DIII-D Safety Program – Incidents and Lessons Learned

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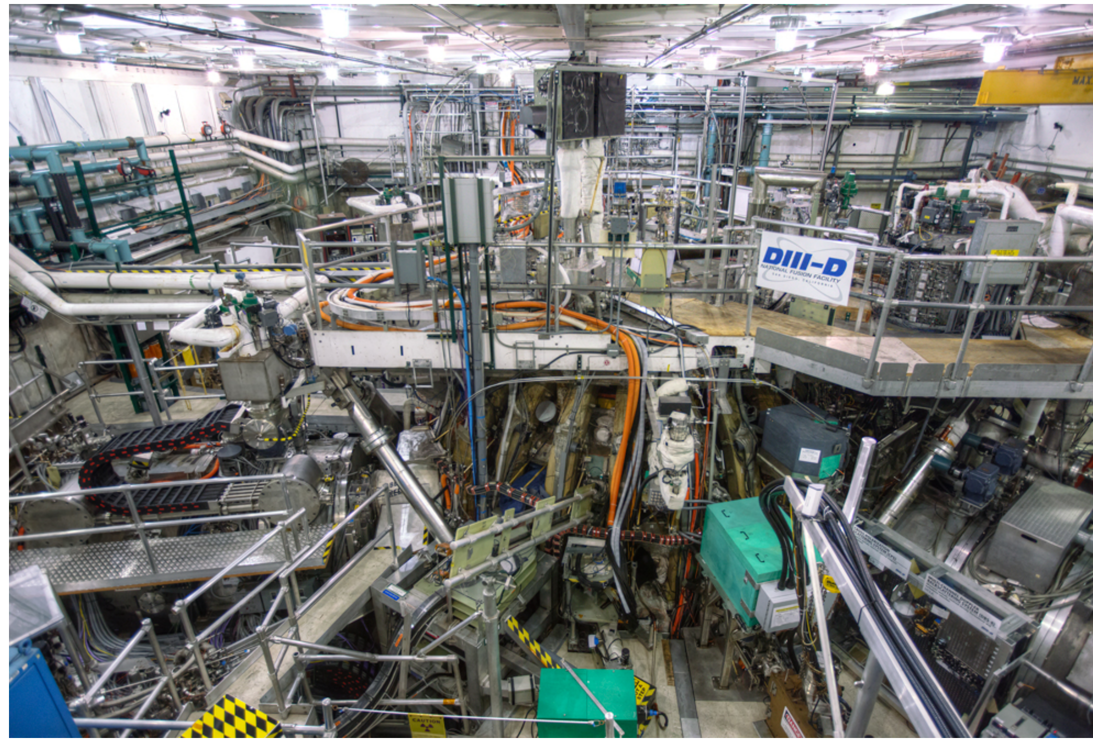
for the DIII-D Team



Presented at the
DOE Accelerator Safety Workshop Thomas Jefferson National Accelerator Facility Newport News, VI

August 15-17, 2017

Work supported in part by U.S. DOE under DE-FC02-04ER54698.

DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

Outline

- **Overview of the DIII-D Facility**
- **DIII-D Safety Program**
- **Review of Recent Incident: LN_2 cryogenic leak**
- **Ongoing improvements to DIII-D Safety Program**

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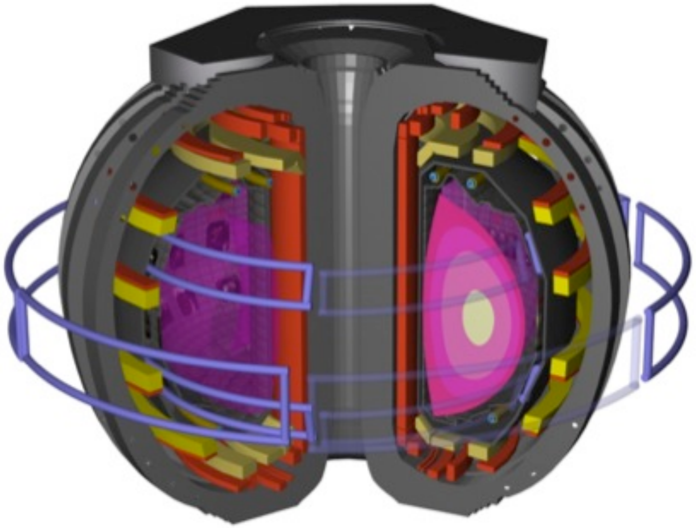
DIII-D Tokamak System Capabilities



DIII-D Tokamak Vacuum Vessel
- 35 m^3 Inconel 625 vessel

Coils
- Toroidal field – 2.2 T on axis
- 18 Poloidal field shaping coils
- 6 external coils, 12 internal coils

Plasma Control
- 18 CPUs, 40 GB real-time CPU network

Heating and Current Drive (injected power/pulse)
- Neutral Beams: 8 sources; 20 MW (80 keV Deuterium)
- Electron Cyclotron (Microwaves): 6 gyrotrons@110 GHz; 3.5 MW (5 s)

Divertor/First Wall/Conditioning
- 3 LHe cryopumps; 15–20,000 l/s
- ATJ graphite
- 350°C bake, boronization, Helium glow discharge between pulses

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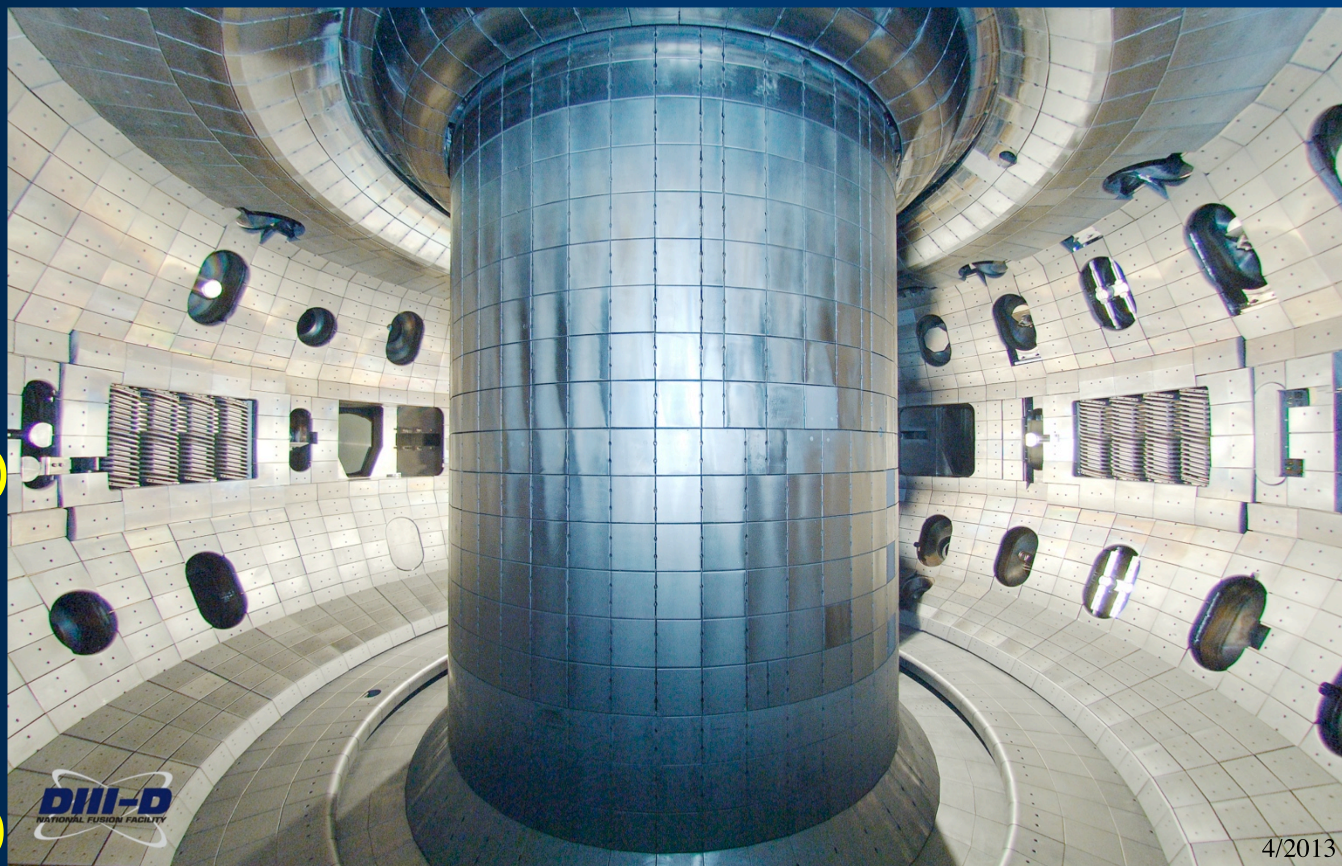
Multiple Hazards Exist at DIII-D

- Ionizing radiation (neutrons, gamma rays, X-rays), tritium
- Electrical (120V - 138 kV AC, >100 kVDC); high current (>100 kA)
- Microwave (110 GHz >1MW), RF (100 MHz >2 MW)
- Magnetic fields (<5T)
- Lasers (Visible and IR, Class I – IV, pulsed and SS)
- Cryogenic (LHe/LN2 – asphyxiation, cold, embrittlement, pressure)
- Explosive & toxic gases (D_2, diborane, Ar, Ne, Xe, N_2, CD_4, CF_4, and CCl_2F_2)
- High pressure (water < 300 psi, hydrauilc < 5000 psi, compressed gases <2200 psi)
- High noise levels
- High temperature surfaces (350°C)
- Confined spaces

Strong Involvement of Collaborators is Essential to the Excellence of the DIII-D Diagnostic Set

- Coherence imaging (LLNL/ANU)
- FIDA (UCI)
- NPAs (UCI)
- IR cameras (LLNL)
- SXR (UCSD)
- Fast ion collectors (UCI)
- BES (U Wisc)
- FIR & μw scattering (UCLA)
- Vertical scanning probe (UCSD)



- UF-CHERS (UW)
- DISRAD (UCSD)
- VUV cameras (LLNL)
- ASDEX gauges (ORNL)
- MSE (LLNL)
- Fast framing camera (UCSD)
- ECE (UT,U Md)

- MDS spectrometer (ORNL)
- Gamma detectors (UCSD)
- Filterscopes (ORNL)
- Visible cameras (LLNL)
- ECEI & MIR (UCD)
- Neutrons (UCI)
- Phase contrast imaging (MIT)
- Radial scanning probe (UCSD)
- CP swing probes (U Tor./GA)
- DBS & CECE (UCLA)
- Langmuir probes (SNL)
- Reflectometers (UCLA)

Aerial View of DIII-D Facility, Located in San Diego, CA

Low & High Pressure Deionized Water Pumping Systems

138kVAC/480VAC Substation

5MW West Substation (Fed from Dunhill)

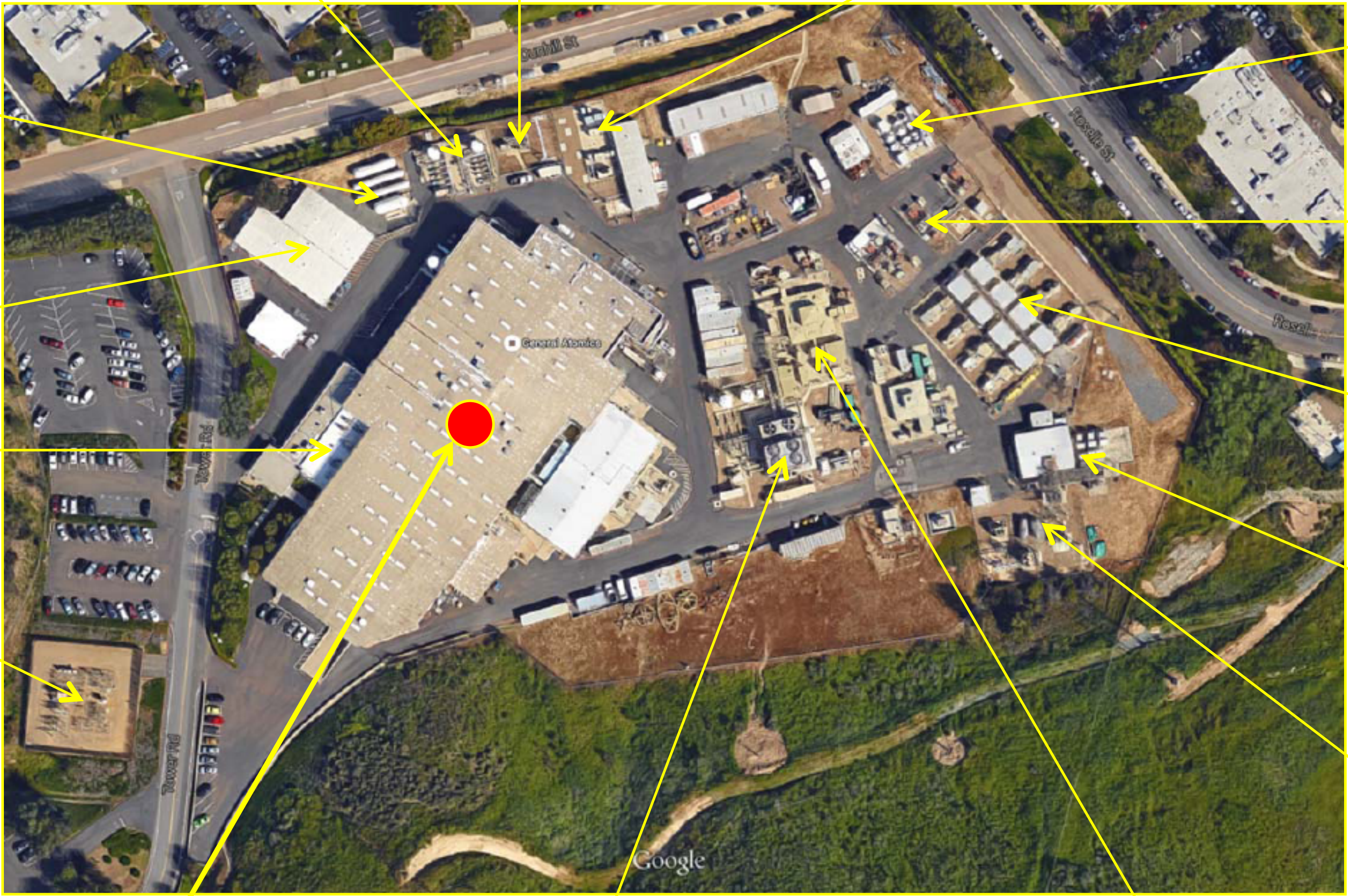
Two RF Transmitter PSs 30kVDC, 125A

Helium Gas Storage

Diagnostics Lab

Control Room

Dunhill Substation



Five Gyrotron PSs 105kVDC, 90A

Eight Neutral Beam PSs 120kVDC, 100A

12.47kVAC Switchgear (from 138kVAC Line)

138KVAC & 69kVAC Substations

DIII-D Machine

Three Cooling Towers

525MVA Motor Generator

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DIII-D INTRODUCTION

Recent Upgrades to DIII-D Operations

- **Tungsten inserts installed in high heat flux areas**
  - Investigate materials that minimize tritium uptake
- **Novel Design of Divertor Structure to spread heat flux over a large area**
  - Use of 3D printer for mock-up of tiles and creation of mounting templates.
- **Completed development of high power 1.5 MW gyrotron (117.5 GHZ) for plasma current drive**
- **Developed high power Helicon antenna (476 MHz)**
- **Coating walls with lithium and Silicon Carbide**
  - Health and Hazard issues that need to be addressed
  - Safety Program that evolves with our new upgrades

Outline

- Overview of the DIII-D Facility
- **DIII-D Safety Program**
- Review of Recent Incident: LN_2 cryogenic leak
- Proactive Safety initiatives

DIII-D Safety Program Supported by General Atomics Corporate Safety Organizations

- **DIII-D Operates Under a DOE Cooperative Agreement**
- **Externally regulated by Cal-OSHA and other state and local regulations**
- **Radiological exposure governed by State of California Radiation Control Regulations (Title 17). DIII-D procedures and ALARA program set targets below legal limits.**
- **DIII-D program supported by General Atomics Corporate Environmental Safety & Health Group and Health Physics Group**
- **DIII-D Safety Committee and Energy Group Safety Officer (employee of GA ES&H Group)**
- **DIII-D Emergency Response Team**

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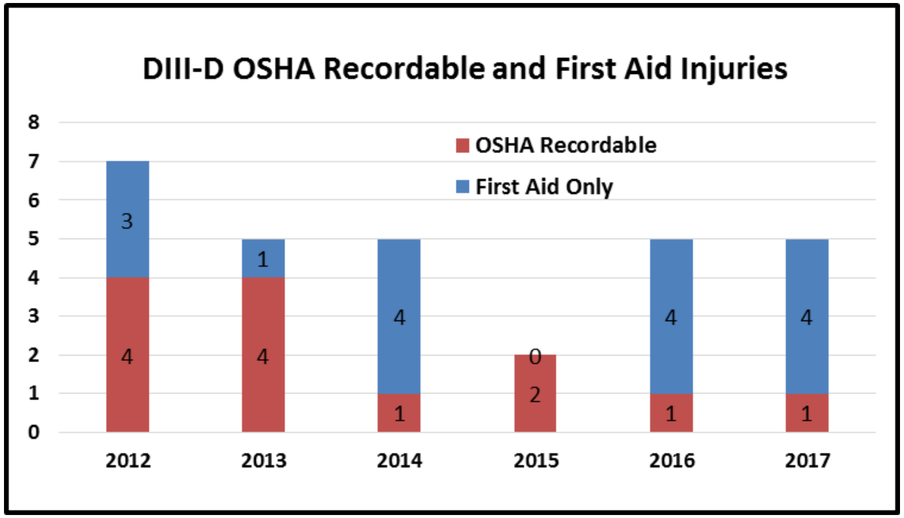
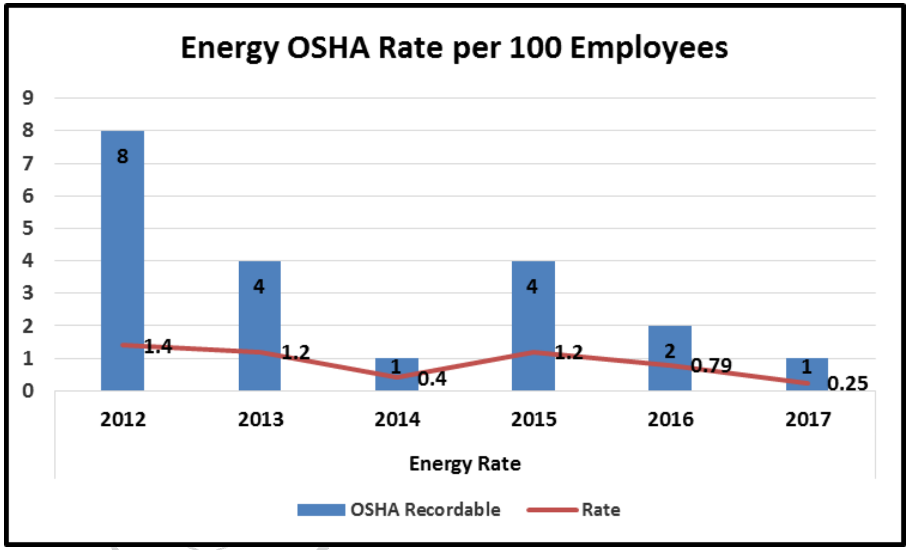
Overview of DIII-D Safety Program

- **The Safety Program at DIII-D is based on Integrated Safety Management (ISM). It has been a successful system for assuring safe and efficient operations**
  - Hazards identified for each task and engineered controls are put in place to protect personnel & equipment
  - Safety training for all personnel is regularly evaluated, provided on an on-going basis, and tracked
  - Processes and procedures are in place to control work
  - Lessons learned from incidents/near-misses are used to strengthen the Safety program

- **DIII-D has created an environment with relative freedom from danger, risk, or threat of harm, injury, or loss to personnel and property**

DIII-D Safety Program – OSHA Recordable injuries have decreased from 2012





- **Injuries have decreased in past 5 years**
  - Categorizing incidents
  - Improved investigations
  - Targeted safety initiatives
  - Improved safety awareness
  - Encourage 'Near Miss' reporting

- **The chart displays the OSHA rate per 100 Energy employees. One injury is occurring per 400 Energy employees**

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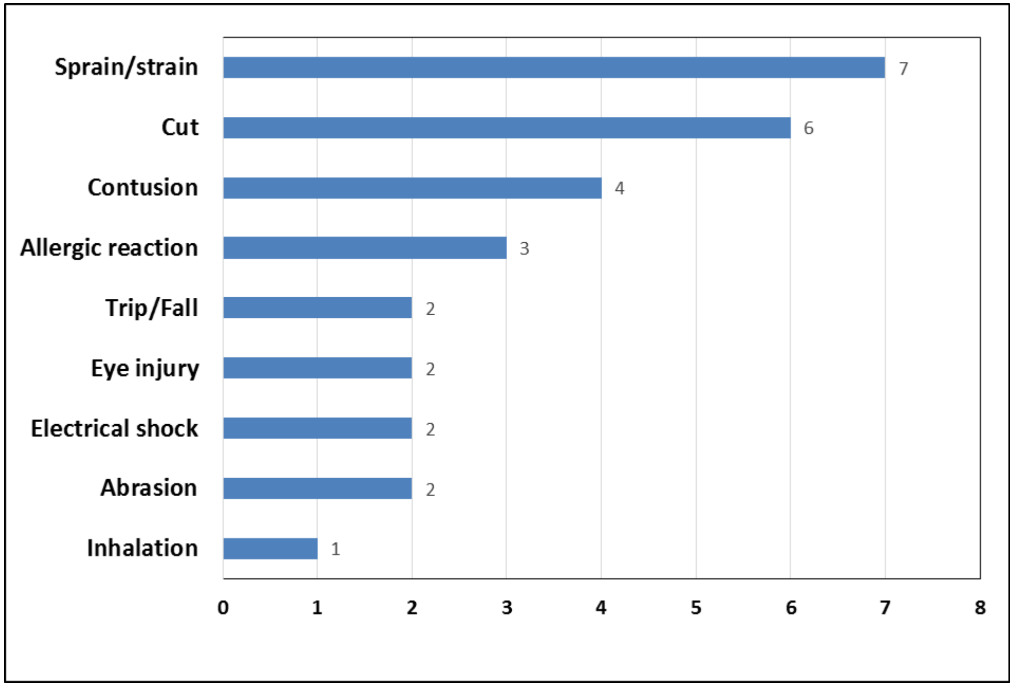
DIII-D Safety Program – Most Injuries Due to Normal "Low Tech" Work Activity

- Engineering controls are in place for high hazard areas such as high voltage and laser rooms to ensure that injuries do not occur
- Most injuries have occurred due to muscle strain and cuts from normal work activity
- Electrical shocks occurred from low power supplies



Injury Types from 2011-2016

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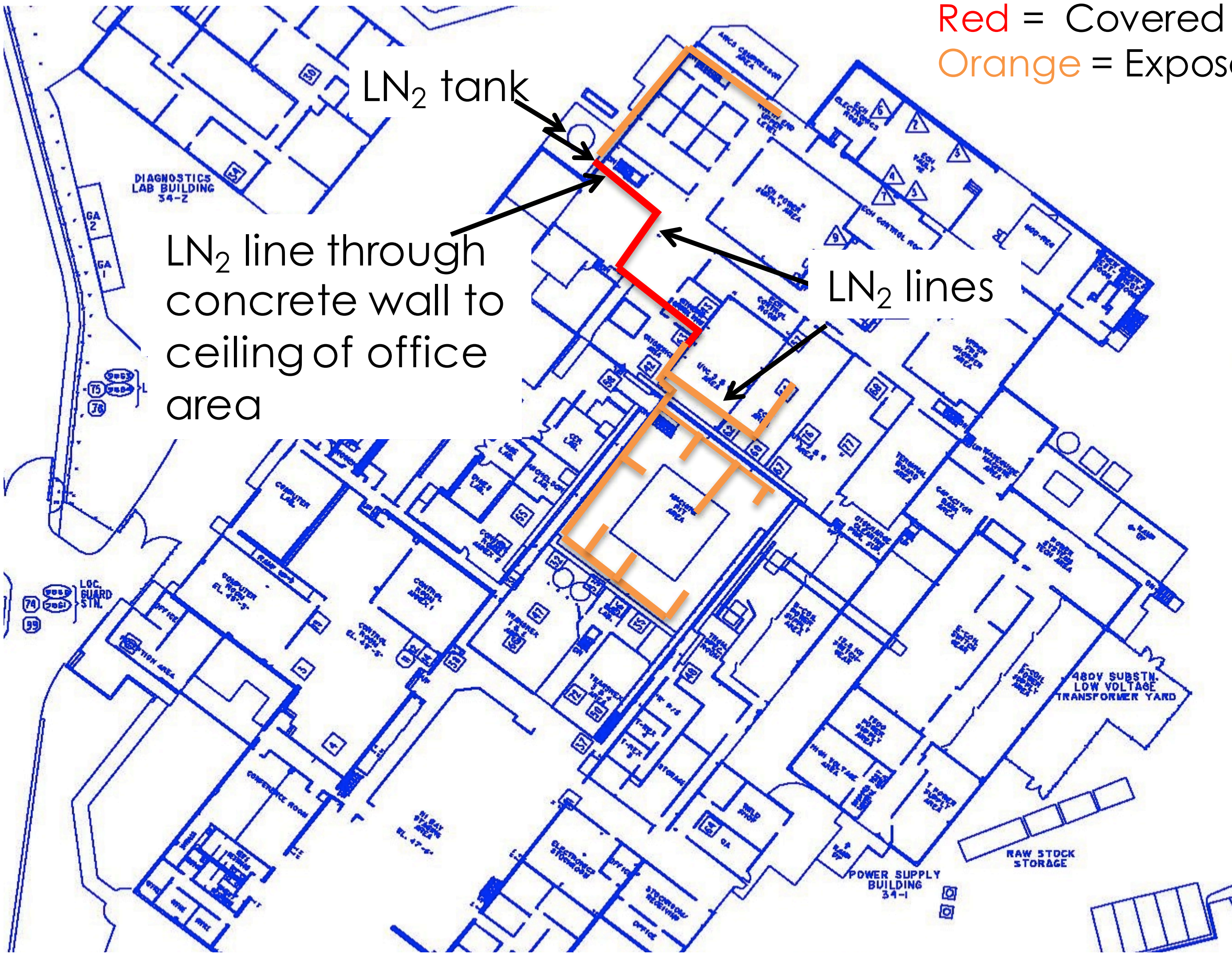
- **Review of Recent Incident: LN_2 cryogenic leak**
- Ongoing Improvements to DIII-D Safety Program

LN_2 cryogenic leak: Summary

- On Tuesday 2/21/17 at 2:00 am a line carrying liquid nitrogen from a 11,000 gallon LN_2 tank on the West side of the main building failed and released LN_2 into the ceiling above several office areas
- A total of ~4000 gallons of LN_2 was released before the LN_2 flow was stopped
- The failure resulted from a joint clamp securing a bayonet connector. A bolt had rusted through after 30 years of use
- The large amount of LN_2 released froze a water pipe and a sprinkler system riser pipe. The frozen pipes cracked and released a large amount of water through the ceiling and into the office space below
- There were no injuries

Incident Location

Red = Covered by ceiling
Orange = Exposed



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Incident Time Line

~ 2:00 am – LN_2 leak began, the level of LN_2 in the tank began a sharp drop

3:18 – 3:26 – Room smoke detector starts giving "Trouble" faults (not an Alarm).

4:00 – GA Security Guard arrives on site. Acknowledges fault. Walks around outside of building looking for smoke.

~ 4:30 – GA Security contacts DIII-D management, reports that the smoke detector is in Trouble (not Alarm), and there was no smoke on this walk around the facility. DIII-D management told them smoke detector would be checked in the morning.

~ 4:55 – Technician arriving on site and sees "fog" as they pass by the affected office area. The technician sees frost on the cement floor above the leak. Technician opens exterior doors for ventilation.

~ 5:00 – The technician suspects a cryogen leak and contacts the Cryo Operator who goes to the Cryo control room to start LN_2 shut down.

~ 5:10 – The Cryo Operator starts shutting down systems that use LN_2.

~ 5:30 – Technician rope off affected office area.

~ 5:56 – Cryo Operator shuts off LN_2 by hitting emergency stop button (LN_2 tank level stops dropping)

~ 6:45 am – After arrival of additional staff, technicians get O_2 meter before entering affected office areas. When levels read low, blowers are setup to ventilate rooms.

Loose Bayonet Connector

Stainless Steel Clamp with Carbon Steel Bolt

Preliminary Analysis

- Proximate Cause: Failed carbon steel bolt on clamp for bayonet connector. The bolt that failed was 30 years old, exposed to the outside climate, and not inspected since it was installed in the ceiling. Lines are double jacketed with a vacuum inter-space except at the bayonet connector
- Severity of Problems: Exposure to LN_2 could cause extreme cold burns. GN_2 gas a possible asphyxiation hazard
- Alarms: There was not an alarm that unambiguously alerted to operators of the failure
- Response: Knowledgeable technicians quickly identified the problem. Appropriate actions were taken to eliminate the problem. Safety Training and understanding of the key systems were key in resolving the problem safely

LN_2 Leak: Corrective Action

- Replace failed bolt with stainless steel bolt. Inspect the other bayonet connectors and replace any suspect bolts
- Building entrance sealed to keep moisture off bolt
- Yearly inspection of all bayonet connectors on LN_2 line has been added to the preventative maintenance schedule. Access panels in the roof have been added to inspect the bayonet connectors
- Rate of change alarm of LN2 tank level added to Cryo Programmable Logic Controller (PLC). Output wired to Alarm System that is monitored by Security Guards
- Thermocouples installed at bayonet fittings to detect leaks. Wired to Cryo PLC which will generate an output to the Alarm System

LN_2 Leak: Corrective Action (cont.)

- **Add additional oxygen monitors in rooms through which a GN_2 or LN_2 line runs. Wire to Alarm system. Also investigating adding voice alarms to oxygen alarms to alert personnel to leave the area as already has been done in other locations at DIII-D**
- **Provide training to a more general audience on the hazards of oxygen deficient atmospheres due to nitrogen displacement,** *i.e.* **train a wider audience than just LN_2 users and gaseous N_2 users. Include in training locations of LN_2 tanks, lines, and indications that LN_2 may be present**

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Safety Upgrades in an Older Facility

- **Access Control for hazardous areas is accomplished through locks and Kirk Key Control**
- **As a secondary measure door interlocks are installed. Areas are divided into sections with interlocks wired in series with a single interlock for each area running to the Main Control Room. This interlock is ORed and then sent to an Emergency Crash System (ABORT) which turns off power supplies and opens breakers**
- **Wiring is old (>30 years) and not well documented. Adding on new areas can be difficult. Serial wiring makes troubleshooting difficult**
- **Investigating Distributed Safety System to incrementally add-on and begin piecemeal replacement**
  - Versafe from GE as add-on to existing Profinet linked PLC drops
  - SIL-3 rated hardware
  - Programmable functionality. Increased Diagnostics

Group Wide Safety Meetings Held to Build Safety Culture

- **Division wide input requested for safety issues. A list of action items was developed and is being pursued**
- **Improve the training of non-DIII-D personnel (janitors, Security personnel, etc)**
- **Revise existing Lock-Out/Tag-Out DIII-D procedures. New procedure should require:**
  - Improved written, system specific procedures written and approved
  - Easy availability of system-specific procedures (local & on-line)
- **A Task Group was formed to update the After Hours work/lone worker procedures**
- **A Task Group was formed to update the "Pit Run" procedures.**
  - DIII-D runs pulsed shots. Access to the Machine Hall "Pit" is allowed between shots to adjust and diagnose experimental hardware

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Summary

- **DIII-D has a successful system for assuring safe and efficient operations**
  - Hazards identified for each task and mitigation is put in place to protect personnel & equipment
  - Safety training for all personnel is regularly evaluated, provided on an on-going basis, and tracked
  - Processes and procedures in place to control work
- **Lessons learned from investigations of both injuries and 'near miss' incidents have significantly improved the safety program**
- **Wide use of engineered controls are key to strong safety record at DIII-D**
- **Most injuries result from common industrial-type hazards – training and safety awareness is key**