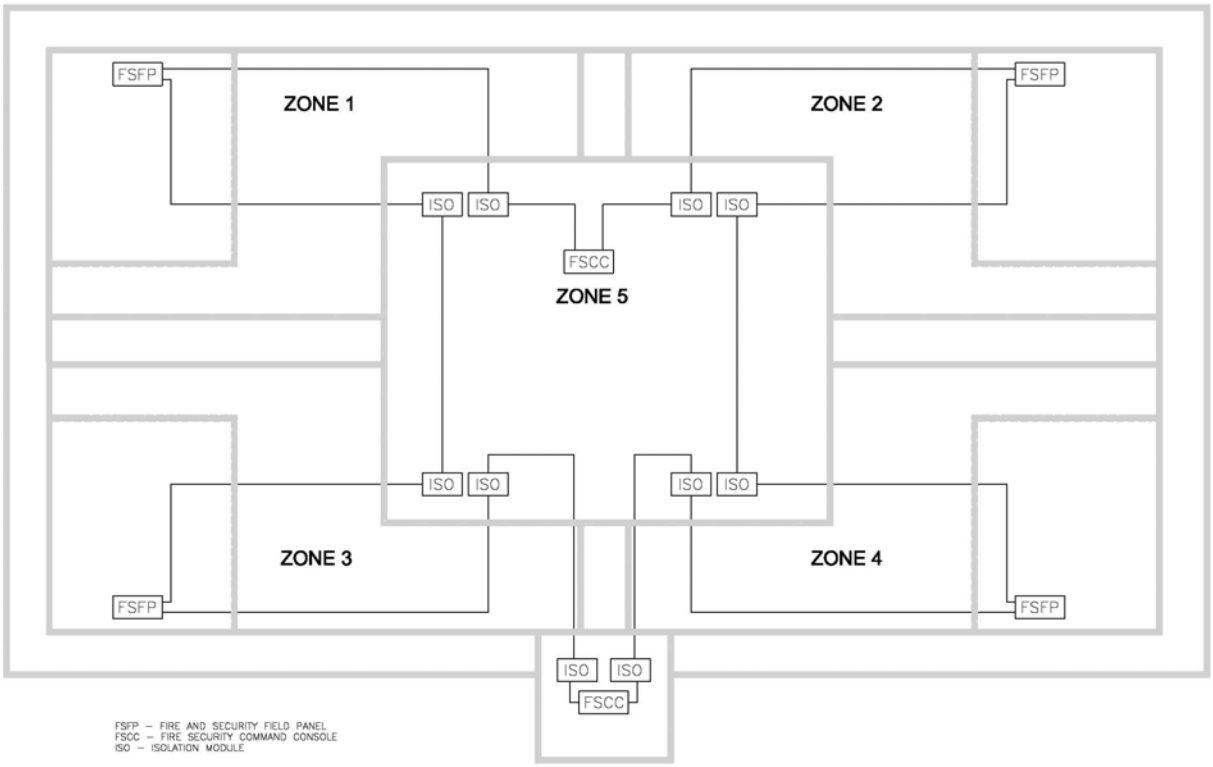


Figure 7-1. Fire and security system architecture

7-4. Interface to SCADA systems

Within each zone, the FSFP is directly interfaced to HVAC control systems, fire sprinkler systems, and any other systems that are necessary to provide the required performance. None of these interfaces, or the control actions that take place over them, should depend on the communication network or signals from other zones. Each FSFP should report a common zone alarm condition to the SCADA system PLC in that zone, which will relay it to the command center SCADA PLC.

a. A fire or security alarm within a peripheral zone will cause the command center PLC to isolate the command center from the utility sources served from that zone in anticipation of disruption or transient conditions in them.

b. Loss of communication to the FSFP in any zone, as detected by the FSCC in the command center, should also initiate preemptive isolation from that zone’s utility supplies.

CHAPTER 8
COMMISSIONING

8-1. General commissioning

Commissioning, the process of verifying and documenting that the installed systems are in compliance with the design intent and specified performance criteria, is critical to the performance of utility systems in C4ISR facilities in general.

a. In one sense, application of the LVD concept may simplify the commissioning process, as it permits independent commissioning of the utility systems of each peripheral zone. If the scaleable, or modular, approach to design is used, as described in chapter 2, Fundamentals of Limited Vulnerability Design, the same process and procedures can be applicable to all of these zones.

b. On the other hand, the systems within the command center that allow it to be successfully isolated from the peripheral zones are more complex than typical and may represent a potential single point of failure for the mission.

c. For these reasons, the following features of the commissioning process in an LVD facility require special emphasis:

(1) The SCADA system, particularly within the command center, must be thoroughly commissioned.

(2) Functional testing under actual operating load or simulated (load bank) conditions must occur to verify the ability of the peripheral zone systems to support the command center load under all contingency conditions.

(3) Design features that ensure integrity of barriers between zones, such as conduit seals and wall penetration systems, which typically may not be included in the scope of commissioning, must be addressed.

(4) Commissioning procedures should be developed that will verify not only the operation of the isolation means in the utility supplies to the command center but also that the isolation will take place quickly enough for internal systems to be unaffected by the external event.

(5) Commissioning should include an integrated system test that simulates the worst-case event that the systems are designed to survive.

8-2. Applicable commissioning codes and standards

In addition to the ASHRAE Guideline 1, which provides valuable guidance for commissioning HVAC systems, the primary references for commissioning utility systems in C4ISR facilities are the following:

a. TM 5-601, Supervisory Control and Data Acquisition Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities, chapter 8

b. TM 5-694, Commissioning of Electrical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

c. TM 5-697, Commissioning of Mechanical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities

8-3. Commissioning process

The LVD concept provides an opportunity to improve the traditional commissioning process by intentionally not taking full advantage of the reduction in labor afforded by the modular design of the peripheral zones. Two or more commissioning teams, working from the same definition of design intent and performance criteria, can independently develop and execute testing procedures, with each team commissioning an appropriate fraction of the peripheral zones. At the completion of testing, the teams debrief with the intention of reviewing each problem or malfunction revealed by each team's test procedure and verifying that the alternate procedure(s) would also have identified that problem or malfunction. If the teams determine that a problem may be able to slip through a procedure undetected, duplicate procedures may be applied to the systems.

CHAPTER 9
OPERATION AND MAINTENANCE

9-1. General operation and maintenance

Effective operation and maintenance (O&M) management is critical to obtaining the designed levels of reliability and performance of utility systems in any C4ISR facility. In a facility based on the LVD concept, O&M procedures must account for and maintain the independence of peripheral zone utility systems as well as provide effective concurrent maintenance of the systems within the command center.

a. A critical component of required O&M for facilities using the LVD concept is a sensor calibration program. Survivability of the command center depends on prompt detection of threat conditions, which for CBR threats is highly dependent on accurate sensor operation.

b. Failure to detect an event may result in compromised ventilation supply to the command center; detecting an event where none exists (nuisance alarm) results in unnecessary isolation of the command center from a source, reducing the redundancy of its supplies, which may negatively impact reliability and availability.

9-2. Applicable codes and standards

The primary references for O&M of C4ISR facilities are the following:

a. TM 5-692-1, Maintenance of Mechanical and Electrical Equipment at Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities – Recommended Maintenance Practices.

b. TM 5-692-2, Maintenance of Mechanical and Electrical Equipment at Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities – System Design Features.

c. TM 5-698-2, Reliability-Centered Maintenance (RCM) for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities.

9-3. Maintenance scheduling

The minimum N+2 redundancy criterion described in chapter 2, Fundamentals of Limited Vulnerability Design, is intended to provide the O&M staff with the flexibility to schedule downtime for the utility systems in a single zone without compromising the facility's ability to meet the mission RAM criteria. Care should be taken to prevent scheduled outages from affecting systems in more than one zone unless it can be demonstrated that there is no interdependency between the affected systems; for example, it may be permissible to shut down a heating pump in Zone 1 and a cooling pump in Zone 2, but only if there are no control interfaces between the heating and cooling systems that would allow work on one system to impact the availability of the other.

9-4. Periodic testing

As described in chapter 8, Commissioning, the ability of the mission-critical zone to survive an event in a peripheral zone depends on the proper function of the devices and associated controls that serve to isolate the mission-critical zone’s utility systems from the compromised zone. This capability should be periodi-

cally verified through an integrated system test (also referred to as a "pull-the-plug" test). Such a test should simulate the worst-case event that the systems are designed to survive. In the case of the example facility, that event would be simultaneous loss of outside utilities and one zone's mechanical and electrical systems while a utility system in another zone is out of service. A test plan should be developed for the facility. The plan should identify the detailed requirements and frequency for periodic testing.

9-5. Spare parts stocking

Many factors should be taken into consideration for stocking spare parts. Some of the primary considerations are quantity, location, and storage containment.

a. Determine the on-site spare parts stocking levels for utility systems and equipment based on the manufacturers' recommendations, equipment criticality, mission time, and component reliability data.

b. In addition to providing an adequate parts supply to maintain the required operational availability, consider the LVD concept in selecting the means and location of spare parts storage.

c. Distribute parts among the zones and store them in proximity to the equipment with which they are to be used to prevent a single threat event from affecting all spare parts of a particular type.

d. If space permits, stock critical parts for zone utility equipment in the command center zone to protect them from loss due to peripheral zone events.

e. Store parts that could be damaged by environmental, radiation, or electromagnetic exposure in suitable enclosures or cabinets.

9-6. Disaster recovery

A C4ISR disaster can be defined as an unplanned occurrence or event that results in an inability to support a mission within the current environment. Such an event can be caused by natural (geological or meteorological), accidental (human- or equipment-caused), or intentional (terrorist) actions. Because it is paramount that a critical mission continue after a disaster occurs, on-site management should prepare by developing a disaster recovery plan, which provides contingency guidelines for continued operations (continued mission) after a disaster occurs.

a. Recovery plans, developed for any number of potential scenarios that can affect operations, require careful preparation. If need be, mock disaster scenarios can be "played out" to identify weaknesses in the plan, which can be amended to correct for disparities. Appendix A, References, includes a comprehensive list of guidance and documentation necessary for preparing recovery plans and related site recovery activities.

b. In the event that a disaster recovery plan is not available for the facility, site management should, at a minimum, develop a disaster recovery responsibility matrix. While not a substitution for a complete recovery plan, this matrix provides some guidance for coordinating the continued operation after a disaster occurs. As a starting point, appendix E, Disaster Recovery, provides a matrix that includes a key listing of potential disasters (Potential Disaster Scenarios) aligned with suggested primary site contacts and affected areas within the C4ISR installation. By identifying the disaster scenario and affected site, the reader can identify the primary contact person responsible for coordinating first response efforts. Some scenarios may not directly affect a specific site within the installation but result in issues that indirectly impact operations.

c. For example, biological hazards (key item C) will not directly impact the operation of a power generator but may result in personnel not being available to maintain the power-generating equipment. Primary coordination with medical personnel will identify this issue. Medical personnel can then review the situation with the secondary response person (Facility Manager), who can make adjustments to operations to compensate for the lack of personnel in the maintenance function.

APPENDIX A

REFERENCES

Required Publications

Government Publications

Department of the Army

TM 5-601, Supervisory Control and Data Acquisition Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities, pending publication. (cited in paragraphs 2-4a, 2-6a(1), 6-4, 6-5c, 6-2b, 7-1b, and 8-2a).

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IEEE Standard 1100, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment, 1999. (cited in paragraph 5-2a and 5-5h).

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National Fire Protection Association (NFPA)

NFPA 1600, Standard on Disaster/Emergency Management and Business Continuity Programs, current applicable edition.

NFPA 1620, Recommended Practice for Pre-Incident Planning, current applicable edition.

APPENDIX B

LIST OF ACRONYMS AND ABBREVIATIONS

ADA	Americans With Disabilities Act
ADP	Automatic Data Processing
AHJ	Authority Having Jurisdiction
AHU	Air-Handling Unit
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AT/FP	Anti-Terrorism/Force Protection
ATS	Automatic Transfer Scheme
BCT	Biological/Chemical Detection Transmitter
BFP	Backflow Preventer
Btu	British Thermal Unit
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance
CAC	Computer Air-Conditioning Unit
CC	Command Center
CBMS	Chemical Biological Mass Spectrometer
CBR	Chemical, Biological, or Radiological
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosives
CDC	Centers For Disease Control and Prevention
CFR	Code of Federal Regulations
CH	Chiller
CHWP	Chilled Water Pump
CHWR	Chilled Water Return
CHWS	Chilled Water Supply
CT	Cooling Tower
CWP	Condenser Water Pump
CWR	Condenser Water Return
CWS	Condenser Water Supply
DoD	United States Department of Defense
EF	Exhaust Fan
EOCSOP	Emergency Operations Center Standard Operating Procedures
ETG	Environmental Technologies Group
ETSW	Ethernet Switch
FD	Fire Damper
FEMA	Federal Emergency Management Agency
FSCC	Fire and Security Command Console
FSFP	Fire and Security Field Panel
GFP	Ground Fault Protection
GSF	Gross Square Feet
HMI	Human-Machine Interface
HQUSACE	Headquarters, U.S. Army Corps of Engineers
hr	Hour
HVAC	Heating, Ventilation, and Air-Conditioning
HWP	Heating Water Pump
HWR	Heating Water Return

HWS	Heating Water Supply
I/O	Input/Output
IBC	International Building Code
IEEE	Institute Of Electrical and Electronics Engineers
IMS	Ion Mobility Spectrometer
IRS	Infrared Spectrometer
ISA	Instrumentation, Systems, and Automation Society
ISO	Isolation Module
kW	Kilowatt(S)
kWhr	Kilowatt-Hour
LVD	Limited Vulnerability Design
MALDI-TOF-MS	Matrix-Assisted Laser Desorption Ionization-Time of Flight-Mass Spectrometry
MAU	Makeup Air-Handling Unit
MEMS	Micro-Electrical/Mechanical Systems
MINICAMS	Miniature Automatic Continuous Agent Monitoring System
MOEMS	Micro-Optical Electrical/Mechanical Systems
MTTF	Mean Time To Fail
MTTR	Mean Time To Repair
N	Number of Sources Required To Meet The Load
N.C.	Normally Closed
N.O.	Normally Open
NEC	National Electrical Code
NFPA	National Fire Protection Association
NIJ	National Institute of Justice
NRTL	Nationally Recognized Testing Laboratory
O&M	Operation and Maintenance
OIT	Operator Interface Terminal
OSHA	Occupational Safety And Health Administration
P	Primary
PLC	Programmable Logic Control
PPE	Personal Protective Equipment
PREP	Power Reliability Enhancement Program
PY-GC-IMS	Pyrolysis-Gas Chromatography-Ion Mobility Spectrometer
RAM	Reliability, Availability, And Maintainability
RCM	Reliability-Centered Maintenance
RIO	Remote I/O Hardware
RSCAAL	Remote Sensing Chemical Agent Alarm
S	Secondary
SAW	Surface Acoustic Wave
SCADA	Supervisory Control And Data Acquisition
SF	Square Feet
SMC	Software Management Computer
TM	Technical Manual
TSWG	Technical Support Working Group
UBC	Uniform Building Code
UFAS	Uniform Federal Accessibility Standards
UFC	Unified Facilities Criteria
UL	Underwriters Laboratories Inc.
UPS	Uninterruptible Power Supply
USD (AT&L)	Under Secretary of Defense For Acquisition, Technology, and Logistics

V	Volt(S)
W	Watt(S)
XFMR	Transformer

APPENDIX C

AVAILABILITY ANALYSIS OF EXAMPLE FACILITY SYSTEMS

Introduction:

Coinciding with the development of the technical manual, an availability (inherent) analysis of the electrical and mechanical delivery concept model was done. The primary focus of the study was to demonstrate that the model was capable of providing 6-9s availability to the mission critical area (zone 5).

To show the robustness and interaction of key components for both electric and heating ventilation and air conditioning (HVAC) designs, both elements were incorporated into a single availability model, taken directly from the descriptors presented in the main portion of the technical manual. The "Go" methodology (a software program that utilizes Boolean algebra to calculate reliability and availability metrics) was selected and used to calculate availability metrics for both the electrical and mechanical systems.

Modeling Assumptions:

- Automatic transfer switches are actually circuit breakers controlled by programmable logic controllers (PLCs).
- PLCs within each "general" zone are considered single units and provide control for the electric and HVAC systems within the specified zone.
- PLCs located within the command center (zone 5) are modeled in pairs for redundancy considerations and control electric and HVAC operations within zone 5. Additionally, they operate isolation valves at the points where chilled and returned water for supporting zones (1-4) enter.
- Mission critical mechanical power is supplied to the mission by mechanical 'A' (MECH 'A') and mechanical 'B' (MECH 'B').
- Mission critical electric power is supplied to the mission by uninterruptible power supply 'A' (UPS 'A'), and uninterruptible power supply 'B' (UPS 'B').
- For modeling considerations, the two maintenance power ties (outlined in the main text are not considered part of the model.
- A single commercial utility power delivery feed was included in the model, though the availability of that feed was "set to zero" to demonstrate the independence (exclude outside power utility usage) of the model.
- Each zone is capable of delivering 100 percent of the required power to the given zone and mission command center (zone 5).
- Each "zone load output" supplies power to the electric and mechanical systems within the specified zone.
- In order to provide 2 of 4 HVAC operation (zones 1-4), 2 of 4 electric power delivery is necessary to support that function. Likewise, 2 of 4 HVAC available systems are necessary.
- In order to maintain balanced air pressure within the building, 2 of 4 air handling units (AHU) are necessary (for compensated zones 1-4). Additionally, 2 of 4 makeup air handling (MAH) units are necessary for zone 5 support.
- Due to facility capability size, first and second floors contain computer air conditioning units (CAC) are in the necessary 4 of 6 and 2 of 4 configurations, respectively.

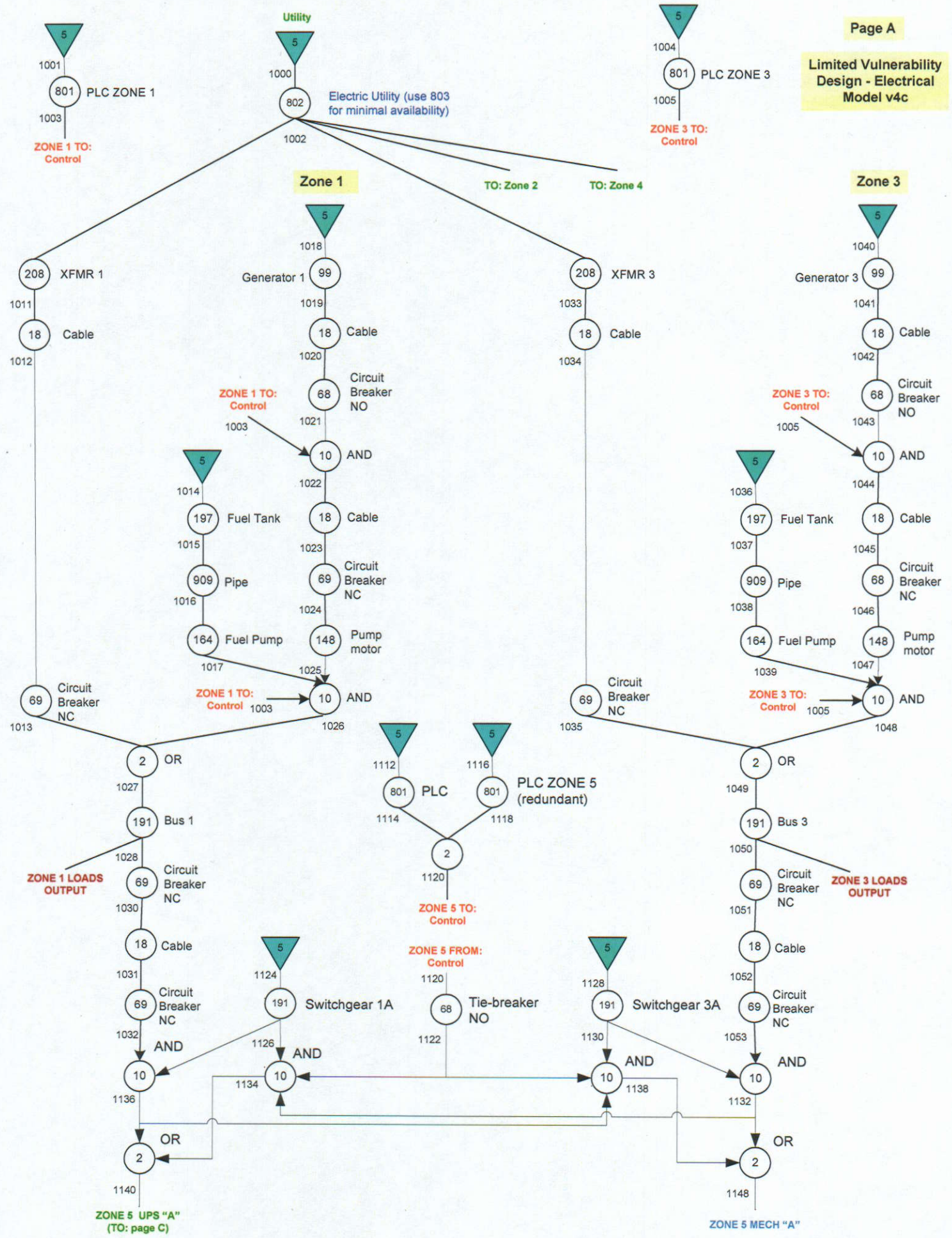
- Make-up water for each zone includes a reserve water tank. Additionally, two independent water sources are included but modeled with minimal availability (to show independence from commercial utility resources).
- Commercial electric power availability is set to a minimum (to show independence from commercial utility resources).
- The model includes major component systems but does not include in-depth detail (including wiring, control and support components).
- Reliability data used for the model components were selected according to design criteria and the specific applications outlined in the main text.
- Commercial water supplies for the mission site were included in the model to demonstrate where they would "normally" connect in with the water delivery system. However, mathematically they were removed by assigning "zero" to the inherent availability value, insuring independence of external water supplies at the mission site.

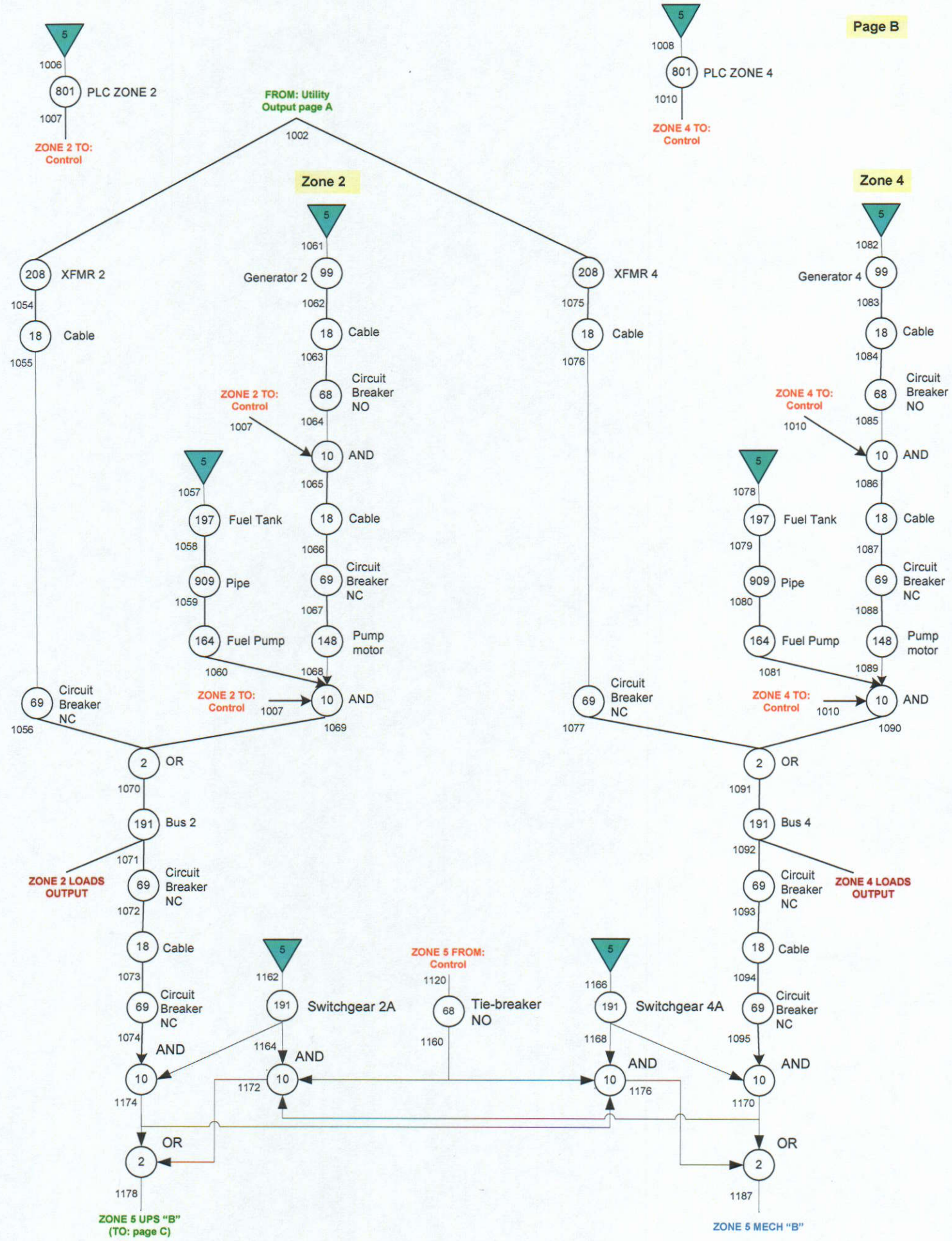
Analysis Results:

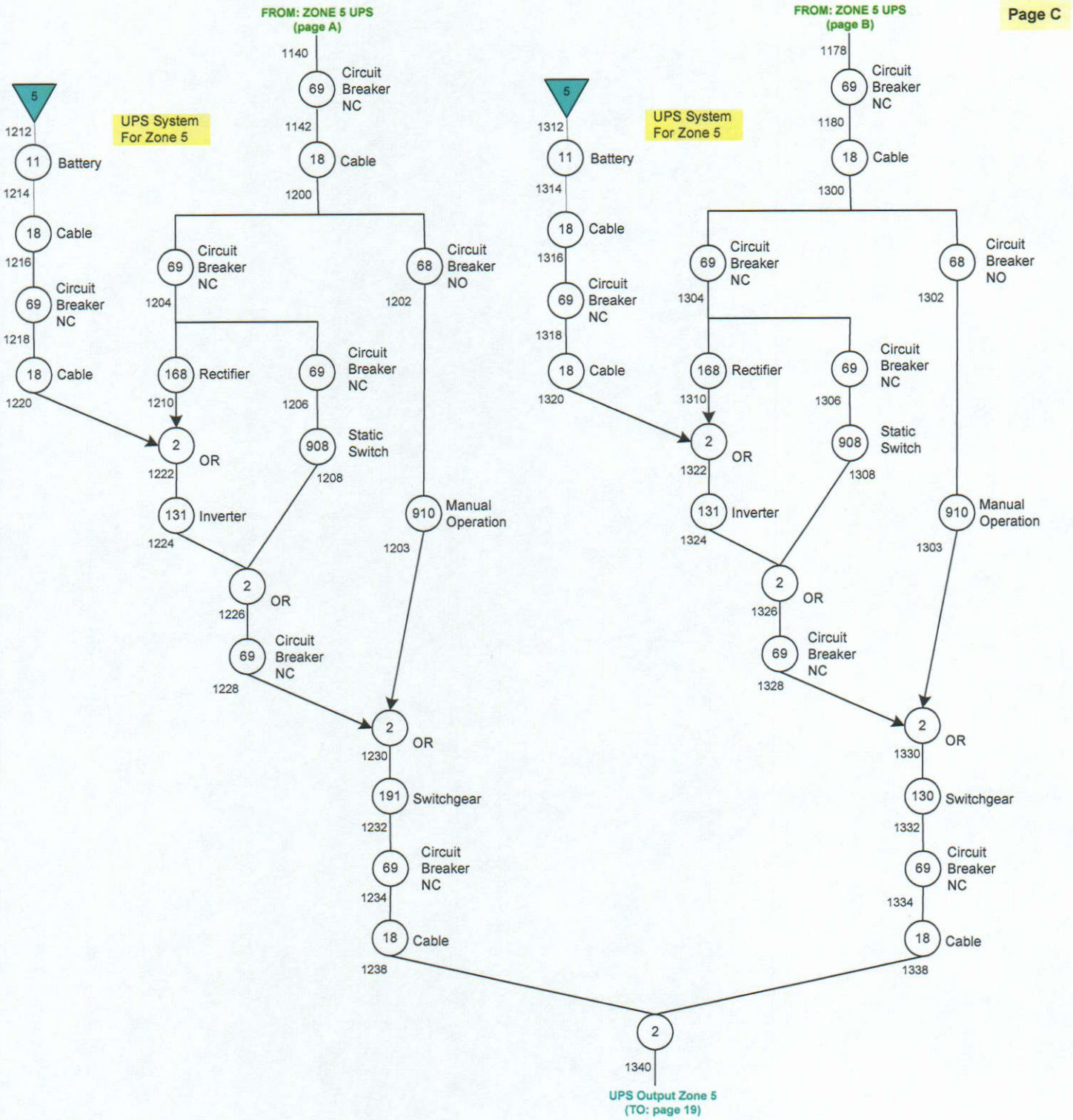
The results of the analysis have shown that the concept model for mission critical power and mechanical (HVAC) availability is robust, insuring that the facility meets the criteria of 6-9s availability. Hence, the design demonstrates that a C4ISR installation designed, using the Limited Vulnerability Design criteria can be built and operated globally, regardless of the ability to be supplied by existing commercial power and water delivery facilities. For comparison purposes, the inherent availabilities for various model signal points can be reviewed on the table, located on page 20 of the model summary.

Overall Conclusions:

1. The electrical power and mechanical HVAC delivery concept model described in main text of technical manual provides an overall availability (inherent) to the critical mission (zone 5) of greater than 6-9s, regardless of whether commercial water and electric power utilities are available at the facility site.
2. Because the model availability (inherent) is greater than 6-9s, sensitive electromechanical systems can operate with minimal disruptions.
3. With an availability (inherent) greater than 6-9s (excluding external electric power and water) the location of a C4ISR facility can be designed according to this criteria and located globally.

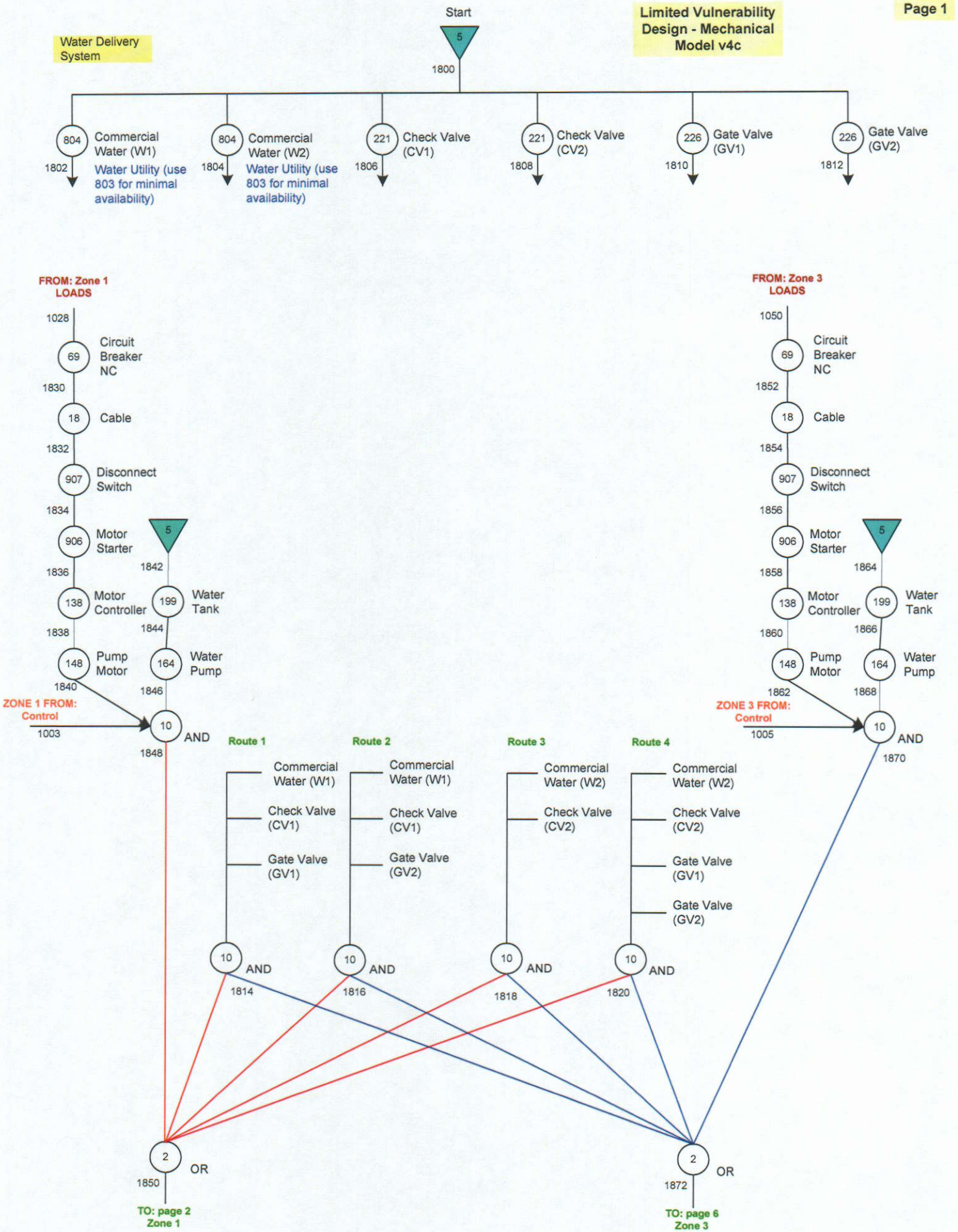

Page A
Limited Vulnerability Design - Electrical Model v4c
Utility
Electric Utility (use 803 for minimal availability)
PLC ZONE 1
ZONE 1 TO: Control
PLC ZONE 3
ZONE 3 TO: Control
TO: Zone 2
TO: Zone 4
Zone 1
Zone 3
XFMR 1
XFMR 3
Generator 1
Generator 3
Cable
Circuit Breaker NO
Circuit Breaker NC
AND
Fuel Tank
Pipe
Fuel Pump
Pump motor
OR
Bus 1
Bus 3
ZONE 1 LOADS OUTPUT
ZONE 3 LOADS OUTPUT
PLC
PLC ZONE 5 (redundant)
ZONE 5 TO: Control
ZONE 5 FROM: Control
Tie-breaker NO
Switchgear 1A
Switchgear 3A
ZONE 5 UPS "A" (TO: page C)
ZONE 5 MECH "A"

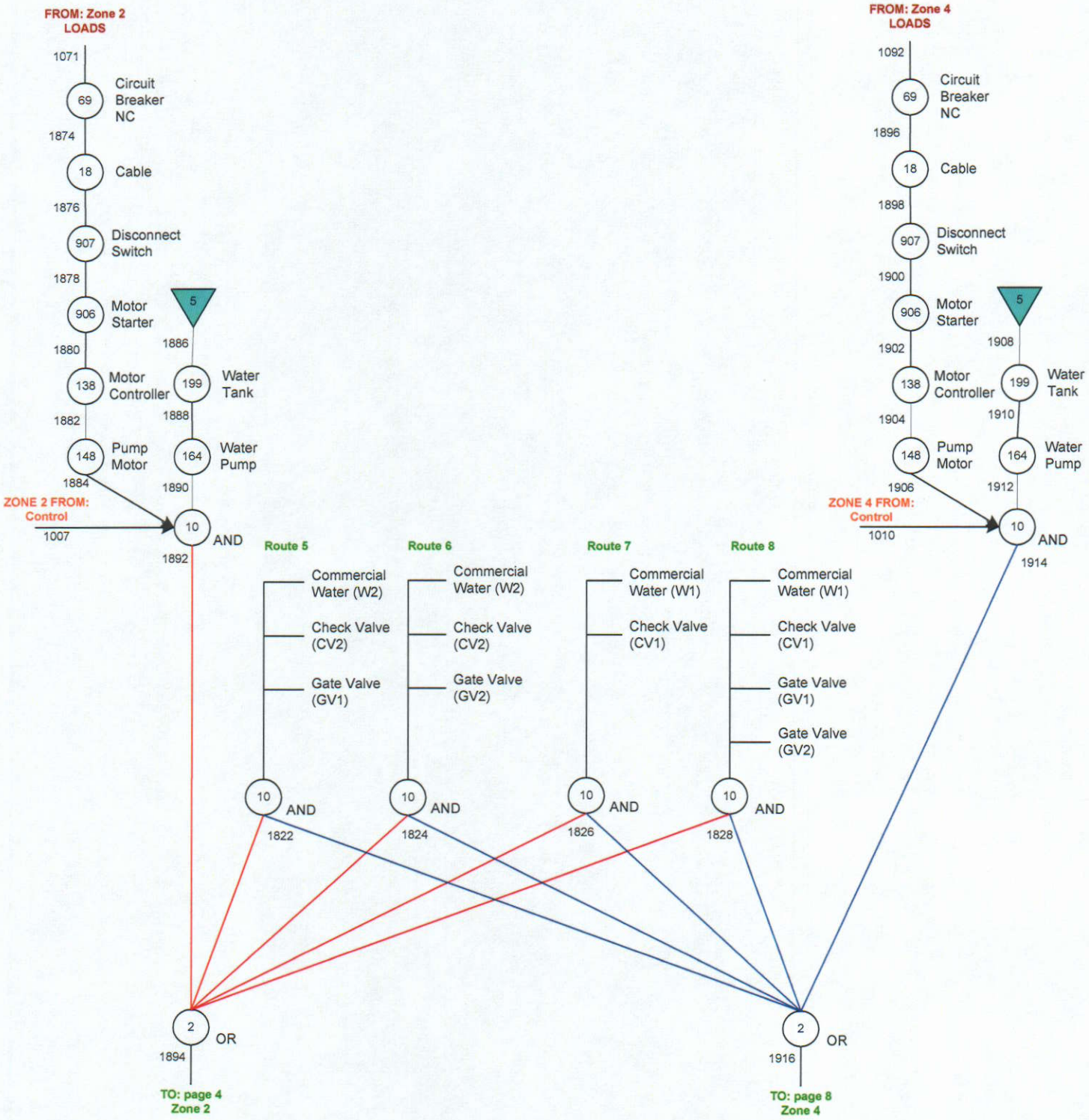

Page B
5
1006
801
PLC ZONE 2
1007
ZONE 2 TO:
Control
FROM: Utility
Output page A
1002
5
1008
801
PLC ZONE 4
1010
ZONE 4 TO:
Control
Zone 2
Zone 4
208
XFMR 2
1054
18
Cable
1055
208
XFMR 4
1075
18
Cable
1076
5
1061
99
Generator 2
1062
18
Cable
1063
68
Circuit
Breaker
NO
1064
ZONE 2 TO:
Control
1007
10
AND
1065
5
1082
99
Generator 4
1083
18
Cable
1084
68
Circuit
Breaker
NO
1085
ZONE 4 TO:
Control
1010
10
AND
1086
5
1057
197
Fuel Tank
1058
909
Pipe
1059
164
Fuel Pump
1060
18
Cable
1066
69
Circuit
Breaker
NC
1067
148
Pump
motor
1068
5
1078
197
Fuel Tank
1079
909
Pipe
1080
164
Fuel Pump
1081
18
Cable
1087
69
Circuit
Breaker
NC
1088
148
Pump
motor
1089
69
Circuit
Breaker
NC
1056
ZONE 2 TO:
Control
1007
10
AND
1069
69
Circuit
Breaker
NC
1077
ZONE 4 TO:
Control
1010
10
AND
1090
2
OR
1070
2
OR
1091
191
Bus 2
1071
191
Bus 4
1092
ZONE 2 LOADS
OUTPUT
69
Circuit
Breaker
NC
1072
ZONE 4 LOADS
OUTPUT
69
Circuit
Breaker
NC
1093
18
Cable
1073
18
Cable
1094
5
1162
191
Switchgear 2A
1164
ZONE 5 FROM:
Control
1120
68
Tie-breaker
NO
1160
5
1166
191
Switchgear 4A
1168
69
Circuit
Breaker
NC
1074
AND
10
1174
1172
AND
10
10
1176
AND
10
1170
69
Circuit
Breaker
NC
1095
AND
2
OR
1178
ZONE 5 UPS "B"
(TO: page C)
2
OR
1187
ZONE 5 MECH "B"

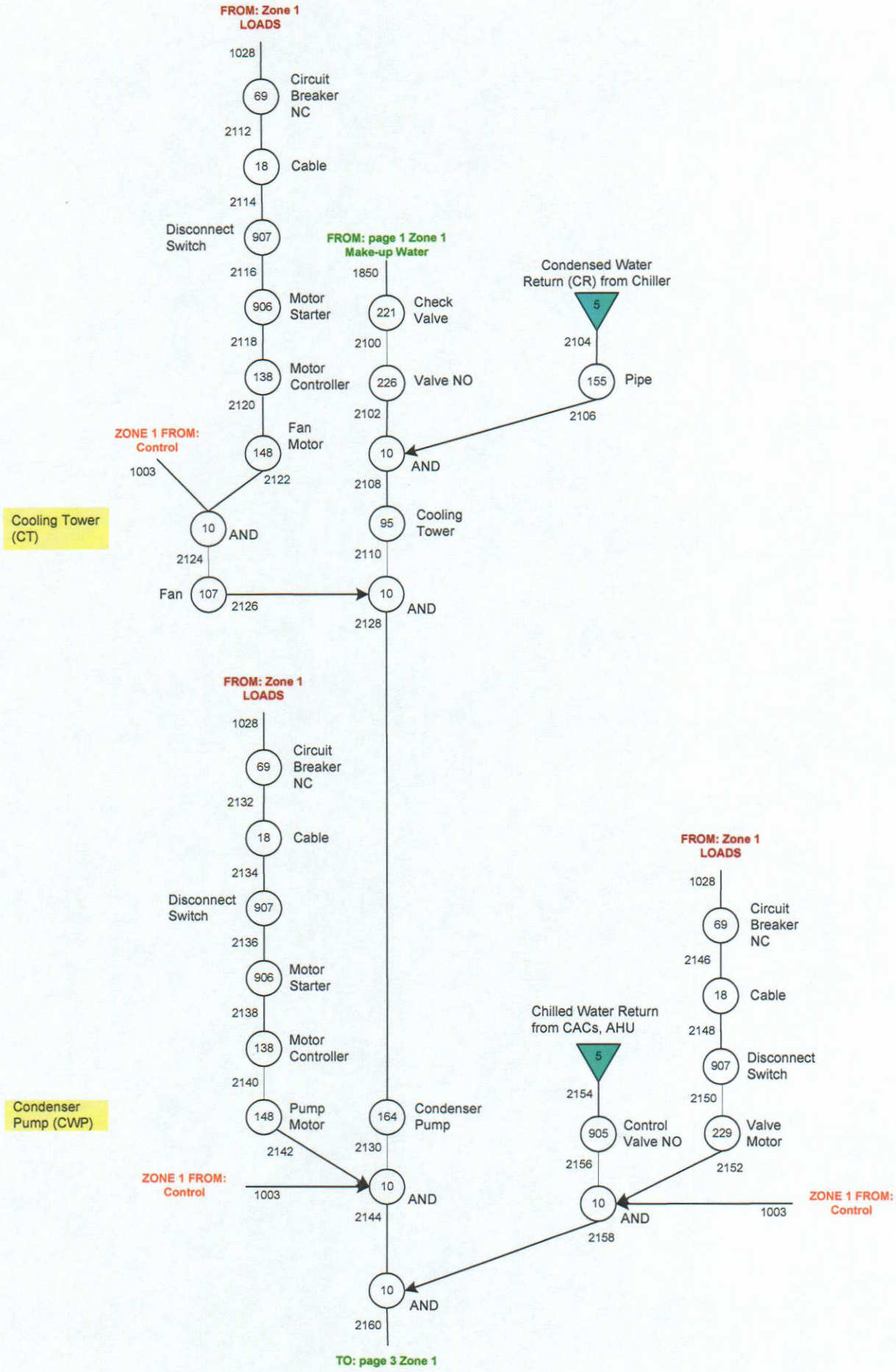

FROM: ZONE 5 UPS
(page A)
1140
69
Circuit Breaker NC
1142
18
Cable
1200
5
1212
UPS System For Zone 5
11
Battery
1214
18
Cable
1216
69
Circuit Breaker NC
1218
18
Cable
1220
69
Circuit Breaker NC
1204
68
Circuit Breaker NO
1202
168
Rectifier
1210
69
Circuit Breaker NC
1206
2
OR
1222
908
Static Switch
1208
131
Inverter
1224
910
Manual Operation
1203
2
OR
1226
69
Circuit Breaker NC
1228
2
OR
1230
191
Switchgear
1232
69
Circuit Breaker NC
1234
18
Cable
1238
FROM: ZONE 5 UPS
(page B)
1178
69
Circuit Breaker NC
1180
18
Cable
1300
5
1312
UPS System For Zone 5
11
Battery
1314
18
Cable
1316
69
Circuit Breaker NC
1318
18
Cable
1320
69
Circuit Breaker NC
1304
68
Circuit Breaker NO
1302
168
Rectifier
1310
69
Circuit Breaker NC
1306
2
OR
1322
908
Static Switch
1308
131
Inverter
1324
910
Manual Operation
1303
2
OR
1326
69
Circuit Breaker NC
1328
2
OR
1330
130
Switchgear
1332
69
Circuit Breaker NC
1334
18
Cable
1338
2
1340
UPS Output Zone 5
(TO: page 19)

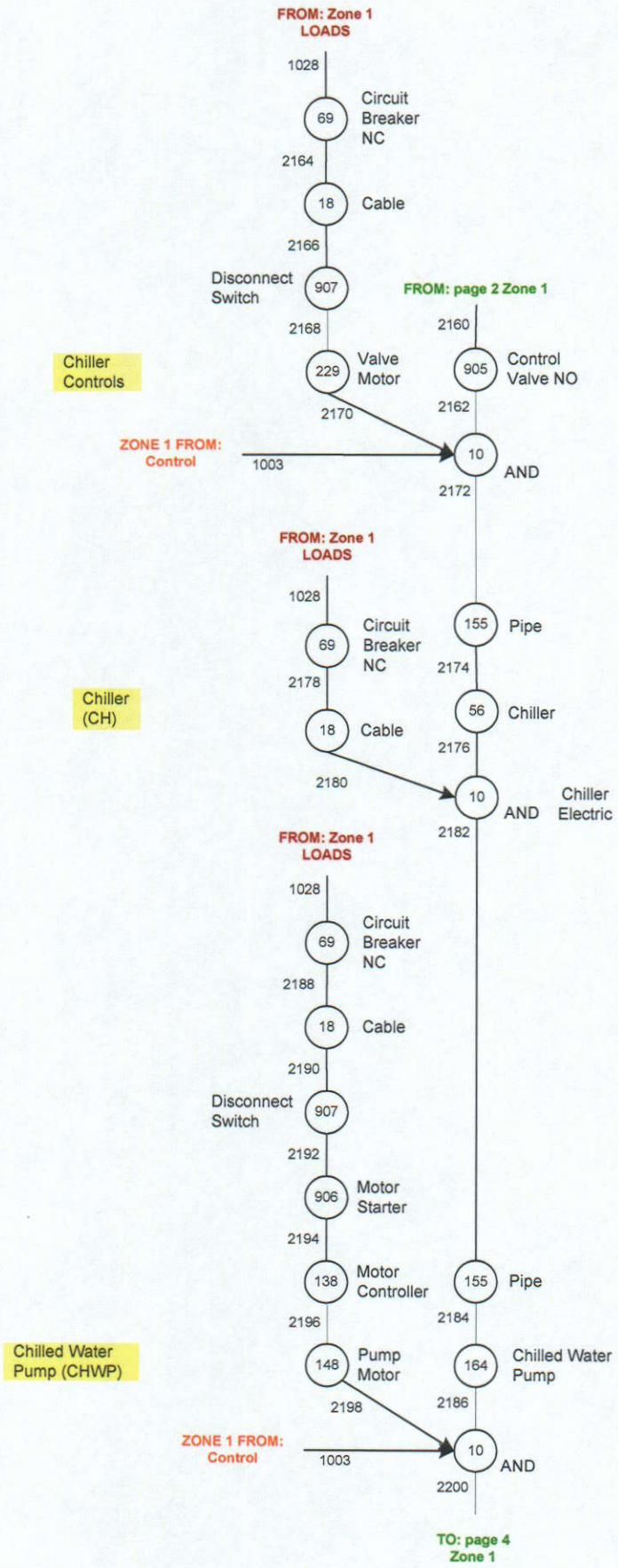
Limited Vulnerability Design - Mechanical Model v4c

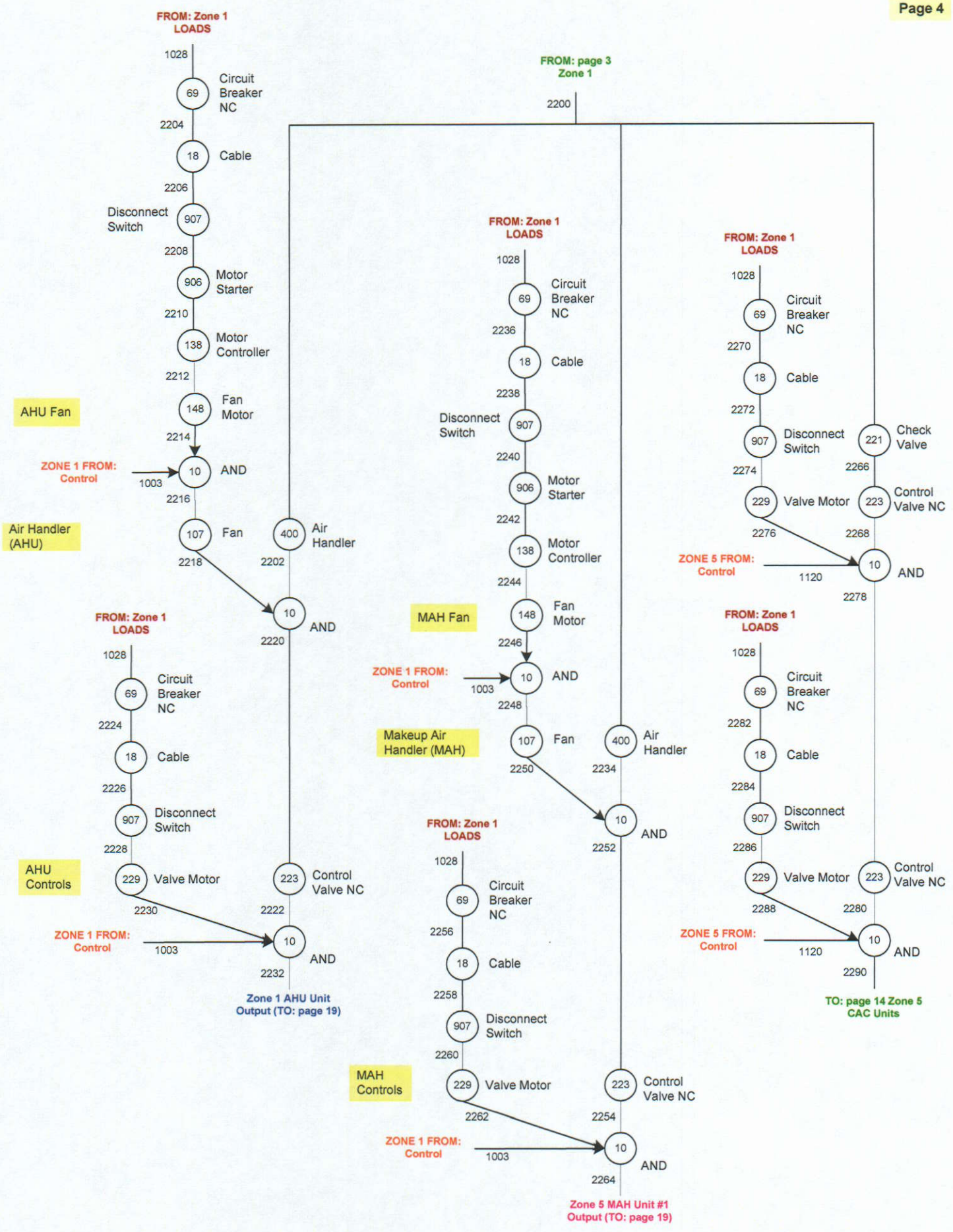
Water Delivery System

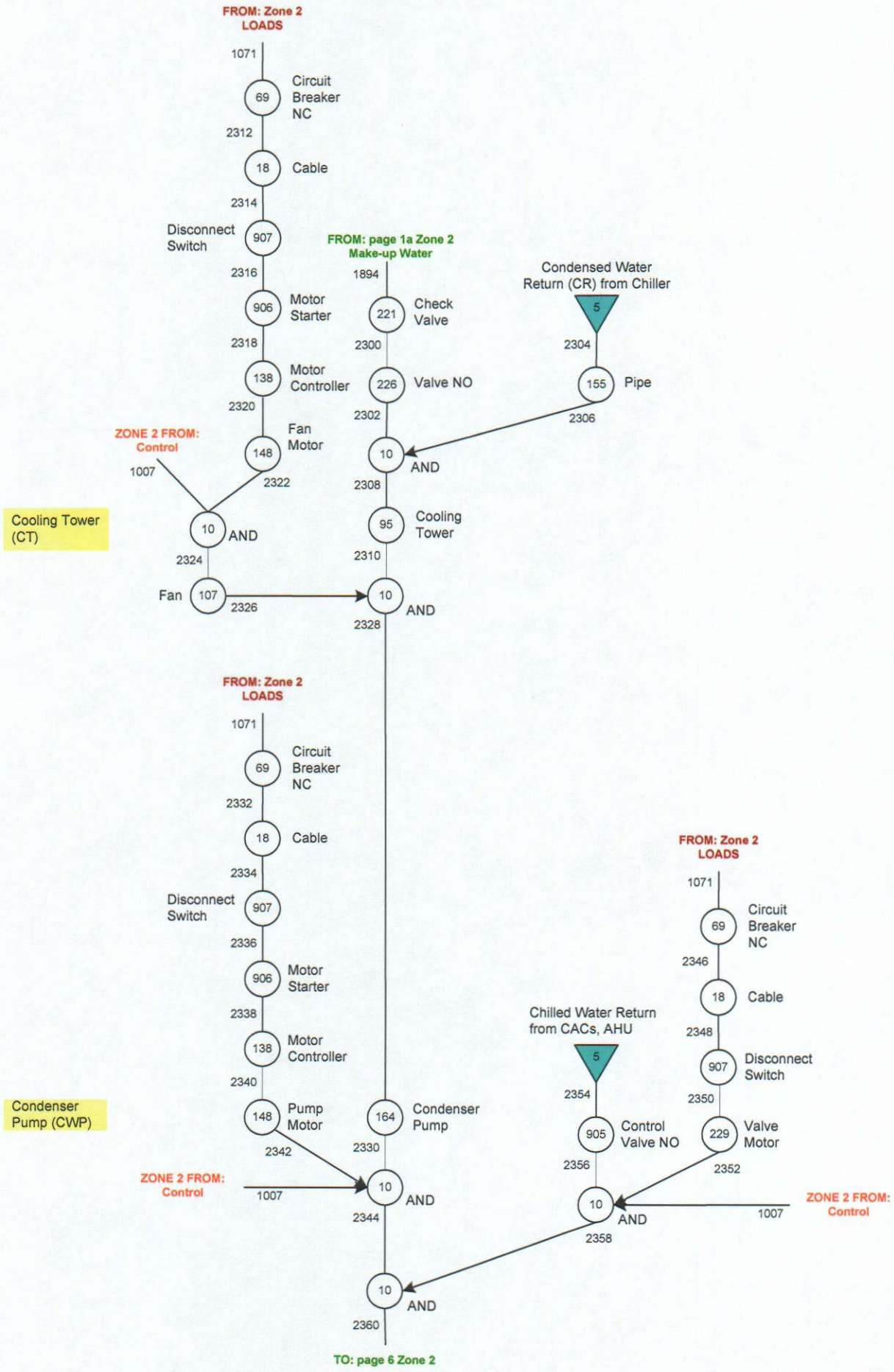


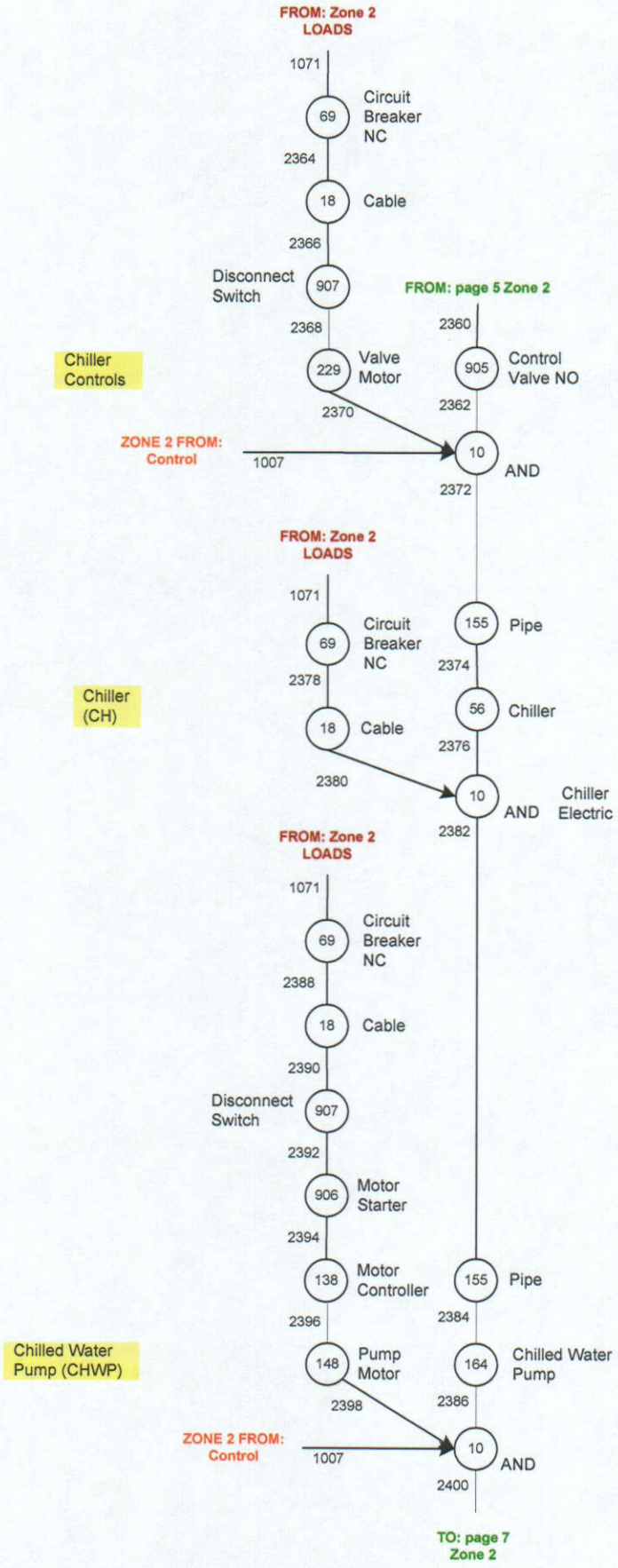

FROM: Zone 2
LOADS
1071
69
Circuit Breaker NC
1874
18
Cable
1876
907
Disconnect Switch
1878
906
Motor Starter
5
1886
1880
138
Motor Controller
199
Water Tank
1882
1888
148
Pump Motor
164
Water Pump
1884
1890
ZONE 2 FROM: Control
1007
10
AND
1892
Route 5
Commercial Water (W2)
Check Valve (CV2)
Gate Valve (GV1)
Route 6
Commercial Water (W2)
Check Valve (CV2)
Gate Valve (GV2)
Route 7
Commercial Water (W1)
Check Valve (CV1)
Route 8
Commercial Water (W1)
Check Valve (CV1)
Gate Valve (GV1)
Gate Valve (GV2)
10
AND
1822
10
AND
1824
10
AND
1826
10
AND
1828
2
OR
1894
TO: page 4
Zone 2
FROM: Zone 4
LOADS
1092
69
Circuit Breaker NC
1896
18
Cable
1898
907
Disconnect Switch
1900
906
Motor Starter
5
1908
1902
138
Motor Controller
199
Water Tank
1904
1910
148
Pump Motor
164
Water Pump
1906
1912
ZONE 4 FROM: Control
1010
10
AND
1914
2
OR
1916
TO: page 8
Zone 4

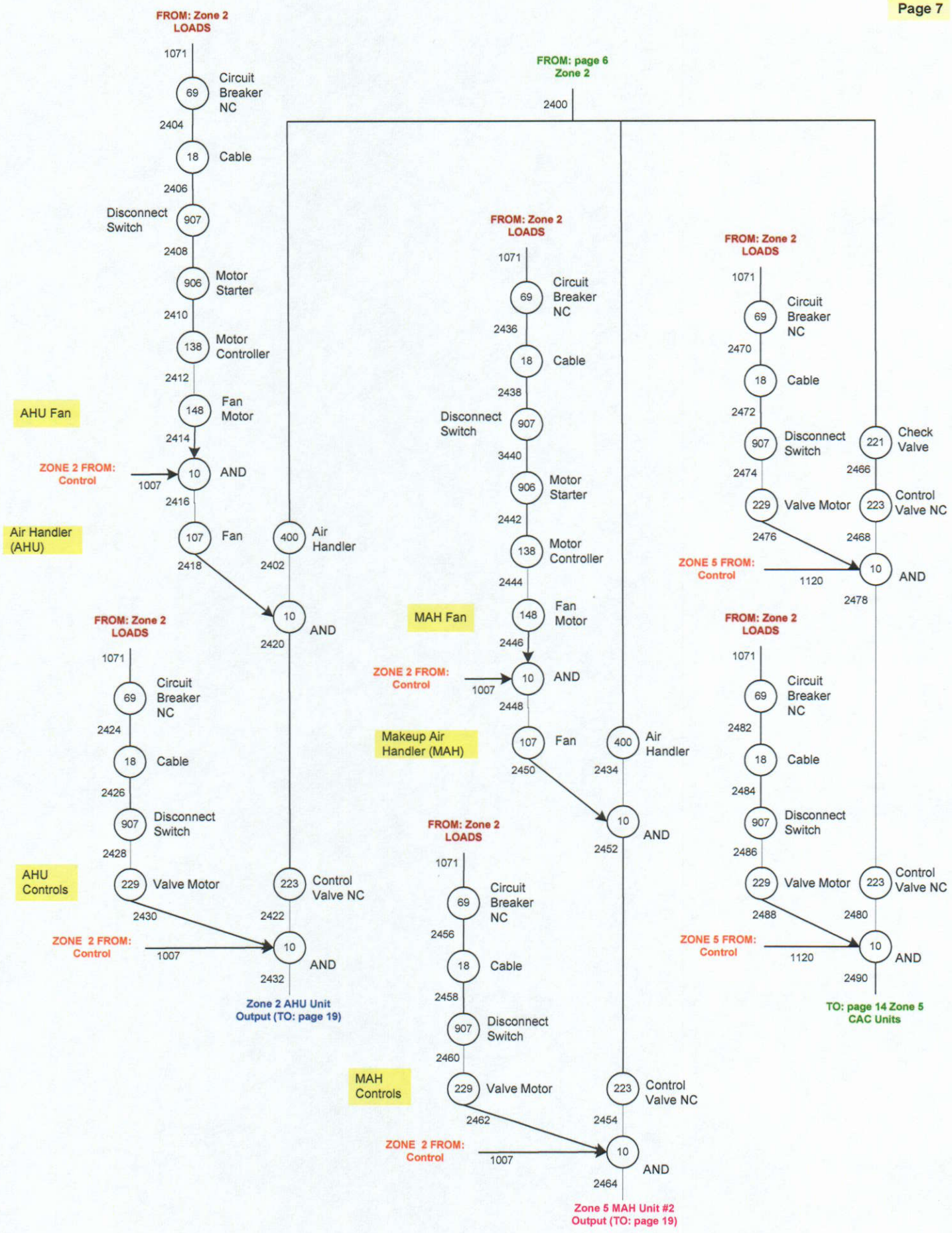

FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2112
18
Cable
2114
Disconnect Switch
907
2116
906
Motor Starter
2118
138
Motor Controller
2120
148
Fan Motor
2122
ZONE 1 FROM: Control
1003
Cooling Tower (CT)
10
AND
2124
Fan
107
2126
FROM: page 1 Zone 1 Make-up Water
1850
221
Check Valve
2100
226
Valve NO
2102
Condensed Water Return (CR) from Chiller
5
2104
155
Pipe
2106
10
AND
2108
95
Cooling Tower
2110
10
AND
2128
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2132
18
Cable
2134
Disconnect Switch
907
2136
906
Motor Starter
2138
138
Motor Controller
2140
Condenser Pump (CWP)
148
Pump Motor
2142
ZONE 1 FROM: Control
1003
164
Condenser Pump
2130
10
AND
2144
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2146
18
Cable
2148
907
Disconnect Switch
2150
229
Valve Motor
2152
Chilled Water Return from CACs, AHU
5
2154
905
Control Valve NO
2156
10
AND
2158
ZONE 1 FROM: Control
1003
10
AND
2160
TO: page 3 Zone 1

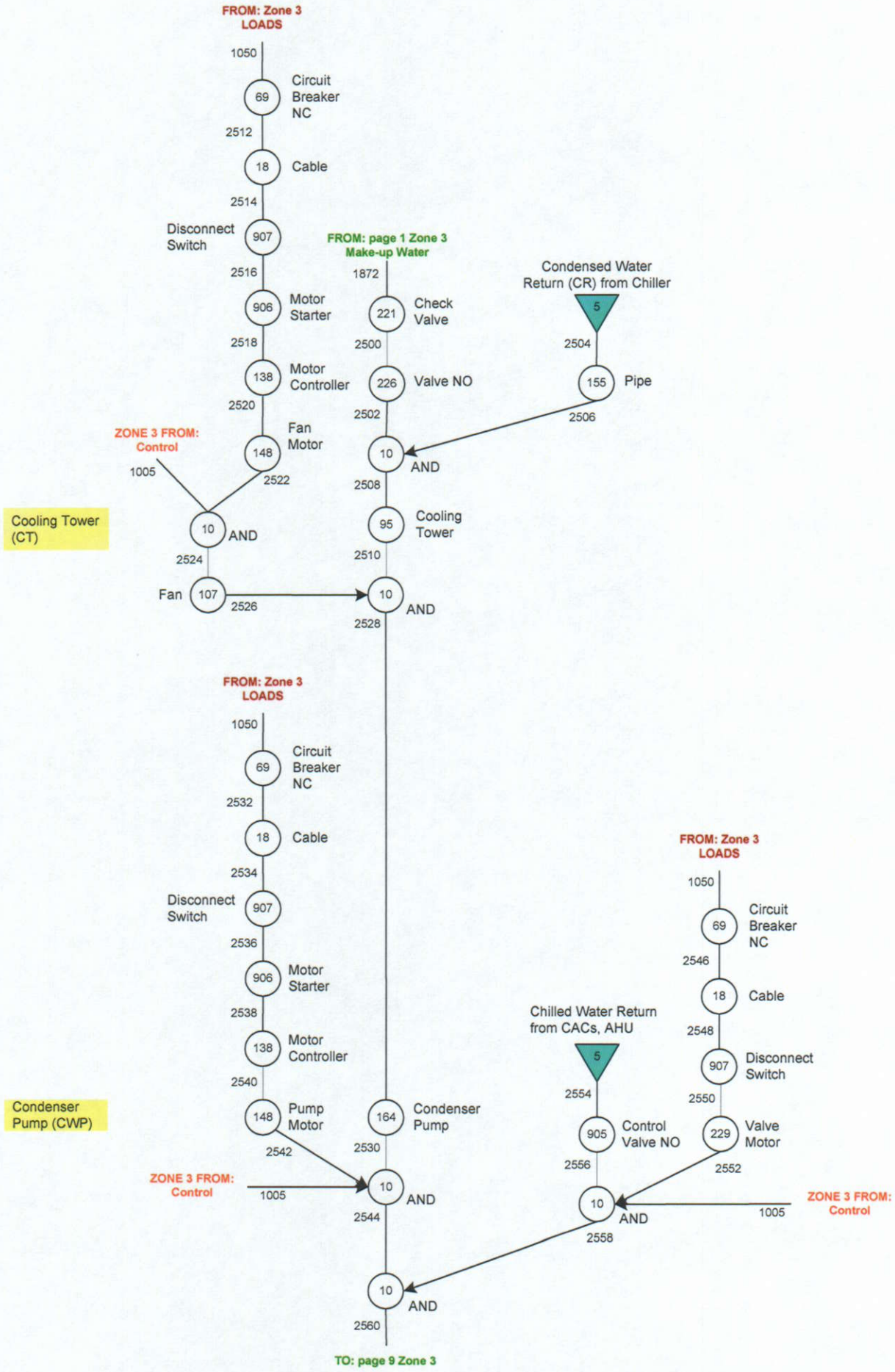

FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2164
18
Cable
2166
Disconnect Switch
907
2168
Chiller Controls
229
Valve Motor
2170
FROM: page 2 Zone 1
2160
905
Control Valve NO
2162
ZONE 1 FROM: Control
1003
10
AND
2172
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2178
Chiller (CH)
18
Cable
2180
155
Pipe
2174
56
Chiller
2176
10
AND
Chiller Electric
2182
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2188
18
Cable
2190
Disconnect Switch
907
2192
906
Motor Starter
2194
138
Motor Controller
2196
Chilled Water Pump (CHWP)
148
Pump Motor
2198
ZONE 1 FROM: Control
1003
10
AND
2200
155
Pipe
2184
164
Chilled Water Pump
2186
TO: page 4 Zone 1

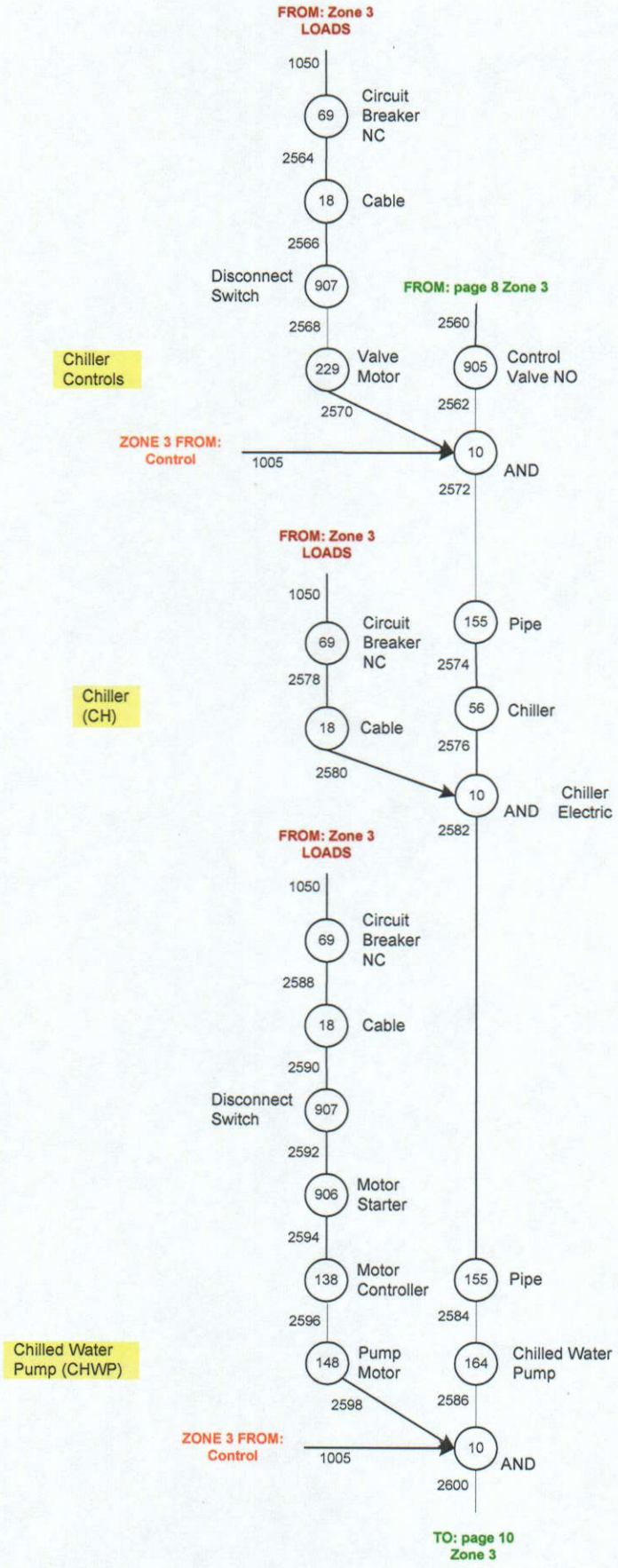

FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2204
18
Cable
2206
Disconnect Switch
907
2208
906
Motor Starter
2210
138
Motor Controller
2212
AHU Fan
148
Fan Motor
2214
ZONE 1 FROM: Control
1003
10
AND
2216
Air Handler (AHU)
107
Fan
2218
400
Air Handler
2202
10
AND
2220
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2224
18
Cable
2226
907
Disconnect Switch
2228
AHU Controls
229
Valve Motor
2230
223
Control Valve NC
2222
ZONE 1 FROM: Control
1003
10
AND
2232
Zone 1 AHU Unit Output (TO: page 19)
FROM: page 3 Zone 1
2200
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2236
18
Cable
2238
Disconnect Switch
907
2240
906
Motor Starter
2242
138
Motor Controller
2244
MAH Fan
148
Fan Motor
2246
ZONE 1 FROM: Control
1003
10
AND
2248
Makeup Air Handler (MAH)
107
Fan
2250
400
Air Handler
2234
10
AND
2252
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2256
18
Cable
2258
907
Disconnect Switch
2260
MAH Controls
229
Valve Motor
2262
223
Control Valve NC
2254
ZONE 1 FROM: Control
1003
10
AND
2264
Zone 5 MAH Unit #1 Output (TO: page 19)
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2270
18
Cable
2272
907
Disconnect Switch
2274
221
Check Valve
2266
229
Valve Motor
2276
223
Control Valve NC
2268
ZONE 5 FROM: Control
1120
10
AND
2278
FROM: Zone 1 LOADS
1028
69
Circuit Breaker NC
2282
18
Cable
2284
907
Disconnect Switch
2286
229
Valve Motor
2288
223
Control Valve NC
2280
ZONE 5 FROM: Control
1120
10
AND
2290
TO: page 14 Zone 5 CAC Units

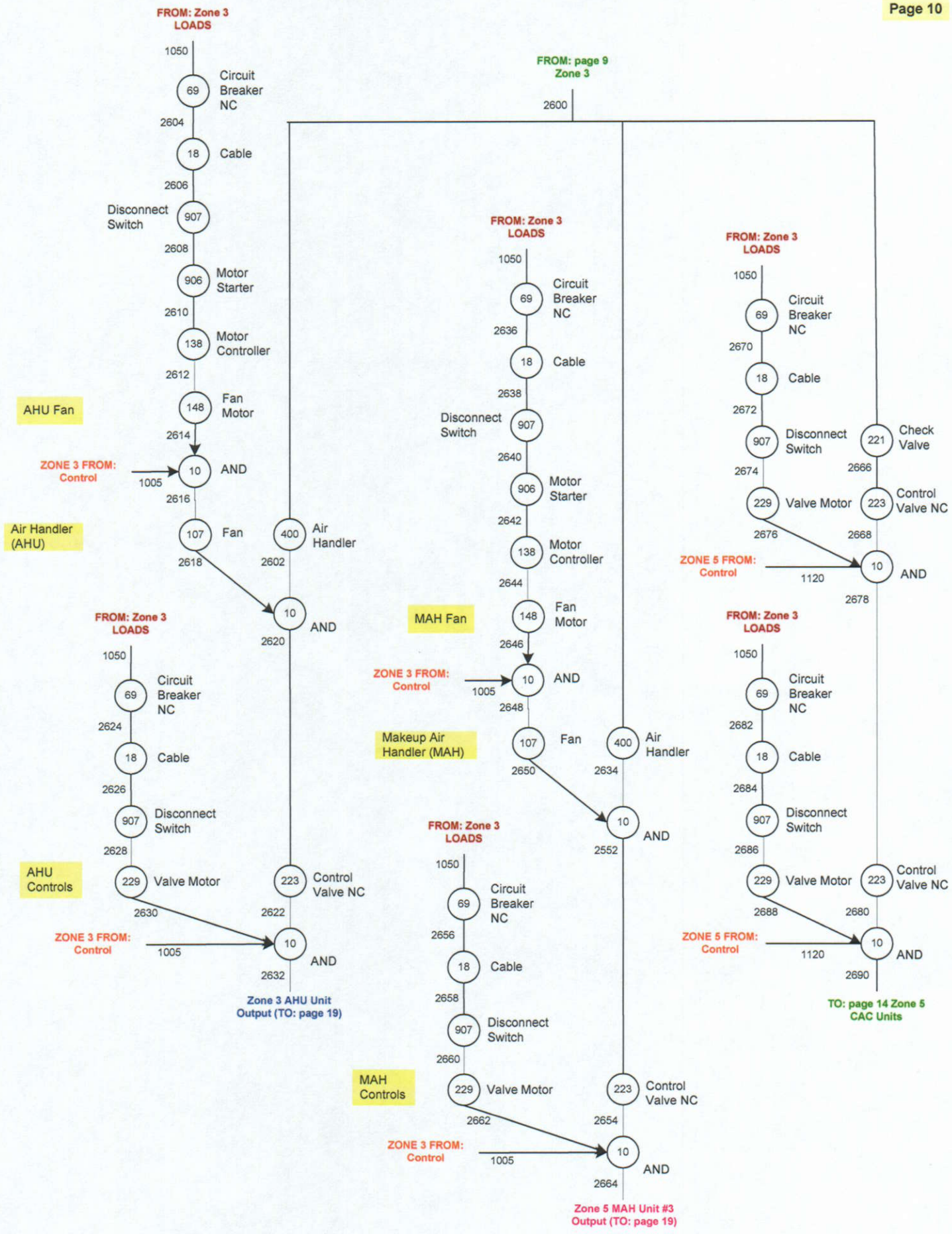

FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2312
18
Cable
2314
Disconnect Switch
907
2316
906
Motor Starter
2318
138
Motor Controller
2320
ZONE 2 FROM: Control
1007
148
Fan Motor
2322
Cooling Tower (CT)
10
AND
2324
Fan
107
2326
FROM: page 1a Zone 2 Make-up Water
1894
221
Check Valve
2300
226
Valve NO
2302
Condensed Water Return (CR) from Chiller
5
2304
155
Pipe
2306
10
AND
2308
95
Cooling Tower
2310
10
AND
2328
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2332
18
Cable
2334
Disconnect Switch
907
2336
906
Motor Starter
2338
138
Motor Controller
2340
Condenser Pump (CWP)
148
Pump Motor
2342
ZONE 2 FROM: Control
1007
164
Condenser Pump
2330
10
AND
2344
10
AND
2360
TO: page 6 Zone 2
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2346
18
Cable
2348
907
Disconnect Switch
2350
229
Valve Motor
2352
Chilled Water Return from CACs, AHU
5
2354
905
Control Valve NO
2356
10
AND
2358
ZONE 2 FROM: Control
1007

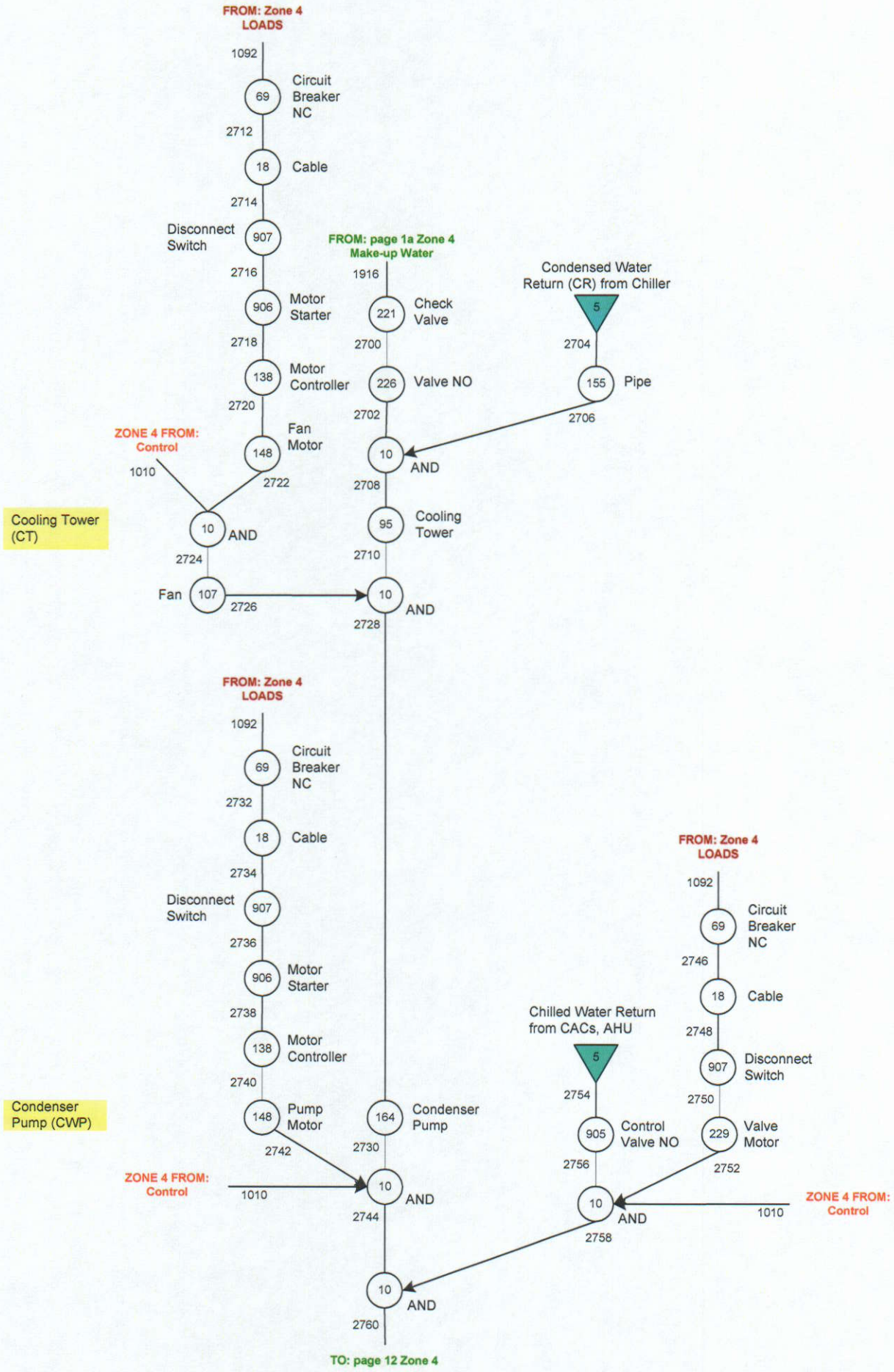

FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2364
18
Cable
2366
Disconnect Switch
907
2368
Chiller Controls
229
Valve Motor
2370
FROM: page 5 Zone 2
2360
905
Control Valve NO
2362
ZONE 2 FROM: Control
1007
10
AND
2372
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2378
Chiller (CH)
18
Cable
2380
155
Pipe
2374
56
Chiller
2376
10
AND
Chiller Electric
2382
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2388
18
Cable
2390
Disconnect Switch
907
2392
906
Motor Starter
2394
138
Motor Controller
2396
Chilled Water Pump (CHWP)
148
Pump Motor
2398
155
Pipe
2384
164
Chilled Water Pump
2386
ZONE 2 FROM: Control
1007
10
AND
2400
TO: page 7 Zone 2

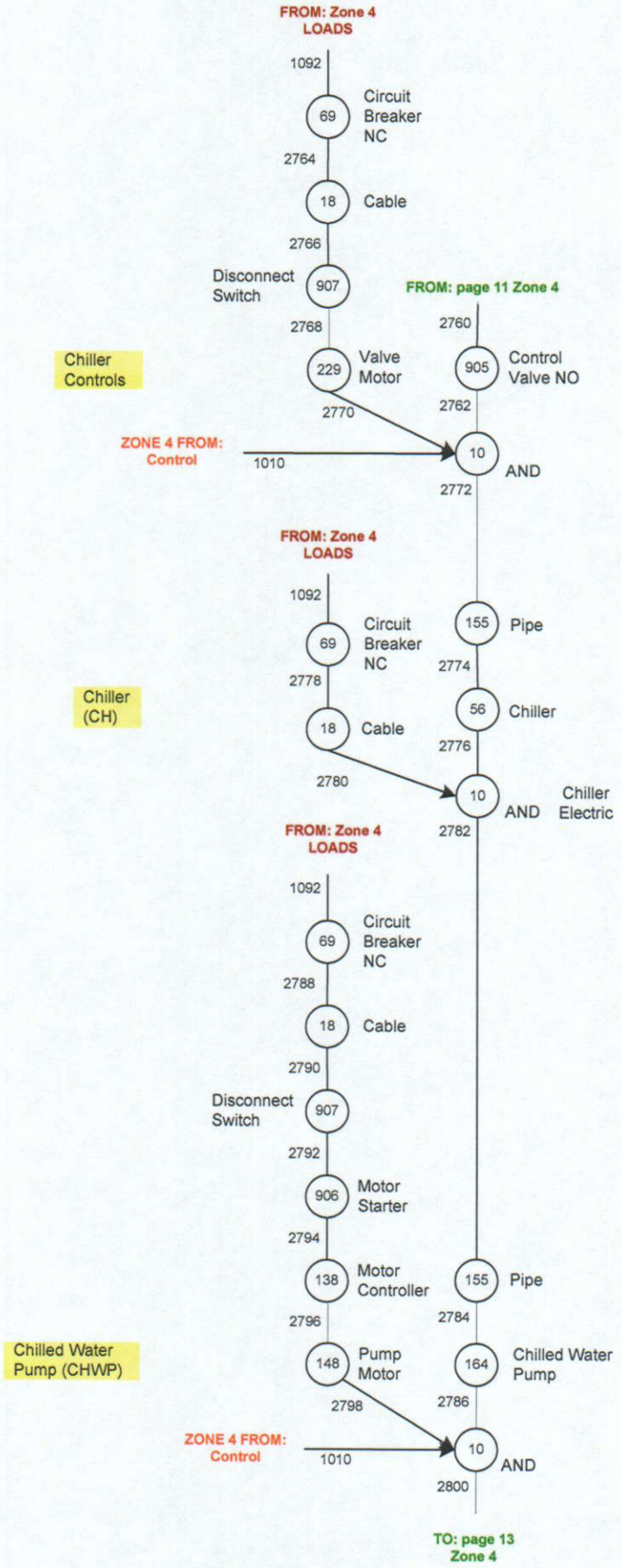

FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2404
18
Cable
2406
Disconnect Switch
907
2408
906
Motor Starter
2410
138
Motor Controller
2412
AHU Fan
148
Fan Motor
2414
ZONE 2 FROM: Control
1007
10
AND
2416
Air Handler (AHU)
107
Fan
2418
400
Air Handler
2402
10
AND
2420
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2424
18
Cable
2426
907
Disconnect Switch
2428
AHU Controls
229
Valve Motor
2430
223
Control Valve NC
2422
ZONE 2 FROM: Control
1007
10
AND
2432
Zone 2 AHU Unit Output (TO: page 19)
FROM: page 6 Zone 2
2400
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2436
18
Cable
2438
Disconnect Switch
907
3440
906
Motor Starter
2442
138
Motor Controller
2444
MAH Fan
148
Fan Motor
2446
ZONE 2 FROM: Control
1007
10
AND
2448
Makeup Air Handler (MAH)
107
Fan
2450
400
Air Handler
2434
10
AND
2452
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2456
18
Cable
2458
907
Disconnect Switch
2460
MAH Controls
229
Valve Motor
2462
223
Control Valve NC
2454
ZONE 2 FROM: Control
1007
10
AND
2464
Zone 5 MAH Unit #2 Output (TO: page 19)
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2470
18
Cable
2472
907
Disconnect Switch
2474
221
Check Valve
2466
229
Valve Motor
2476
223
Control Valve NC
2468
ZONE 5 FROM: Control
1120
10
AND
2478
FROM: Zone 2 LOADS
1071
69
Circuit Breaker NC
2482
18
Cable
2484
907
Disconnect Switch
2486
229
Valve Motor
2488
223
Control Valve NC
2480
ZONE 5 FROM: Control
1120
10
AND
2490
TO: page 14 Zone 5 CAC Units

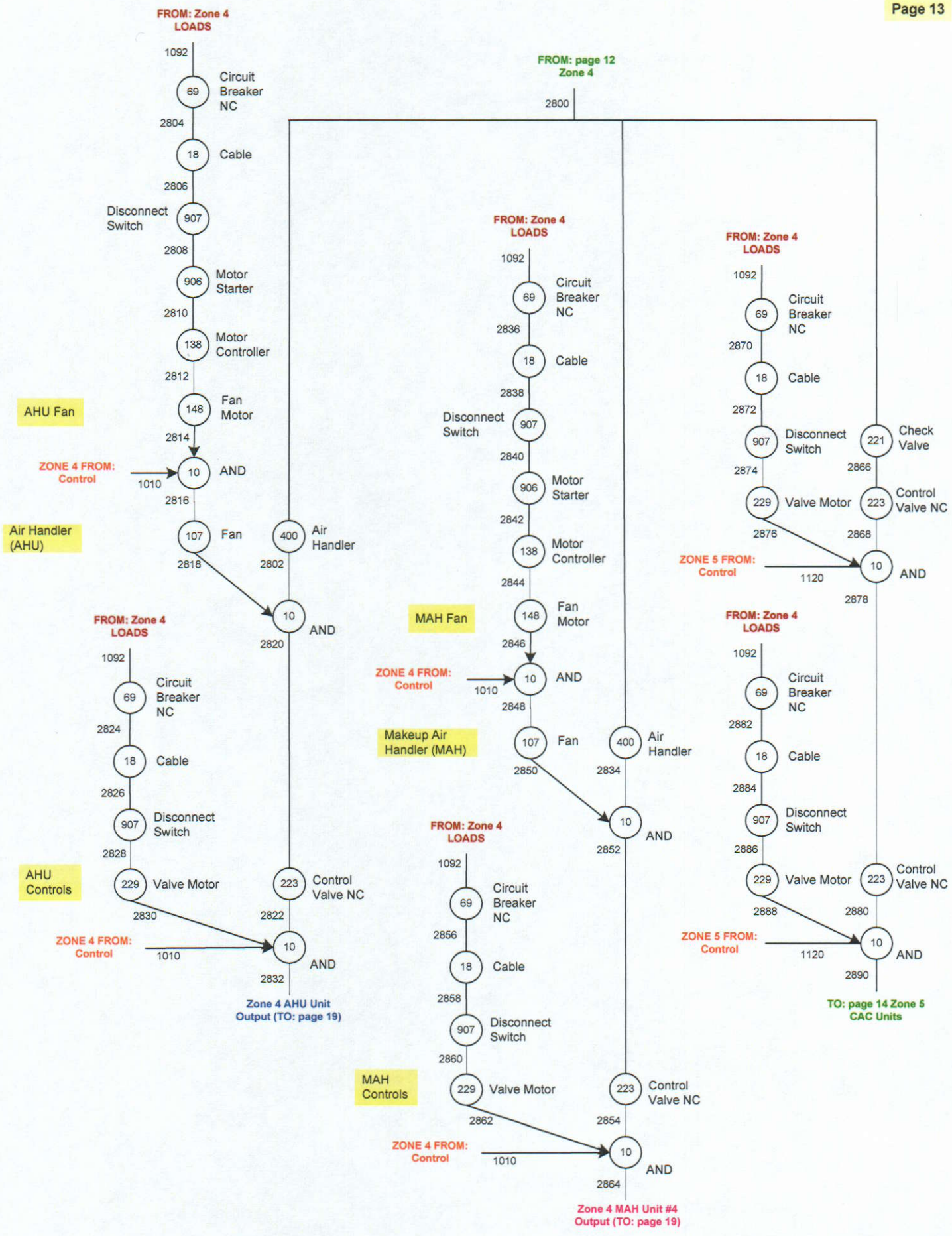

FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2512
18
Cable
2514
Disconnect Switch
907
2516
906
Motor Starter
2518
138
Motor Controller
2520
148
Fan Motor
2522
ZONE 3 FROM: Control
1005
Cooling Tower (CT)
10
AND
2524
Fan
107
2526
FROM: page 1 Zone 3 Make-up Water
1872
221
Check Valve
2500
226
Valve NO
2502
Condensed Water Return (CR) from Chiller
5
2504
155
Pipe
2506
10
AND
2508
95
Cooling Tower
2510
10
AND
2528
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2532
18
Cable
2534
Disconnect Switch
907
2536
906
Motor Starter
2538
138
Motor Controller
2540
Condenser Pump (CWP)
148
Pump Motor
2542
ZONE 3 FROM: Control
1005
164
Condenser Pump
2530
10
AND
2544
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2546
18
Cable
2548
907
Disconnect Switch
2550
229
Valve Motor
2552
Chilled Water Return from CACs, AHU
5
2554
905
Control Valve NO
2556
10
AND
2558
ZONE 3 FROM: Control
1005
10
AND
2560
TO: page 9 Zone 3

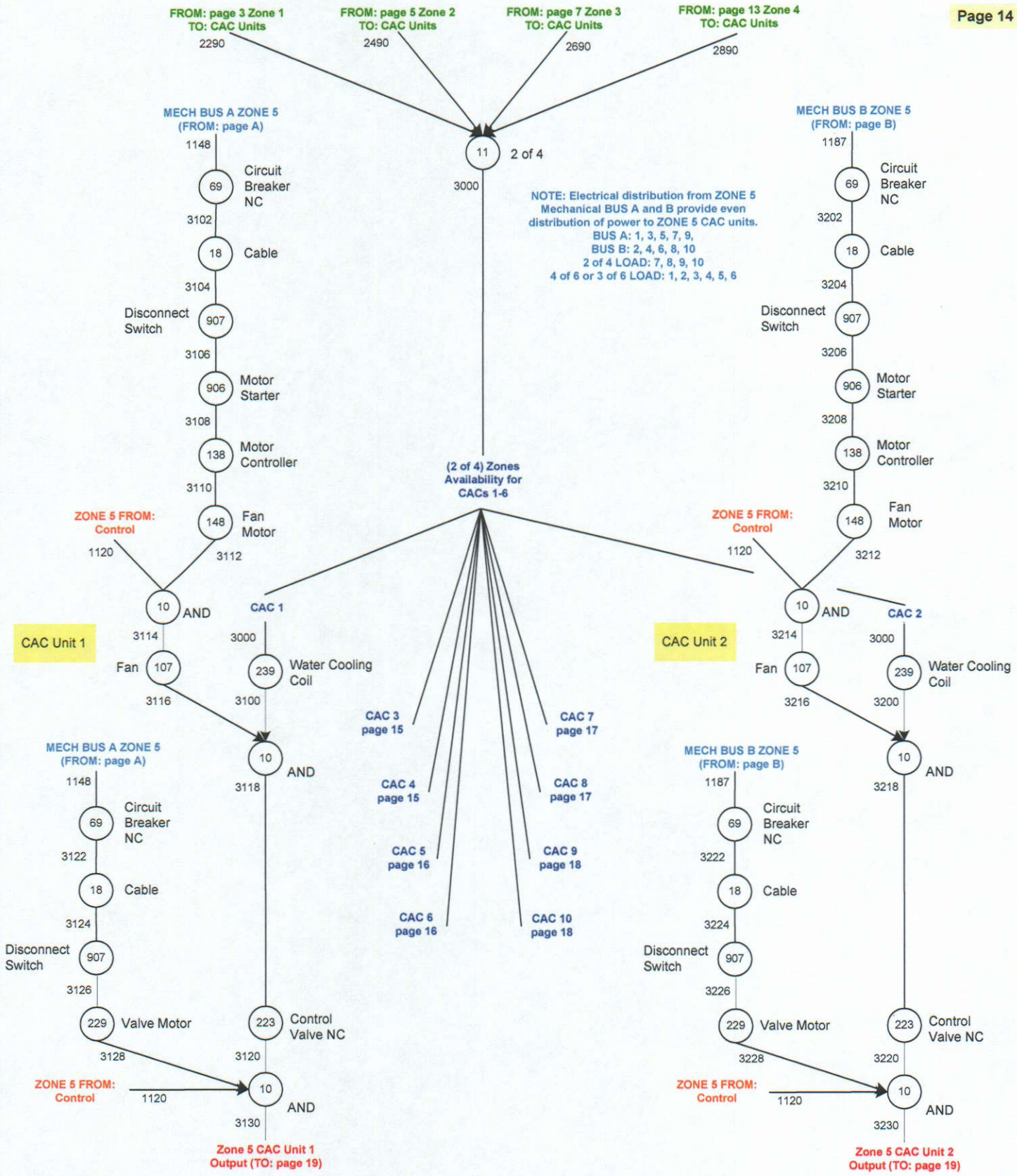

FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2564
18
Cable
2566
Disconnect Switch
907
2568
Chiller Controls
229
Valve Motor
2570
FROM: page 8 Zone 3
2560
905
Control Valve NO
2562
ZONE 3 FROM: Control
1005
10
AND
2572
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2578
Chiller (CH)
18
Cable
2580
155
Pipe
2574
56
Chiller
2576
10
AND
Chiller Electric
2582
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2588
18
Cable
2590
Disconnect Switch
907
2592
906
Motor Starter
2594
138
Motor Controller
2596
Chilled Water Pump (CHWP)
148
Pump Motor
2598
155
Pipe
2584
164
Chilled Water Pump
2586
ZONE 3 FROM: Control
1005
10
AND
2600
TO: page 10 Zone 3

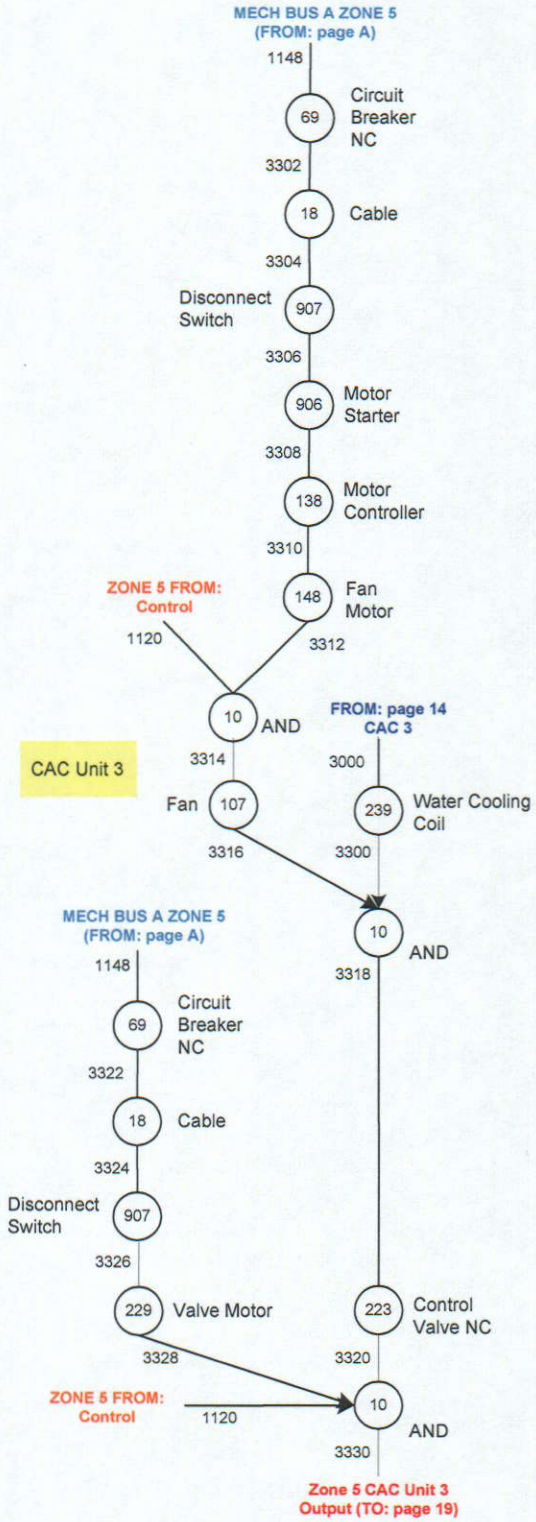

FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2604
18
Cable
2606
Disconnect Switch
907
2608
906
Motor Starter
2610
138
Motor Controller
2612
AHU Fan
148
Fan Motor
2614
ZONE 3 FROM: Control
1005
10
AND
2616
Air Handler (AHU)
107
Fan
2618
400
Air Handler
2602
10
AND
2620
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2624
18
Cable
2626
907
Disconnect Switch
2628
AHU Controls
229
Valve Motor
2630
223
Control Valve NC
2622
ZONE 3 FROM: Control
1005
10
AND
2632
Zone 3 AHU Unit Output (TO: page 19)
FROM: page 9 Zone 3
2600
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2636
18
Cable
2638
Disconnect Switch
907
2640
906
Motor Starter
2642
138
Motor Controller
2644
MAH Fan
148
Fan Motor
2646
ZONE 3 FROM: Control
1005
10
AND
2648
Makeup Air Handler (MAH)
107
Fan
2650
400
Air Handler
2634
10
AND
2552
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2656
18
Cable
2658
907
Disconnect Switch
2660
MAH Controls
229
Valve Motor
2662
223
Control Valve NC
2654
ZONE 3 FROM: Control
1005
10
AND
2664
Zone 5 MAH Unit #3 Output (TO: page 19)
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2670
18
Cable
2672
907
Disconnect Switch
2674
221
Check Valve
2666
229
Valve Motor
2676
223
Control Valve NC
2668
ZONE 5 FROM: Control
1120
10
AND
2678
FROM: Zone 3 LOADS
1050
69
Circuit Breaker NC
2682
18
Cable
2684
907
Disconnect Switch
2686
229
Valve Motor
2688
223
Control Valve NC
2680
ZONE 5 FROM: Control
1120
10
AND
2690
TO: page 14 Zone 5 CAC Units

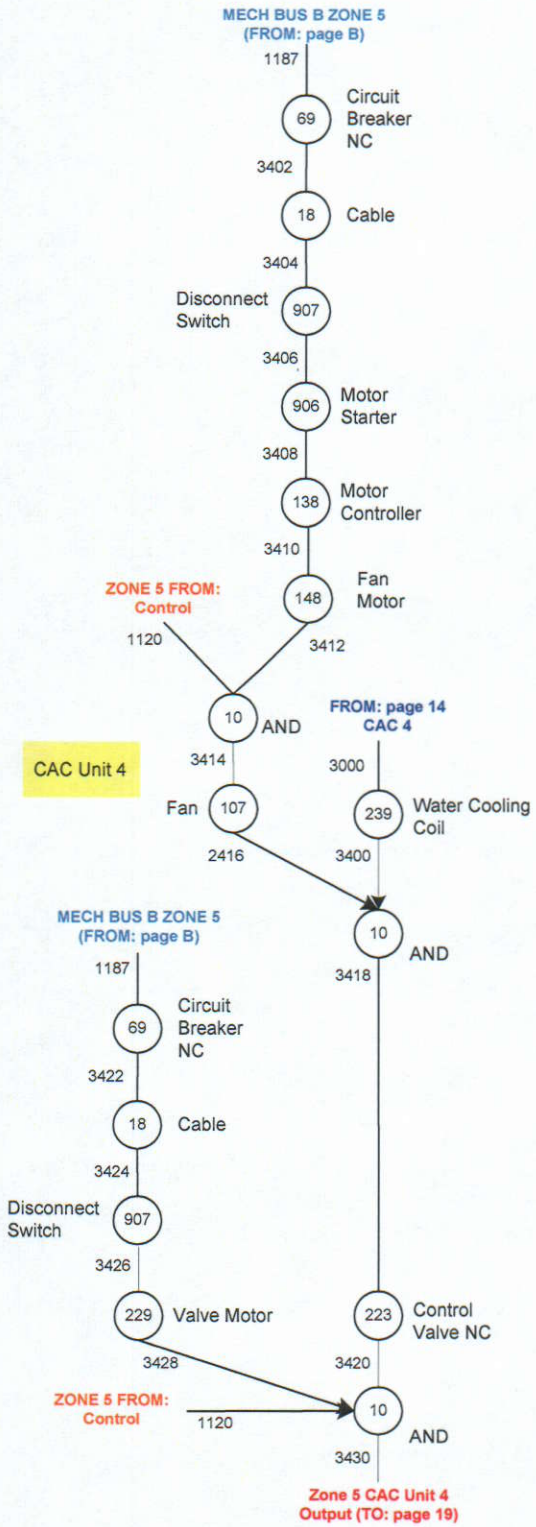

FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2712
18
Cable
2714
Disconnect Switch
907
2716
906
Motor Starter
2718
138
Motor Controller
2720
148
Fan Motor
2722
ZONE 4 FROM: Control
1010
Cooling Tower (CT)
10
AND
2724
Fan
107
2726
FROM: page 1a Zone 4 Make-up Water
1916
221
Check Valve
2700
226
Valve NO
2702
Condensed Water Return (CR) from Chiller
5
2704
155
Pipe
2706
10
AND
2708
95
Cooling Tower
2710
10
AND
2728
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2732
18
Cable
2734
Disconnect Switch
907
2736
906
Motor Starter
2738
138
Motor Controller
2740
Condenser Pump (CWP)
148
Pump Motor
2742
ZONE 4 FROM: Control
1010
164
Condenser Pump
2730
10
AND
2744
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2746
18
Cable
2748
907
Disconnect Switch
2750
229
Valve Motor
2752
Chilled Water Return from CACs, AHU
5
2754
905
Control Valve NO
2756
10
AND
2758
ZONE 4 FROM: Control
1010
10
AND
2760
TO: page 12 Zone 4

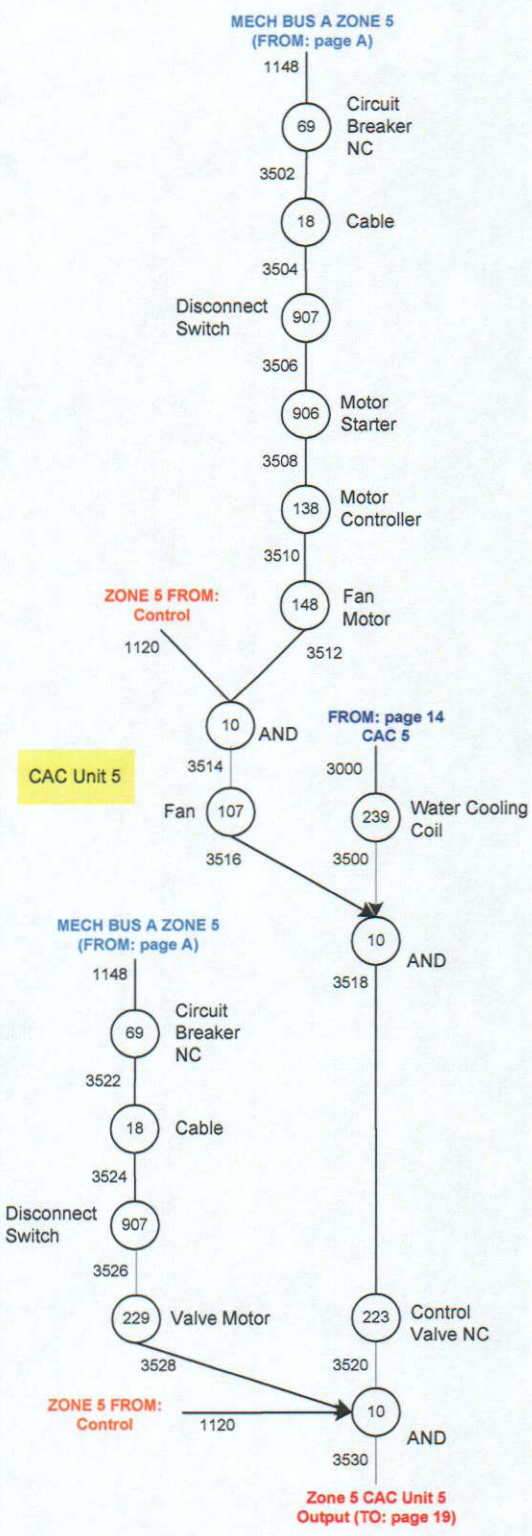

FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2764
18
Cable
2766
Disconnect Switch
907
2768
Chiller Controls
229
Valve Motor
2770
ZONE 4 FROM: Control
1010
FROM: page 11 Zone 4
2760
905
Control Valve NO
2762
10
AND
2772
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2778
Chiller (CH)
18
Cable
2780
155
Pipe
2774
56
Chiller
2776
10
AND
Chiller Electric
2782
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2788
18
Cable
2790
Disconnect Switch
907
2792
906
Motor Starter
2794
138
Motor Controller
2796
Chilled Water Pump (CHWP)
148
Pump Motor
2798
ZONE 4 FROM: Control
1010
155
Pipe
2784
164
Chilled Water Pump
2786
10
AND
2800
TO: page 13 Zone 4

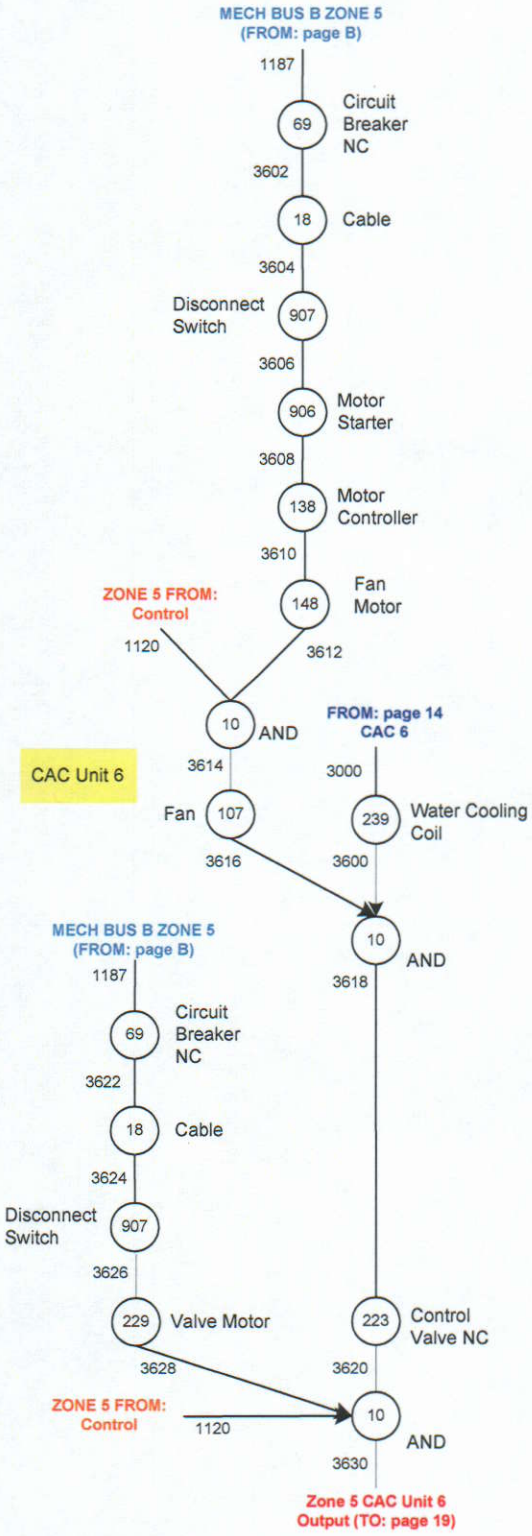

FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2804
18
Cable
2806
Disconnect Switch
907
2808
906
Motor Starter
2810
138
Motor Controller
2812
AHU Fan
148
Fan Motor
2814
ZONE 4 FROM: Control
1010
10
AND
2816
Air Handler (AHU)
107
Fan
2818
400
Air Handler
2802
10
AND
2820
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2824
18
Cable
2826
907
Disconnect Switch
2828
AHU Controls
229
Valve Motor
2830
223
Control Valve NC
2822
ZONE 4 FROM: Control
1010
10
AND
2832
Zone 4 AHU Unit Output (TO: page 19)
FROM: page 12 Zone 4
2800
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2836
18
Cable
2838
Disconnect Switch
907
2840
906
Motor Starter
2842
138
Motor Controller
2844
MAH Fan
148
Fan Motor
2846
ZONE 4 FROM: Control
1010
10
AND
2848
Makeup Air Handler (MAH)
107
Fan
2850
400
Air Handler
2834
10
AND
2852
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2856
18
Cable
2858
907
Disconnect Switch
2860
MAH Controls
229
Valve Motor
2862
223
Control Valve NC
2854
ZONE 4 FROM: Control
1010
10
AND
2864
Zone 4 MAH Unit #4 Output (TO: page 19)
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2870
18
Cable
2872
907
Disconnect Switch
2874
229
Valve Motor
2876
221
Check Valve
2866
223
Control Valve NC
2868
ZONE 5 FROM: Control
1120
10
AND
2878
FROM: Zone 4 LOADS
1092
69
Circuit Breaker NC
2882
18
Cable
2884
907
Disconnect Switch
2886
229
Valve Motor
2888
223
Control Valve NC
2880
ZONE 5 FROM: Control
1120
10
AND
2890
TO: page 14 Zone 5 CAC Units

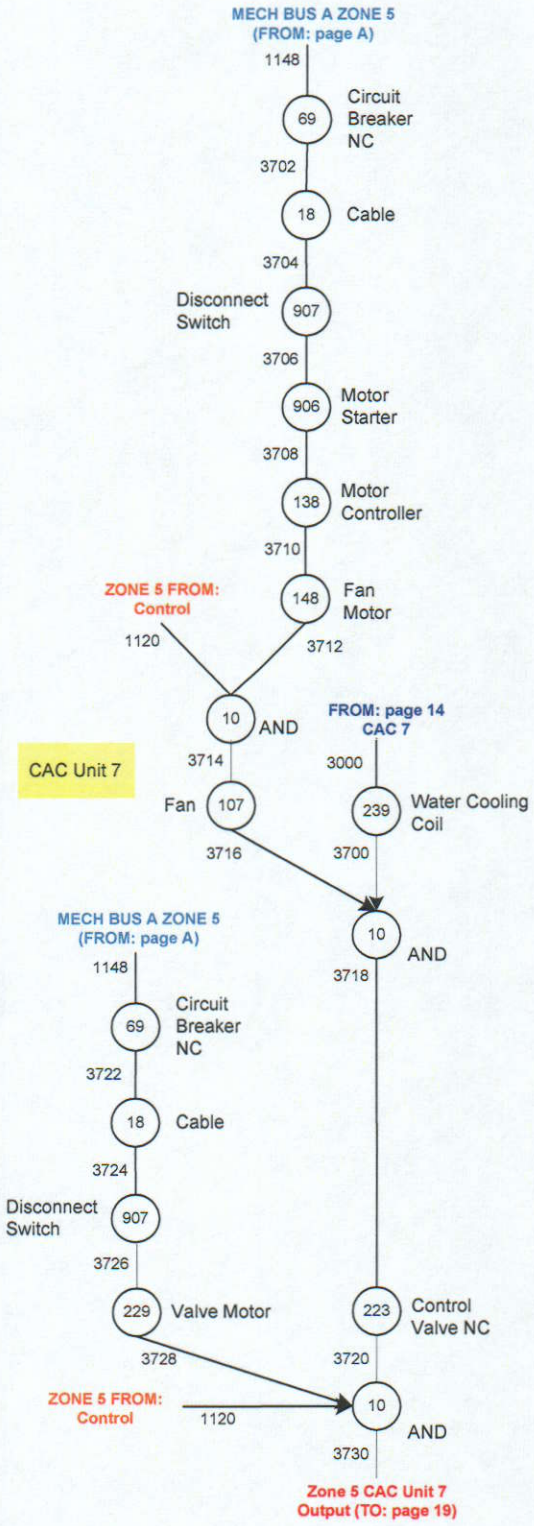

FROM: page 3 Zone 1
TO: CAC Units
2290
FROM: page 5 Zone 2
TO: CAC Units
2490
FROM: page 7 Zone 3
TO: CAC Units
2690
FROM: page 13 Zone 4
TO: CAC Units
2890
11
2 of 4
3000
NOTE: Electrical distribution from ZONE 5 Mechanical BUS A and B provide even distribution of power to ZONE 5 CAC units.
BUS A: 1, 3, 5, 7, 9,
BUS B: 2, 4, 6, 8, 10
2 of 4 LOAD: 7, 8, 9, 10
4 of 6 or 3 of 6 LOAD: 1, 2, 3, 4, 5, 6
(2 of 4) Zones Availability for CACs 1-6
MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3102
18
Cable
3104
Disconnect Switch
907
3106
906
Motor Starter
3108
138
Motor Controller
3110
148
Fan Motor
3112
ZONE 5 FROM: Control
1120
10
AND
3114
Fan
107
3116
CAC Unit 1
CAC 1
3000
239
Water Cooling Coil
3100
10
AND
3118
MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3122
18
Cable
3124
Disconnect Switch
907
3126
229
Valve Motor
3128
223
Control Valve NC
3120
ZONE 5 FROM: Control
1120
10
AND
3130
Zone 5 CAC Unit 1 Output (TO: page 19)
CAC 3 page 15
CAC 4 page 15
CAC 5 page 16
CAC 6 page 16
CAC 7 page 17
CAC 8 page 17
CAC 9 page 18
CAC 10 page 18
MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3202
18
Cable
3204
Disconnect Switch
907
3206
906
Motor Starter
3208
138
Motor Controller
3210
148
Fan Motor
3212
ZONE 5 FROM: Control
1120
10
AND
3214
Fan
107
3216
CAC Unit 2
CAC 2
3000
239
Water Cooling Coil
3200
10
AND
3218
MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3222
18
Cable
3224
Disconnect Switch
907
3226
229
Valve Motor
3228
223
Control Valve NC
3220
ZONE 5 FROM: Control
1120
10
AND
3230
Zone 5 CAC Unit 2 Output (TO: page 19)

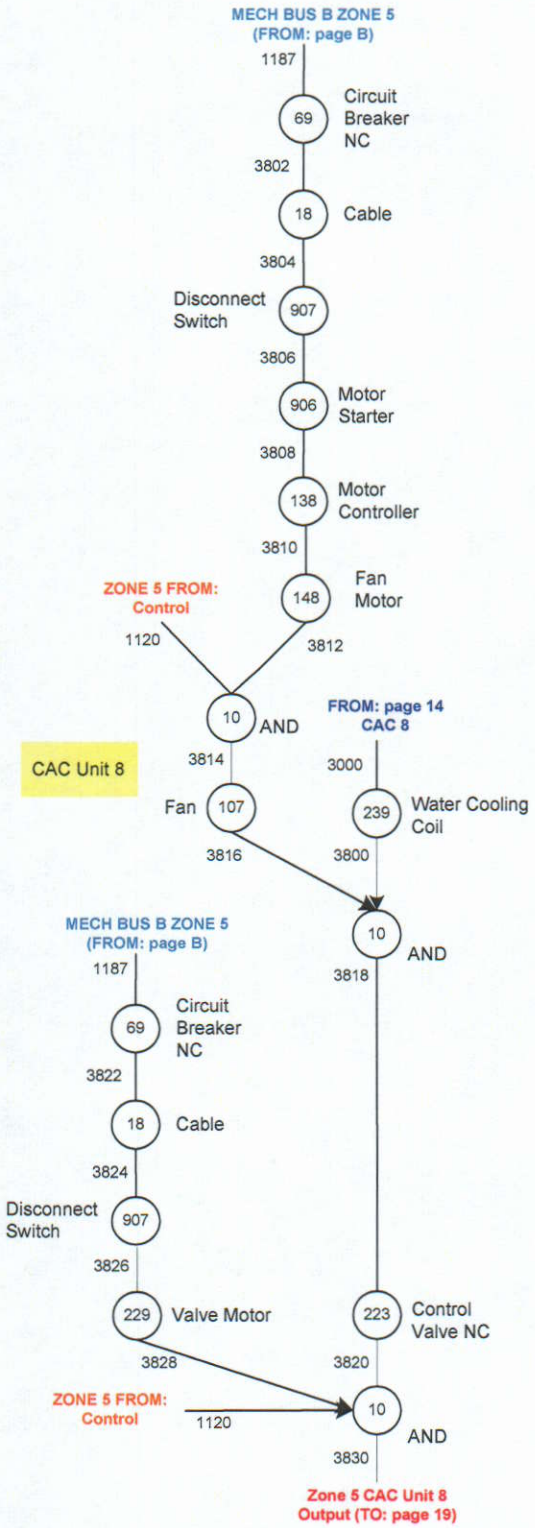

MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3302
18
Cable
3304
Disconnect Switch
907
3306
906
Motor Starter
3308
138
Motor Controller
3310
ZONE 5 FROM: Control
148
Fan Motor
1120
3312
10
AND
FROM: page 14 CAC 3
CAC Unit 3
3314
3000
Fan
107
239
Water Cooling Coil
3316
3300
10
AND
3318
MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3322
18
Cable
3324
Disconnect Switch
907
3326
229
Valve Motor
223
Control Valve NC
3328
3320
ZONE 5 FROM: Control
1120
10
AND
3330
Zone 5 CAC Unit 3 Output (TO: page 19)

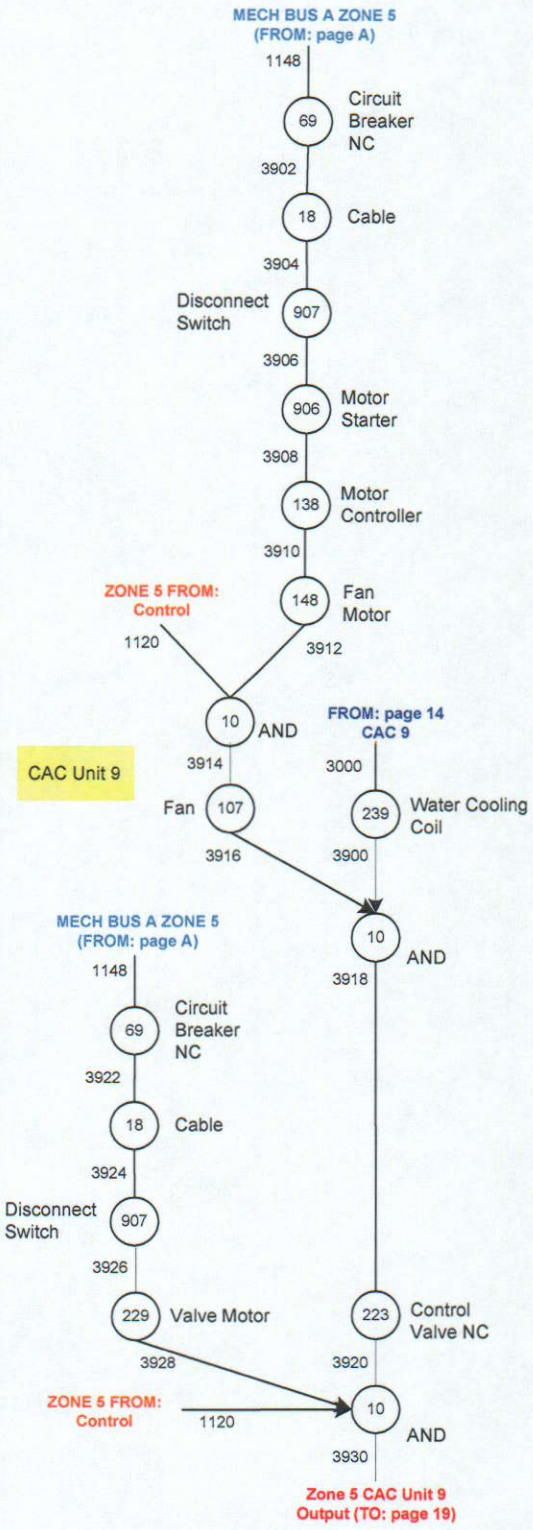

MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3402
18
Cable
3404
Disconnect Switch
907
3406
906
Motor Starter
3408
138
Motor Controller
3410
ZONE 5 FROM: Control
148
Fan Motor
1120
3412
10
AND
FROM: page 14 CAC 4
CAC Unit 4
3414
3000
Fan
107
239
Water Cooling Coil
2416
3400
10
AND
3418
MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3422
18
Cable
3424
Disconnect Switch
907
3426
229
Valve Motor
223
Control Valve NC
3428
3420
ZONE 5 FROM: Control
1120
10
AND
3430
Zone 5 CAC Unit 4 Output (TO: page 19)

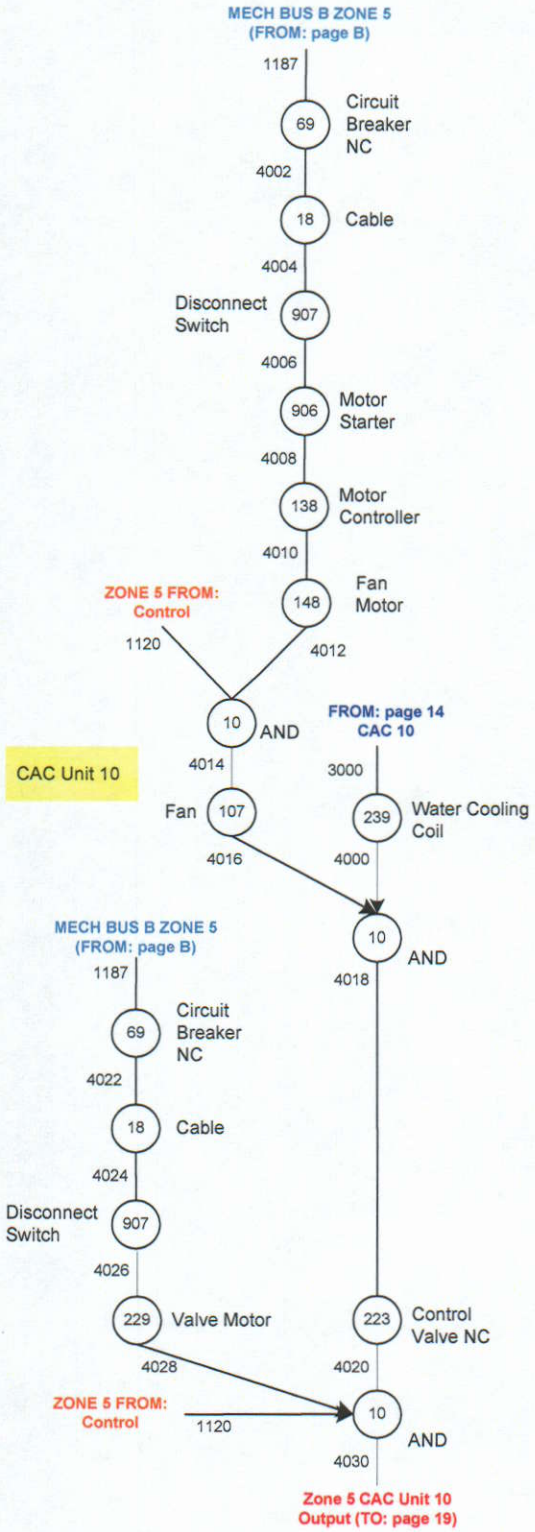

MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3502
18
Cable
3504
Disconnect Switch
907
3506
906
Motor Starter
3508
138
Motor Controller
3510
ZONE 5 FROM: Control
148
Fan Motor
1120
3512
10
AND
FROM: page 14 CAC 5
CAC Unit 5
3514
3000
Fan
107
239
Water Cooling Coil
3516
3500
MECH BUS A ZONE 5
(FROM: page A)
10
AND
3518
1148
69
Circuit Breaker NC
3522
18
Cable
3524
Disconnect Switch
907
3526
229
Valve Motor
223
Control Valve NC
3528
3520
ZONE 5 FROM: Control
1120
10
AND
3530
Zone 5 CAC Unit 5 Output (TO: page 19)

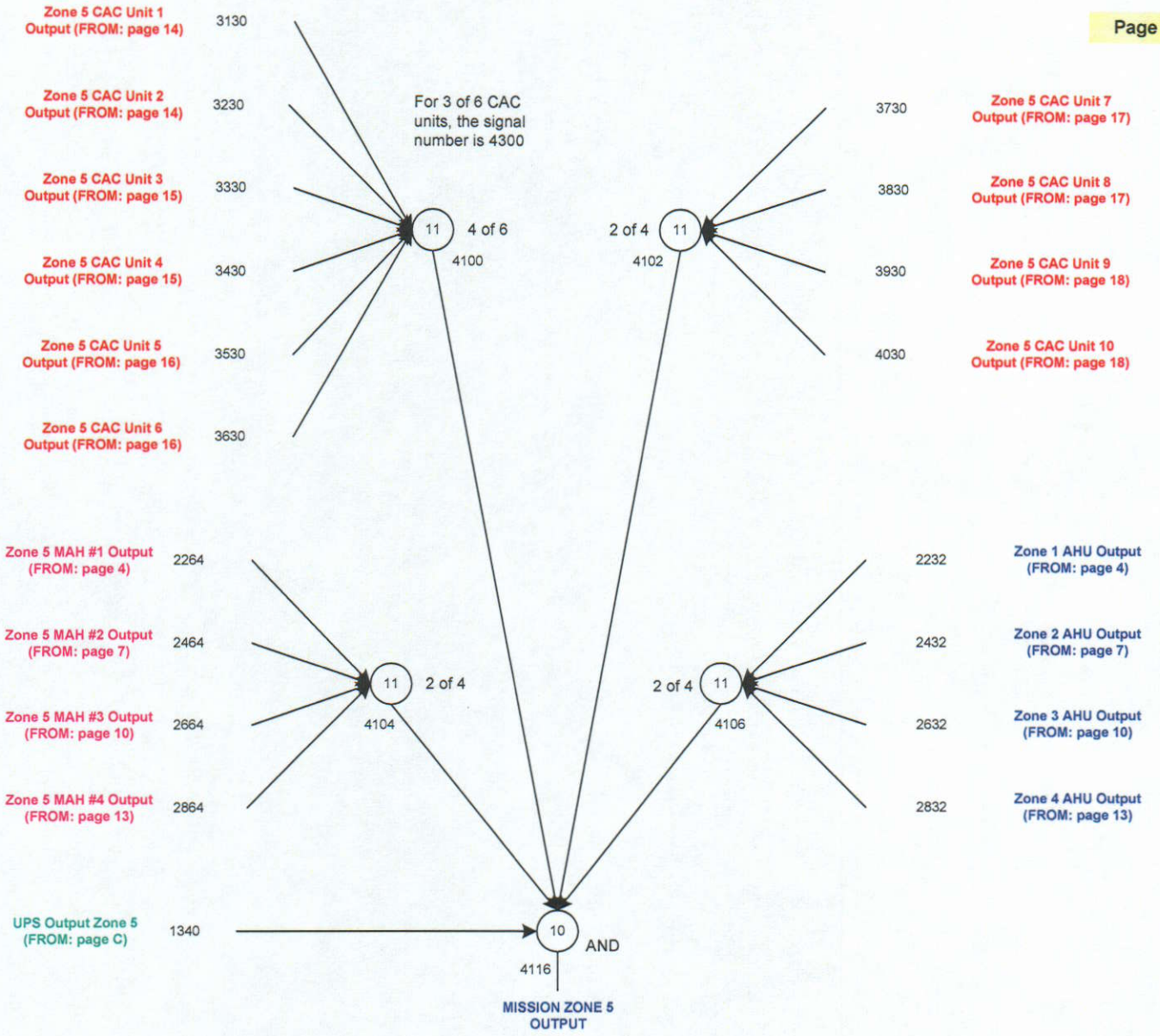

MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3602
18
Cable
3604
Disconnect Switch
907
3606
906
Motor Starter
3608
138
Motor Controller
3610
ZONE 5 FROM: Control
148
Fan Motor
1120
3612
10
AND
FROM: page 14 CAC 6
CAC Unit 6
3614
3000
Fan
107
239
Water Cooling Coil
3616
3600
MECH BUS B ZONE 5
(FROM: page B)
10
AND
3618
1187
69
Circuit Breaker NC
3622
18
Cable
3624
Disconnect Switch
907
3626
229
Valve Motor
223
Control Valve NC
3628
3620
ZONE 5 FROM: Control
1120
10
AND
3630
Zone 5 CAC Unit 6 Output (TO: page 19)


MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3702
18
Cable
3704
Disconnect Switch
907
3706
906
Motor Starter
3708
138
Motor Controller
3710
ZONE 5 FROM: Control
148
Fan Motor
1120
3712
10
AND
FROM: page 14 CAC 7
CAC Unit 7
3714
3000
Fan
107
239
Water Cooling Coil
3716
3700
10
AND
3718
MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3722
18
Cable
3724
Disconnect Switch
907
3726
229
Valve Motor
223
Control Valve NC
3728
3720
ZONE 5 FROM: Control
1120
10
AND
3730
Zone 5 CAC Unit 7 Output (TO: page 19)


MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3802
18
Cable
3804
Disconnect Switch
907
3806
906
Motor Starter
3808
138
Motor Controller
3810
ZONE 5 FROM: Control
148
Fan Motor
1120
3812
10
AND
FROM: page 14 CAC 8
CAC Unit 8
3814
3000
Fan
107
239
Water Cooling Coil
3816
3800
10
AND
3818
MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
3822
18
Cable
3824
Disconnect Switch
907
3826
229
Valve Motor
223
Control Valve NC
3828
3820
ZONE 5 FROM: Control
1120
10
AND
3830
Zone 5 CAC Unit 8 Output (TO: page 19)


MECH BUS A ZONE 5
(FROM: page A)
1148
69
Circuit Breaker NC
3902
18
Cable
3904
Disconnect Switch
907
3906
906
Motor Starter
3908
138
Motor Controller
3910
ZONE 5 FROM: Control
148
Fan Motor
1120
3912
10
AND
FROM: page 14 CAC 9
CAC Unit 9
3914
3000
Fan
107
239
Water Cooling Coil
3916
3900
MECH BUS A ZONE 5
(FROM: page A)
10
AND
3918
1148
69
Circuit Breaker NC
3922
18
Cable
3924
Disconnect Switch
907
3926
229
Valve Motor
223
Control Valve NC
3928
3920
ZONE 5 FROM: Control
1120
10
AND
3930
Zone 5 CAC Unit 9 Output (TO: page 19)


MECH BUS B ZONE 5
(FROM: page B)
1187
69
Circuit Breaker NC
4002
18
Cable
4004
Disconnect Switch
907
4006
906
Motor Starter
4008
138
Motor Controller
4010
ZONE 5 FROM: Control
148
Fan Motor
1120
4012
10
AND
FROM: page 14 CAC 10
CAC Unit 10
4014
3000
Fan
107
239
Water Cooling Coil
4016
4000
MECH BUS B ZONE 5
(FROM: page B)
10
AND
4018
1187
69
Circuit Breaker NC
4022
18
Cable
4024
Disconnect Switch
907
4026
229
Valve Motor
223
Control Valve NC
4028
4020
ZONE 5 FROM: Control
1120
10
AND
4030
Zone 5 CAC Unit 10 Output (TO: page 19)



See page 20 for other potential output signal variations to achieve the mission (as defined on page 20).

Availability at:	Signal Point	Signal	# 9's	Notes
Zone 5 UPS	1340	1	>7-9	
Zone 5 Mech A	1148	0.99998821	4-9	
Zone 5 Mech B	1187	0.99998821	4-9	
4 of 6 CAC	4100			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
Zone 1-4 AHU	4106			
AND	4108	0.99997635	4-9	
3 of 6 CAC	4103			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
Zone 1-4 AHU	4106			
AND	4110	0.99999987	6-9	
4 of 6 CAC	4100			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
AND	4112	0.99997635	4-9	
3 of 6 CAC	4103			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
AND	4114	0.99999988	6-9	
4 of 6 CAC	4100			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
Zone 1-4 AHU	4106			
Zone 5 UPS	1340			
AND	4116	0.99997635	4-9	(Combination represented in model - page 19)
3 of 6 CAC	4103			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
Zone 1-4 AHU	4106			
Zone 5 UPS	1340			
AND	4118	0.99999987	6-9	
4 of 6 CAC	4100			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
Zone 5 UPS	1340			
AND	4120	0.99997635	4-9	
3 of 6 CAC	4103			
2 of 4 CAC	4102			
Zone 1-4 MAH	4104			
Zone 5 UPS	1340			
AND	4122	0.99999988	6-9	

APPENDIX D

EXAMPLE OF UTILITY CAPACITY CALCULATION

D-1 Applicability of this example

This example is intended to illustrate the application of the redundancy and capacity criteria described in chapter 2, Fundamentals of Limited Vulnerability Design, to the selection of utility system capacity for a facility following the LVD concept. It is based solely on the example C4ISR facility, is limited to a single utility, and uses assumptions that are not valid for all facilities, missions, or geographic locations. Therefore, this should be considered an example only and not indicative of the utility requirements of any actual facility. The calculation below applies to the facility configuration described in chapter 3, Architectural and Structural Systems, and presents a methodology for determining the required size of electrical services to meet the specified redundancy criteria. The facility consists of 35,000 GSF. The area is assumed to be divided approximately equally among the four peripheral zones and the command center.

D-2 Calculation of required electrical capacity

The required electrical capacity can be calculated as described below, using assumptions for the design loading of each zone. The capacity is calculated for the following two alternative configurations of the command center electrical system:

a. Configuration 1 in figure D-1 is the simple automatic bus transfer scheme described in chapter 5, Electrical Systems. Each zone source must be capable of supplying 100 percent of the command center load.

b. Configuration 2 as shown in figure D-2, is the command center is supplied by a ring bus with network protectors. With the greater redundancy of this scheme, each zone source must be capable of supplying only 50 percent of the command center load.

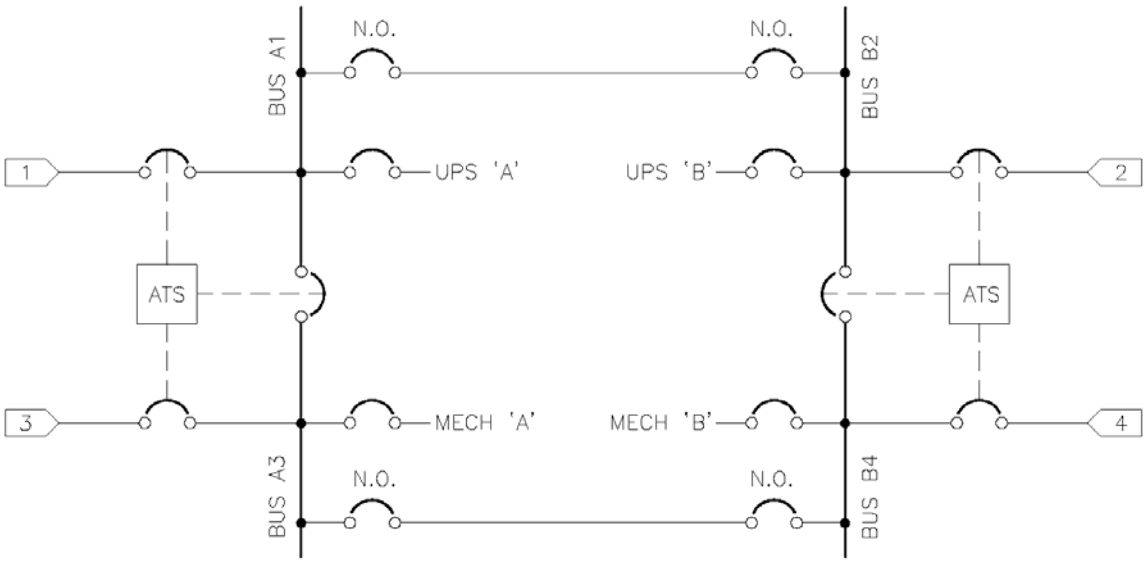


Figure D-1. Single-line diagram – automatic transfer scheme

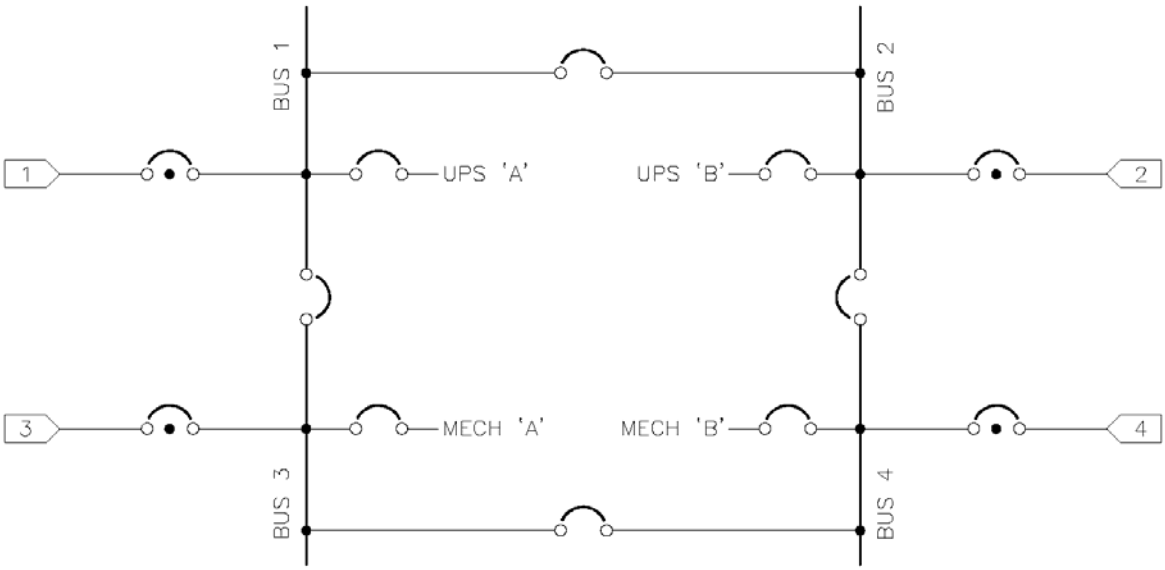


Figure D-2. Single-line diagram – ring bus with network protectors

c. The calculation of the required electrical capacity consists of the following steps:

1. Calculate command center electrical load

Upper level – people and consoles:	7,000 SF @ 25 W/SF = 175 kW
Lower level – servers and communications gear:	7,000 SF @ 50 W/SF = 350 kW
Total command center load:	525 kW

2. Calculate command center cooling load

(525 kW x 3,412 Btu/kWhr)/12,000 Btu-hr/ton = 150 tons cooling

3. Calculate peripheral zone electrical load

Office space – electronic-intensive use:	7,000 SF @ 10 W/SF = 70 kW
Mechanical HVAC (estimated):	50 kW
Total peripheral zone load:	120 kW

4. Calculate cooling capacity for each service

Based on four peripheral zones, each must support itself and 50 percent of the command center load, as follows:

Peripheral zone:	7,000 SF @ 200 SF/ton = 35 tons
50 percent of command center:	150 x 0.5 = 75 tons
Required zone chiller capacity:	110 tons

5. Calculate electrical service capacity

a. Configuration 1

Zone electrical load from step 3:	120 kW
100 percent of command center load from step 1:	525 kW
Zone chilled water system:	110 tons x 1.0 kW/ton = 110 kW
Total required service capacity:	755 kW

b. Configuration 2

Zone electrical load from step 3:	120 kW
50 percent of command center load from step 1:	263 kW
Zone chilled water system:	110 tons x 1.0 kW/ton = 110 kW
Total required service capacity:	493 kW

D-3. Additional considerations

In this example, the more complex command center electrical configuration of figure D-2 reduces the required capacity of each zone service by one-third. The designer would weigh these cost savings at the zone level against the increased cost of the switchgear at the command center level. In selecting a final design, the designer should also consider the potential risk of human error associated with the more complex configuration and the impact of such risk on reliability.

APPENDIX E

DISASTER RECOVERY SUGGESTED PRIMARY CONTACT MATRIX

DISASTER RECOVERY - SUGGESTED PRIMARY CONTACT MATRIX

C4ISR Effected Site	Primary Contact							
	Facility Manager	Maintenance Manager	Information Technology Manager	Computer Technician	Site Security	Medical Personnel (Impact On Area Personnel)	Hazardous Materials Team	Fire Response Unit
POWER DELIVERY SYSTEM / AREAS								
Zone 1-4 generator(s)	A,E1,E4,F1,F3,G11	B1,B6,D4,D7	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 Power delivery equipment failure (cables, switchgear, breakers, etc.)	A,E1,E4,F1,F3,G11	B1,B6,D7	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 Power delivery equipment failure (cables, switchgear, breakers, etc.)	A,B1,B6,E1,E4,F1,F3,G11	B1,B6,D7	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 UPS system(s) do not function	A,B1,B6,E1,E4,F1,F3,G11	B1,B6,D7			D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
HVAC SYSTEM / AREAS								
Zone 1-4 Make-up water not available/low	A,E1-3,F1-3,G10	B,D6			D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 Primary component(s) fail (Chiller, AHU, Cooling tower, Pumps)	A,E1-4,F1-3,G10	B,D6	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 Makeup water support equipment failure (pipes, valves)	A,E1-3,F1-2,G10	B-1,D6	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 HVAC controls fail	A,E1-2, E4,F1-2,G10	B-1,D6	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 heating/zone pressure service failure	A,E1,E4,F1-3,G10	B,D4,D6	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 HVAC computer air conditioning service failure	A,E1-2,F1-2,G10	B,D6	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 HVAC heating/zone pressure service failure	A,E1,E4,F1-3,G10	B,D4,D6	D8,H1-2,H5	D9,H6	D5,D10,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
BUILDING SECURITY AND EGRESS SYSTEMS								
Video monitoring, personnel entrance, and surveillance equipment, controls, wiring	A,E1,E5,F1	B1,B3-6	D8,H1-2,H5	D9,H6	D5,D10,E4,F4,G1,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Fire sensors, autonomous pathogen detection response systems activation	A,E1,E5,F1	B1,B3-6	D8,H1-2,H5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Fire supression system activation or failure	A,E1,E5,F1	B1-2,B5-6	D8,H1-2,H5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Egress system failure (doors, elevators, etc)	A,E1,F1	B	D8,H1-2,H5	D9,H6	D5,D10,E4,F4,G1,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
INFORMATION TECHNOLOGY								
Zone 1-4 Computer servers	A,E5,F1	B1,B5-6	D8,H1-5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 Computer terminals	A,E5,F1	B1,B5-6	D8,H1-5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 1-4 Computer cabling, connectors, etc.	A,E5,F1	B1,B5-6	D8,H1-5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 Computer servers	A,E5,F1	B1,B5-6	D8,H1-5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 Computer terminals	A,E5,F1	B1,B5-6	D8,H1-5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
Zone 5 Computer cabling, connectors, etc	A,E5,F1	B1,B5-6	D8,H1-5	D9,H6	D5,D10,E4,F4,G5-9	C,D12	D1-2,G12-13	D3,D11,G2-4
BUILDING STRUCTURAL DAMAGE								
Zone 1-4 External walls and structure	A,B					D12	G12-13	D3,D11,G2-4
Zone 1-4 Internal walls and structure	A,B					D12	G12-13	D3,D11,G2-4
Zone 5 Internal walls and structure	A,B					D12	G12-13	D3,D11,G2-4

Potential Disaster Scenarios

Reference Code		Reference Code	
A	**Geological Hazards (naturally occurring)**	**F**	**Intentional Human Caused Utility Related disruptions (Terrorism)**
A1	Earthquake. Volcano, Tsunami	F1	External electric power utility disruption
A2	Landslide, mudslide, glacier	F2	External domestic water utility disruption
		F3	External natural gas utility disruption
B	**Meteorological hazards (naturally occurring)**	F4	External communications systems interruptions
B1	Flood, flash flood		
B2	Fire (forest)	**G**	**Intentional Human Caused (Terrorism)**
B3	Snow (storm), Ice, hail, sleet	G1	Misinformation
B4	Windstorm, tropical cyclone, hurricane, tornado, water spout, dust/sand storm	G2	Fire (Arson)
B5	Extreme temperatures	G3	Building/structure collapse (bomb induced)
B6	Lightning strikes	G4	Internal site explosion and fire (bomb induced)
		G5	Security system tampering
C	**Biological hazards (naturally occurring)**	G6	Fire sensors, autonomous pathogen detection response systems tampering
C1	Diseases that impact humans (colds, flu, etc)	G7	Forced building or zone entry
C2	Animal or insect infestation on site	G8	Building and zone access entrance tampering
		G9	Communications systems disrupted/damaged
D	**Accidental (human or equipment caused)**	G10	HVAC equipment failure, including controls
D1	Hazardous material (chemical, radiological, biological) spill or release into air	G11	Power delivery equipment failure, including controls
D2	Hazardous material (chemical, biological) spill or release into water	G12	Hazardous material (chemical, radiological, biological) spill or release into air
D3	Internal site explosion/fire (mechanical/electrical equipment malfunction)	G13	Hazardous material (chemical, biological) spill or release into water
D4	Fuel/resource shortage		
D5	Internal communications systems interruptions (equipment failure)	**H**	**Intentional Informational Technology disruption (Terrorism)**
D6	HVAC equipment failure, including controls	H1	Computer server/terminal virus, worm, etc.
D7	Power delivery equipment failure, including controls	H2	Computer server power disruption
D8	Server equipment failure	H3	Computer terminal power disruption (without aid of UPS)
D9	Terminal equipment failure	H4	Computer terminal power disruption (with aid of UPS)
D10	Security equipment failure	H5	Computer server cable/contact damage
D11	Fire suppression system equipment failure	H6	Computer terminal cable/contact damage
D12	Human sickness		
E	**Accidental External Utility Related disruptions**		
E1	Electric power utility disruption		
E2	Domestic water utility disruption		
E3	Domestic water pollution, contamination		
E4	Natural gas utility disruption		
E5	External communications systems interruptions		

GLOSSARY

1. Glossary

-A-

AGENT: A substance in the form of a toxic industrial chemical or toxic industrial material, biological or radiological agent, or military chemical, which together with the delivery tactic is a type of threat.

-C-

COMMISSIONING: The process of verifying and documenting that the installed systems are in compliance with the design intent and specified performance criteria.

-D-

DELIVERY TACTIC: The method of delivering a CBR agent (external or internal release).

DESIGN BASIS THREAT: "The threat (aggressors, delivery tactics, and associated weapons, tools, or explosives) against which assets within the building must be protected and upon which the security engineering design of the building is based" (UFC 4-010-01).

-H-

HYDRONIC: Of or relating to a system of heating or cooling that involves transfer of heat by a circulating fluid in a closed system of pipes.

-I-

INFILTRATION: The uncontrolled exchange of the building's interior air with outside air.

-L-

LEVEL OF PROTECTION: The degree to which an asset is protected against injury or damage from a CBR event.

LVD MODEL: A set of principles to apply in designing a C4ISR facility that is compartmentalized and provides multiple service pathways for all utilities to the critical load as protection against an internal terrorist attack intended to interrupt the mission.

-N-

N+2: Pertaining to a system in which N units operating in parallel are required to supply the necessary capacity, with two additional or spare units provided so that maintenance activities and failures do not result in an inability to supply the required capacity. The same definition applies as the number of spare units is varied (N+1, N+3, etc.).

2N: Pertaining to a system in which N units operating in parallel are required to supply the necessary capacity, with the number of units provided being double that.

-S-

STACK EFFECT: Thermally driven air density differences between the building indoor and outdoor ambient conditions.

-T-

THREAT: Aggressors, delivery tactics, and associated weapons, tools, or explosives against which a facility is protected; established by evaluating aggressor likelihood and objectives with respect to the assets.

TON: unit of refrigeration equal to 12,000 Btu per hour.

-V-

VESICANT: a chemical that causes skin blisters.

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