NAVIGATING UNCHARTED WATERS
LESSONS LEARNED IN THE "CLASS 5" LASER LAB

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AGENDA

- LM corporate business areas
- Rotary and Mission Systems and Directed Energy
- The need for, and development of Class 5
- Class 5 controls, construction of HEL labs
- Exposure incident
- Lessons learned
- Other challenges
- Call to action

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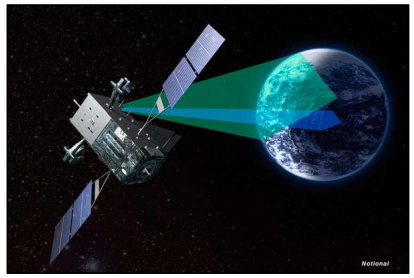
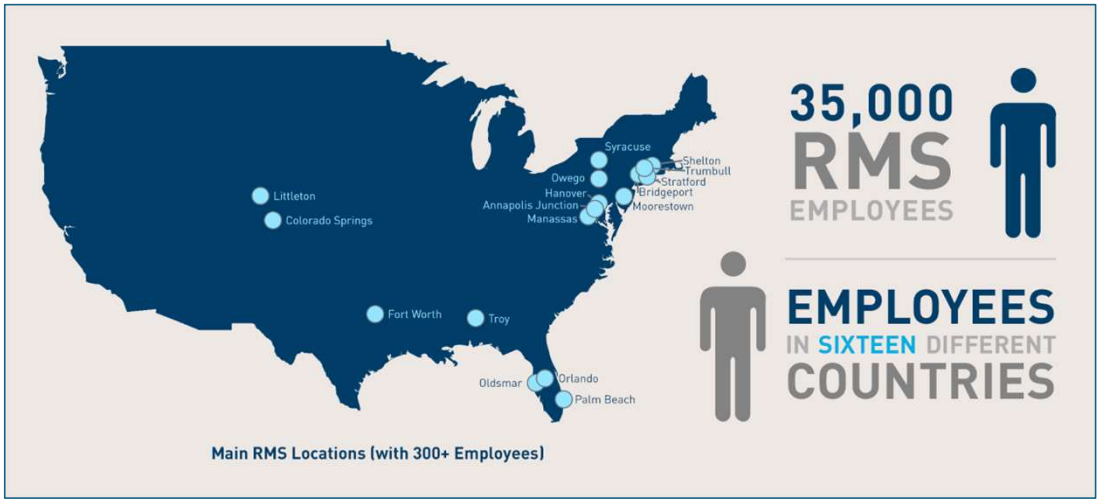
CORPORATE STRUCTURE – BUSINESS AREAS

Aeronautics
Space
Missiles and Fire Control
Rotary and Mission Systems (RMS)
Prime BA for Directed Energy systems





RMS developed a “Class 5” Safety Program

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OUR DIRECTED ENERGY JOURNEY

10kW ➡ 30kW ➡ 60kW ➡ 80kW ➡ 300kW ····· 500kW ····· ?

Progress Accomplished

Roadmap for the Future

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NEED FOR CLASS 5 LASER SAFETY

- Kilowatt CW to petawatt pulsed lasers widespread, growing
- Hazards exceed scope of ANSI Z136
- OSHA General Duty Clause – Address recognized hazards
- Lockheed Martin and DOE collaboration
- Class 5 lasers >10kW for CW
- 10^{15} W/cm^2 peak irradiance <0.25 seconds
- Weaponized lasers, designed to destroy, penetrate materials, IDLH, hazardous diffuse reflections
- Avoid burden on existing industry
- Consider burn-through rates of materials, infrastructure
- Thermal management, battery ops
- Multiple, redundant interlock systems
- Error prevention techniques, huddles
- Eyewear no longer considered

Photo Credit: LBNL

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DEVELOPMENT PROCESS – NOT A "NEW" IDEA

1. White Paper arguing for ANSI updates, new hazard class
2. Assemble team of SMEs
3. Propose changes to ANSI Z136.1
4. Develop appendix, table with recommendations
5. Add to Corporate Command Media to set industry standard
6. Work with ANSI board to publish (longer term goal)
7. Benchmark with collaborators and competitors

Winner of 2022 NSC Innovation Award

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CLASS 5 SAFETY CONTROLS

a) Personnel exclusion – Remote operation, breakdown of PPE

b) Beam shields, laser barriers – Construction materials considered

c) Beam blocks, dumps – Special design, may require thermal management

d) Containment of specular, diffuse reflections – Low power alignments, dry runs

e) Optical damage sensors – Stray light, smoke detection, temp monitoring

f) Entryway controls – Key controlled interlock, status indicators

g) Operational checklists – Error prevention, consistency

h) Detailed alignment procedures – Highest risk, 90% of incidents

i) Back reflections – Small percentage of reflected HEL beam can far exceed MPE

j) Two-Person Rule – Working alone prohibited

k) Environmental considerations – Temperature, humidity, particle counts

l) System Safety – Interface safety review for software bugs, logic errors

m) Failure Modes & Effects Analysis – Machine, personnel safety, address risks

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HIGH ENERGY LASER SAFETY – MOORESTOWN, NJ & BOTHELL, WA

- World class laser lab, highly engineered for safety with robust construction materials
- FFMEA prior to construction, justifications for investment
- Real-time audiovisual and thermal monitoring
- Redundant interlocks, multiple E-stops
- Internal and external stray light sensors
- Atmospheric monitoring for refrigerant leaks, smoke, fire
- Reinforced graphite sliding panels over roll-up door
- Cleanroom particle counters monitor cleanliness in ISO7, 5 volumes
- Supporting the future of Directed Energy technology!

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EXPOSURE EVENT

Event

Background

System operators were calibrating the Tracking Illuminator Laser (TILL), when two employees stepped onto the roof of the structure, walking through energized beam.

Incident

Employees (E1, E2) were standing on scaffold when one had an urgent hardware concern regarding a motor controlling focal length. E1 knew the TILL was energized, but at that moment the only concern was getting to that motor before it failed. E1 got on top of the structure, and E2, a junior engineer, followed to assist. Both reported feeling a warm sensation on hand and leg which led them to realize the TILL was energized. Proper eye protection was worn. While no injuries resulted, the employees reported to the Wellness Center for an evaluation, then referred to an Ophthalmologist. No one was supposed to be on the roof during this process. Employees neglected to follow fall protection requirements. Reporting was delayed until the following day.

Cause(s)

Root Cause

Procedural Breakdown, Human Factors

Contributing Factors:

- The TILL is used infrequently, but on this day, it was energized for prolonged periods of time at 10% of max output
- TILL produces an infrared wavelength invisible to the eye
- Two of the four employees in the clean room had their attention dedicated to diagnostic readouts Human Factors

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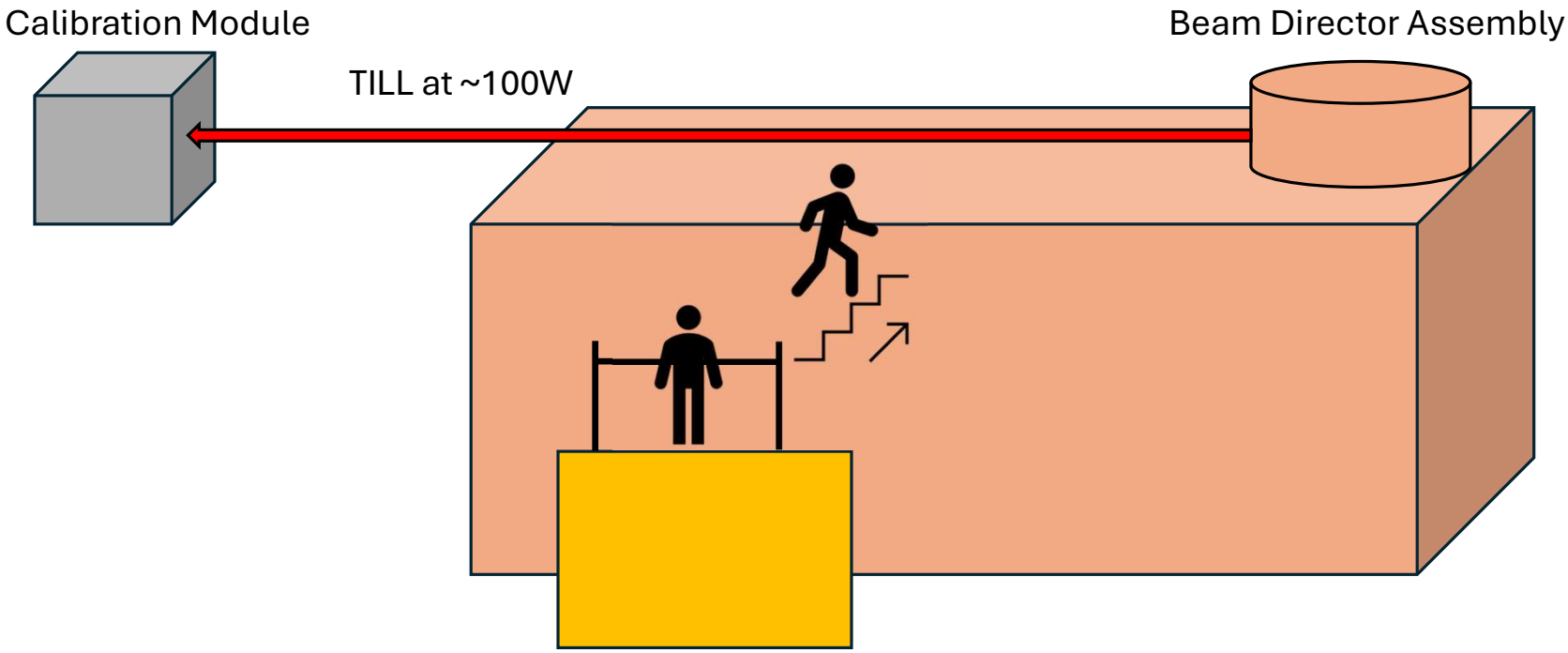
INCIDENT DIAGRAM



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CORRECTIVE ACTION IMPLEMENTATION

Corrective Actions

1. Retraining efforts – Required review of general safety training and SOP
2. Final barrier to entry to hazardous zone. New chain barriers, signage on scaffolding and scissor lift
3. Install beacon lights near access points
4. Steps added to SOP and pre-fire checklist
5. LSO validation of eyewear coverage for TILL wavelengths
6. In-person safety discussion on real world laser accidents.
7. Training on basic RCA/CA
8. Lasing prohibited with personnel on roof. Access prohibited unless reviewed and approved
9. Required presence of a level 4 operator dedicated to safety supervision
10. Audit of laser eyewear
11. Present CAP, and process improvements to program personnel across various locations

Enterprise Learning

Key Takeaways and Focus Topics

- Human factors must be accounted for even in the most highly engineered environments
- Deviation from normal scope of operations introduces new potential failure modes
- Fall protection requirements violated the moment employees stepped from scaffold onto roof
- Avoid delayed reporting or waiting to seek medical evaluation

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FALL PROTECTION SOLUTIONS

- Using roof as a tie-off point was problematic
- Hindered mobility
- Risk of hitting ground before fall arrest engagement
- Solution must fit within space
- No new sources of particulate contamination
- ESH engaged with Fallproof Systems
- Solicited capital funding for PortaGantry
- Adjustable dimensions vertically and horizontally
- Holds up to 3 trolleys for tie offs, movable / lockable

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REFRIGERANT DETECTION SENSOR

- Lab has multiple sensors, detectors
- Atmosphere monitored for refrigerant leaks (R134A)
- Sensor went bad, but checklist requires verification of functio
- Request to repair would take weeks
- Program under intense schedule pressures
- ESH loaned program hand-held detector
- Approved use as a temporary workaround
- Must be in lab space when people are present
- Sniff test before entering cleanroom from vestibule
- Users received atmospheric monitoring training

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UNCOMMANDED LASER EMISSION INDICATION

- Incident occurred while powering up
- System was placed in Ready-No Lase, all subsystems powered
- The HEL Emitting discrete was observed asserted
- Steps taken to confirm laser emission
- Upon observation of Laser Emitting, attempted to power off
- System appeared “locked” and unable to remove power
- System powered down manually
- Detectors did not indicate laser emission – laser may have fired internally
- Readouts returned to normal after reboot
- Root Cause: One laser module sending false indication signal, removed from configuration

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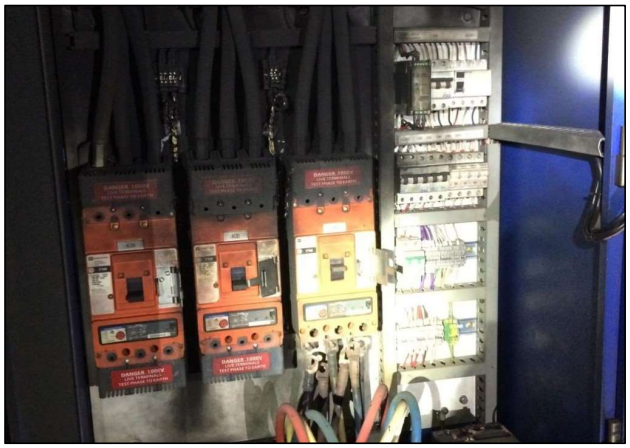
INTERNAL ARCING EVENT

- Occurred while transitioning from Idle to Standby
- Audible click detected as breaker tripped and abruptly removed power
- Evidence of arcing within Thermal Management System (TMS)
- TMS connected to a breaker with higher amperage than intended
- Overheating causing barriers to melt and make contact
- Replacement parts ordered or hand carried to site next day
- Root Causes: torque values out of spec, wire tinning, design issues



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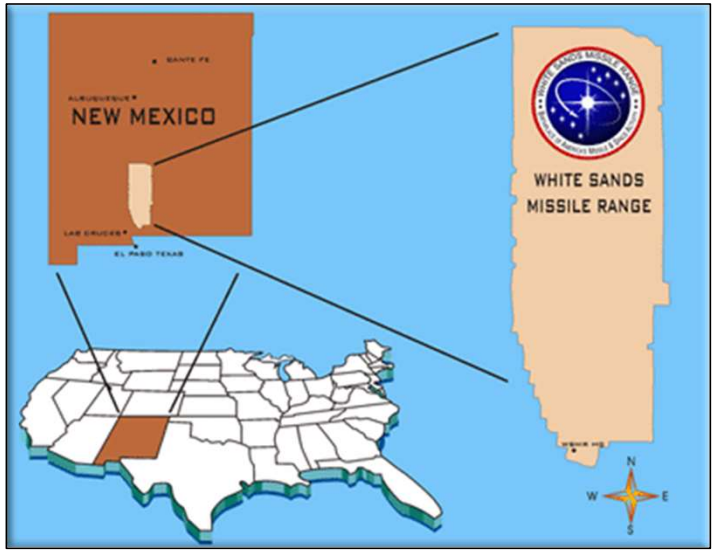
OTHER CHALLENGES

- Justification for safety systems, construction materials – FMEA
- Addressing problems not anticipated in FMEA
- Scope creep, managing change
- Checklists that change or get longer
- Workarounds for unplanned events
- Rotating personnel – Visiting staff, customers, contractors
- Staffing limitations – Knowledge continuity, attrition
- Component wear – Photodiode shelf life
- Field testing – Range safety, remote location constraints, LSO coverage, personnel availability, field repair capability?



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LASER SAFETY COMMUNITY CALL TO ACTION

- Class 5 controls to be integrated in Z136.8
- Get ahead of the issue, implement controls
- Early adoption of error prevention techniques
- Use Structured Improvement Activities (Lean 6-sigma) to develop solutions
- Learn from the experience of others
- Engage with Industrial Hygiene and Electrical SMEs
- Buy-in from leadership
- Use the community for support, collaboration

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THANK YOU!
QUESTION, COMMENTS, CONCERNS ARE WELCOME

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