Wildfire Webinar Series: Webinar 1

Sensing & Detection | Fire Testing Capabilities

April 8, 2021

Patricia A. Hoffman

Acting Assistant Secretary and

Principal Deputy Assistant Secretary

Office of Electricity

U.S. DEPARTMENT OF ENERGY

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Distribution Arcing Fault Detection & Signature Library

Aaron Wilson
Oak Ridge National Laboratory

April 8, 2021

Contents

- Objective
- High-fidelity optical sensor
- Arcing fault detection overview
- Signature library overview and high-level framework
- Contacts

Objective

- ORNL, LLNL are working with PG&E on the installation of a high-fidelity optical sensor cluster on an electric distribution feeder (substation outlet) to capture grid signatures that can be used as early indicators of arcing to *identify and mitigate fire risk.*
- To capture real signatures, the sensor cluster has been installed in an operational utility service area. The novelty of the project is in both the high-fidelity sensor technology and analytical methodology on custom purpose platform.
  - Higher sampling frequency than DFA may expose new signatures and inform on sensor requirements for economical deployment at scale
  - Additional measurement quantities (Acoustics/Vibration)

High-Fidelity Optical Sensor

- At the core of the technology is a passive optical sensing mechanism capable of monitoring AC voltage (10kV-115kV), current (5-2000A), acoustics, temperature, and vibration.
- The frequency range of the optical detection can be tuned to cover over 30kHz bandwidth.
- The variety of sensing parameters integrated into the cluster also includes temperature, vibration and acoustics.
  - Facilitates correlation between different parameters (voltage/current/vibration/etc.) for signature learning
- Nominal sampling rate is 20kHz but can be increased up to 2MHz

Arcing Fault Detection

- Optical sensor recordings (captured by ORNL) are being compared against electrical disturbances captured by a micro-PMU (LLNL)
  - Direct comparisons between magnitude, phase, and event duration for event verification and optical sensor validation
  - "Oscillographic" nature of optical sensor combined with high sampling rate provides additional "color" to micro-PMU recordings
  - Verified event optical sensor recordings are ingested into the Signature Library
- Arcing events are relatively rare. Building a data set for analytics training/testing will require exploiting knowledge about arcing faults from existing public data repositories in addition to events captured by the optical sensor/micro-PMU.
  - Research question: *what "features" can the optical sensor detect in an arcing fault that traditional sensing mechanisms cannot?*
- LLNL maintains a shared document of new event metadata, such as time, event type, etc. micro-PMU data files provided to ORNL upon request.

Signature Library

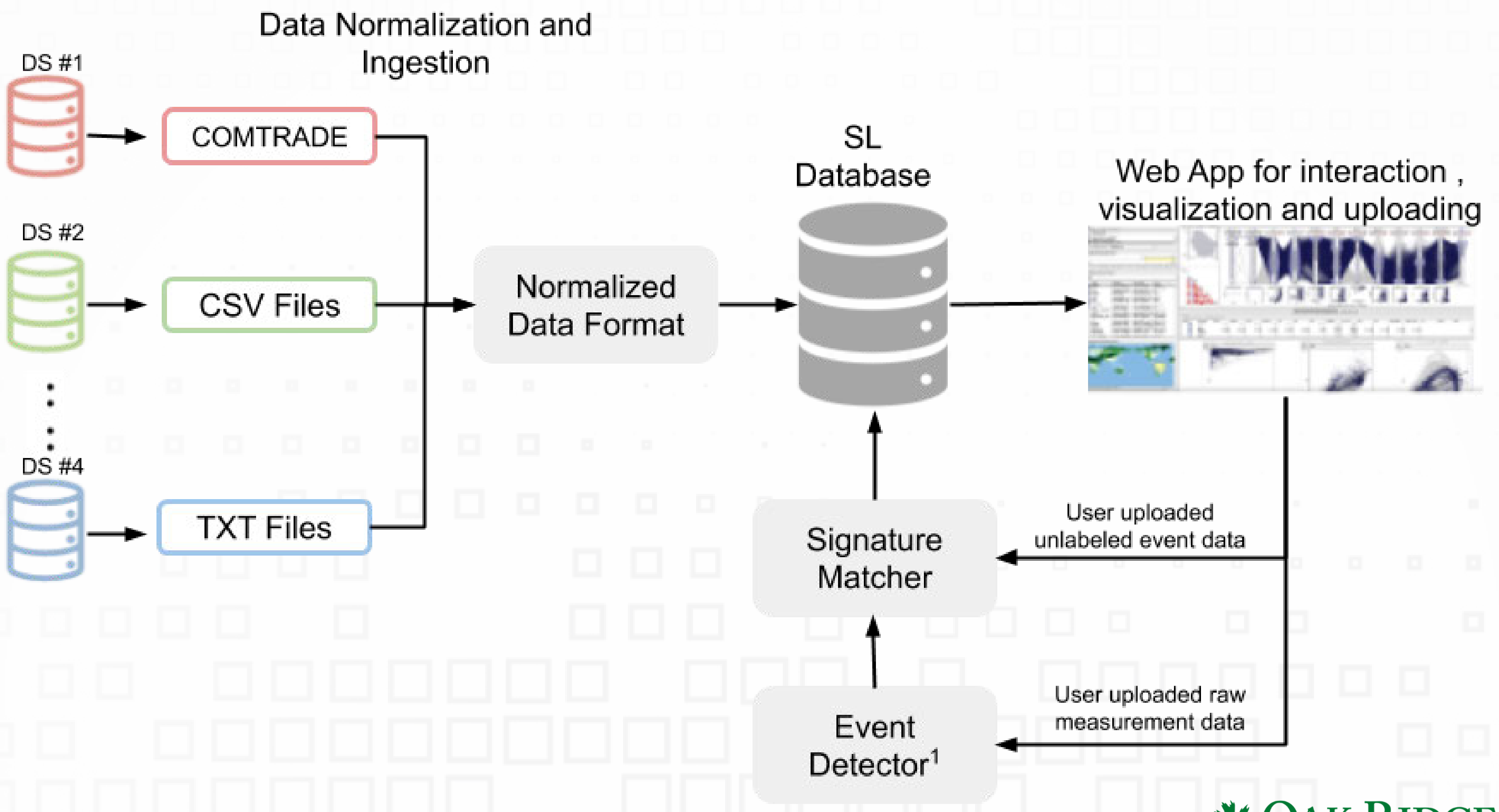
Objective

- Build a Signature Library Framework
  - The signature library (SL)
    - is a collection of labeled events or anomalies
    - will enable machine learning and traditional analytics research to predict and monitor power grid health.
  - A signature is a set of measurements (voltage, current, frequency, etc.) that characterize an event which could be an anomaly.

Framework allows us to

- Ingest, store and access event signature from disparate sources

Signature Library Framework



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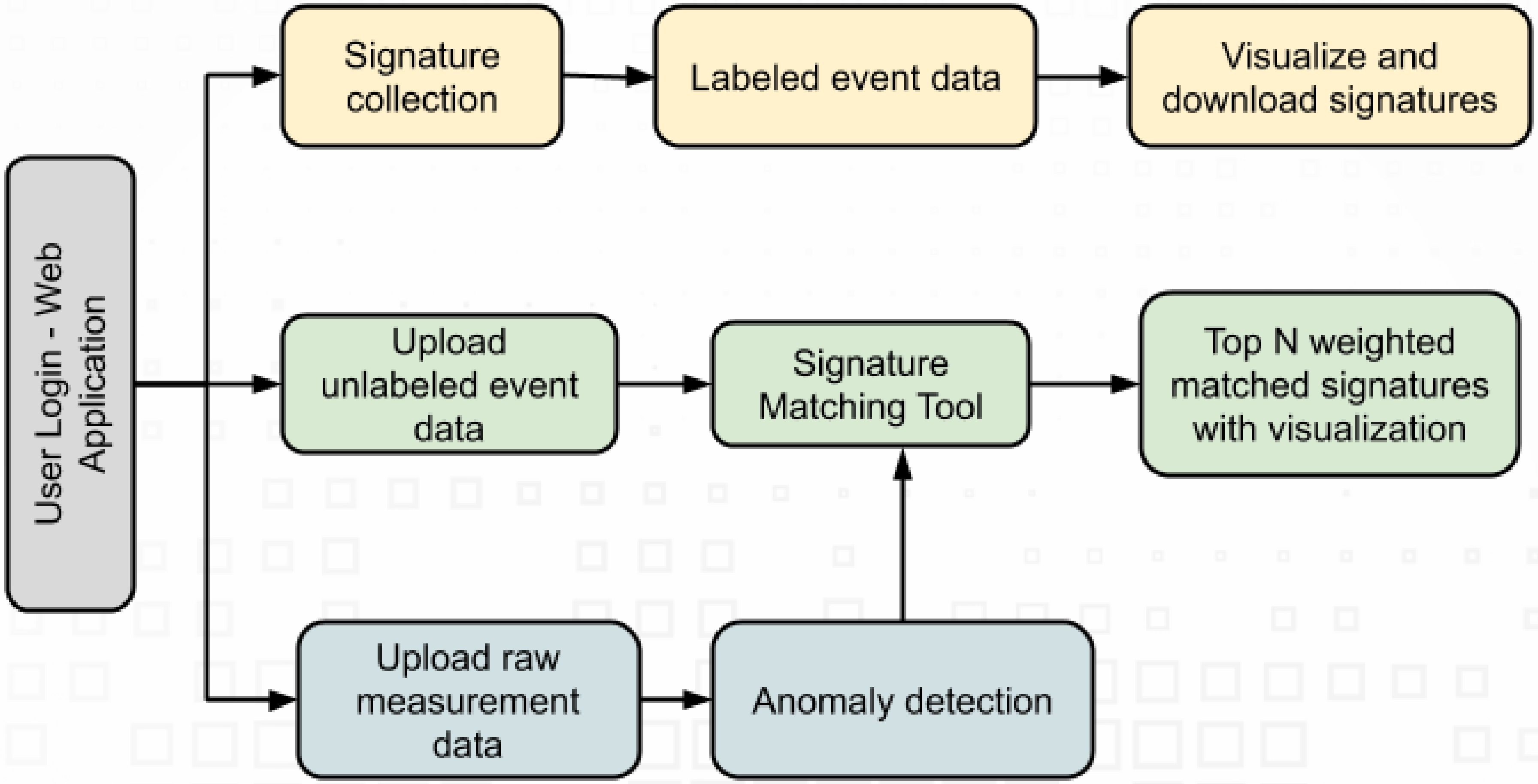
Signature Library Framework



Contacts

Tom King
kingtjjr@ornl.gov

- Nisha Srinivas
- srinivasn1@ornl.gov

Ryan Kerekes
kerekesra@ornl.gov

Aaron Wilson
wilsonaj@ornl.gov

Joseph Olatt
olattjv@ornl.gov

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Structural Health Monitoring (SHM) of Compression Connectors in Overhead Transmission Lines

Hong Wang, Mechanical Properties & Mechanics Group, Oak Ridge National Laboratory

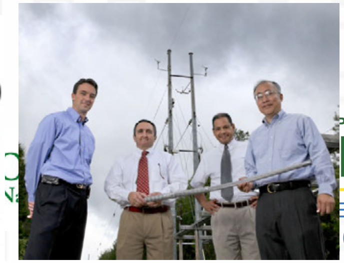
Acknowledgements
This research was sponsored by the Laboratory Directed Research and Development (LDRD) Seed Money Program of ORNL, managed by UT-Battelle, LLC, for the US Department of Energy. Mark McGranaghan of the EPRI and Dominic Lee of ORNL for providing supporting letters. Jy-An Wang, Randy Parten, Michael Lance, Shane Hawkins, and Shirley Waters of ORNL for their help.

Apr. 8, 2021

Relevant Capabilities on Advanced Cables & Conductors

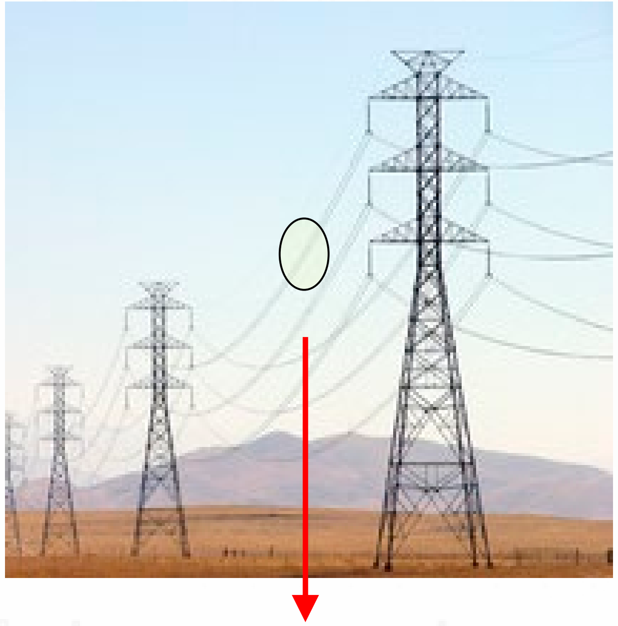
- Testing Capabilities
  - Controlled current or temperature
  - Conductor and accessories
  - Up to 300 C
  - 2400 feet of conductor
  - Low Voltage, 0 to 400 Vdc
  - High Current, up to 5,000 Adc
- Advanced Conductor Research
  - Accelerated aging test
  - Remaining Life Analysis
  - Superhydrophobic – salt fogging and de-icing
  - Composite core materials

MELCOT: Methodology for Estimating the Life of Power Line Conductor-Connector Systems Operating at High Temperatures



Transmission lines need to be monitored for wildfire mitigation

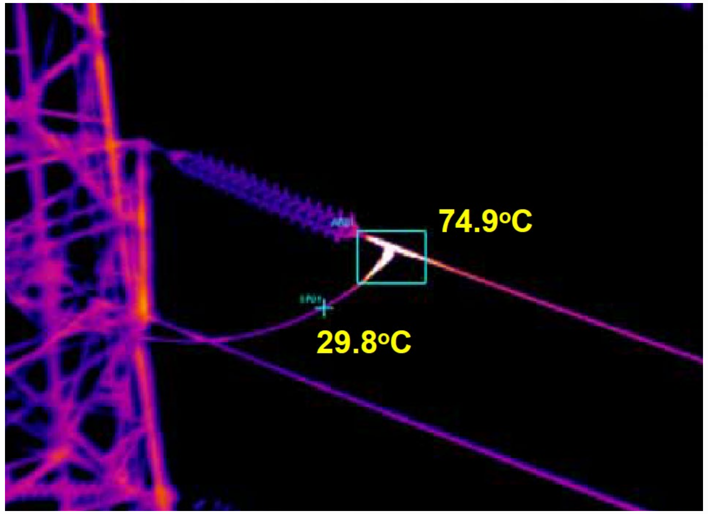
- Triggering mechanisms
  - Downed lines, vegetation contact, conductor slap, …
- Contributing factors
  - Transmission lines are more than 25 years old, and the performance is degraded.
- Mitigation strategies
  - Transmission line monitoring, especially of structural health, is needed for a better wildfire mitigation.
  - Compression connectors in overhead transmission lines (OHTL) is the focus of project.



Current technologies cannot meet urgent need for structural monitoring of OHTL compression connectors

- Structural information is limited or unavailable in existing inspection methods
  - Optical camera
  - Ohmstik
  - Infrared camera
  - EMAT
- Field/ airborne survey is routine based or as required
  - Only providing intermittent data
  - Labor intense

Ohmstik Plus
(SensorLink, 2012)



Infrared image for a connector
(Kritayakornupong, C., 2010)

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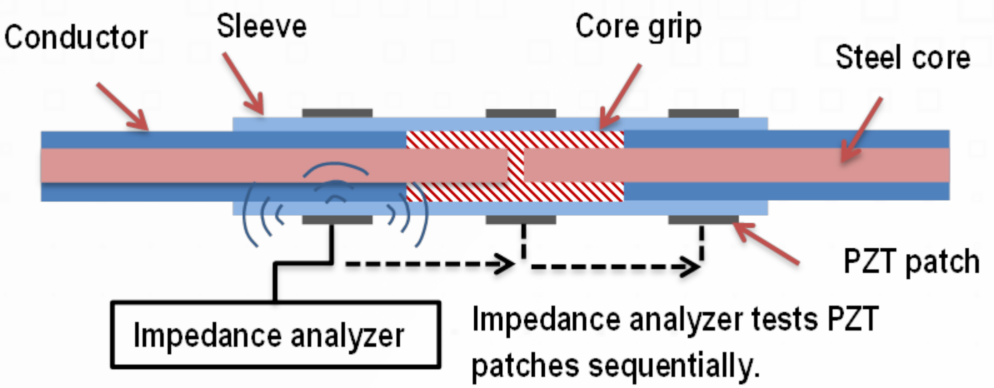
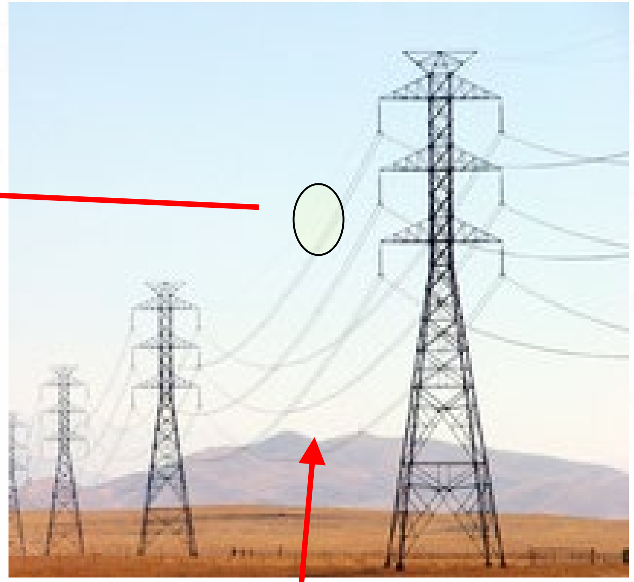
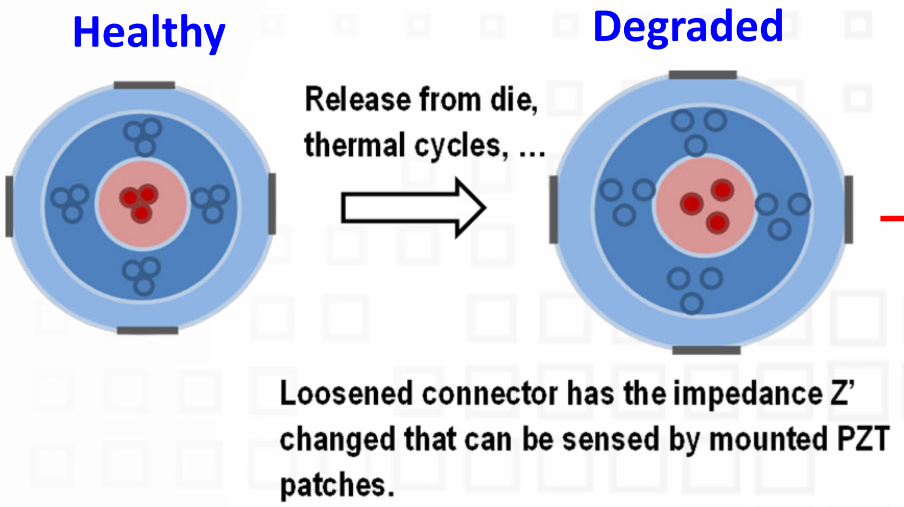
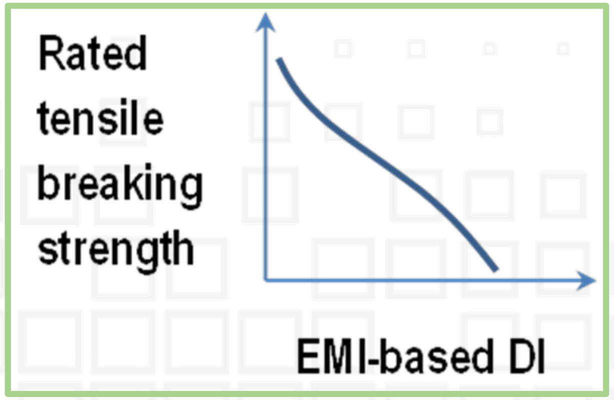
Smart patch-based electromechanical impedance (EMI) provides promising to SHM of connectors









- Structural impedance change can be captured by EMI signature;
- EMI signature can be characterized by an index, so called damage index (DI);
- The DI can be correlated to RTBS/ pull out.

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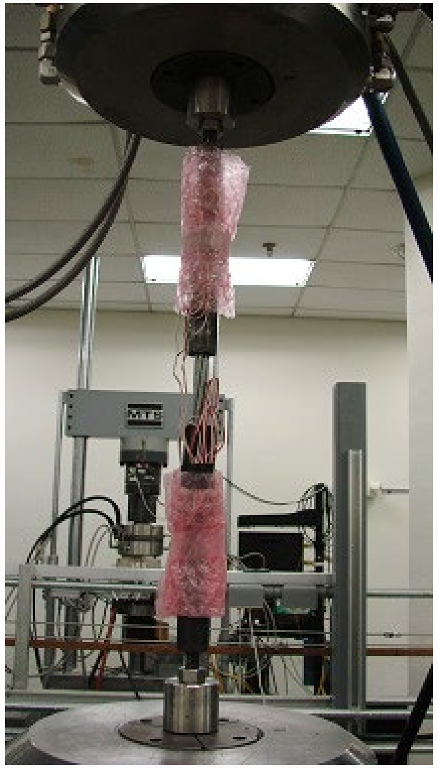
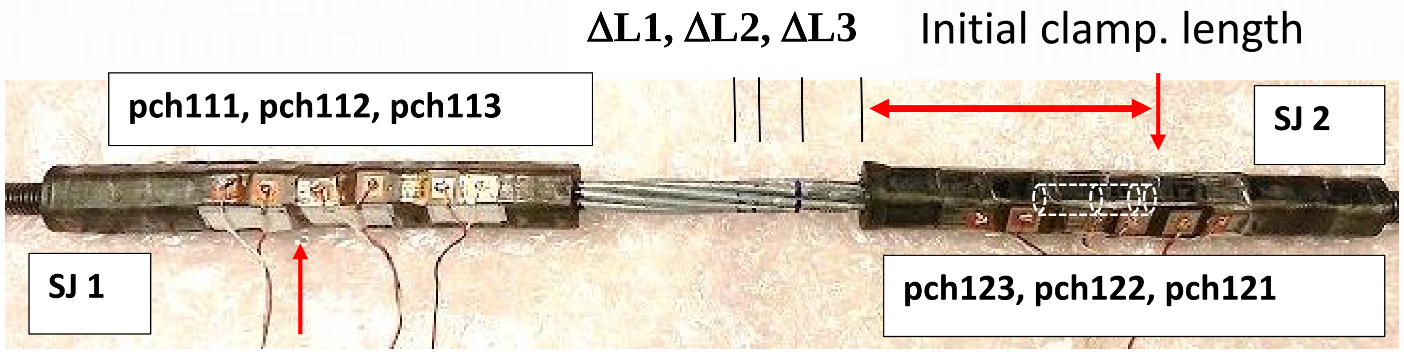
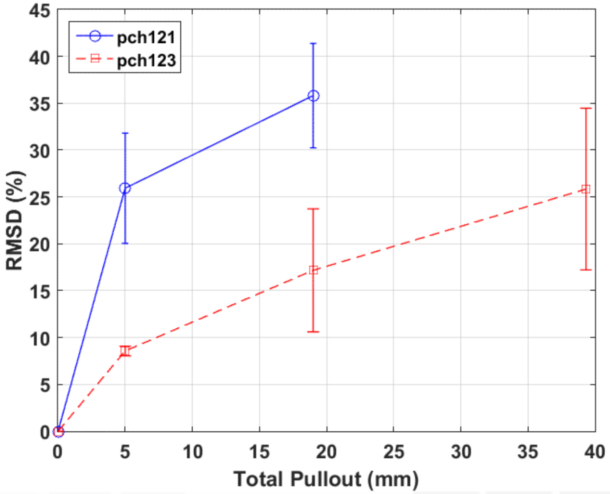
Damage index (root mean squared deviation, RMSD) correlates to pullouts of the steel core



Mechanical testing of connector specimen used to introduce pullout



Specimen tested w/ smart patches mounted. Pullouts of steel core ΔLi (i = 1, 2, 3) are marked.



- Pullouts signify the loss of clamping length of connector, a direct measurement of structural damage.
- With this input, the mechanical strength can be estimated.

Goal and Status

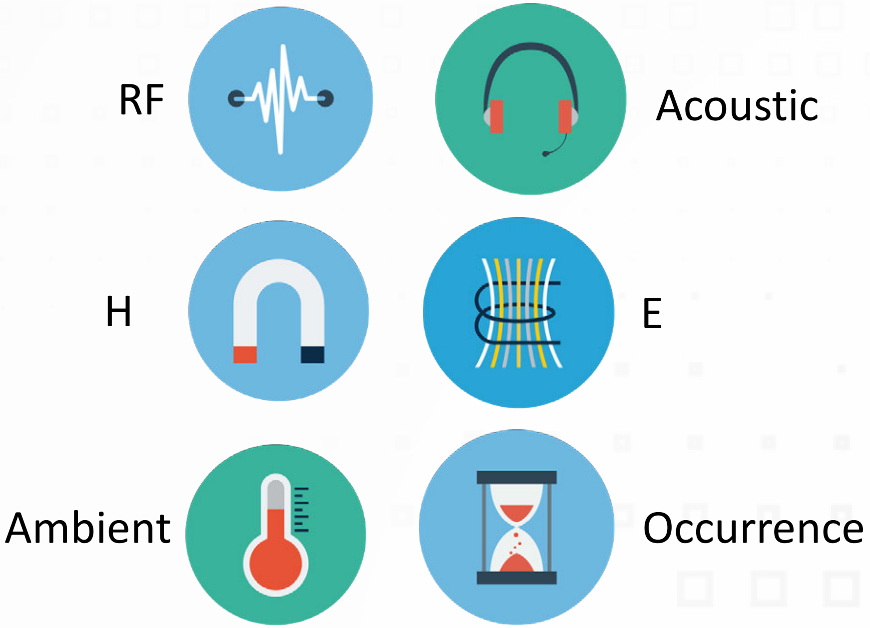
- To develop a smart patch-based structural health monitoring system for the OHTL compression connectors, which is missing in the current technologies.
- Status
  - US patent has been issued: US 10,641,840 B2, May 5, 2020
  - R&D patent license has been awarded to DigiCollect (New York, NY)
- Comments & suggestions
  - Contact: wangh@ornl.gov; 865-574-5601

Real-time Aerial Sensors for Extreme Environments

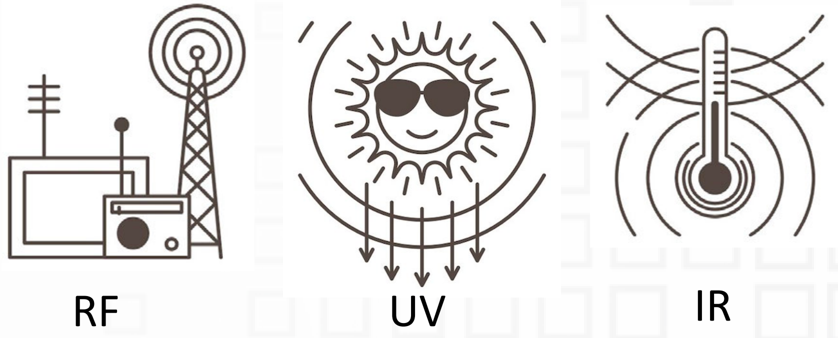
Peter Fuhr, Ph.D. Grid Communications & Security Group Leader
Tech Director UAS Research Lab

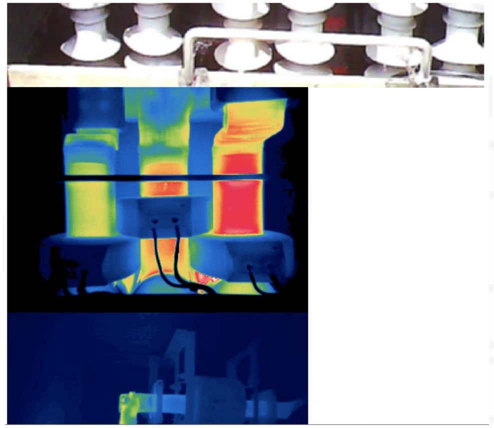
April 8, 2021

Multivariate Detection (stationary and mobile platforms)



EM Spectrum





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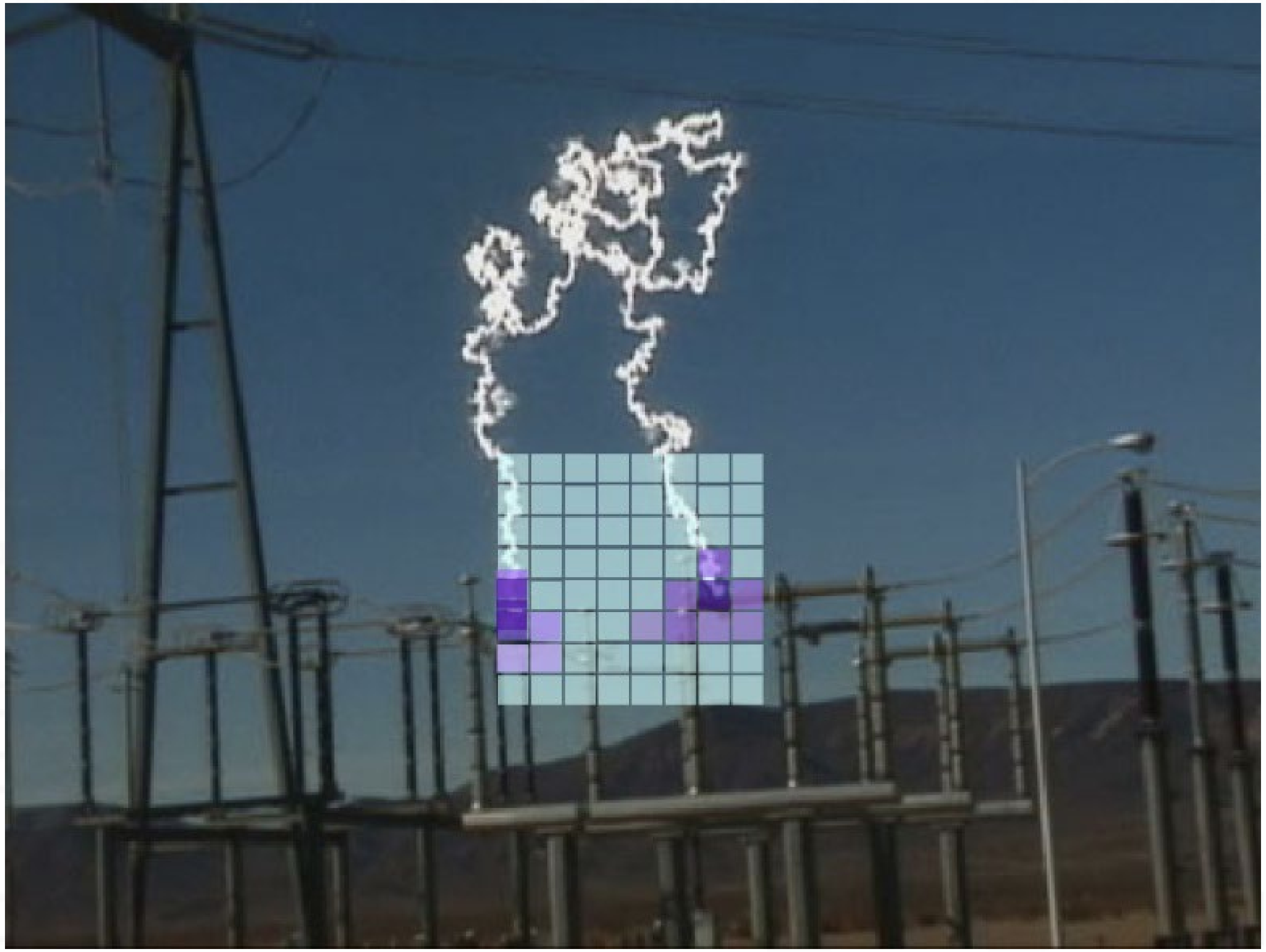
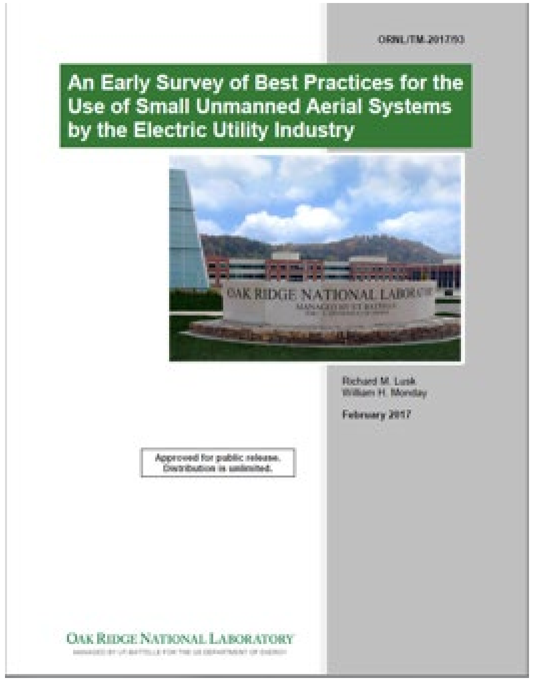
Multivariate Detection (stationary and mobile platforms)



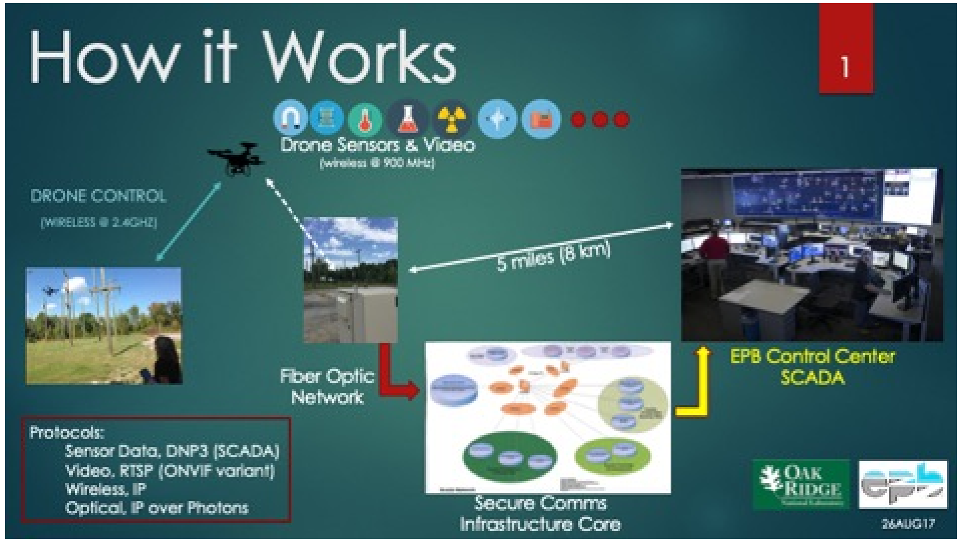
RF Overlay of Substation Arcing

UAS for Grid Visibility (GridViz): UAS-based sensors, visual & thermal imaging realtime viewing in utility control center



http://info.ornl.gov/sites/publications/Files/Pub73072.pdf

Live viewing in utility control center



Video available at: https://youtu.be/xUhnmWIlJD4

Contact: Peter Fuhr (fuhrpl@ornl.gov) or William Monday (mondayw@ornl.gov)

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Hazardous Environment

Asbestos (Amphibole)

$Fe_7Si_8O_{22}(OH)_2$

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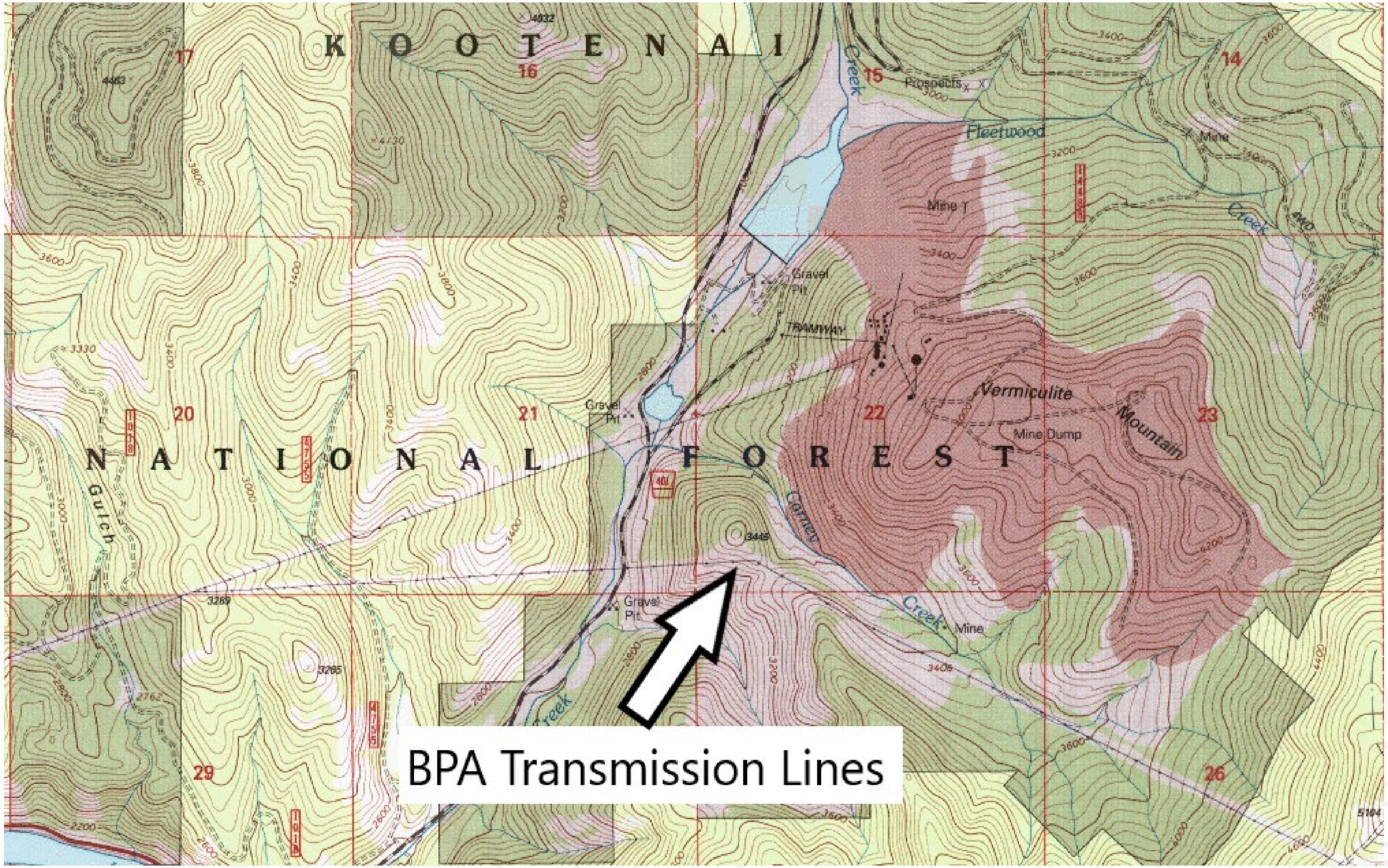
Hazardous Environment + BPA Transmission Lines



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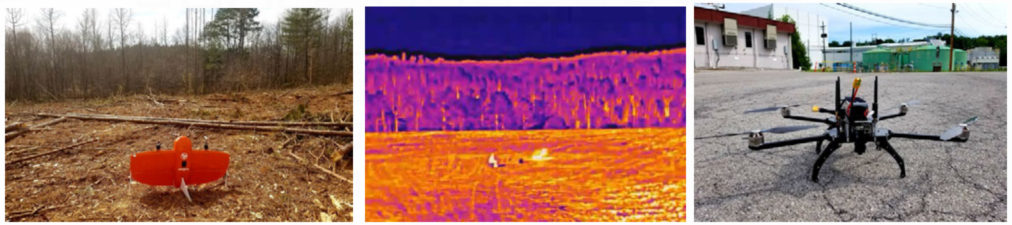
fuhrpl@ornl.gov

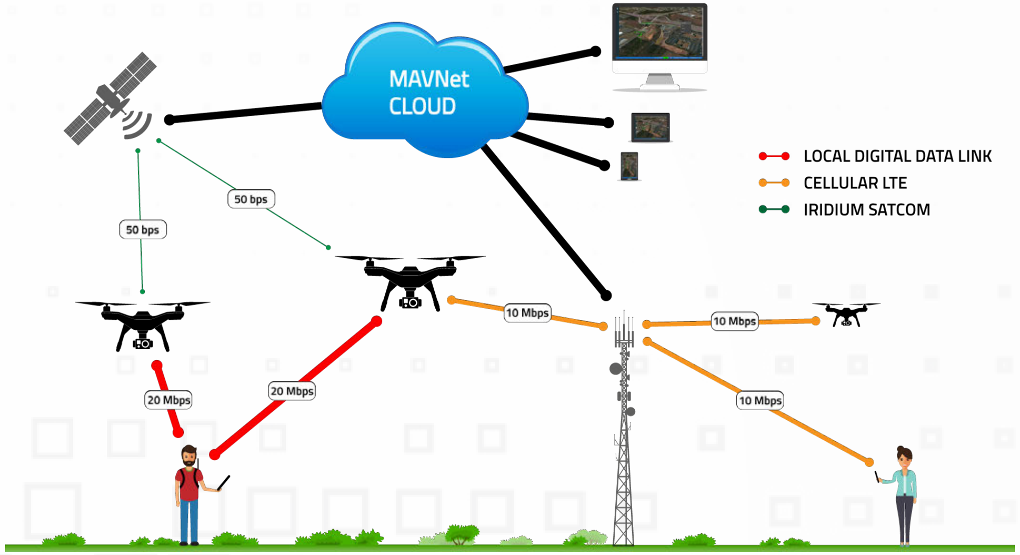
Networked sUAS for Wildfire Mitigation

Andrew Duncan
UAS Tech. Specialist, ORNL

Networked sUAS for Wildfire Mitigation

- Networked sUAS are becoming commercially available
  - Advances in low SWAP-C hardware is making the technology affordable, appropriate, and accessible
  - Multiple connection options:
    - Line-of-Site: Mesh networks, Digital data links
    - Cellular: Auterion, Verizon, Skydrone, FlytBase
    - Satellite: Cobham, Honeywell, Open Source DIY
- Advantages
  - Easily share data between:
    - Users
    - Vehicles
    - Ground assets
  - Operate multiple vehicles
  - Access to more powerful cloud processing architectures
  - Gain "whole picture" of situational awareness





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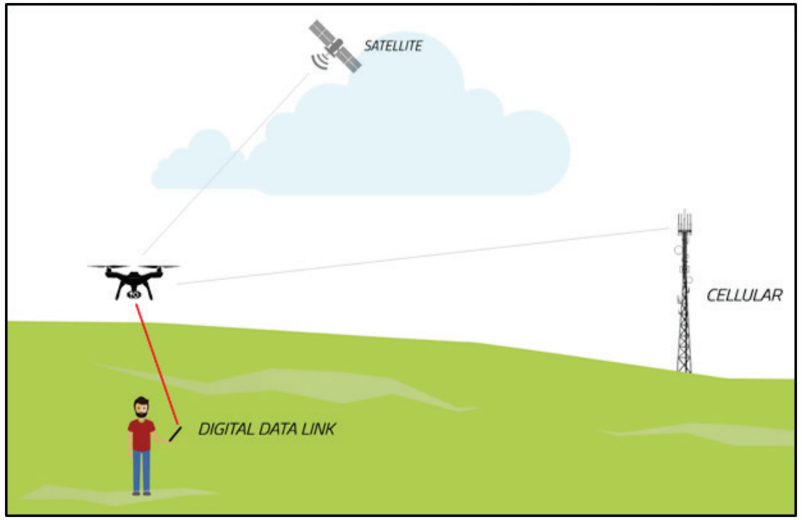
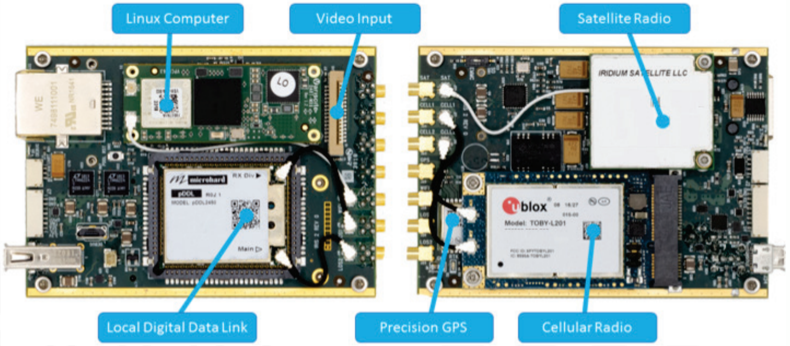
MAVNet: Multi-Modal Autonomous Vehicle Network

- Developed at ORNL in 2018; commercially licensed in 2020; patent pending
- Multi-network sUAS command, control, and compute solution
- Integrates three communication technologies for redundancy and reliability in a variety of environments.
  - Line-Of-Sight (LOS):
    - Very high bandwidth connection
    - Operations in close proximity to the pilot
  - Cellular:
    - High bandwidth connection
    - Extended range flight operations where cellular service is available
  - SATCOM:
    - Low bandwidth connection
    - Global operations
    - Disaster response where infrastructure is damaged





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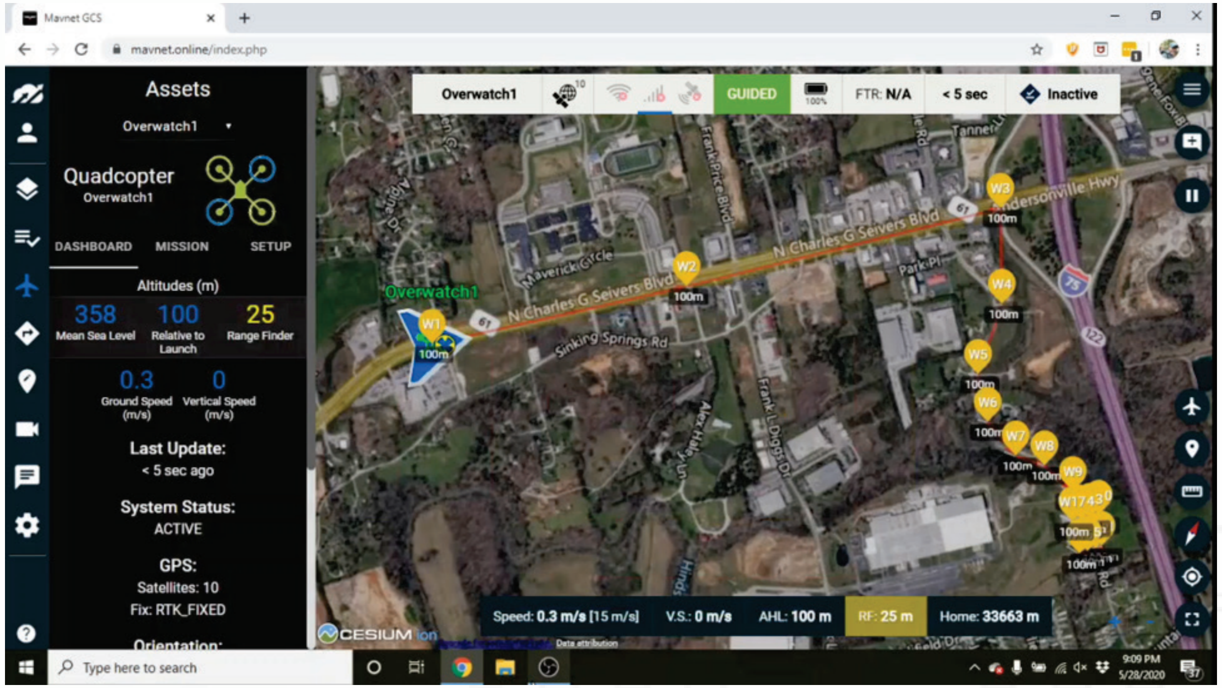
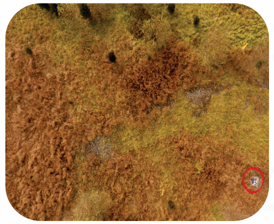
MAVNet: Multi-Modal Autonomous Vehicle Network



- Web-Based Ground Control System
  - Allows for multiple users to view data or command aircraft based on authorization levels
  - Requires no specialized software; available on mobile
  - Solutions developed for personnel tracking, weather monitoring, and data processing
  - APIs developed for further applications
- Example Application: Post-Disaster Infrastructure Inspection
  - AI-driven autonomous sUAS power distribution inspection
  - ORNL-developed algorithms conduct autonomous inspections and provide real-time damage information across MAVNet



Search And Rescue

Disaster Response

Infrastructure Inspection

Security

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SAND2021-3953 PE

Thermal Test Complex (TTC) at Sandia National Laboratories

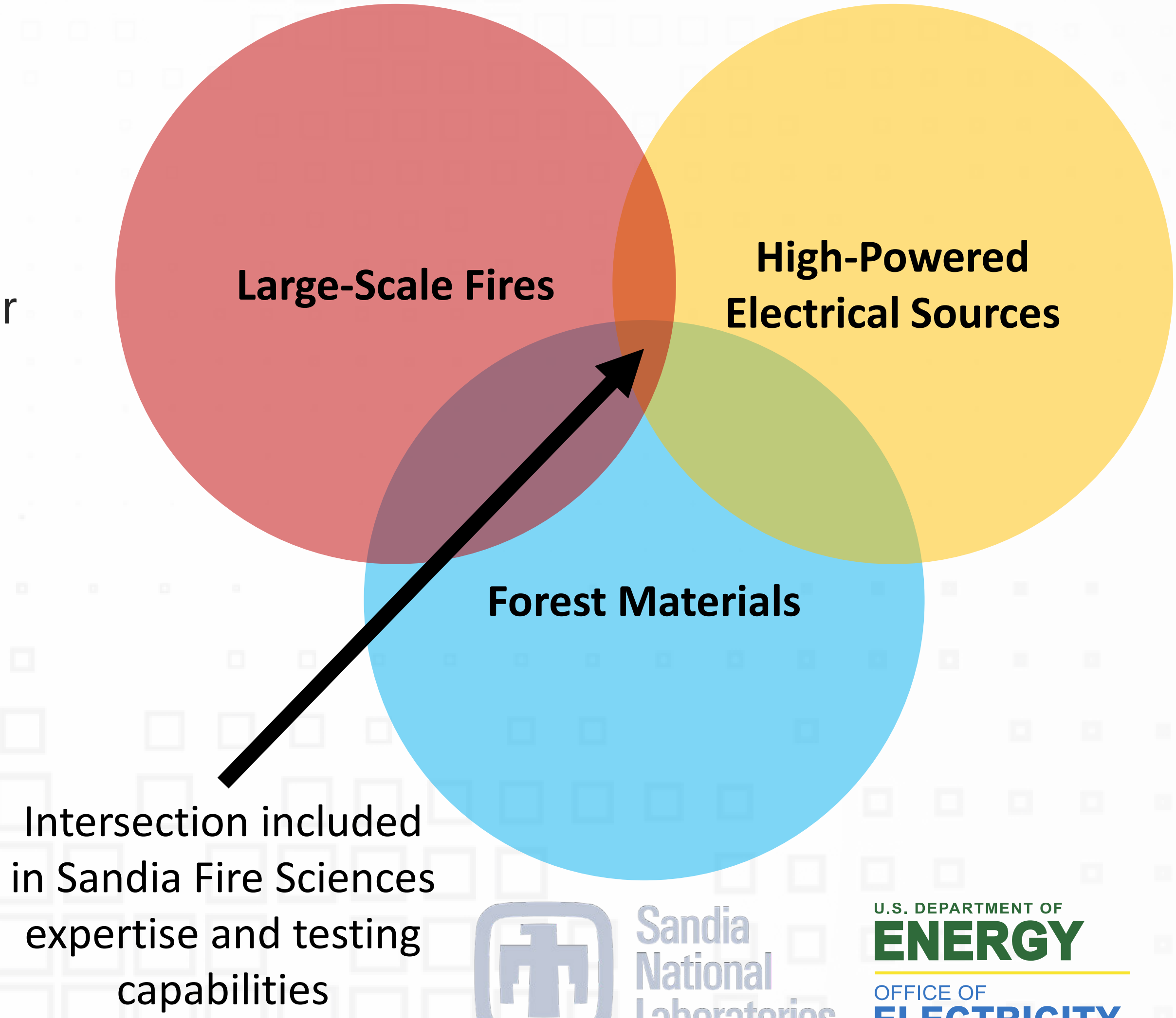
Dr. Randy C. Shurtz; rshurtz@sandia.gov; (505) 284-6540

Fire Science and Technology Department

April 8, 2021

Fires, Forests, and Electrical Sources

- Good historical safety record for power transmission through forests
- Increased wildland fires in recent years cause concern
  - Excess dry forest materials probably contributes
  - Electrical transmission equipment may ignite fires or act as a compounding hazard for some events
- Sandia Fire Science and Technology Department has capabilities that can improve understanding of current and future wildfire risks
  - Specialized experience
  - Unique test facilities



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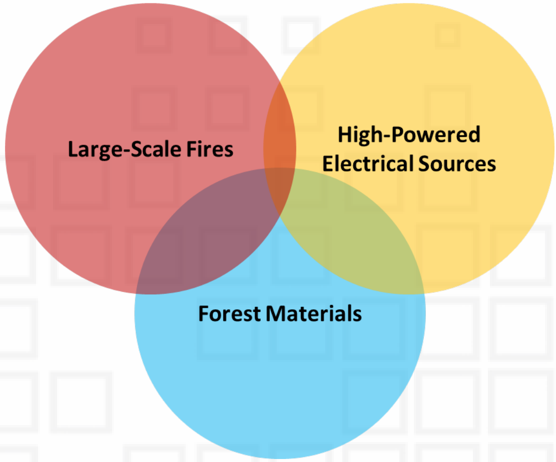
Sandia Fire Science and Technology Department

- Sandia Fire Sciences designs and executes fire tests
  - Measurement, analysis and simulation of fire scenarios
- Experience includes customized fire testing of a wide variety of materials, sizes, shapes
- Safe testing of fire scenarios with intersecting hazards
  - High-power electrical sources
  - Conductive soot-laden gas
  - Solid, liquid and gaseous fuels
  - Toxic gases
  - Elevated pressure



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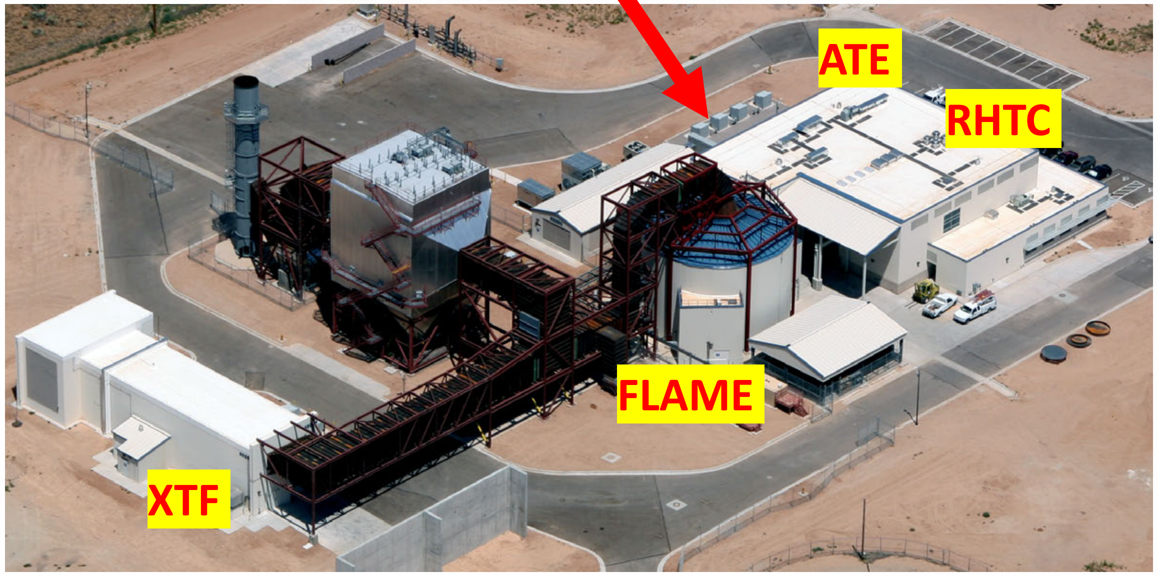
Sandia Thermal Test Complex (TTC)

- Located at Albuquerque, NM site of Sandia National Laboratories
- Controlled capabilities developed to evaluate weapons safety in abnormal thermal environments (e.g., fires)
- Capabilities often used in discovery and model validation testing for other agencies such as NASA, USDOT, US Coastguard, and DOE.
- TTC facilities include
  - **Fire Laboratory for Accreditation of Modeling by Experiment (FLAME)**
  - **Crosswinds Test Facility (XTF)**
  - Radiant Heat Test Cell (RHTC)
  - Abnormal Thermal Environments (ATE)
- Online self-guided tour of TTC available at http://tours.sandia.gov/TTC/ttc_info.html
- Additional fire testing facilities available at Lurance Canyon Burn Site

5 MW Electrical Substation



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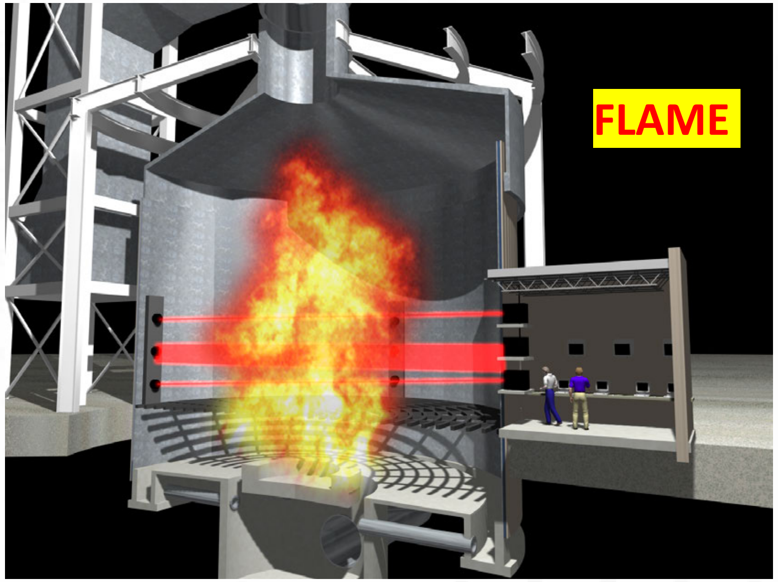
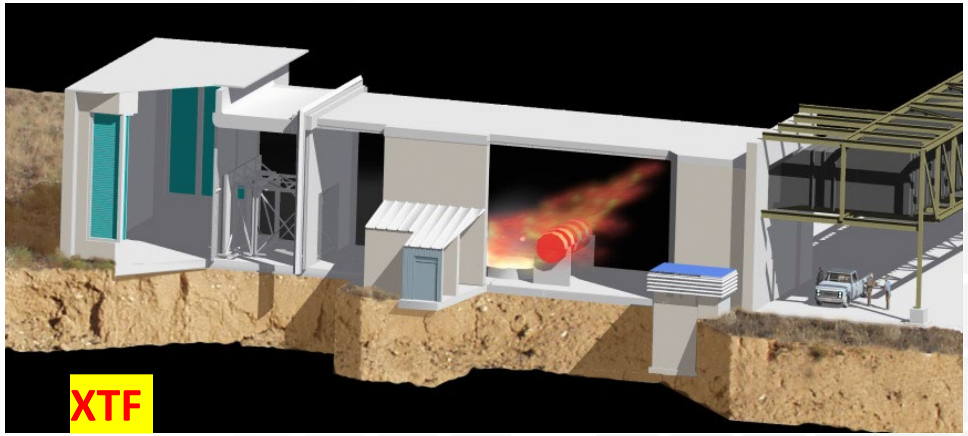
Fire Testing Capabilities

- TTC is a unique facility designed to study large outdoor fire scenarios under laboratory control
  - Developed to provide validation data for fire simulations
- Some TTC facilities have access to a 5 MW electrical source
  - FLAME and XTF can characterize interactions between large electrical sources and fires
- FLAME is representative of low-wind outdoor fires
- XTF is representative of outdoor fires driven by strong crosswinds





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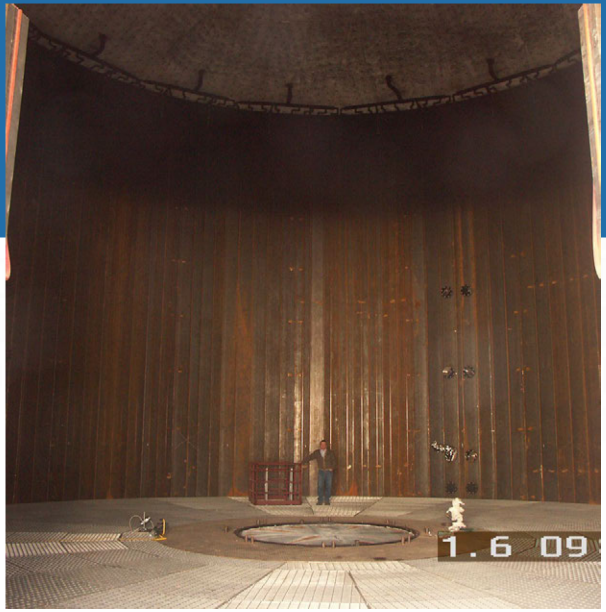
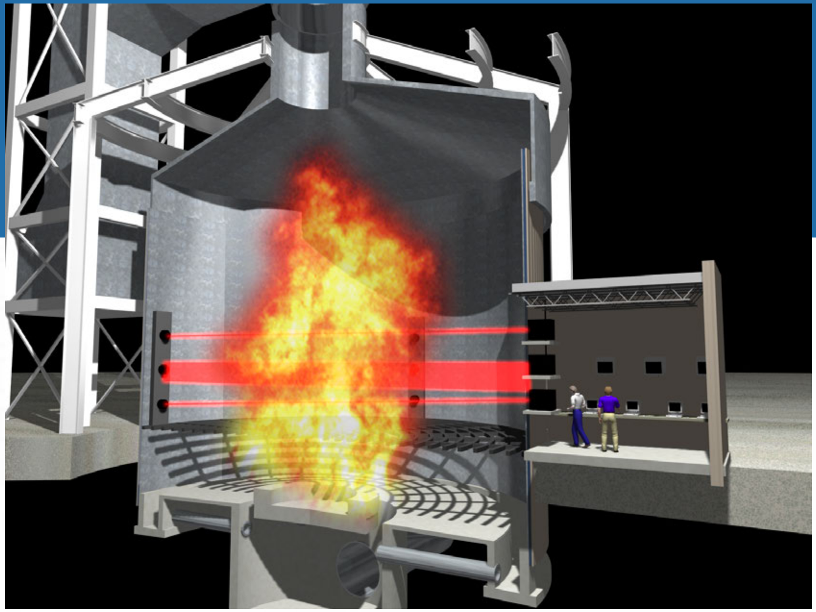
FLAME

- Developed to simulate outdoor fires
  - Up to 20 MW thermal, 10-ft diameter pan
  - Test cell dimensions 50 ft high x 60 ft diameter
- Controlled convective-radiative test environment
  - Vertical airflow up to 150,000 CFM
  - Water-cooled walls
- Access for advanced optical diagnostics as well as conventional thermal and flow measurements
  - We provide measurements of temperatures, heat fluxes, flows of air and fuel, soot production, visible and infrared video, etc.
- Unique combination of 5 MW electrical power source and controlled fire environment is well-suited for studies of
  - Wildland ignition from power lines
  - Influence of existing fires on powered equipment





7 MW Hydrogen Fire

20 MW JP-8 Fire

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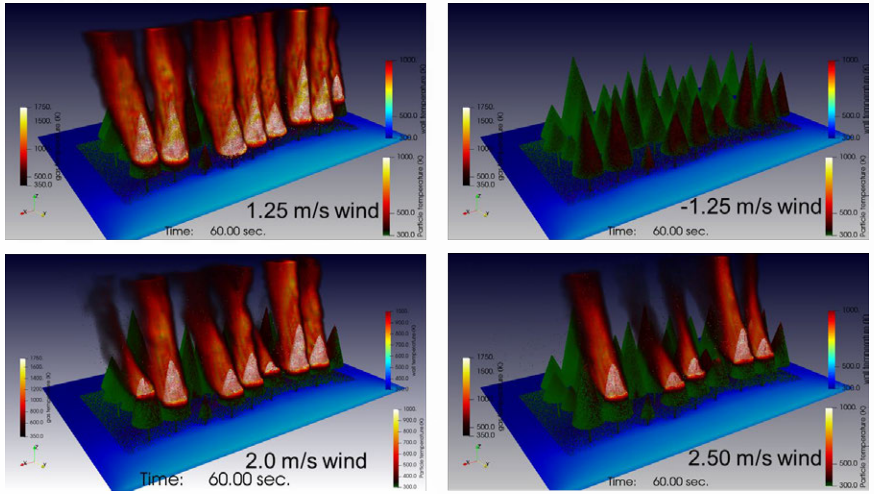
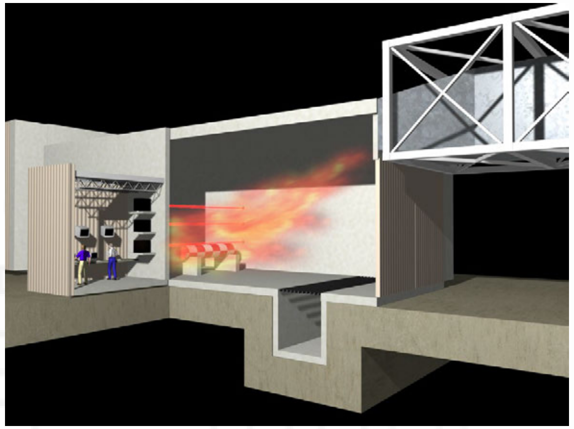
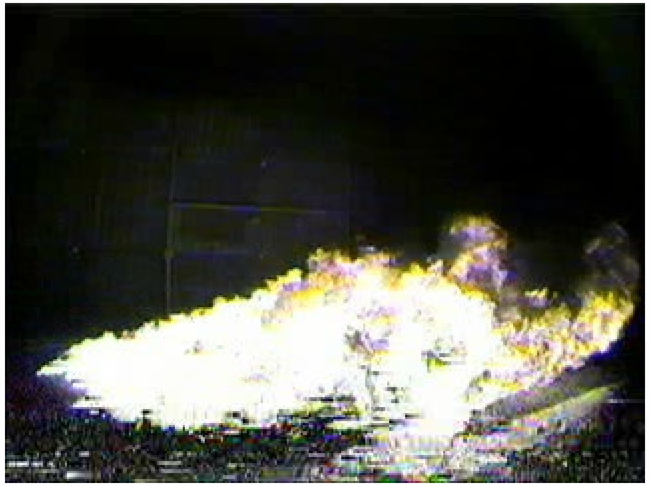
Crosswinds Test Facility (XTF)

- Developed to simulate wind-driven outdoor fires
  - Up to 20 MW thermal fire with 20 mph winds
  - Airflow range of 8,500 – 170,000 SCFM
  - Test Cell dimensions 25 ft x 25 ft by 83 ft long
  - Refractory concrete walls in XTF enable tests that include up to ~100 lb TNT
- Measurement capabilities comparable to FLAME facility
  - X-ray measurement techniques available upon request
- XTF has access to same 5 MW power supply as FLAME; uniquely suited to studying
  - Effects of high cross winds on wildland ignition from electrical power sources
  - Effects of wind-driven fires on powered electrical equipment
  - Flame spread in wildland materials driven by high crosswinds







20 MW Fire in
2 m/s Cross Wind

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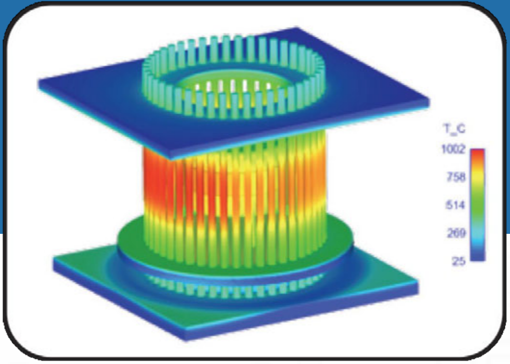
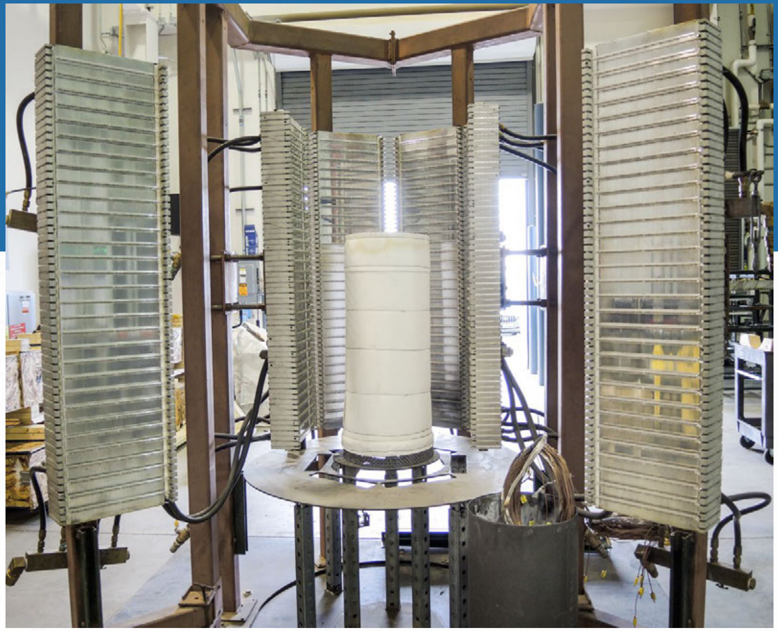
Other Fire Testing Facilities



- Radiant Heat Test Cell (RHTC)
  - Dial-a-fire capability for repeatable abnormal thermal conditions
    - Utilizes same 5 MW power source as FLAME and XTF
    - Multiple power sources rated individually at 480 VAC, 1000 Amps
  - Arrays of quartz lamps for heating to 1000ºC in ~45 seconds
  - Custom SiC rod ovens for higher temperatures
- Abnormal Thermal Environments (ATE)
  - Bench-scale heat sources (ovens and small pools)
- Lurance Canyon Burn Site
  - Remote location for largest fire tests



30 cm JP-8 Pool Fire in ATE

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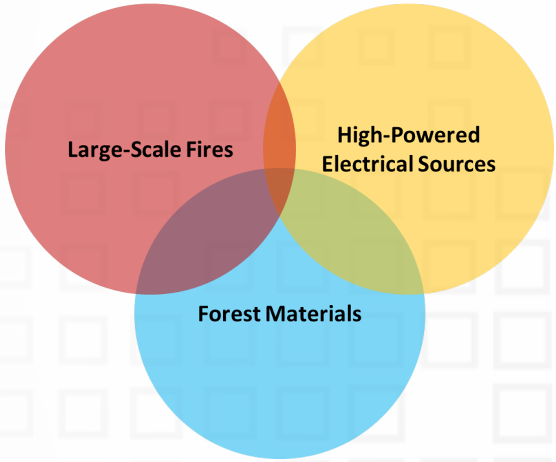
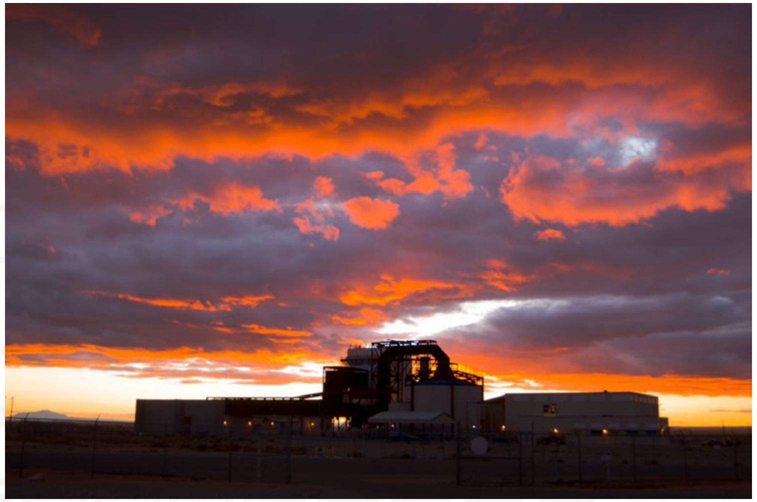
Wildfire Ignition Studies with Sandia Fire Sciences

- Sandia Fire Sciences has expertise to design and safely execute fire tests with complex intersecting hazards
- Available measurements in well-controlled fires include temperatures, heat fluxes, airflow, soot production, etc.
  - Dry climate at NM site facilitates testing wildland fuels with different levels of moisture
  - TTC thermal sources range from bench scale to tens of megawatts
- TTC has a dedicated 5 MW electrical substation used for simulated fires
  - May also be utilized to consider interactions between fires and large electrical sources





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Testing of Wildland Ignitions from High-Flux Sources

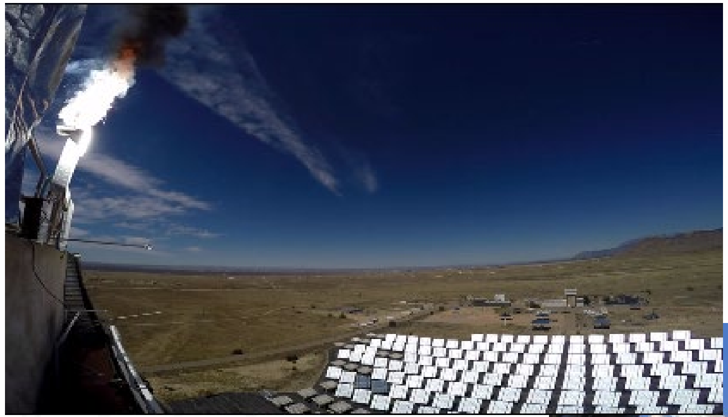
Dr. Alexander L. Brown; albrown@sandia.gov; Fire Science and Technology Department
With Margaret E. Gordon and Francisco Alvarez

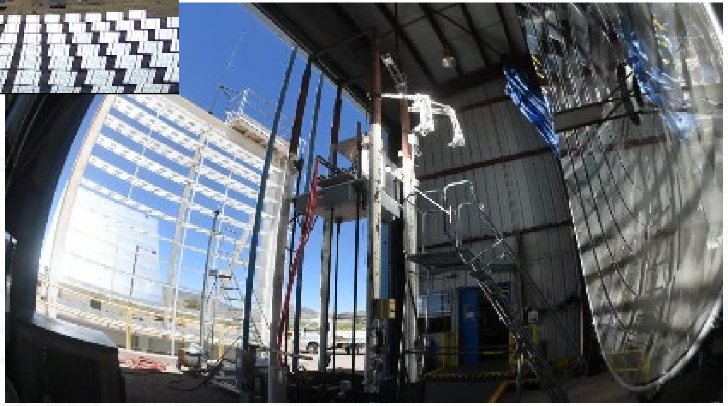
SAND2021-3957 C

April 8, 2021

Capabilities Summary

- The National Solar Thermal Test Facility (NSTTF) at Sandia is DOE's user facility for concentrating solar energy for power application and materials testing
- The NSTTF has several facilities recently used for fire testing relevant to wildland fires
  - NW effects funding by DTRA from 2016-2019
  - Nuclear Winter Funding in 2021 by NA-24
- Large-scale tests at the Solar Tower
  - ~5 MW concentrated solar power
  - 480 V, 100 amp electrical power
- Smaller-scale tests at the Solar Furnace
  - Up to 3 MW/m^2 with a spot size of about 5 cm in diameter
- NSTTF facilities also used to test:
  - Re-entry ablators
  - Cable response to metal fire environments
  - NW effects on infrastructure





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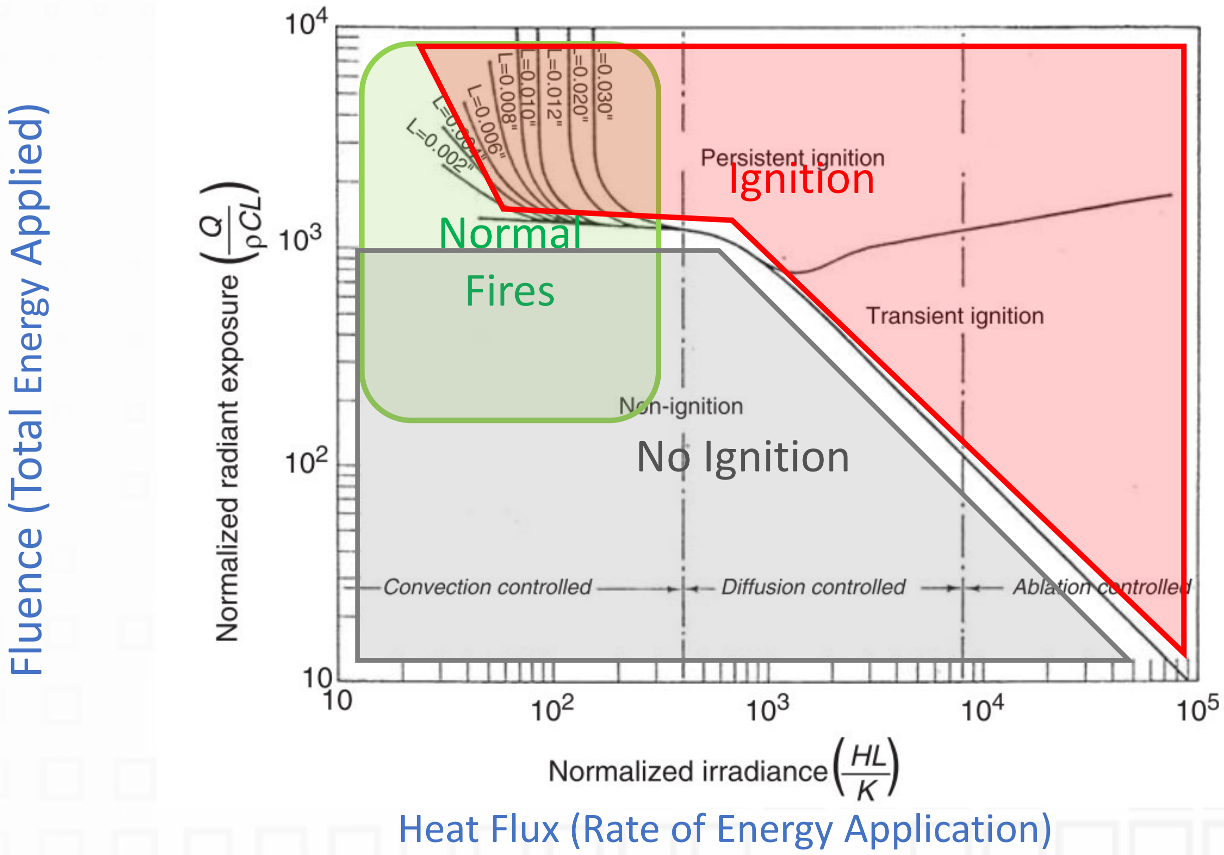
High Flux Ignition Data Important and Lacking

- Many materials exhibit different ignition behavior depending on the thermal exposure, scale, moisture, wind, etc.
- Stan Martin et al. (1965) summarized ignition data for blackened cellulose in terms of flux/fluence regimes



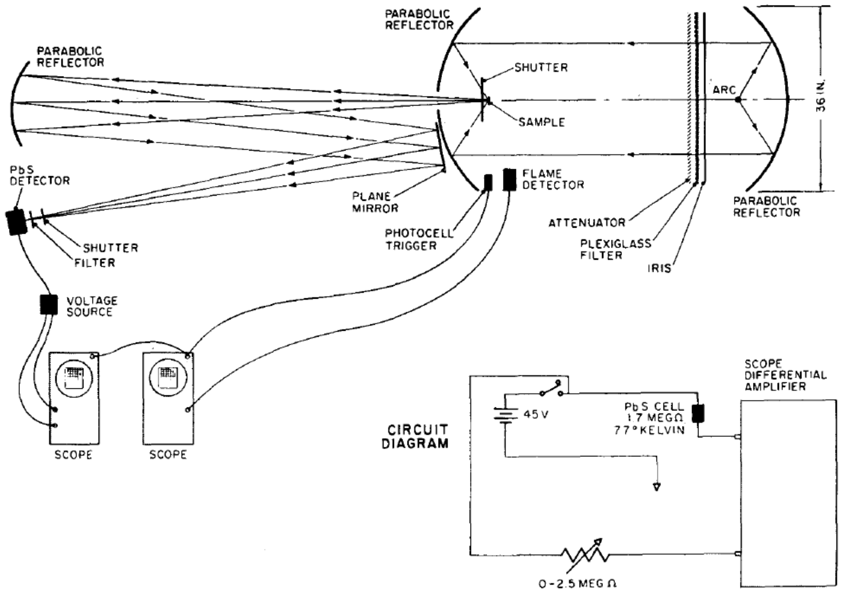
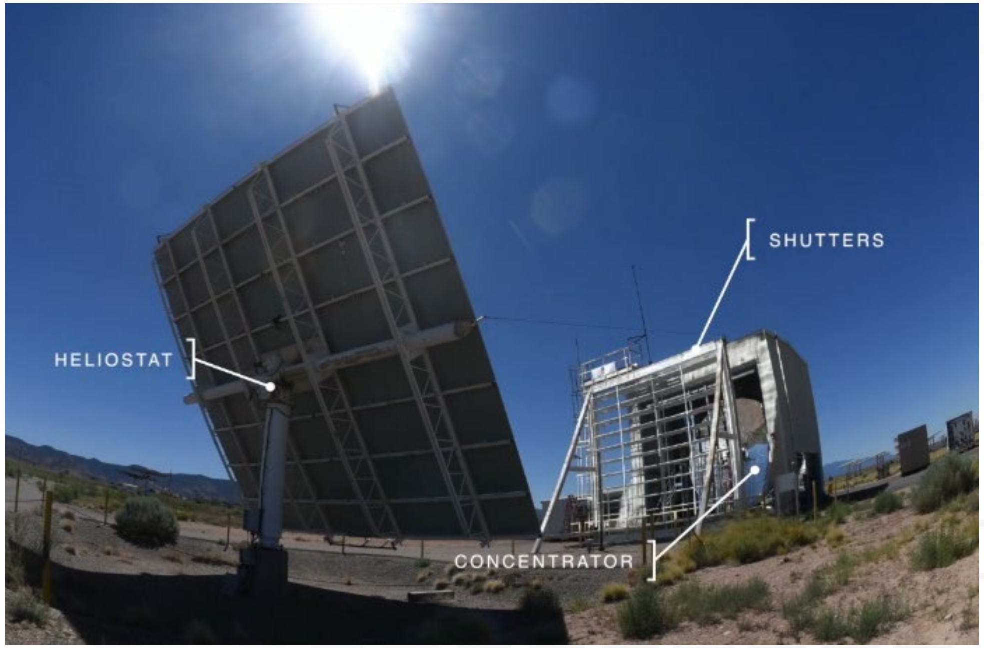


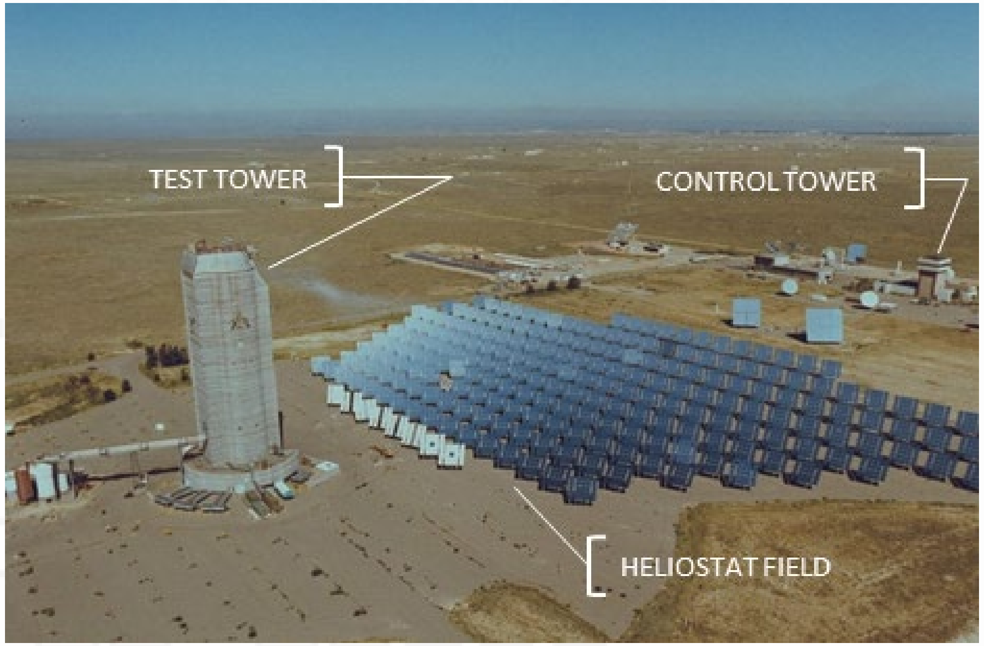
Fig. 4. Apparatus for the measurement of temperatures of the irradiated surface of cellulose.

- Little has been done on NW (high flux) ignitions since the Martin tests in the 1950s and 1960s

Facilities

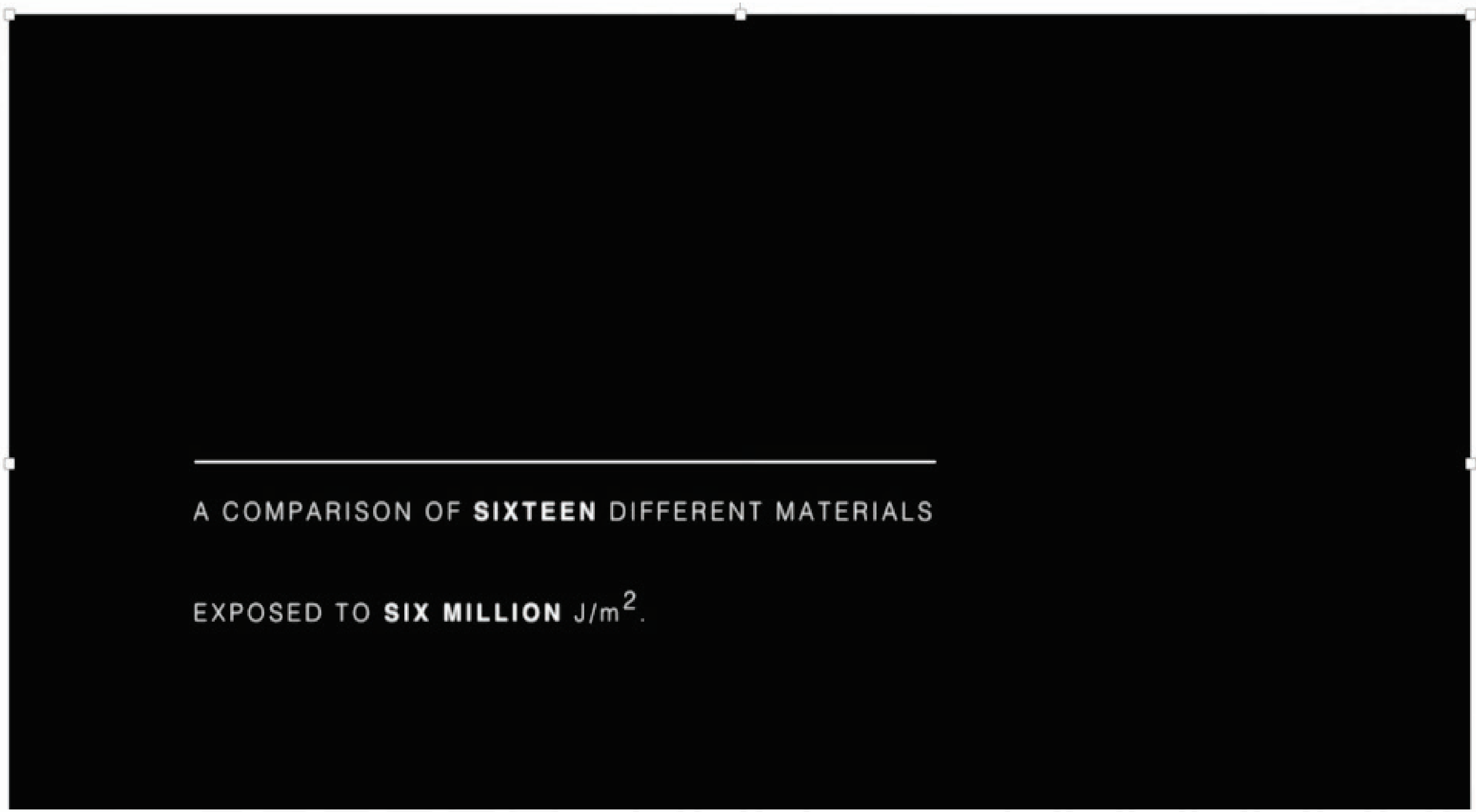
- Two facilities at Sandia can produce very high radiant fluxes (4-6 MW/m^2) by concentrating solar radiation
  - Poor wind control at solar tower
  - Facilities vary significantly in the scale of the exposures during testing
  - Rapid introduction of the radiant power is possible through shutter systems





Solar Furnace Video

- Wide variety of experimental results depending on material type (green needles don't ignite)



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Solar Tower Tree Fire Video
(also on YouTube)

- Green needles would not ignite at the solar furnace at similar flux/fluence conditions, but readily ignite at the solar tower, illustrating a <u>scale effect</u>

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Frontiers in Research

- DTRA work did not focus on wildland ignitions
  - Perhaps a few dozen relevant tests to the ignition of wildland fires
  - Community lacking data on effect of ignition due to moisture content, wind, geometry
- NA-24 work is focused on particle emissions (soot versus organics and yields)
  - Partly relevant to the wildland fire problem too
  - Challenge for this project is understanding the effect of scale (how a city or region behaves)
  - Soot and smoke formation is moderately well understood, new data in progress
- Arc-faults can be caused by fires through multiple mechanisms depending on application
  - Smoke depositing on electrical equipment can create unintended conduction paths for electrical power (this is primarily why computers and the like don't react well to smoke)
  - Smoke can also increase the conductivity of the atmosphere and lead to a discharge
  - Heat can melt or burn insulators and expose conductors

Team Produced Relevant Publications

Journal Publications:

- Brown, A.L., Engerer, J.D., Ricks, A.J., Christian, J., Yellowhair, J., "Datasets for Material Ignition from High Radiant Flux," *Fire Safety Science, 2020*
- Brown, A.L.; Dayton, D.C.; Daily, J.W., "A study of cellulose pyrolysis chemistry and global kinetics at high heating rates," Energy & Fuels, 15, 1286-1294 (2001). https://doi.org/10.1021/ef010084c
- Brown, A.L.; Hames, B.; Daily, J.W.; Dayton, D.C., "Chemical analysis of pyrolytic vapors from wildland trees," Energy & Fuels, 17, 1022-1027 (2003). https://doi.org/10.1021/ef020229v

Conference Papers:

- Engerer, J.D., Brown, A.L., Christian, J.M., "Mass-loss measurements on solid materials after pulsed radiant heating at high heat flux," Paper 2FI-0319, 10th US National Combustion Meeting, College Park MD, USA, 2017.
- Brown, A.L., Engerer, J.D., Ricks, A.J., and Christian, J.M., "Scale Dependence of Material Response at Extreme Incident Radiative Heat Flux," The 2018 ASME/AIAA Joint Thermophysics and Heat Transfer Conference, Atlanta, Georgia, June 25-29, 2018. SAND2018-5209C.
- Engerer, J.D., Brown, A.L., "Spatially Resolved Analysis of Material Response to Destructive Environments Utilizing Three-Dimensional Scans," The 2018 ASME/AIAA Joint Thermophysics and Heat Transfer Conference, Atlanta, Georgia, June 25-29, 2018. SAND2018-5258C.
- Engerer, J.D., Brown, A.L., and Christian, J.M. "Ignition and Damage Thresholds of Materials at Extreme Incident Radiative Heat Flux," The 2018 ASME/AIAA Joint Thermophysics and Heat Transfer Conference, Atlanta, Georgia, June 25-29, 2018. SAND2018-5257C.
- Ricks, A.J., Brown, A.L., and Christian, J.M. "Flash Ignition Tests at the National Solar Thermal Test Facility," The 2018 ASME/AIAA Joint Thermophysics and Heat Transfer Conference, Atlanta, Georgia, June 25-29, 2018. SAND2018-5414C.
- Brown, A.L., Anderson, R.R., Tanbakuchi, A., and Coombs, D., "Diagnostics and Testing to Assess the Behavior of Organic Materials at High Heat Flux," 4th Thermal and Fluids Engineering Conference (TFEC) April 14–17, 2019 Las Vegas, NV, USA, TFEC-2019-27457. (SAND2016-10464 C)
- J.D. Engerer, Brown, A.L., "Pyrolysis under Extreme Heat Flux Characterized by Mass Loss and Three-Dimensional Scans," 4th Thermal and Fluids Engineering Conference (TFEC) April 14–17, 2019 Las Vegas, NV, USA. (SAND 2018-11381C)
- Brown, A.L., Engerer, J.D., Ricks, A.J., and Christian, J.M., (2019) "Ignition from High Heat Flux for Flat Versus Complex Geometry", 9th Symposium on Fire and Explosions Hazards, April 21-26, St. Petersburg, Russia, pp. 970-979. (SAND2018-10277C).
- Brown, A.L., Mendoza, H., Koo, E., Reisner, J., "A High Flux Forest Fire Scenario for Assessing Relative Model Accuracy for CFD Tools," for the Western States Section of the Combustion Institute Meeting, October 14-15, 2019, Albuquerque, NM, SAND2019-10541 C
- Brown, A.L., Engerer, J., Ricks, A., Christian, J., "Initiation of Pyrolysis from High Flux Exposures ," for the Western States Section of the Combustion Institute Meeting, October 14-15, 2019, Albuquerque, NM, SAND2019-10540 C
- Zepper, E.T., Brown, A.L., Scott, S.N., "Parametric Sensitivity Study of Reacting Solids Exposed to High Heat Flux Environments," for the Western States Section of the Combustion Institute Meeting, October 14-15, 2019, Albuquerque, NM
- Mendoza, H. Brown, A.L., Ricks, A., "Modeling High Heat Flux Combustion of Coniferous Trees using Chemically Reacting Lagrangian Particles," for the Western States Section of the Combustion Institute Meeting, October 14-15, 2019, Albuquerque, NM, (SAND2019-10301C)
- Brown, A.L., Engerer, J.D., Ricks, A.J., Christian, J., Yellowhair, J., "Datasets for Material Ignition from High Radiant Flux," for the 13th International Association of Fire Safety Science Conference, April 27-May 1, 2020, Waterloo, Ontario, Canada.

Institutional Reports:

- Brown, A.L., Engerer, J.D., Christian, J.M., and Tanbakuchi, A., "NW Fire Material Effects Solar Furnace Phase 1 Test Results Report," SAND 2017-9869, OUO, September 2017
- Ricks, A.J., Brown, A.L., Christian, J.M., Engerer, J.D., Yellowhair, J., NW Fire and Material Effects Solar Tower Phase 1 Test Results, SAND2020-0482 (OUO)
- Engerer, J.D., Brown, A.L., Christian, J.M., NW Fire and Material Effects: Solar Furnace Phase 2 Test Results – Final Report, SAND2020-3717 (OUO)
- Engerer, J.D., Brown, A.L., Christian, J.M., Ricks, A.J., NW Fire and Material Effects: Solar Furnace Phase 3 Test Results – Final Report, SAND2020-3718 (OUO)

Key Contacts

Aaron Wilson

Oak Ridge National Laboratory

wilsonaj@ornl.gov

Hong Wang

Oak Ridge National Laboratory

wangh@ornl.gov

Peter Fuhr, Ph.D.

Oak Ridge National Laboratory

fuhrpl@ornl.gov

Andrew Duncan

Oak Ridge National Laboratory

duncanam@ornl.gov

Randy Shurtz

Sandia National Laboratories

rshurtz@sandia.gov

Dr. Alexander Brown

Sandia National Laboratories

albrown@sandia.gov

Stewart Cedres

Office of Electricity

stewart.cedres@hq.doe.gov

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Thank You

Our Next Webinar:

Situational Awareness

April 15, 2-4 PM ET

https://www.energy.gov/oe/wildfire-mitigation-webinar-series

Want to Connect?

Contact Stewart Cedres at

stewart.cedres@hq.doe.gov