Safe and Resilient Hospitals

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SAFE HOSPITALS
DURING DISASTERS AND CATASTROPHES

BUILDING RESILIENT, FUNCTIONAL AND SUSTAINABLE HEALTHCARE SYSTEMS

EXTERNAL DISASTERS
Events originating outside the hospital

- EARTHQUAKES
- FLOODS
- HURRICANES
- PANDEMICS
- MASS CASUALTY INCIDENTS
- CONFLICTS

INTERNAL DISASTERS
Events originating inside the hospital

- FIRE
- WATER LEAKS AND FLOODING
- MEDICAL GAS FAILURE
- CYBERATTACKS
- POWER SYSTEM FAILURE
- HAZARDOUS MATERIALS

RISK ASSESSMENT · INFRASTRUCTURE RESILIENCE · EQUIPMENT RELIABILITY

THE ENGINEER'S MISSION
To ensure that when disaster strikes, the hospital continues to heal.

CONTINUITY OF CARE · SAFETY OF PATIENTS & STAFF · COMMUNITY RESILIENCE

SAFE HOSPITALS
DURING DISASTERS AND CATASTROPHES

BUILDING RESILIENT, FUNCTIONAL AND SUSTAINABLE HEALTHCARE SYSTEMS

WHY HOSPITALS FAIL

STRUCTURAL FAILURES

- Collapse
- Severe structural damage

NON-STRUCTURAL FAILURES

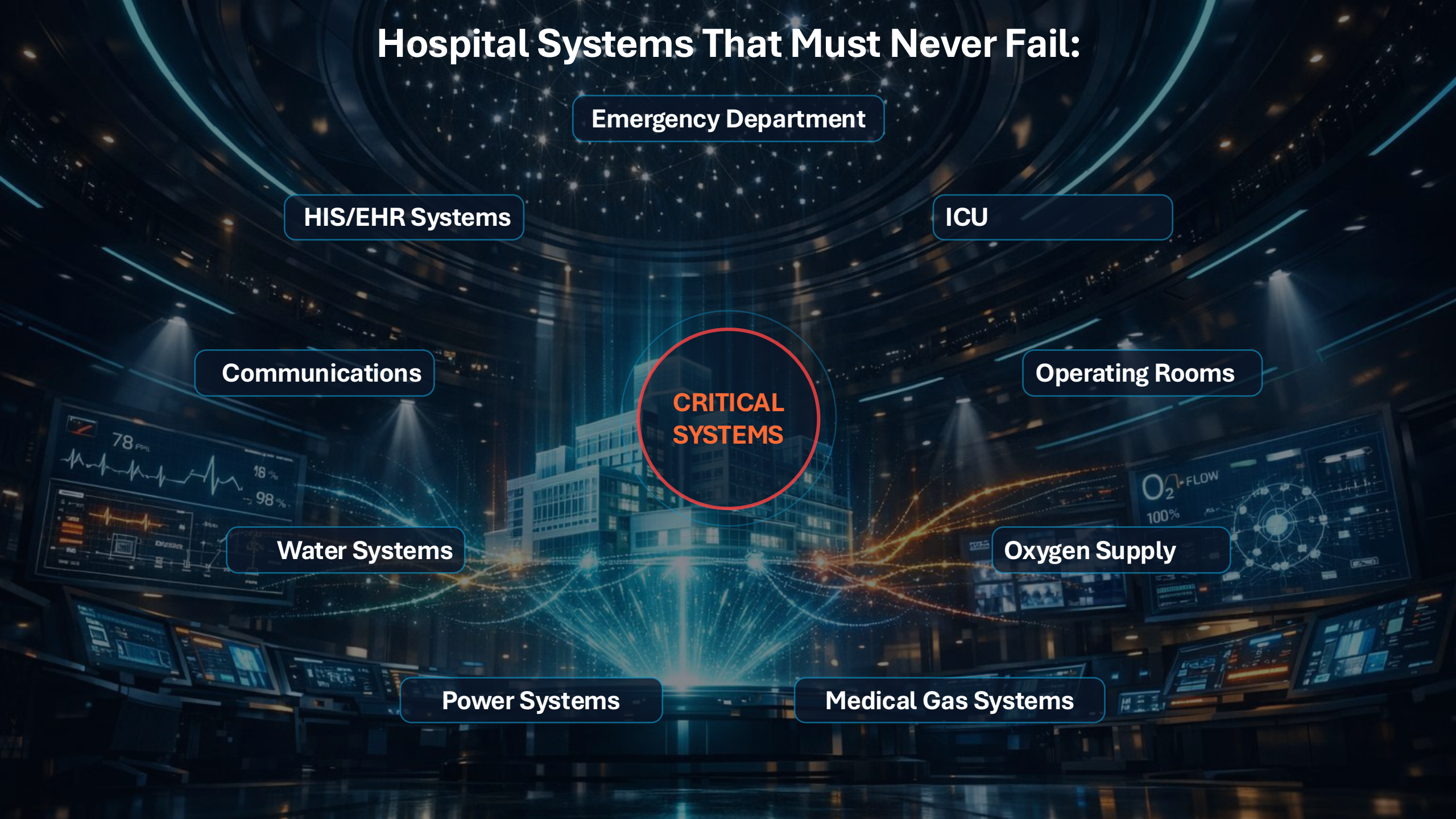
- Utility disruption
- Ceiling failures
- Equipment movement
- Water intrusion
- HVAC failure
- Communication failure

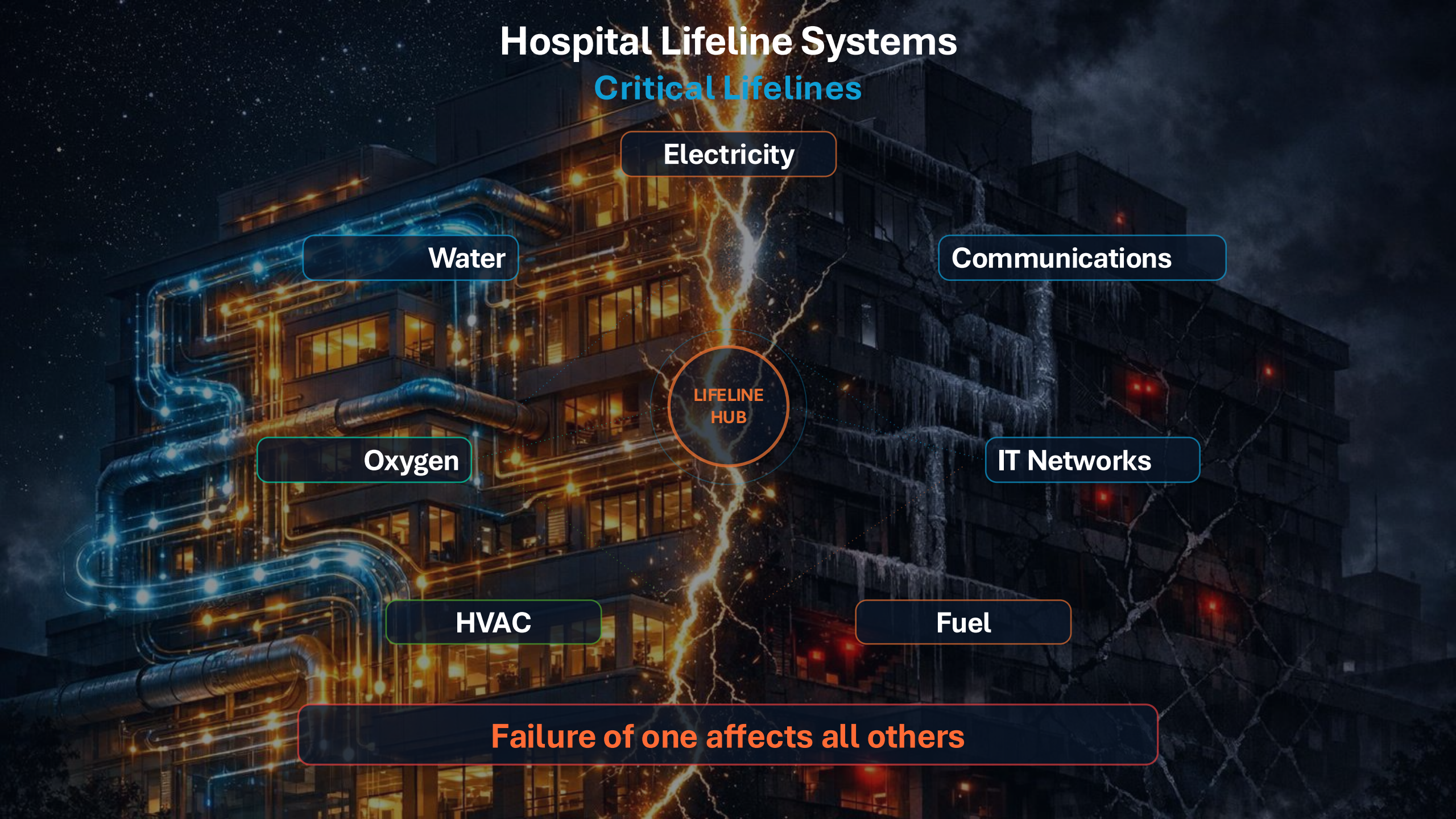
FUNCTIONAL FAILURES

- Staff shortages
- Leadership failures
- Supply shortages
- Information-system failures

KEY MESSAGE

Most modern hospital failures arise from non-structural and functional failures.


Hospital Systems That Must Never Fail:
Emergency Department
HIS/EHR Systems
ICU
Communications
CRITICAL SYSTEMS
Operating Rooms
Water Systems
Oxygen Supply
Power Systems
Medical Gas Systems


Hospital Lifeline Systems
Critical Lifelines
Electricity
Water
Communications
LIFELINE HUB
Oxygen
IT Networks
HVAC
Fuel
Failure of one affects all others

Water Resilience

Hospitals consume massive water volumes used for:

Dialysis

renal replPurified water essential for acement therapy

Sterilization

Instrument decontamination and autoclave operations

HOSPITAL WATER SUPPLY

HVAC

Cooling towers and climate control systems

Decontamination

Emergency hazmat and patient wash-down stations

CASE STUDY

Hurricane Katrina

Major causes of hospital failure

1

Generator Flooding

Backup generators placed in basements were submerged by rising floodwaters

2

Fuel Shortage

Supply routes cut off by flooding left remaining generators without fuel

3

Communication Breakdown

Total power loss disabled radios, phones, and network systems, isolating hospitals

CASCADING FAILURE CHAIN

HOSPITAL RESILIENCE

Can the hospital survive the disaster?

Can the hospital continue providing essential services during and after the disaster?

Evolution of Hospital Safety Concepts

Hospital Safety → Safe Hospitals → Smart Hospitals → Resilient Hospitals

1980s Structural Safety

Focus on building codes and seismic reinforcement of hospital structures

1990s Disaster Preparedness

Emergency planning, evacuation protocols, and hazard mitigation strategies

2000s Safe Hospitals Initiative

WHO-led global campaign ensuring hospitals remain functional during crises

2010s Business Continuity

Smart systems, IoT integration, and operational continuity planning

2020s Resilient Hospitals

Adaptive systems that absorb, recover, and evolve from disruptions

Disaster Preparedness Phase

THE SENDAI FRAMEWORK FOR DISASTER RISK REDUCTION

FOUR PRIORITIES

1. Understanding Risk
2. Strengthening Governance
3. Investing in Resilience
4. Preparedness and Building Back Better

HEALTHCARE RELEVANCE

- Safe Hospitals
- Resilient Infrastructure
- Protected Health Workforce
- Continuity of Care

Technology Hazard Vulnerability Assessment (THVA)

Key Questions

- Which equipment is critical?
- Which equipment is vulnerable?
- What hazards threaten it?
- What are the consequences of failure?
- What backups exist?

Deliverable

- Critical Technology Risk Register

Single Point of Failure Identification Program

Must Find

- Single oxygen source
- Single generator
- Single network server
- Single supplier
- Single maintenance contractor

Goal

- Zero Single Points of Failure

Equipment Resilience Classification

Class A	Immediate threat to life if failed. Examples:, Ventilators, Defibrillators, ECMO
Class B	• Critical clinical support
Class C	• Important but deferrable
Class D	• Nonessential during disaster operations

Equipment Anchoring Program

Earthquakes frequently disable equipment that survives structurally but falls physically.

Must Be Secured

Ventilators	Monitors	Anesthesia machines	Imaging systems	Medical gas cylinders

Preparedness Indicator

Percentage of critical equipment properly anchored

Medical Gas Resilience Assessment

Questions Must Ask:

Can oxygen demand increase 300%?

How many days can oxygen supply last?

What is the backup source?

Where are vulnerabilities located?

COVID-19 Lesson

Oxygen became the most critical drug in the world.

Participation in Hospital Design

The best disaster mitigation begins during construction.

Should Participate in:

- Hospital design reviews
- Utility planning
- Equipment layout
- Future surge planning
- Redundancy design

Not After Construction

- Before Construction

Strategic Spare Parts Program

Many hospitals stock devices but not parts.

Critical Components

- Batteries, Sensors, Power modules, Fuses, Oxygen regulators, Ventilator accessories

Question

- Can equipment operate if global supply chains collapse?

Equipment Surge Capacity Planning

Determine

- Maximum patient surge
- Required ventilators
- Required monitors
- Required pumps
- Required oxygen flow

Formula

- Normal Capacity ≠ Disaster Capacity

Vendor Disaster Preparedness Agreements

Before Disaster

- Establish agreements with vendors.

Questions

- Can they provide emergency support?
- Can they deliver spare parts?
- Can they provide temporary equipment?

Never Negotiate During a Disaster!

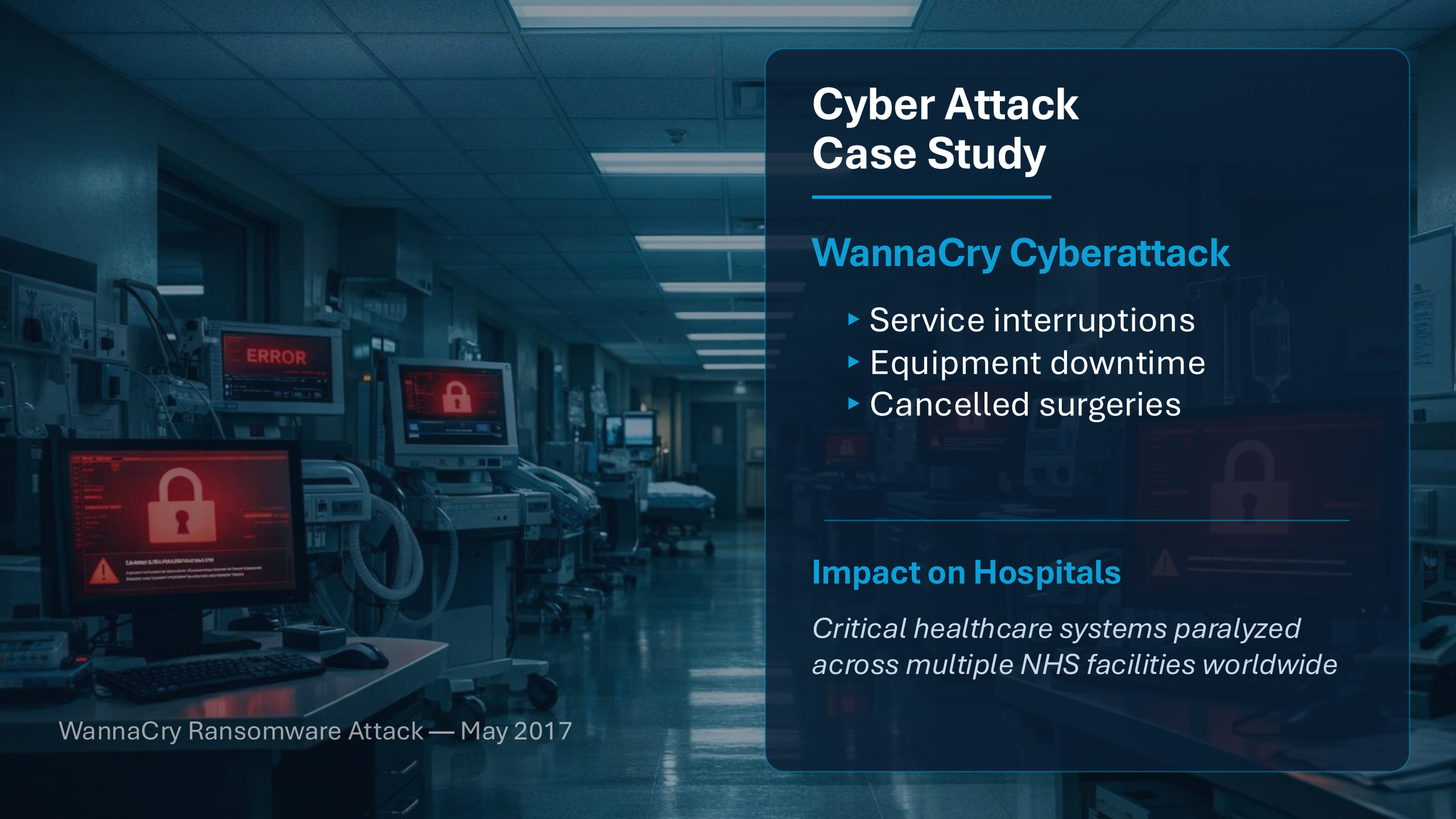
Cyber Preparedness for Medical Equipment

Many modern devices are network-connected

Preparedness Activities

- Asset inventory
- Network segmentation
- Software updates
- Backup procedures
- Incident response plans

Future Disasters May Begin with a Keyboard



Cyber Attack Case Study

WannaCry Cyberattack

- Service interruptions
- Equipment downtime
- Cancelled surgeries

Impact on Hospitals

Critical healthcare systems paralyzed across multiple NHS facilities worldwide

WannaCry Ransomware Attack — May 2017

Smart Hospitals and New Risks

Connected Devices / IoMT

Internet of Medical Things enabling real-time data exchange between bedside devices and clinical systems, creating interconnected care ecosystems.

Wireless Monitoring

Continuous patient vital tracking through cable-free sensors and remote telemetry systems, reducing physical constraints on patient mobility.

Smart Pumps

Intelligent infusion systems with automated dosage verification and network-connected safety alerts for medication delivery accuracy.

Benefits & Vulnerabilities

Enhanced care delivery efficiency alongside expanded attack surfaces and cybersecurity exposure requiring robust network segmentation.

Monitor in Real Time

Key Monitoring Areas

- Equipment readiness
- Oxygen reserves
- Generator status
- Battery status
- Maintenance backlog
- Spare part inventory

MITIGATION
Prevent

PREPAREDNESS
Plan

RESPONSE
Act

RECOVERY
Restore

Leadership Needs Visibility Before Crisis

POWER | MEDICAL GAS | WATER | HVAC | COMMUNICATION | INFORMATION SYSTEMS | MEDICAL EQUIPMENT | HUMAN RESOURCES

Preparedness KPI Dashboard

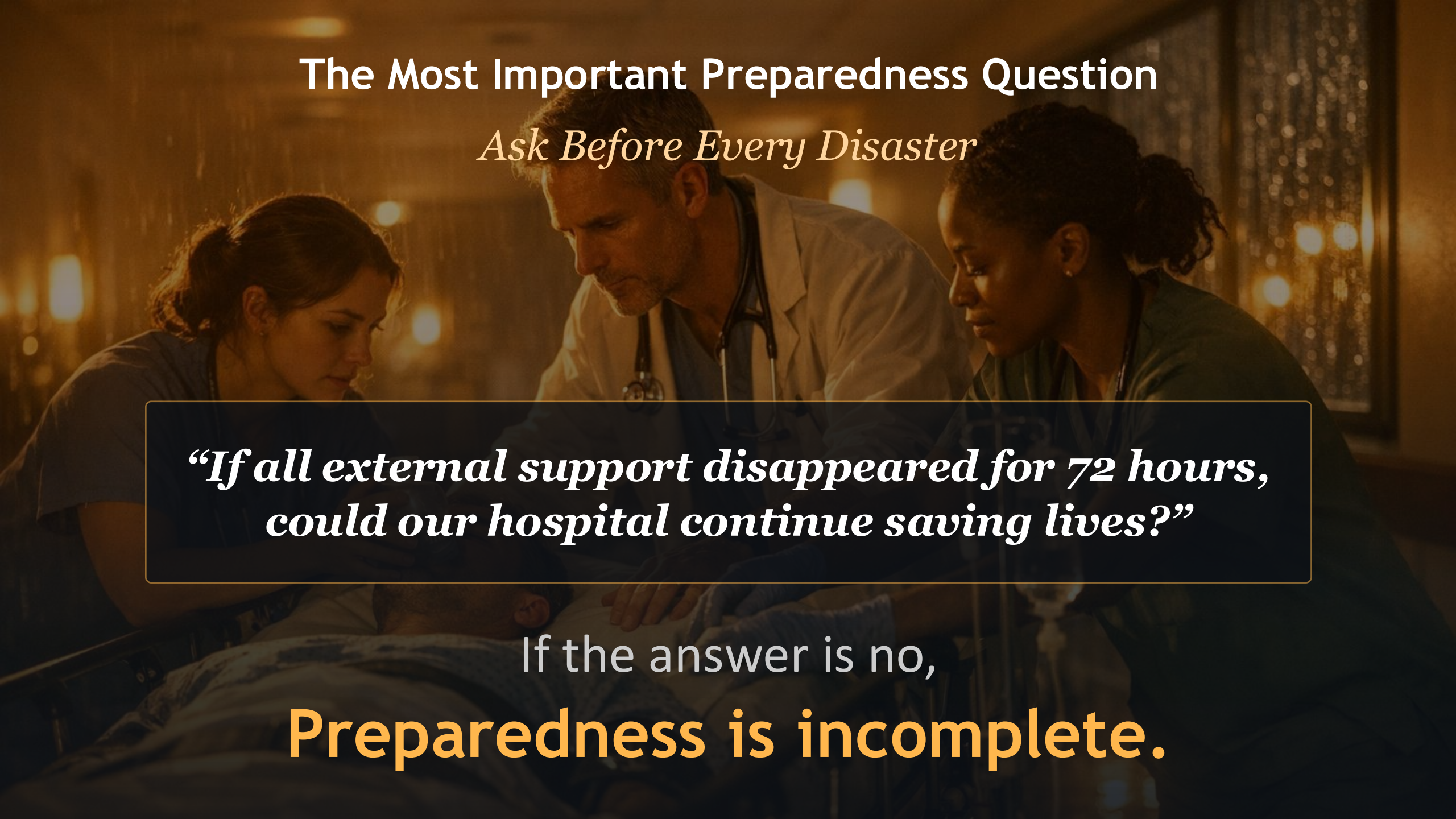
Suggested Indicators

- % critical devices operational
- % anchored equipment
- Generator readiness score
- Oxygen autonomy days
- Emergency stock adequacy
- Preventive maintenance compliance
- Disaster exercise participation rate

What Gets Measured Gets Improved

Disaster Readiness Checklist for Medical Equipment Engineers (Before Disaster**)**

- Equipment inventory
- Backup power testing
- Oxygen reserve verification
- Emergency maintenance kits
- Staff training
- Vendor agreements
- Communication plans
- Cybersecurity review
- Surge planning
- Disaster exercises



The Most Important Preparedness Question

Ask Before Every Disaster

"If all external support disappeared for 72 hours, could our hospital continue saving lives?"

If the answer is no,

Preparedness is incomplete.

Disaster Response Phase

MITIGATION
Prevent
Reduce Risk

PREPAREDNESS
Plan
Train
Equip

RESPONSE
Act
Save Lives

RECOVERY
Restore
Build Back Better

POWER · MEDICAL GAS · WATER · HVAC · COMMUNICATION · INFORMATION SYSTEMS · MEDICAL EQUIPMENT · HUMAN RESOURCES

First 10 Minutes After Disaster Impact Immediate Priorities

Ensure	Ensure personal safety
Activate	Activate disaster communication channels
Report	Report to Hospital Incident Command System
Obtain	Obtain situational awareness
Verify	Verify utility status
Identify	Identify immediate life-support threats

Golden Rule:

Protect Life Before Equipment

Priority Hierarchy

- Staff Safety
- Patient Safety
- Essential Clinical Operations
- Critical Equipment

Equipment Prioritization Matrix

- **Priority 1**

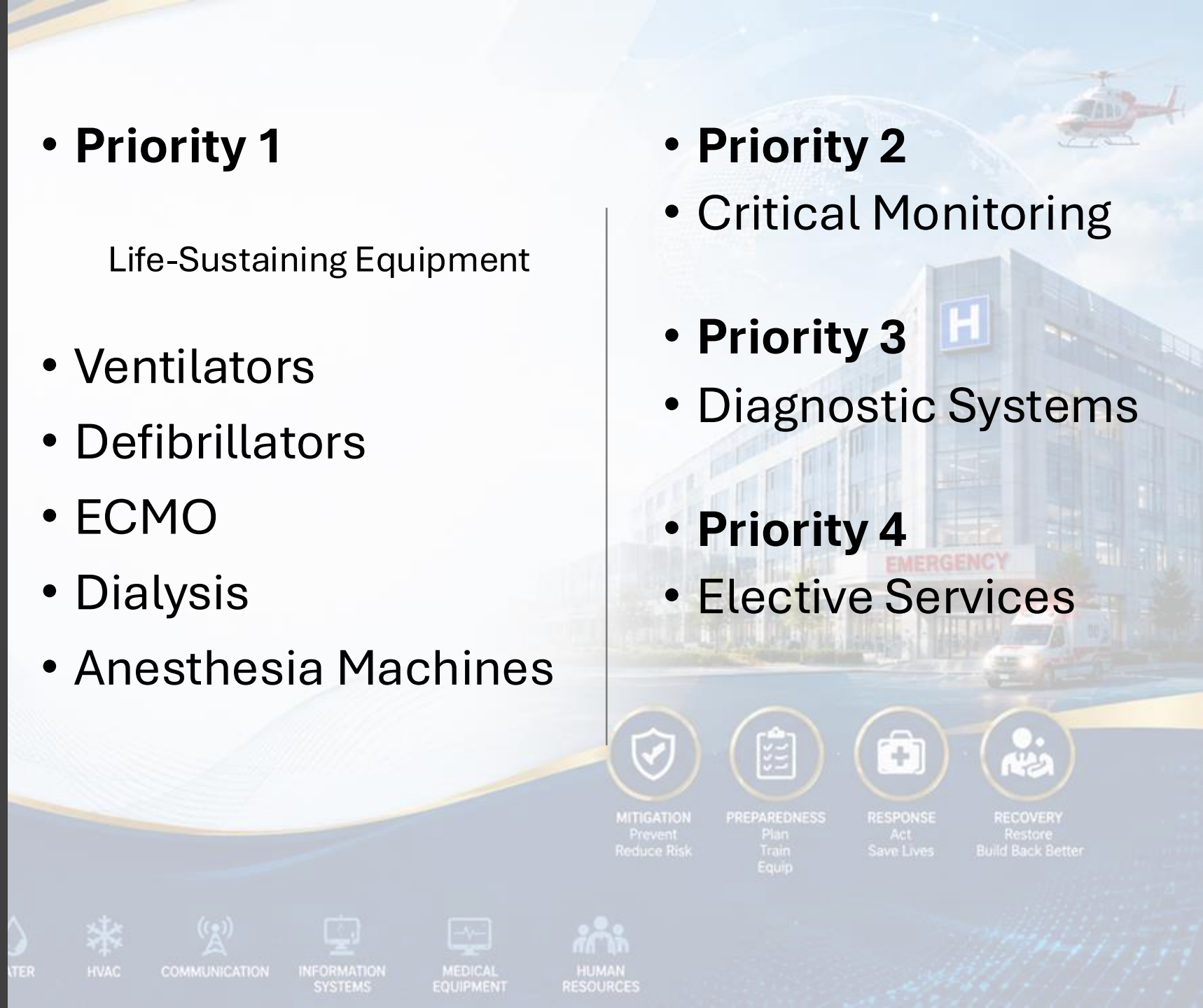
Life-Sustaining Equipment

- Ventilators
- Defibrillators
- ECMO
- Dialysis
- Anesthesia Machines

- **Priority 2**
- Critical Monitoring

- **Priority 3**
- Diagnostic Systems

- **Priority 4**
- Elective Services



The Top 10 Equipment Systems to Assess Immediately

- Emergency power
- Ventilators
- Patient monitors
- Defibrillators
- Oxygen delivery systems
- Infusion pumps
- Anesthesia machines
- Suction systems
- Imaging systems supporting trauma care
- Communications systems

Rapid Assessment

Assess Within First Hour

- Power systems
- Medical gas systems
- ICU equipment
- Emergency department equipment
- Operating room systems
- Communications infrastructure
- Network dependent devices

Output

- Technology Status Report

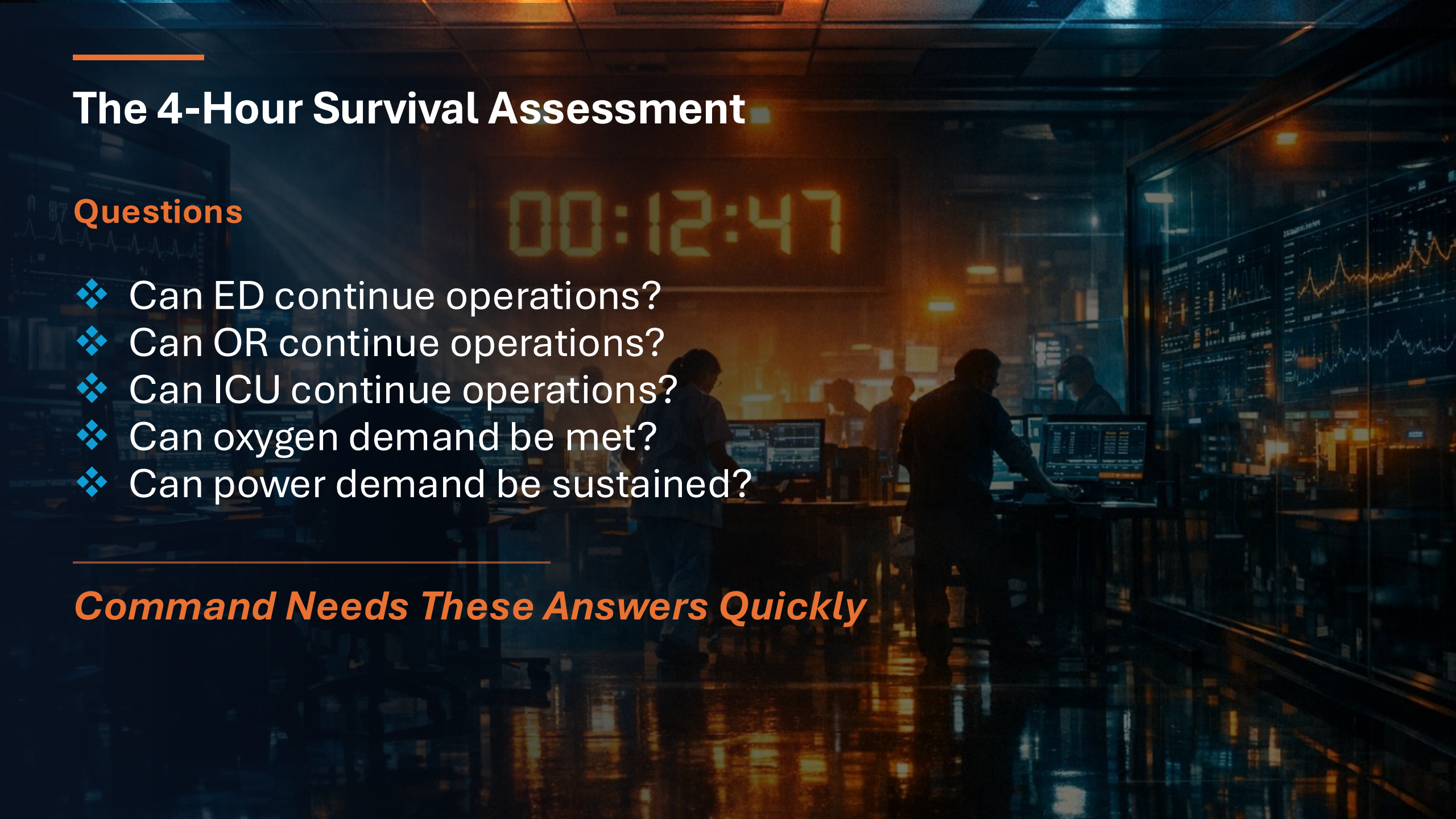
Real-Time Dashboard

Status of:

- Generators
- Oxygen systems
- Ventilators
- Monitors
- Defibrillators
- Imaging systems
- Communications

Purpose

Support command decision-making.



The 4-Hour Survival Assessment

Questions

- Can ED continue operations?
- Can OR continue operations?
- Can ICU continue operations?
- Can oxygen demand be met?
- Can power demand be sustained?

Command Needs These Answers Quickly

Medical Gas Emergency Management

During Surge Events

Monitor:

- Tank levels
- Pipeline pressure
- Consumption rate
- Reserve duration

Calculate Continuously:

- Hours of oxygen remaining

Oxygen Is a Strategic Resource

Oxygen Conservation Strategies

If supply becomes critical,

Support Clinical Leadership by:

- Minimize leaks
- Remove unnecessary flow
- Prioritize critical patients
- Monitor consumption trends

Goal:

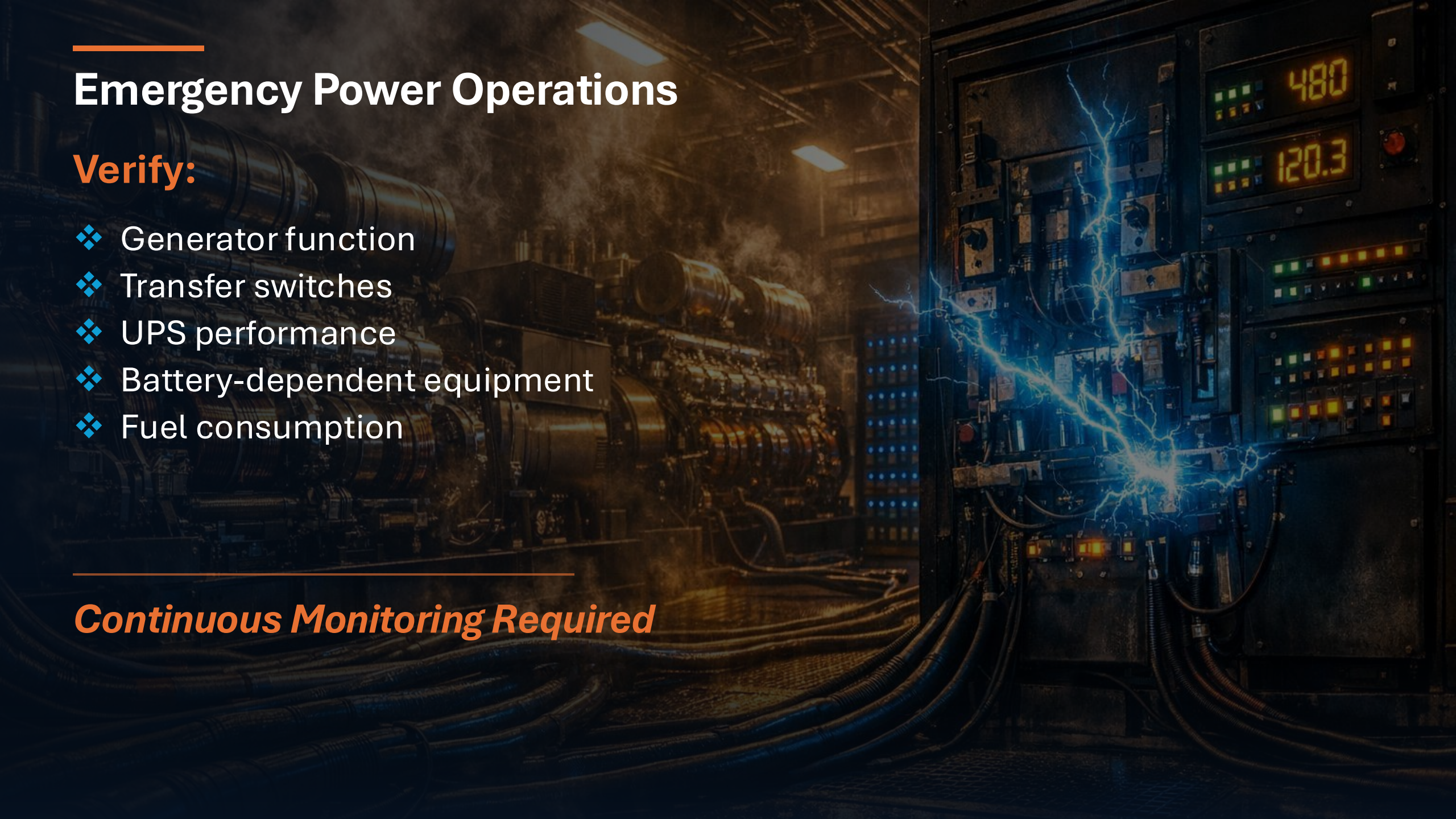
Extend operational endurance

Emergency Power Operations

Verify:

- Generator function
- Transfer switches
- UPS performance
- Battery-dependent equipment
- Fuel consumption

Continuous Monitoring Required



Ventilator Fleet Management

Key Questions

How many ventilators are:

- Available?
- Functional?
- In use?
- Repairable?
- Deployable?

Disaster Principle

Manage the fleet, not individual devices.

Chemical Incident Response

Verify:

- Decontamination systems
- Ventilation systems
- Monitoring equipment
- Water supply

Protect Hospital Infrastructure

from secondary contamination

Hospital Decontamination Facility

Radiological Incident Response

Technical Priorities

- Radiation detectors
- Monitoring systems
- Decontamination equipment
- Isolation areas

Coordinate With:

- Radiation Safety Officer
- Hospital Incident Command

Mass Casualty Incidents

Key Question: Can equipment capacity match patient surge?

1. **Ventilator** utilization
2. **Monitor** utilization
3. **Defibrillator** availability
4. **Oxygen** demand

Capacity Awareness Saves Lives

Documentation During Response

Track:

- Equipment failures
- Repairs
- Relocations
- Resource requests
- Utility disruptions

Documentation Is an Operational Tool, Not an Administrative Burden

Never Trust Building Utilities After a Disaster; Assume Failure Until Verified

Inspect:

- Power
- Medical gases
- Water
- HVAC
- IT systems

Oxygen Systems: The Hidden Vulnerability

Responsibilities

- Monitor pressure
- Predict consumption
- Identify leaks
- Verify backup cylinders

POWER | MEDICAL GAS | WATER | HVAC | COMMUNICATION | INFORMATION SYSTEMS | MEDICAL EQUIPMENT | HUMAN RESOURCES

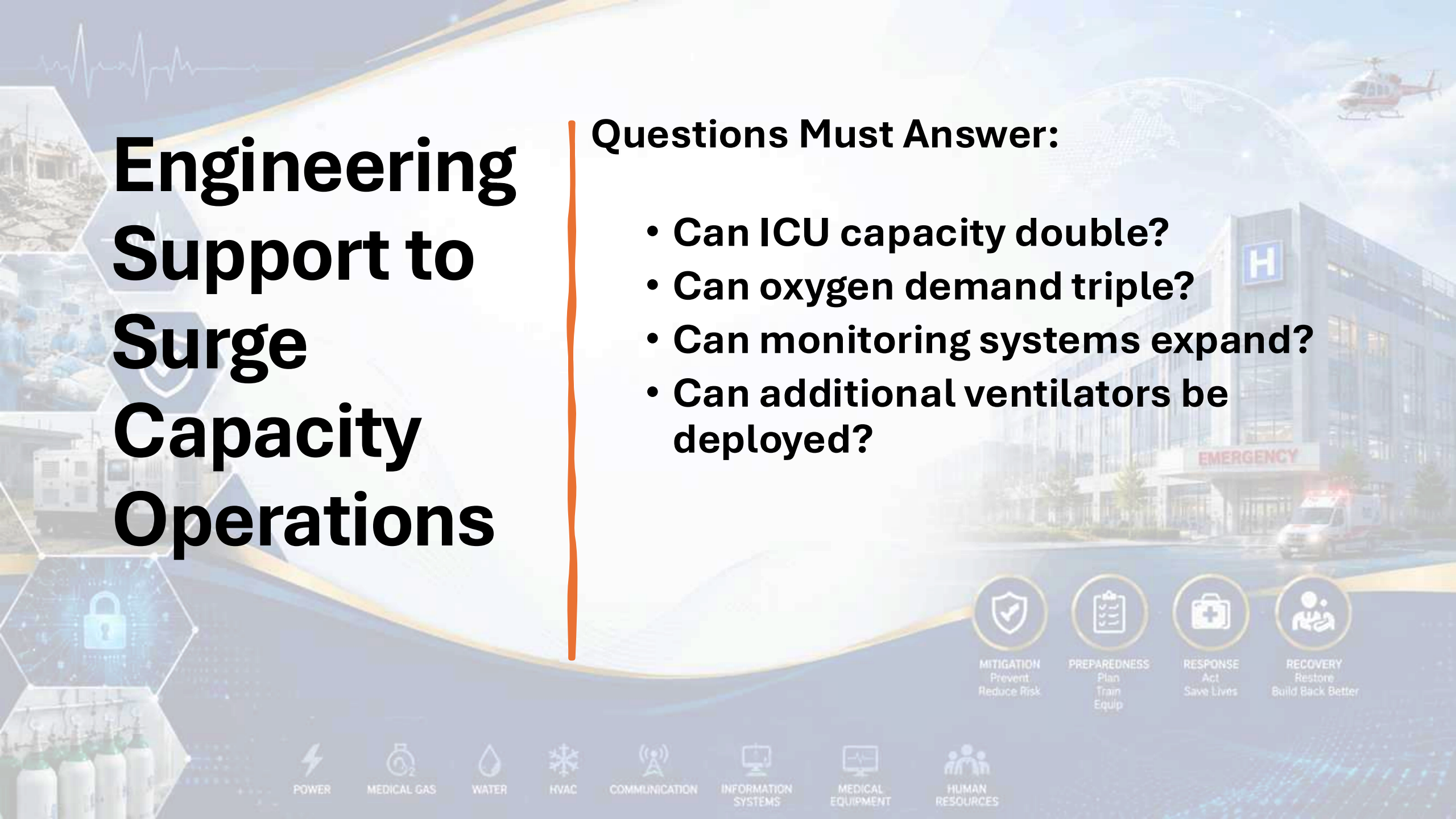
Cybersecurity During Disasters

- **Must Do**
  - Isolate compromised devices
  - Protect backups
  - Maintain cybersecurity protocols
- **Never**
  - Disable cybersecurity controls without authorization.

Engineering Support to Surge Capacity Operations

Questions Must Answer:

- **Can ICU capacity double?**
- **Can oxygen demand triple?**
- **Can monitoring systems expand?**
- **Can additional ventilators be deployed?**



Common Mistakes During Disasters

Mistake 1	Mistake 2	Mistake 3	Mistake 4	Mistake 5
Focusing on low-priority equipment	Poor communication	Lack of documentation	Ignoring personal safety	Failure to prioritize life-support systems

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What We Must NEVER Do

Enter	unsafe structures
Override	safety systems
Bypass	lockout/tagout procedures
Use	damaged medical equipment
Conceal	equipment failures
Operate	outside competency
Ignore	Infection control requirements
Delay	reporting critical failures

Radiation Emergencies:

Must Do

- Verify detector functionality
- Support contamination monitoring
- Protect sensitive equipment
- Coordinate with radiation safety officers

Never

- Handle radioactive materials without authorization and training.

Chemical Incidents:

Must Do

- Support decontamination systems
- Verify negative-pressure areas
- Protect medical devices from contamination
- Ensure water supply continuity

Never

- Bring contaminated equipment into clean treatment zones.

Equipment Documentation During Disaster Response

Every Action Should Be Recorded:

- Equipment status
- Repairs
- Failures
- Relocations
- Resource requests

Why?

- Post-disaster recovery depends on accurate records.

The Situation Report (SITREP)

Report Elements

01 **Infrastructure**
Status

02 **Medical Gas**
Status

03 **Power**
Status

04 **Equipment**
Status

05 **Critical Risks**
Threat Assessment

06 **Resource Requests**
Supply Chain

07 **Recommended Actions**
Next Steps

The Command Team's Primary Technical Intelligence Source

SITREP | Situation Report | 7 Core Elements | Real-Time Intelligence

Recovery Phase:

Post-Disaster After-Action Review

Questions

- What failed?
- Why did it fail?
- What prevented failure?
- What should be improved?

Outcome

- Hospital Improvement Plan

Modular Hospitals

Deployable healthcare infrastructure for rapid emergency response

1

Future Solution

- **Rapid Deployment Units**
  Pre-configured medical modules deployable within 24–72 hours
- **Portable ICU**
  Self-contained critical care with ventilators and monitoring systems
- **Mobile Imaging**
  Transportable X-ray and ultrasound for field diagnostics
- **Container Hospitals**
  Stackable ISO units forming complete hospital facilities on-site

2

Field Hospital Technologies

- **Telemedicine Integration**
  Remote specialist access via high-bandwidth satellite links
- **Autonomous Power Systems**
  Solar and generator hybrid energy for off-grid operation
- **Water Purification**
  Integrated filtration systems for sterile medical-grade water
- **Climate Control**
  HVAC with HEPA filtration for infection control in any environment

3

Critical Equipment Packages

- **Portable Ventilators**
  Battery-powered units with multi-mode ventilation for field use
- **Portable Imaging**
  Compact CT and digital radiography for trauma assessment
- **Satellite Communication**
  Resilient connectivity for coordination and patient data exchange

The Future of Emergency Healthcare Deployment

Future of Hospital Resilience: Emerging Technologies

Transforming Healthcare Through Next Generation Technology Integration

01 AI-Driven Hospitals

Machine learning algorithms for real-time patient triage, predictive diagnostics, and automated resource allocation during crises. AI continuously monitors patient flow, predicts bed demand, and optimizes staff deployment.

02 Autonomous Logistics

Drone-based delivery of medical supplies, robotic pharmacy dispensing, and AGV transport networks. Autonomous systems ensure critical supplies reach patients within minutes, even during facility lockdowns or evacuations.

03 Digital Twins

Virtual replicas of hospital facilities for real-time simulation of disaster scenarios, capacity planning, and infrastructure stress testing. Digital twins model airflow, power loads, and patient movement to identify vulnerabilities before they manifest.

04 Smart Infrastructure

IoT-enabled building management with self-healing HVAC, adaptive lighting, and structural health monitoring. Sensor networks detect water leaks, air quality anomalies, and seismic activity in real time, triggering automated containment protocols and rerouting critical systems.

05 Renewable Microgrids

On-site solar, wind, and battery storage systems that island from the grid during outages. Microgrid controllers balance generation, storage, and load shedding to maintain power for life-critical systems with zero-interruption failover and multi-day autonomy.

Building Hospitals That Anticipate, Adapt, and Recover

AI | Autonomous Logistics | Digital Twins | Smart Infrastructure | Renewable Microgrids

Key Take-Home Messages

“Hospitals Do Not Fail Because Disasters Occur —
Hospitals Fail Because Critical Systems Are Not Resilient.”

The Future Hospital Must Be:

01

Safe

Protection against structural, fire, and seismic threats through code-compliant engineering and hazard-resistant design

02

Smart

Integrated IoT, AI diagnostics, and data-driven operations enabling real-time clinical decision-making

03

Sustainable

Energy-independent systems with renewable power, water recycling, and green infrastructure for long-term operational continuity

04

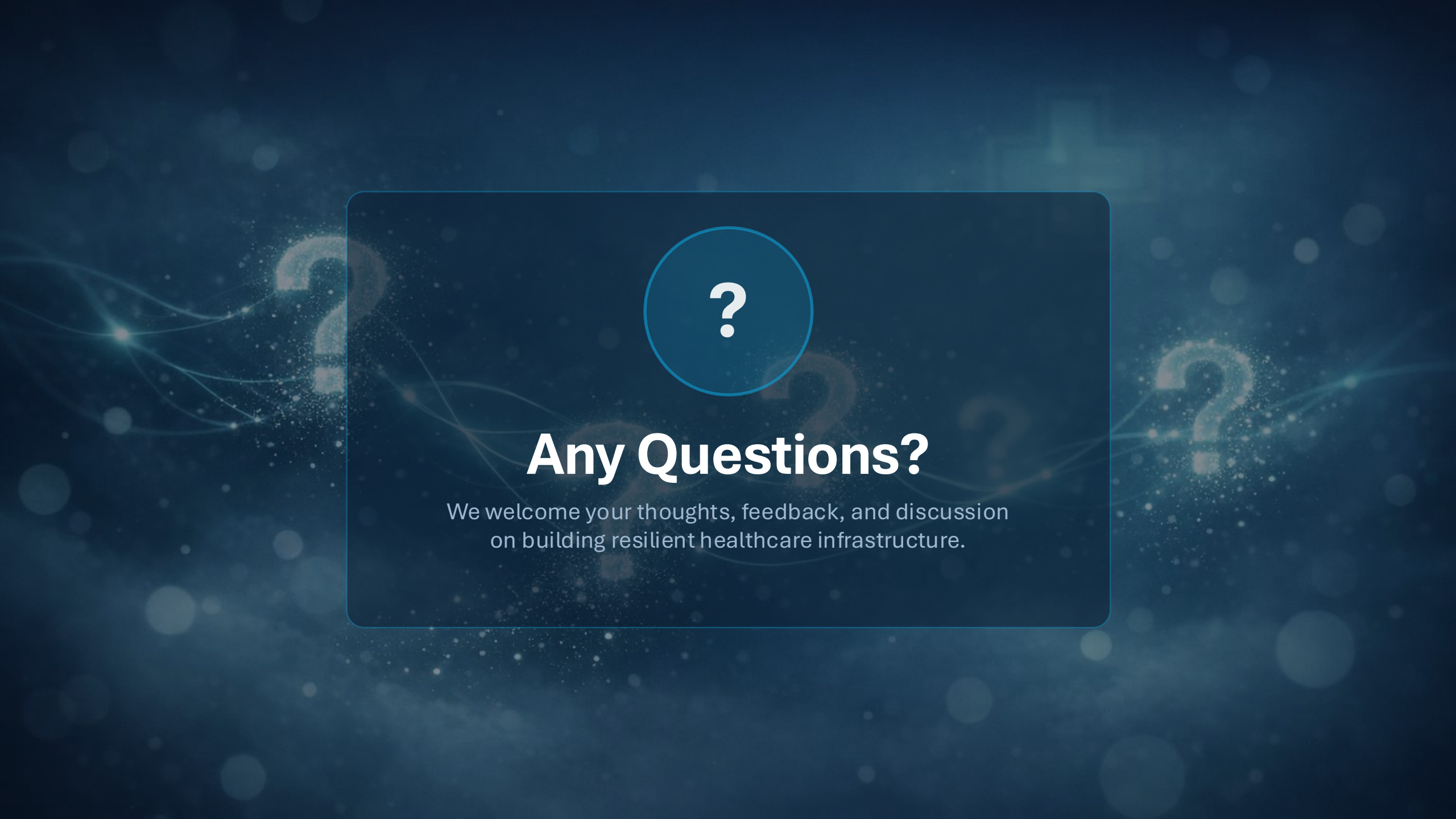
Adaptive

Flexible infrastructure that scales capacity and reconfigures spaces rapidly during surges or crisis events

05

Resilient

Redundant critical systems with fail-safe mechanisms ensuring uninterrupted care delivery under any stress scenario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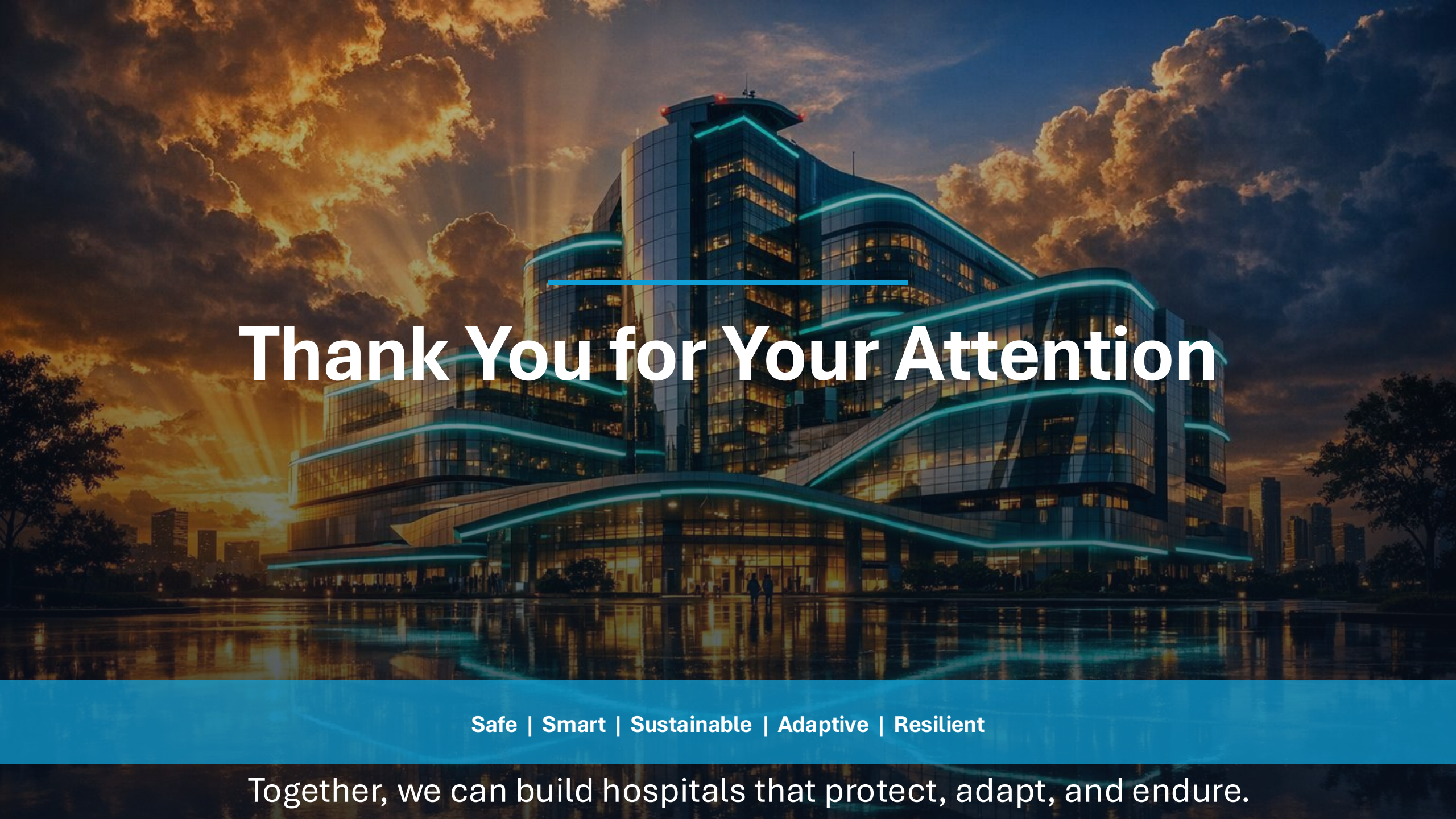
Any Questions?
We welcome your thoughts, feedback, and discussion
on building resilient healthcare infrastructure.



Thank You for Your Attention

Safe | Smart | Sustainable | Adaptive | Resilient

Together, we can build hospitals that protect, adapt, and endure.