Particle Accelerators - Their Hazards and the Perception of Safety

OVERVIEW AND LESSONS LEARNED

Safety Systems Group

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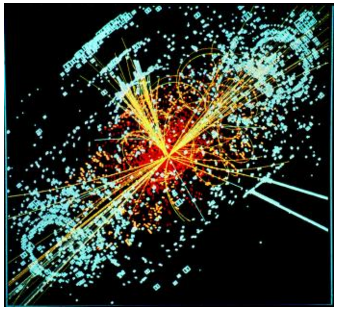
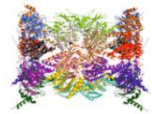
Particle Accelerators

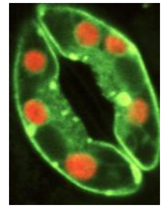
- Medical – Therapy, Surgery, Imagery, Isotope Production
- Industrial – Material Fabrication, Sterilization, Inspection
- Material Science - Probe Atomic Structure, Build Materials at Atomic scale, Waste Treatment
- Fundamental Research – Study of Constituents of Matter, Energy, and Binding Forces

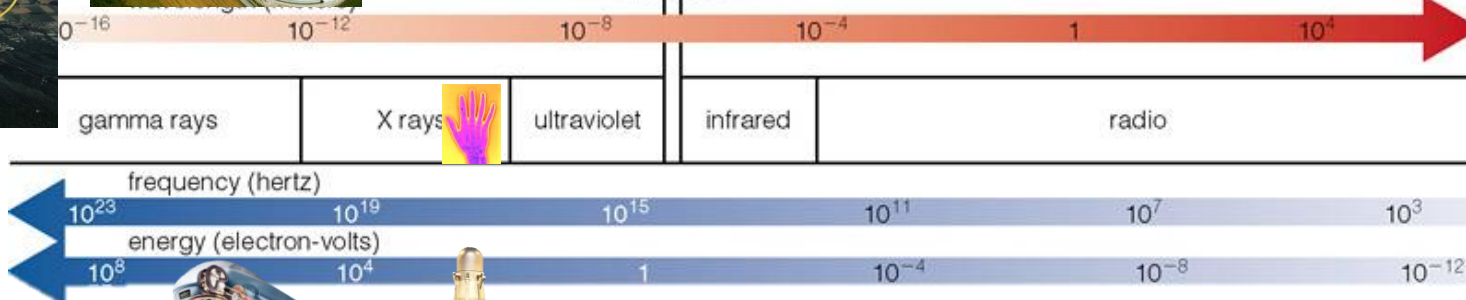
Resolution of a probe is inversely proportional to the energy of the probe – Smaller resolution requires higher energy.

http://lasp.colorado.edu/~bagenal/3720/CLASS4/4Sunlight.html



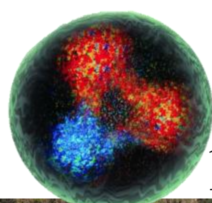




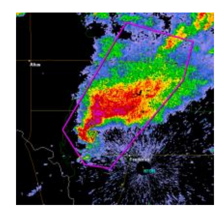


10^{14}

10^{20}



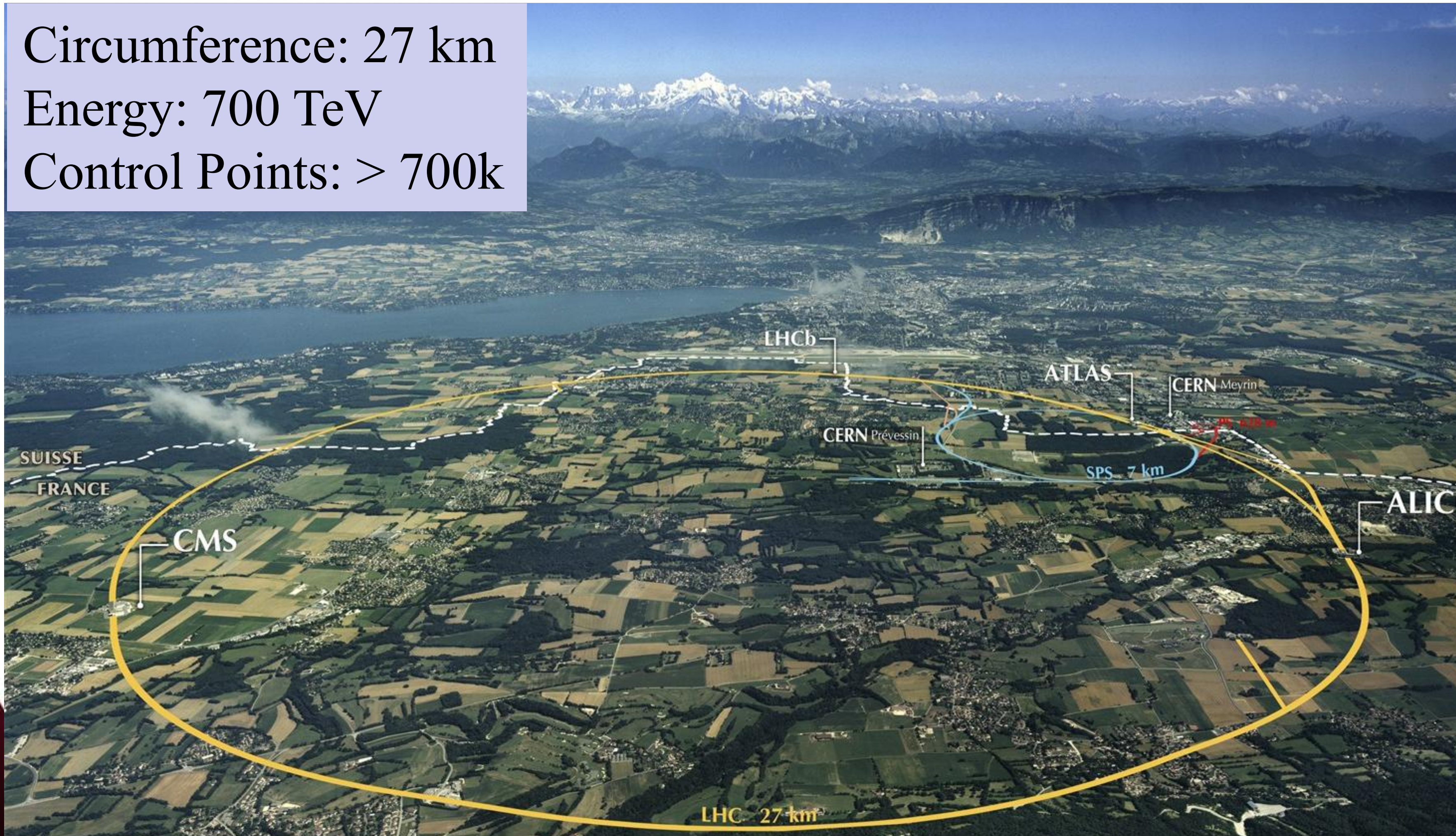
10^{10}



MIT Bates

Large Hadron Collider
Geneva, Switzerland

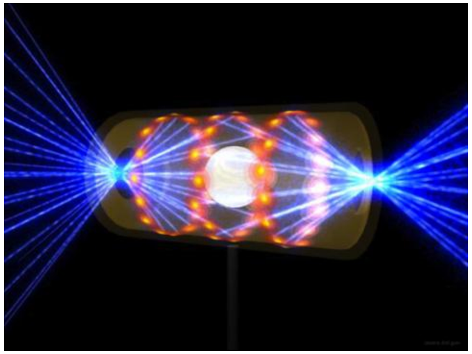
Circumference: 27 km
Energy: 700 TeV
Control Points: > 700k



Fusion Facilities

- 94 PW Class Lasers

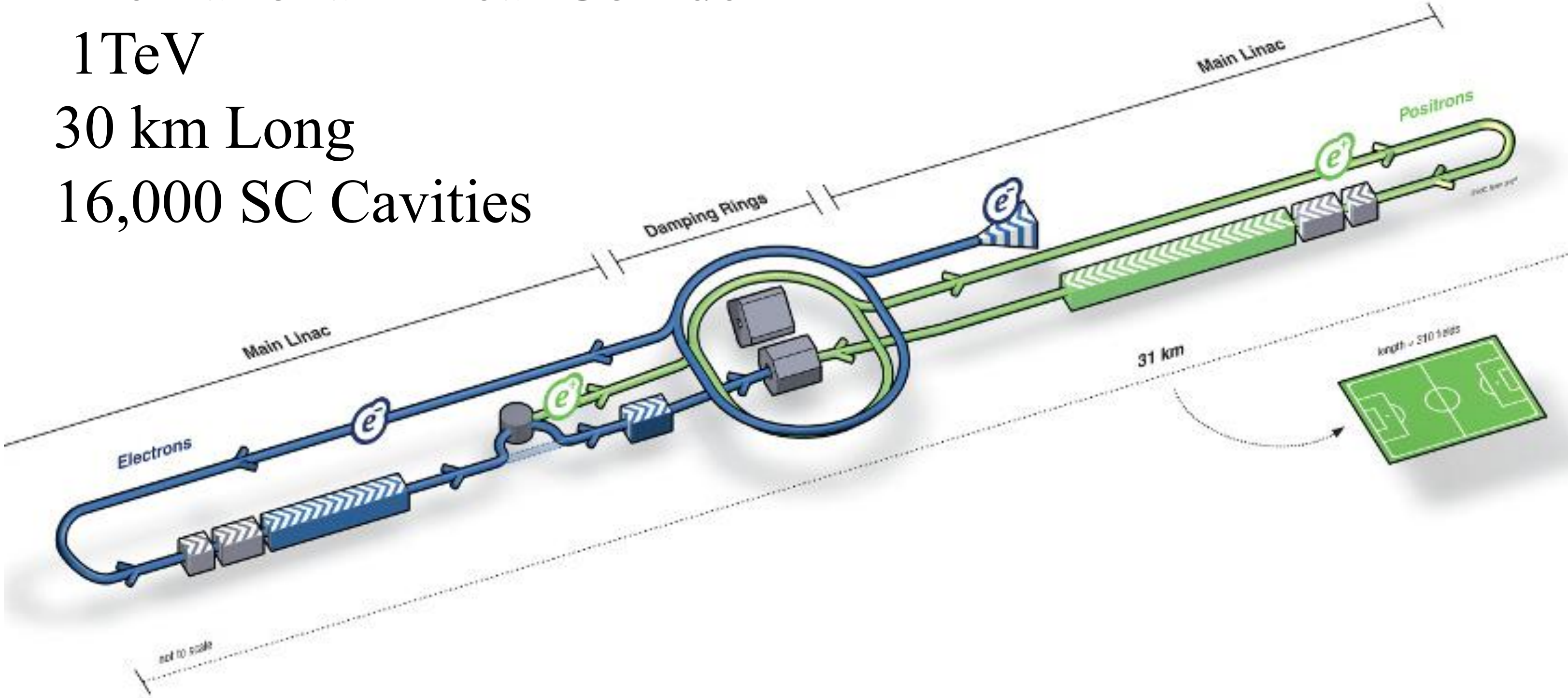
Focus on a 1mm Bead



National Ignition Facility

Next Generation

International Linear Collider
1TeV
30 km Long
16,000 SC Cavities



Jefferson Lab

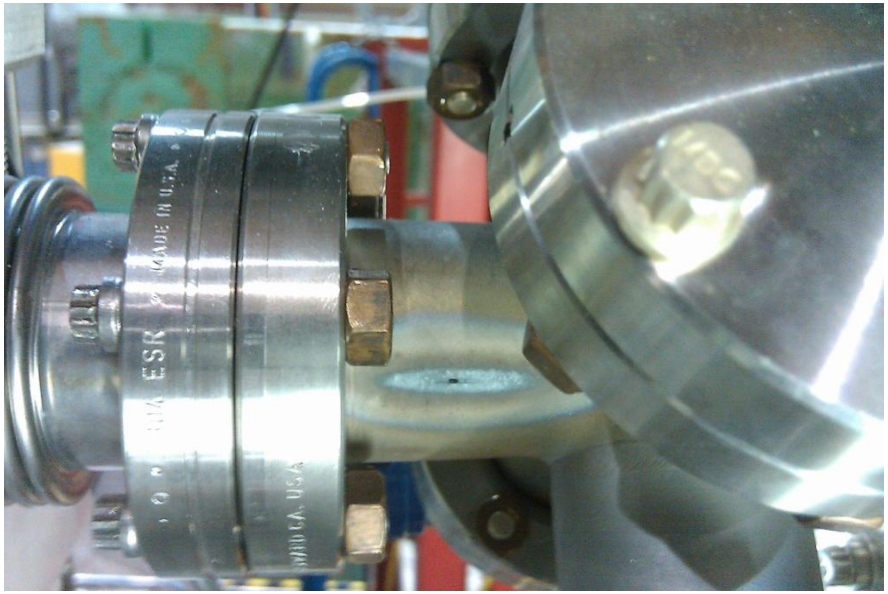
- Continuous Electron Beam Accelerator Facility (CEBAF)
  - 6 GeV, 1MW electron Accelerator
  - Superconducting Accelerators @ 1.8 Kelvin, 30,000 ll He
  - Three Experimental Endstations, Magnetic Fields > 15 T
  - 12GeV upgrade under way
- Free Electron Laser
  - 20 kW IR through 2 kW UV
  - Energy Recovery Recirculating Linac

JLab Facility Large Scale Hazards

Hazard / Area	Prompt Ionizing Radiation	RF non-Ionizing Radiation	Laser Non-ionizing Radiation	Electrocution	Oxygen Deficiency
CEBAF	✓	✓	✓	✓	✓
FEL	✓	✓	✓	✓	✓
Injector Test Cave	✓		✓	✓	
Cryomodule Test Area	✓	✓			✓
Vertical Test Area	✓	✓			

Beam Loss

- 1MW beam can burn through 1/8” steel in 50 uS



JLab Safety Systems

- Personnel Safety Systems
  - Access Controls
  - Critical Devices
  - Equipment Interlocks
  - Audio and Visual Warnings
  - Oxygen Deficiency Monitoring

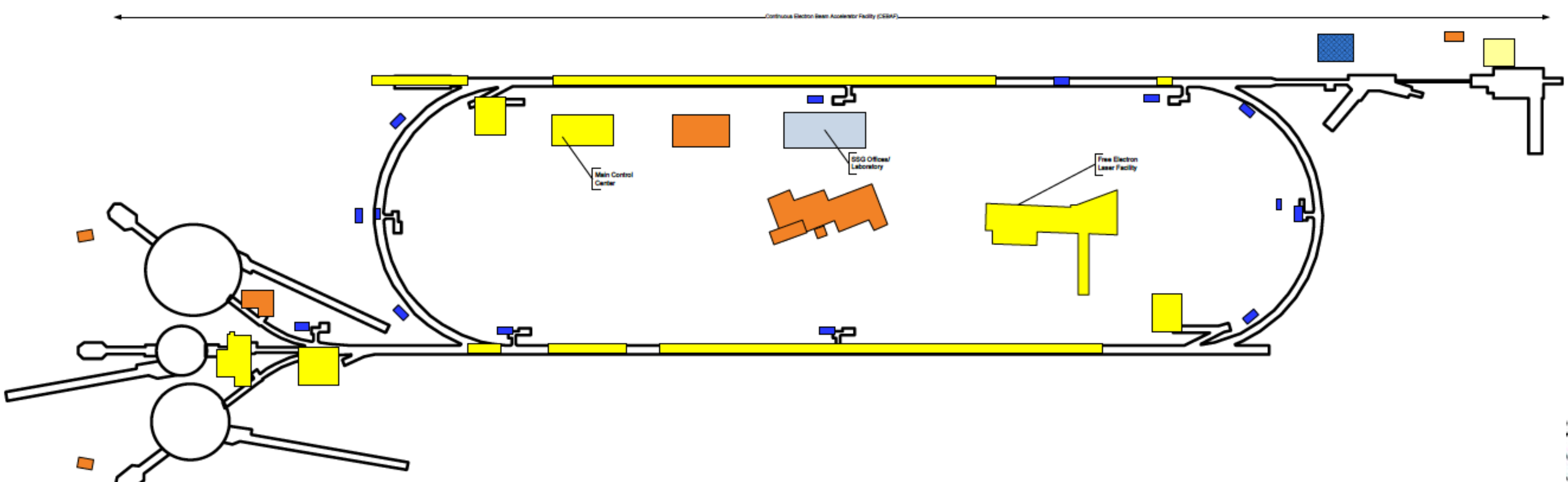
- Machine Protection Systems
  - Beam Loss Monitoring
  - Fast Shutdown

- Safety Envelope Monitoring

CEBAF Personnel Safety Systems

- Access Controls and Interlocks
- Radiation Monitoring
- ODH Monitoring
- 7 Operational Segments
  - Separate, Redundant Safety Systems
  - Can Operate Independently
  - 3,000 total control parameters

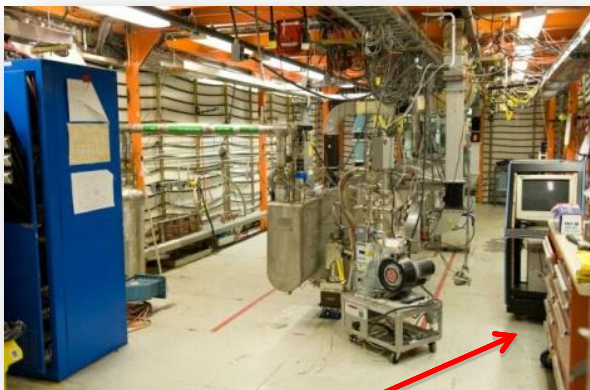
100 MV Cryomodule

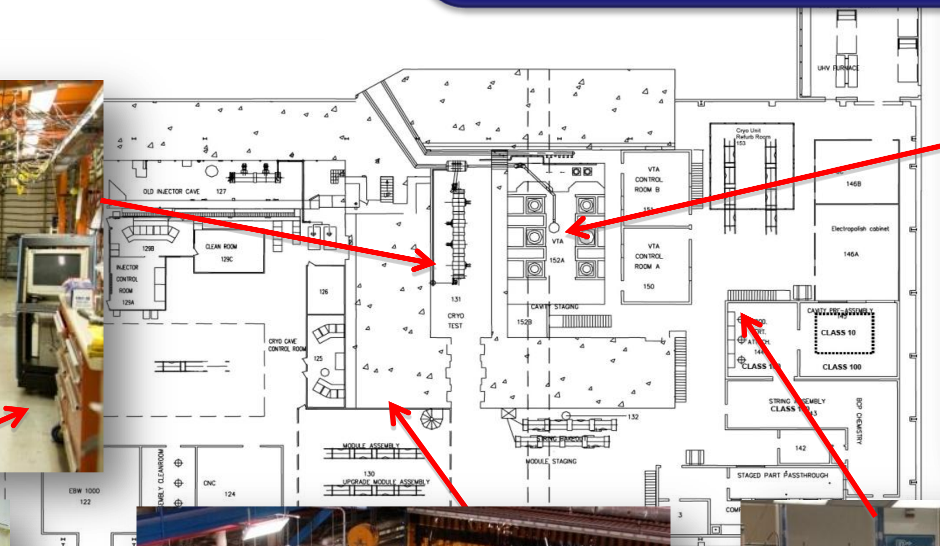


Production/R&D Facilities

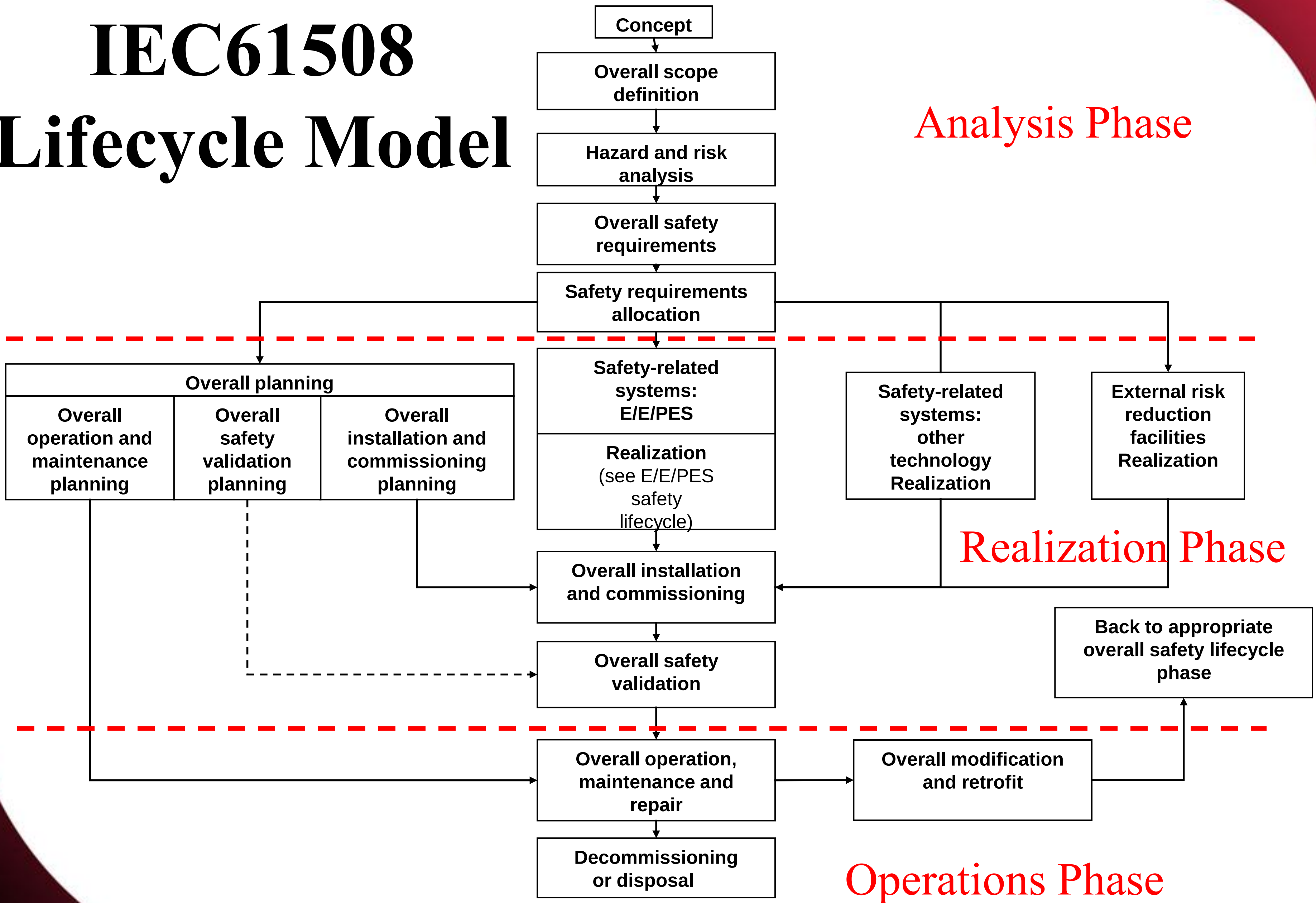
- Machinery
- Acid Processing
- Prompt Ionizing Radiation
- Lasers

Lesson Learned:
Next Generation Superconducting Cavities Generate Enough Radiation to Activate the Surrounding Material

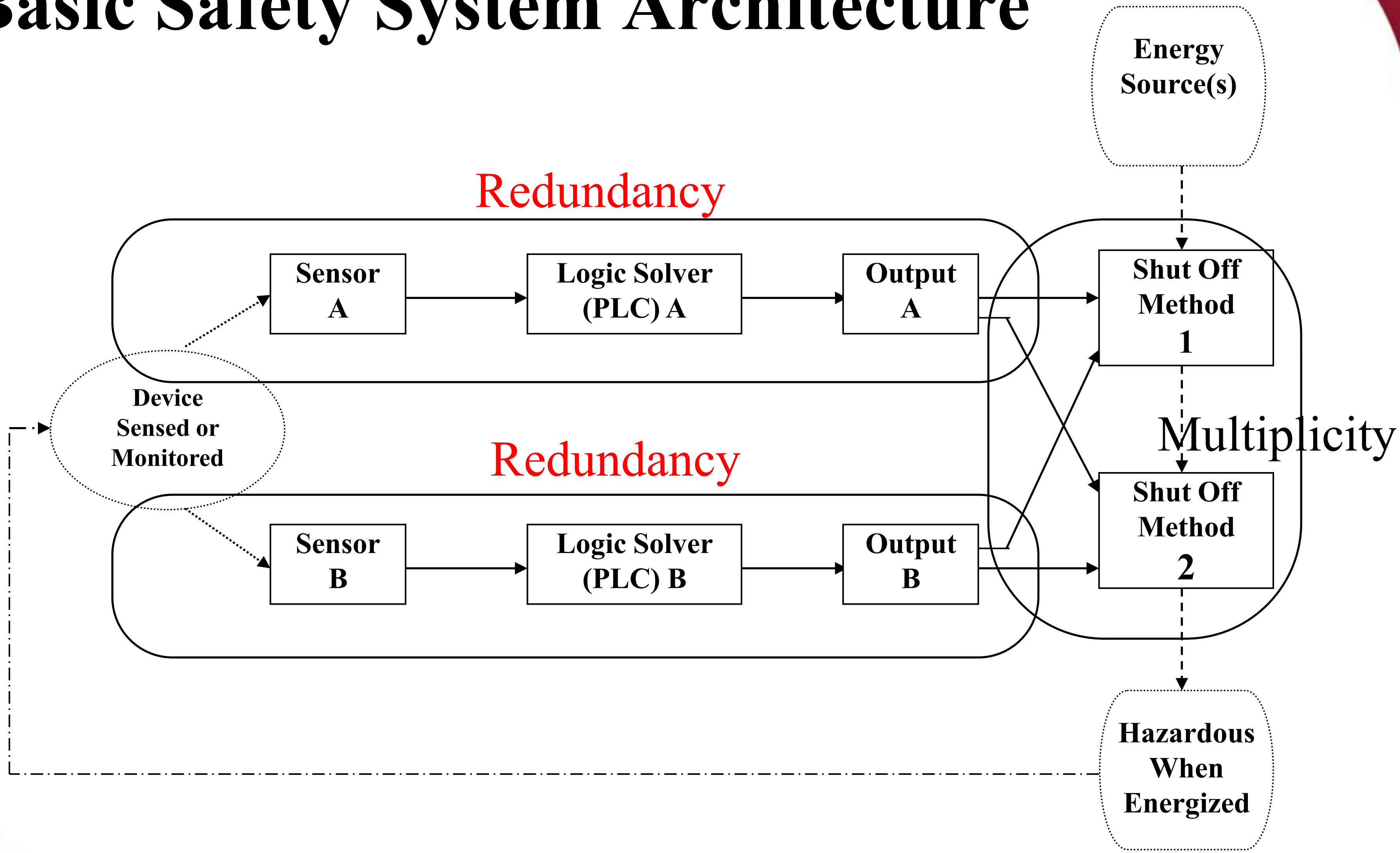




IEC61508 Lifecycle Model



Basic Safety System Architecture



Context?
Constraints?

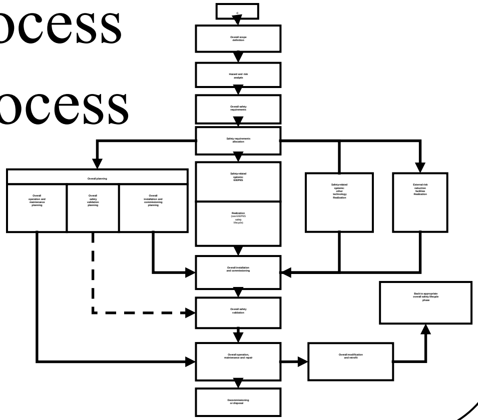
Management Process

Systems Engineering Process

Controls Engineering Process

Software Engineering Process

Assurance Process



Oxygen Deficiency

- He can inert tunnel to < 6% O_2
- Oxygen Monitors in Tunnel
- Penetrations sealed for Radiation and Fire Safety

Lesson Learned:
Fluorescent Lights Extinguish During Release.

Lesson Learned:
Have procedures in place for times when the ODH system is off-line.

JLab Safety Systems Management

- Systems Engineering Process
  - Systems Assurance
  - Software Assurance
  - Cyber Security Assurance

- Based on IEEE/IEC 15288/12207
- Borrow heavily from Aerospace and Chemical Industries

Lesson Learned:
Start with an overall systems engineering process to set the context for managing safety systems

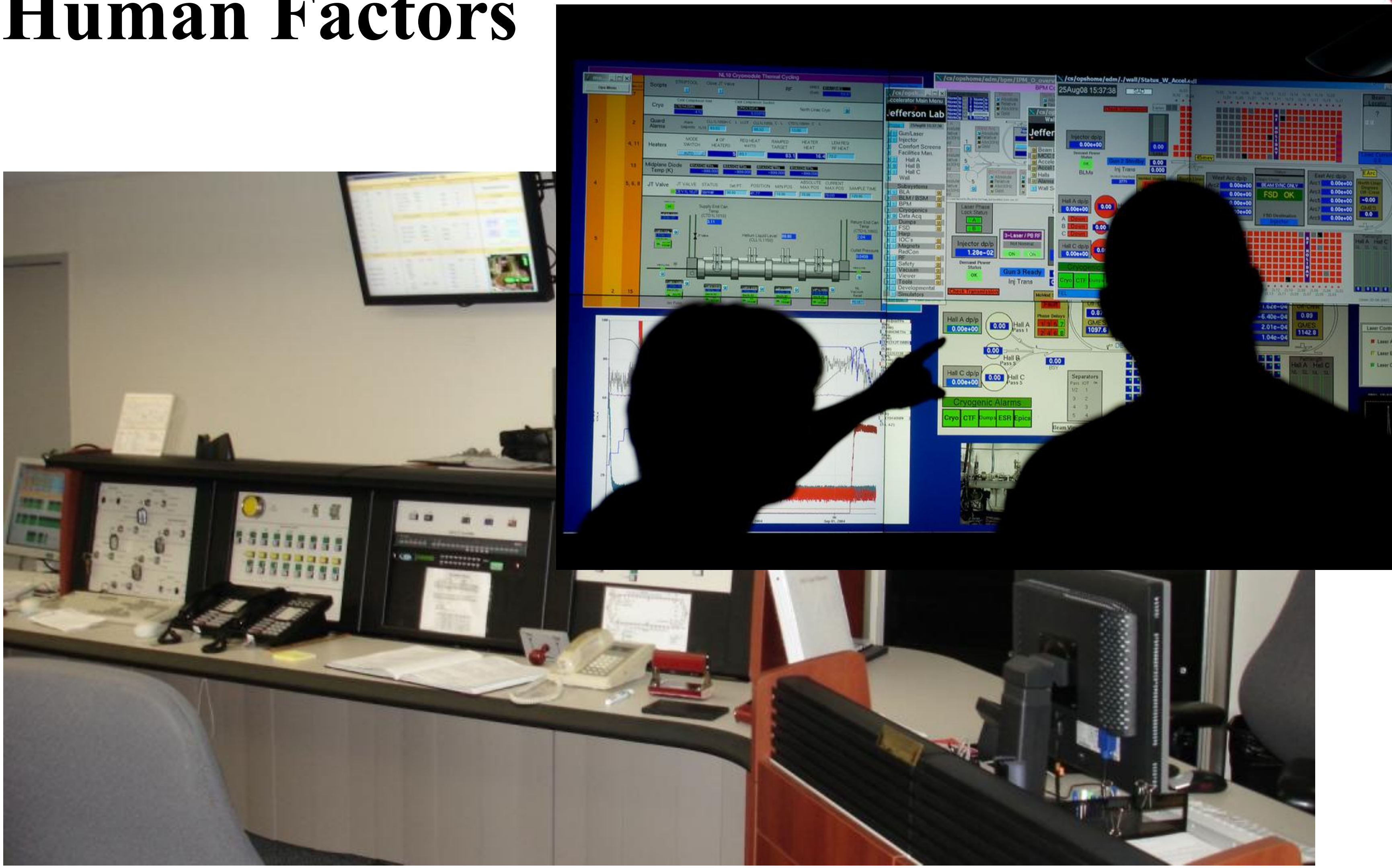
Early Decisions

- Facility Segmentation
  - Identify fail-safe methods for stopping beam transport

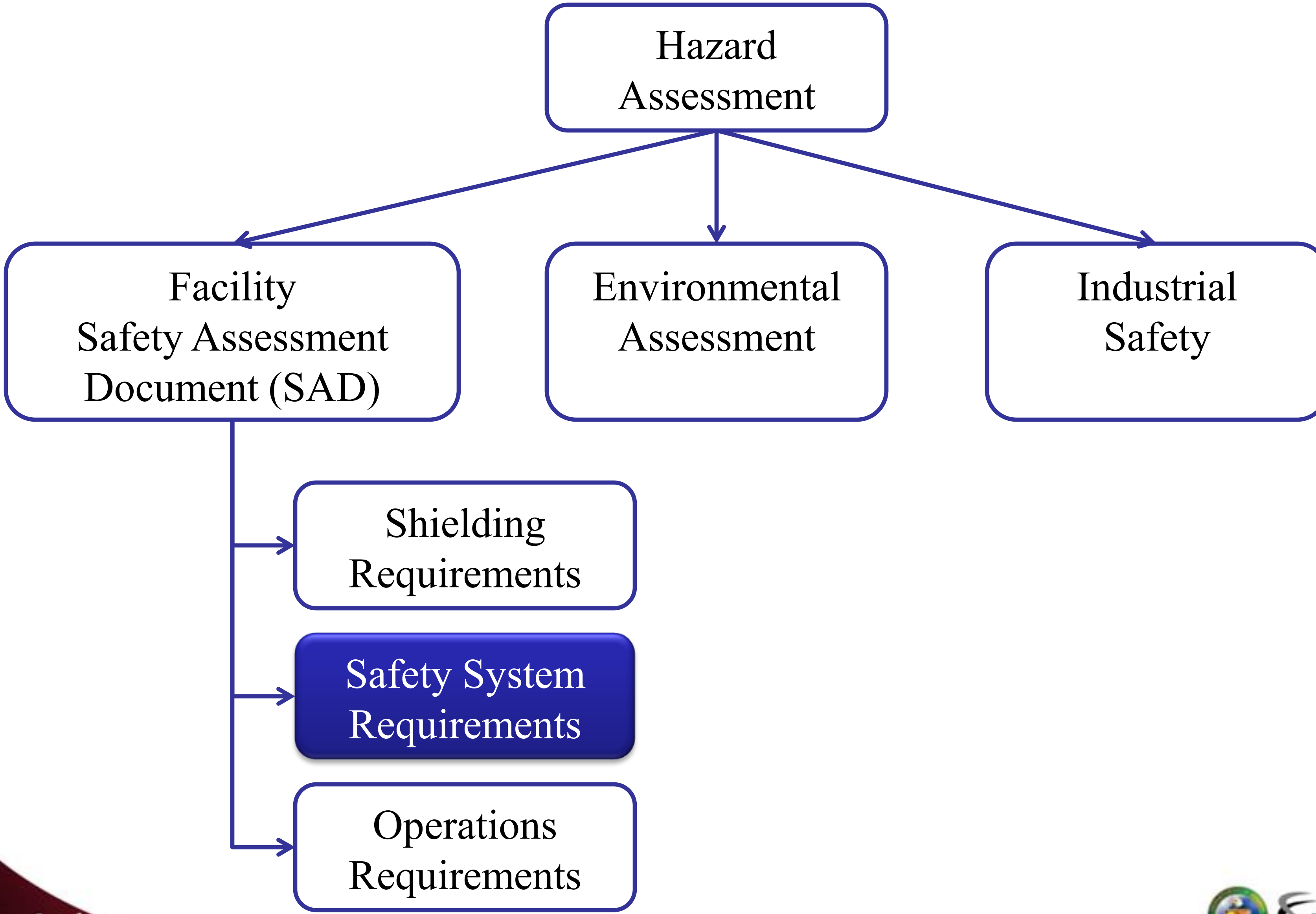
- Civil Construction Requirements
  - Access Portals
  - Segmentation Features
  - Movable Shielding
  - Life Safety Code

Lesson Learned:
Basic Safety System design decisions may impact facility operations and civil design.

Human Factors



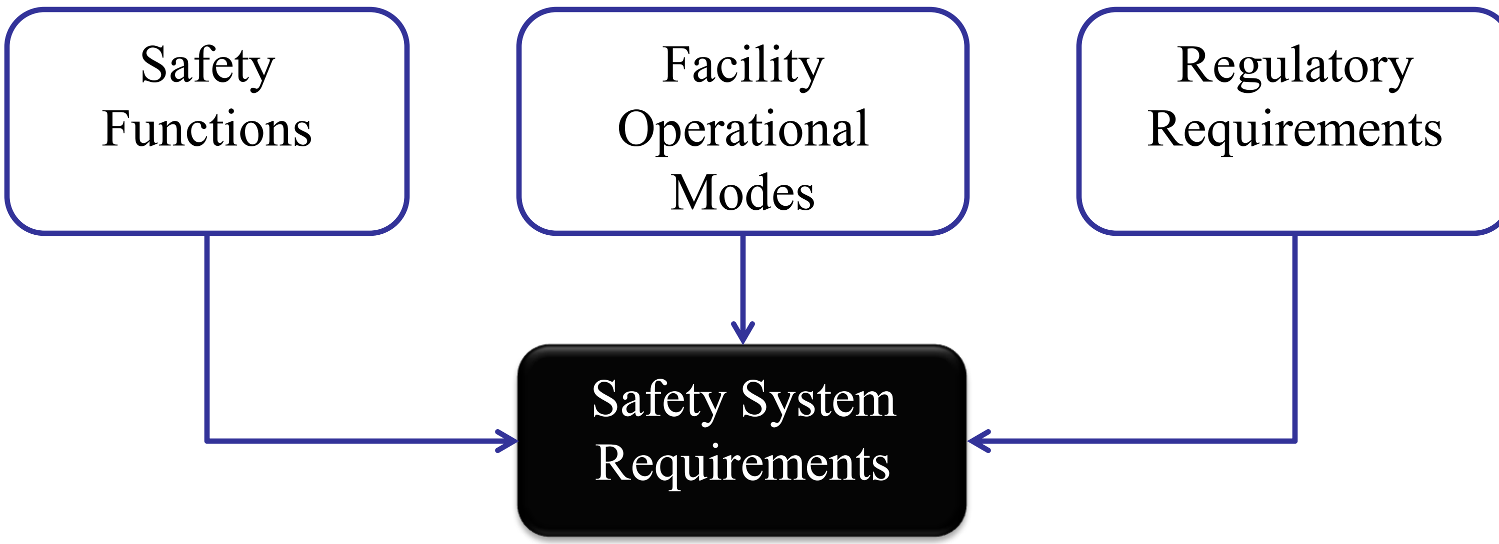
Requirements Flow-Down



CEBAF Safety Functions

Function ID	Safety Function	Required SIL
SF1	Prevent beam transport from exclusion to occupied areas	3
SF2	Shut off interlocked devices when physical barriers between personnel and hazards are unsecured.	2
SF3	Shut off interlocked devices upon activation of an ESTOP	2
SF4	Shut off interlocked devices in support of administrative access to a secure beam enclosure.	2
SF5	Support search and secure operations prior to facility operations.	2
SF6	Inhibit operation of radiation generating devices when a high radiation dose rate associated with the device is detected in an occupied area	1
SF7	Deter unauthorized entry to exclusion areas	1
SF8	Provide visual indications of unsecured safe, secure safe, and unsafe radiological enclosure status.	1
SF9	Provide audible warnings of pending unsafe status of a beam enclosure	1
SF10	Activate audible and visual alarms when the indicated oxygen level in monitored areas drops below 19.5% by volume.	1

Requirements



Does not adequately capture constraints

Current Concerns

- Controls Cyber Security
  - Greatest concern is with engineering development PCs
  - Updating to meet ISA S99, NIST SP800-82
  - Safety Systems Cyber Security Assurance Program
  - Consulting with U.S. ICS-CERT
- Threat at multiple vectors
- Vulnerable components are engineering development workstations, display systems
- Highlights malicious intent as threat
- Active (?) degradation over time
  - APT

Conclusions

- Scale of Hazards are Large and Complex
- Operators are an integral part of the system
- Hazards evolve with facility age and mission
- Disciplines of Systems, Software, Safety, Security overlap
  - Why not integrate them in to one discipline

Thank You

Questions?