Maintenance of the National Ignition Facility (NIF) Controls Hardware System

19th International Conference on Accelerator & Large Experimental Physics Control Systems (ICALEPCS)

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NIF Background

- **1997:** NIF construction began at LLNL and was funded by DOE & NNSA to execute high-energy-density laser experiments for:
  - Discovery science
  - Inertial Confinement Fusion (ICF)
  - Science-based Stockpile Stewardship Program
- **2009:** Operations commenced with 192-laser beam experiments to Target Chamber Center
- **2022:** NIF achieved ICF ignition with target gain

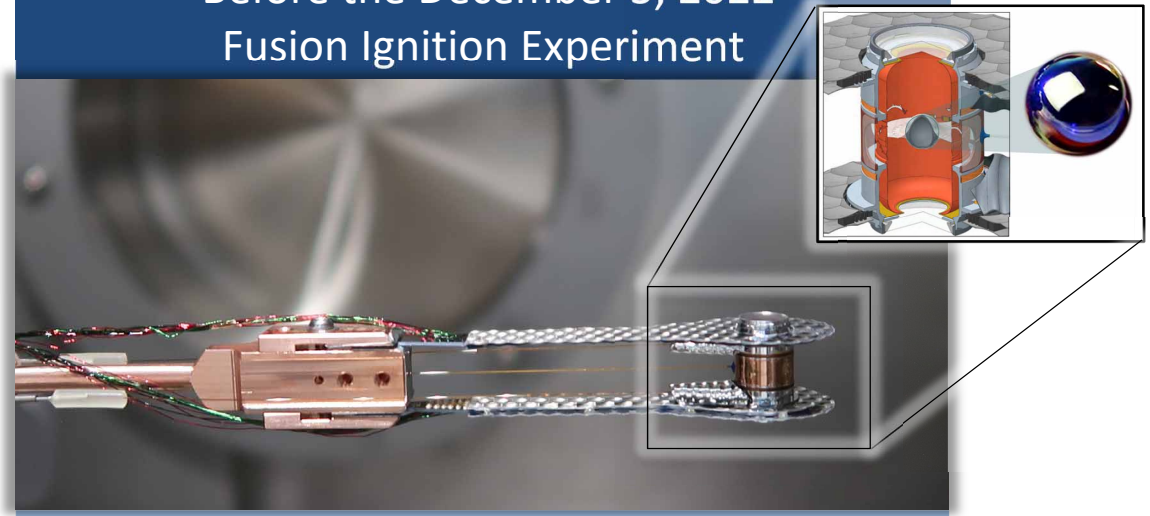
Unique Capabilities for ICF Experiments

Extreme temperatures and pressures found only in stars, giant planets, and exploding nuclear weapons

On December 5, 2022, NIF became the first in history to create a nuclear fusion reaction within a controlled environment.

NIF's Historic Scientific Achievement: Target Gain with ICF

Before the December 5, 2022 Fusion Ignition Experiment



Target stalk holding the hohlraum and cryogenically layered 2 mm DT target capsule

After the December 5, 2022 Fusion Ignition Experiment

Target stalk remnants after NIF delivered 2.05 MJ to target and produced 3.15 MJ of energy

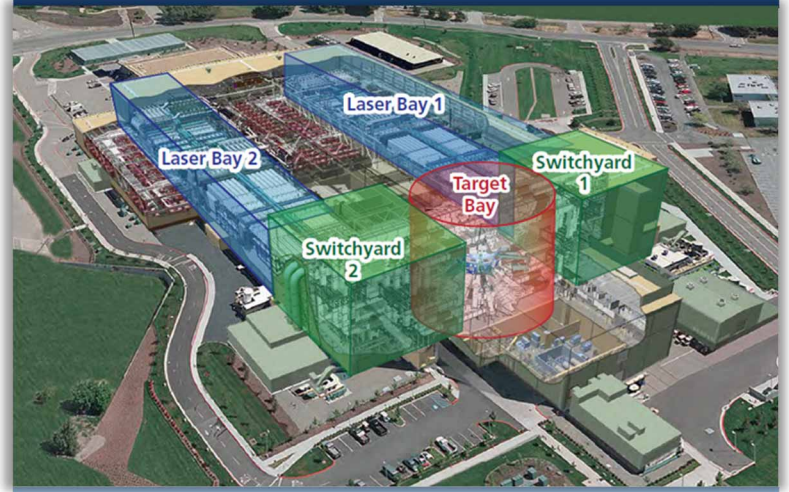
NIF repeated ICF ignition with target gain on July 30, 2023 when it delivered 2.04 MJ to target and produced 3.88 MJ of energy.

A Control System for Fusion Ignition

- NIF's Control system, one of largest and most complex control systems in the world has:
  - **1200** control racks, **2300** processes, **6200** line replaceable control units
  - **Thousands of kilometers** of cabling to connect electrical and optical control points

- NIF Controls are capable of repeatably meeting precision laser requirements
  - **30 billionths of a second** pulses
  - Beams timed on target within **30 trillionths of a second**
  - Beams aligned on target within **50 microns**

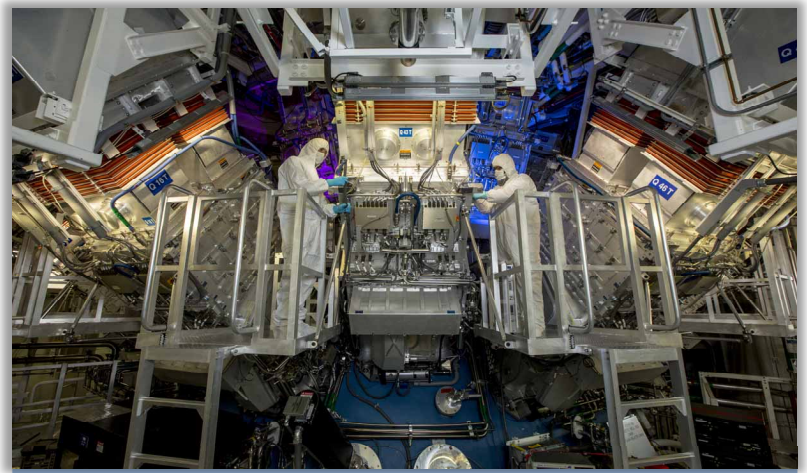
NIF Beampath



Total distance of pulse travel from the initial optical fiber laser to Target Chamber Center: **1500 meters**

A Control System for Fusion Ignition

- NIF Control System has 3 main subsystems:
  - **Integrated Computer Control System** (ICCS)
    - In-house developed software/hardware
  - **Safety Interlock System** (SIS)
    - Allen-Bradley PLC based
  - **Industrial Control System** (ICS)
    - Allen-Bradley PLC based



ICCS, SIS, and ICS together remotely monitor & control over 66,000 devices

- NIF Control System supports the operation of:
  - mirrors, lenses, actuators, sensors, triggers, cameras, digitizers, amplifiers, calorimeters, valves, motors, pressure regulators, and temperature controllers

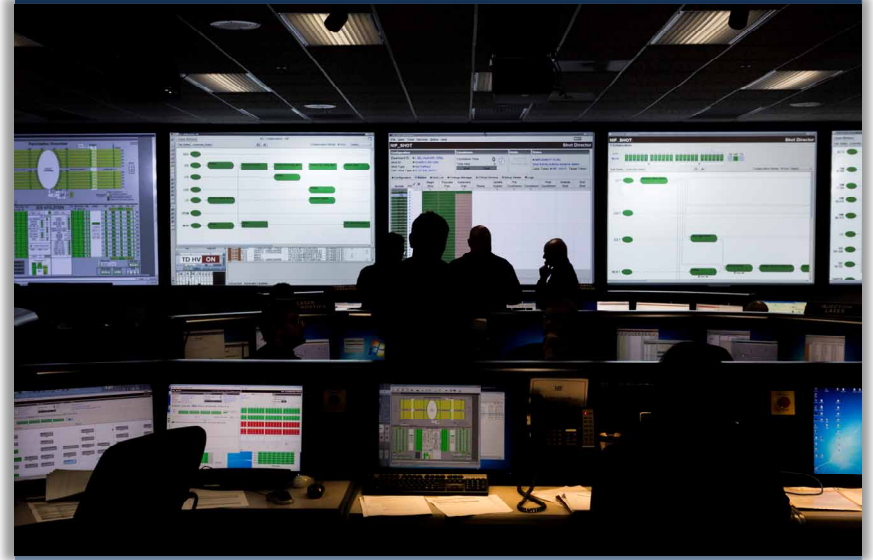
With up to 400 shots/year and 2 million operations/shot,
Controls hardware is continuously exercised and must be meticulously maintained.

Maintenance Windows

- **Scheduled blocks of time** are devoted to:
  - Preventative maintenance
  - Reactive maintenance
  - Install new laser/diagnostic capabilities

Frequency	Duration	Timeframe
Weekly	2 days	Friday, Saturday
Yearly	1-3 weeks	April
Yearly	1-3 weeks	August
Yearly	1-3 weeks	December

NIF Control Room



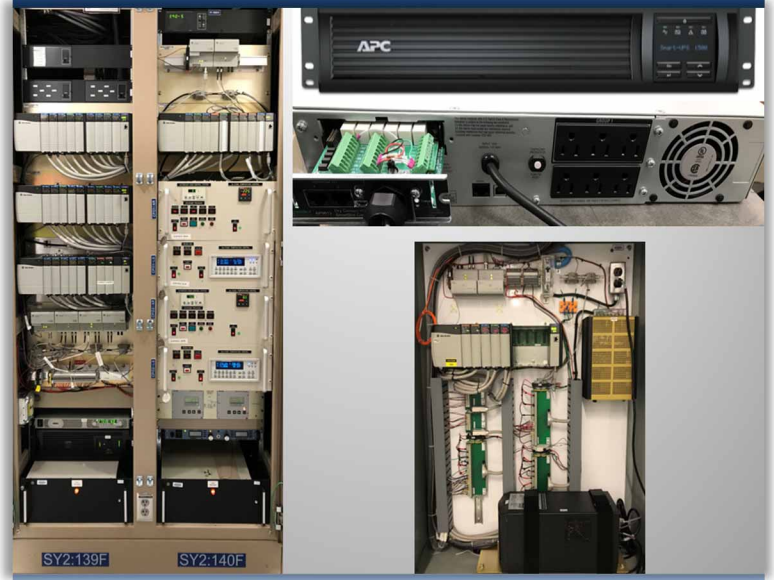
A portion of the Controls team is **on-call 24x7** to troubleshoot and resolve urgent issues impacting laser experiments

Approximately 18 weeks of downtime are set aside for maintenance every year.

Preventative Maintenance

- **SIS periodic testing**
  - 7 systems tested every 6 months
  - Testing and repair requires ½ FTE per year
- **Technology refresh**, replacing:
  - UPS units and I/O cards
  - Servers running Windows XP OS
  - Network switches
  - Power supplies
  - Instrument-based controllers
  - Timing system hardware

UPS Hardware Replacements

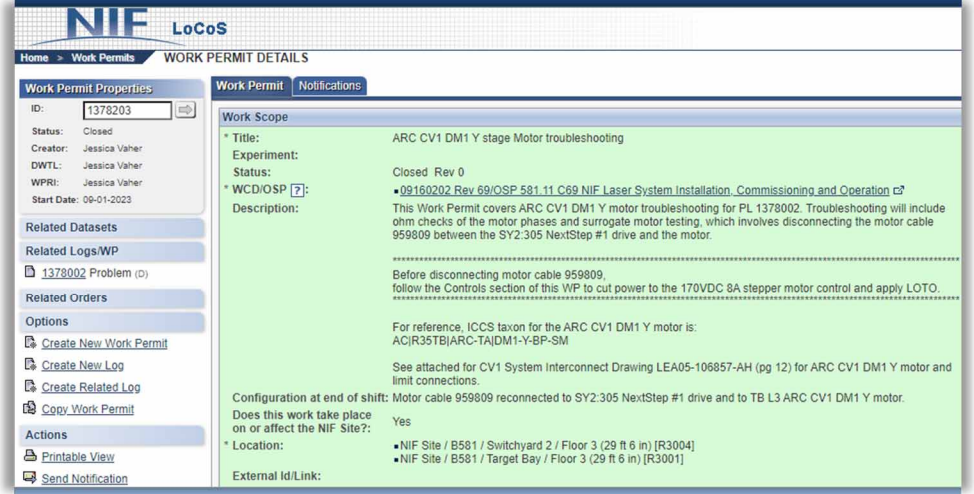


Support critical safety and utility PLC systems such as Tritium Processing and Target Chamber Vacuum

Regularly scheduled preventative maintenance is crucial to ensure high system reliability to sustain the pace of shot operations.

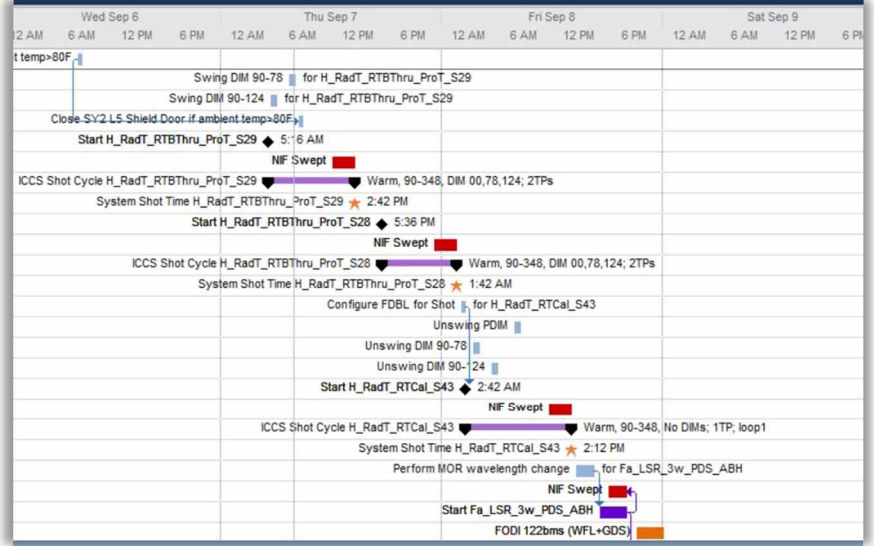
Maintenance Planning

Work Requests & Authorization



JIRA tickets and Problem Logs reviewed daily;
Work Permits created to authorize work

Work Coordination

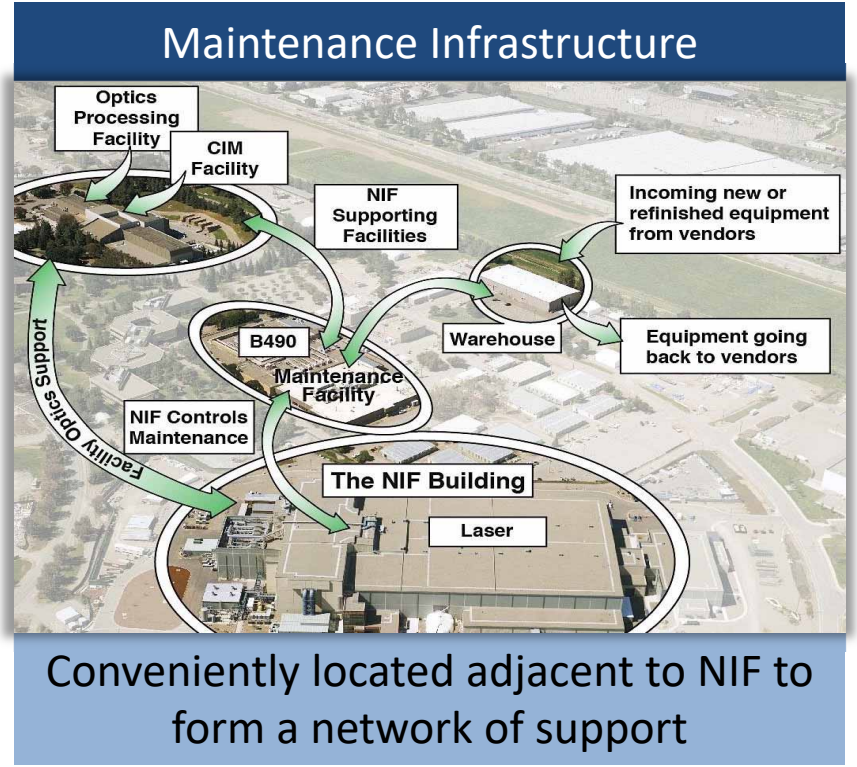


Work groups discuss, prioritize, schedule, and perform work while balancing safety, security, quality, and efficiency

The robust engineered controls and exceptional safety processes established during NIF's inception have led to 14 years of successful operations.

NIF Controls Support Buildings

- **Controls Maintenance & Engineering Facility**
  - Hardware test stations
    - Troubleshoot hardware failures
    - Validate spares inventory
  - Fabrication and soldering stations
    - Build/repair hardware assemblies
    - Terminate cables
- **NIF Warehouse** to store spares inventory
- **ICS and SIS Development Labs**
  - Remote access to PLC systems



Our tested, local spares inventory helps reduce reactive maintenance downtime.

Documentation for Maintenance

- **Enterprise Lifecyle Management (ELM)** stores and manages:
  - Mechanical/Electrical drawings
  - Engineering design data
  - Procedures
  - Configured System documents
- **Controls Information Retrieval System (CIRS)** cross references data to assist with troubleshooting

SIS Periodic Test Procedures

CIRS Quick Lookup Tool

NIF JCIRS Home ICCS Racks Cables

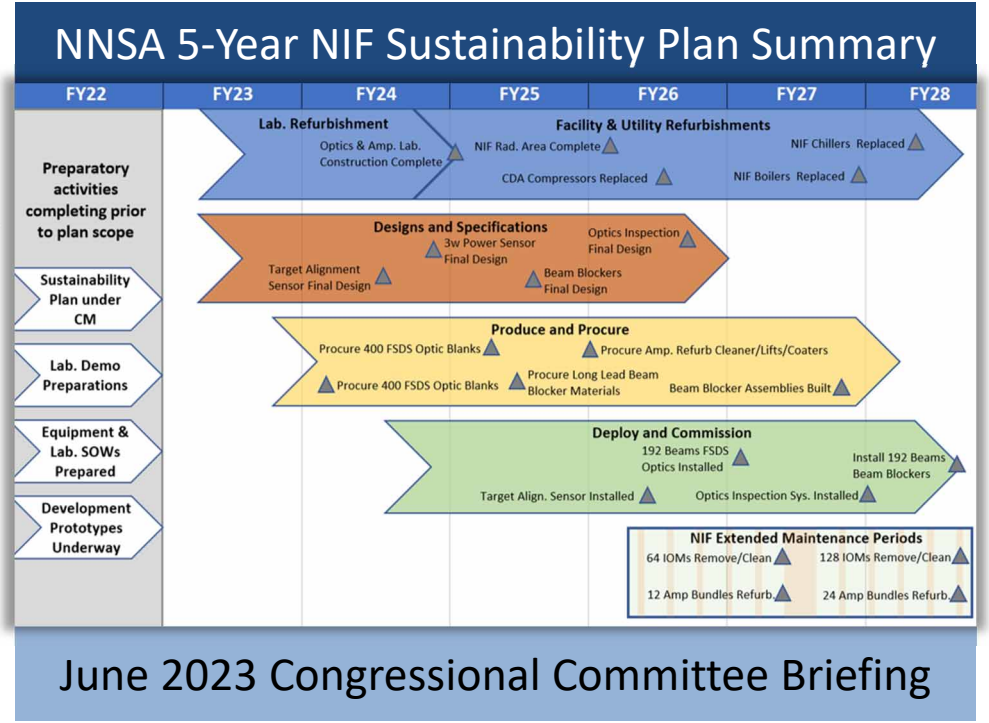
Popout MOTOR: AC|B111|SY_IOM|LM5-SM-X

Alignment Control Configuration	
FEP VME CHASSIS	LEA05-106508 [BOM]
> LOCATION	SY1:501:16
> RACK DRAWING	LEA99-001812
> RACK INTERCONNECT DIAGRAM	LEA99-301812
FEP PROCESSOR MODULE	
> IP NODE	
> SUBSYSTEM (A,B,C)	A
> BACKPLANE SLOT (1-7,1-10,1-21)	A1 FRONT BOTTOM
> CHASSIS SLOT (1-21)	1 FRONT BOTTOM
> SERIAL NUMBER	
OMS VME58-8 MOTION CONTROLLER MODULE	N5998-18980
> MODULE SCHEMATIC	
> FEP SUBUNIT	A
> BACKPLANE SLOT (1-7,1-10,1-21)	A2 FRONT BOTTOM
> CHASSIS SLOT (1-21)	2 FRONT BOTTOM
> SERIAL NUMBER	
> HARDWARE ADDRESS	0x2000
8-CHAN MOTOR DRIVER MODULE	LEA96-286012
> MODULE SCHEMATIC	LEA96-286011

These documentation systems are vital to facilitate maintenance in NIF.

Ensuring Maintainability

- **NIF 5-year Sustainment Plan**
  - Spans 30 large-scale projects at NIF
  - Focuses on degrading systems that have significant project impact
- **Current efforts for technology refresh**
  - Purchasing new old stock
  - Finding vendor fit/form/function replacements
  - Redesigning hardware onsite



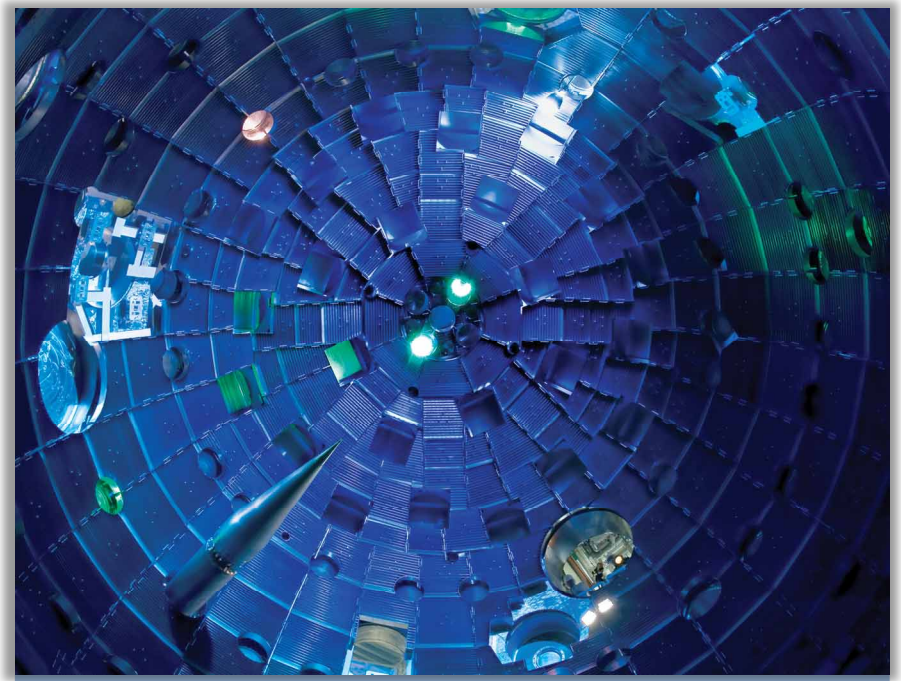
June 2023 Congressional Committee Briefing

The Controls team is a significant part of sustainment to replace or recapitalize systems. Some of these systems have increased failure rates due to operating in the higher laser energy and neutron yield conditions that NIF is now routinely capable of.

Conclusion

- The level of system complexity matches the level of rigor with which the maintenance program must be implemented, while adhering to the high safety standards NIF values for work processes and procedures

- Our goal at NIF is to keep equipment, personnel, and the environment safe as we continue to lead groundbreaking scientific discoveries and contribute to national and global security



A view of the target positioner from the bottom of the Target Chamber

Our extensive maintenance program has served NIF well and will continue to do so as we embark on the NNSA 5-year NIF Sustainability Plan to continue progress.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