FORENSIC ENGINEERING:

“When Things go Wrong in Electrical Power Plants ”

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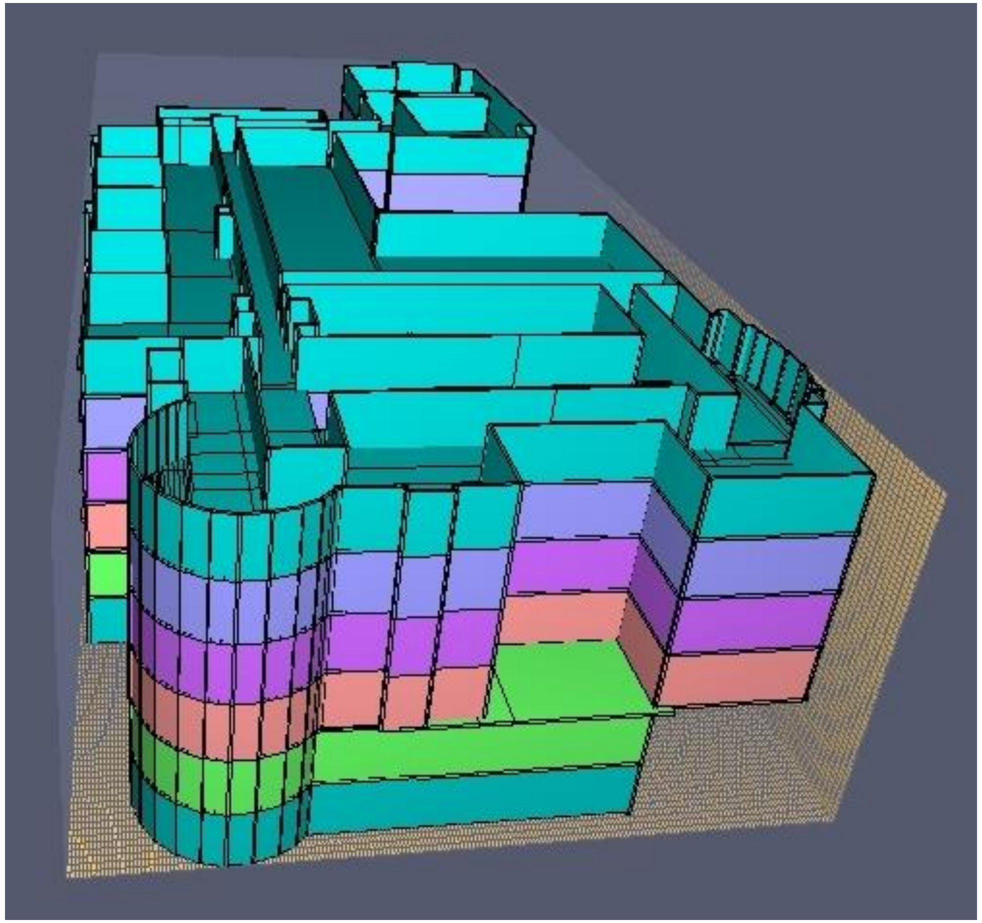
Fire Protection Engineering is a *Subfield* in the Electrical Engineering and Computer Science

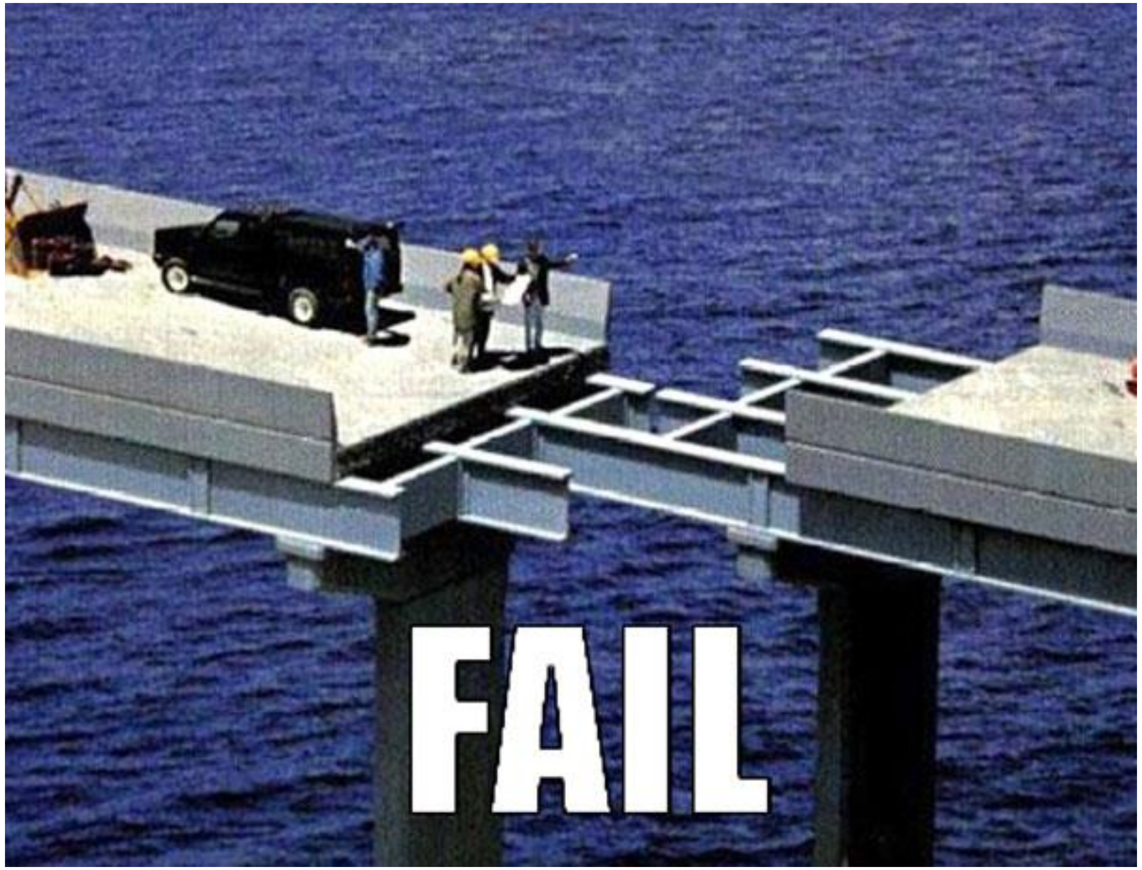
Many Common Areas of Intersection

- Safe design, operation, and risk assessments of electrical power distribution systems (*e.g., NRC cable tray problems, risk and hazard assessments*)
- Fire alarm design and smoke detection systems
- Lightning protection (*plasma sciences*)
- High-performance computer modeling (*UT's "mini-Titan" design*)
- Forensic engineering



Definition of Failure

- A comprehensive definition of "*failure*," as used by the Technical Council on Forensic Engineering of the American Society of Civil Engineers
  - ***Failure* is an unacceptable difference between expected and observed performance**. [Leonards 1982]



Causes of Failure

- The underlying source of a failure is sometimes found in ignorance, incompetence, negligence, and avarice, the “four horsemen of the engineering apocalypse” [FitzSimons 1986].
- There is always a technical/physical explanation for a failure, but the reasons failure occurs are often procedural.

Causes of Structural Failure in Buildings

- 1. *Site Selection and Site Development Errors:*
  - Land-use planning errors, insufficient or nonexistent geotechnical studies, unnecessary exposure to natural hazards.
- 2. *Programming Deficiencies:*
  - Unclear or conflicting client expectations, lack of clear definition of scope or intent of project.
- 3. *Design Errors:*
  - Errors in concept, lack of redundancy, failure to consider a load or combination of loads, connection details, calculation errors, misuse of computer software, detailing problems including selection of incompatible materials or assemblies which are not constructible, failure to consider maintenance requirements and durability, inadequate or inconsistent specifications for materials or expected quality of work.
- 4. *Construction Errors:*
  - Nonconformance to design intent, excavation and equipment accidents, excessive construction loads, improper sequencing, premature removal of shoring and formwork, inadequate temporary support.
- 5. *Material Deficiencies:*
  - Material inconsistencies, premature deterioration, manufacturing or fabrication defects.
- 6. *Operational Errors:*
  - Alterations to structure, change in use, negligent overloading, inadequate maintenance.

Example CASE STUDY –

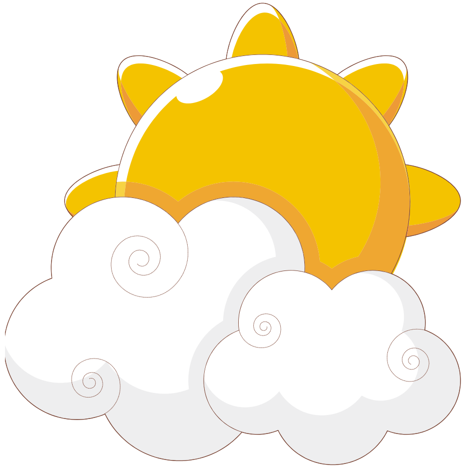
WHEN THINGS <u>Really</u> GO WRONG

Fire at Watts Bar
Hydroelectric Plant
September 27, 2002

TVA’s Watts Bar Hydroelectric Fire

- September 27, 2002, 8:15 a.m. fire at Spring City, TN
- Originally estimated at $25-30 million direct loss
- Initial fire investigation led by U.S. TVA Police

Weather Conditions



Temperature: 71.6°

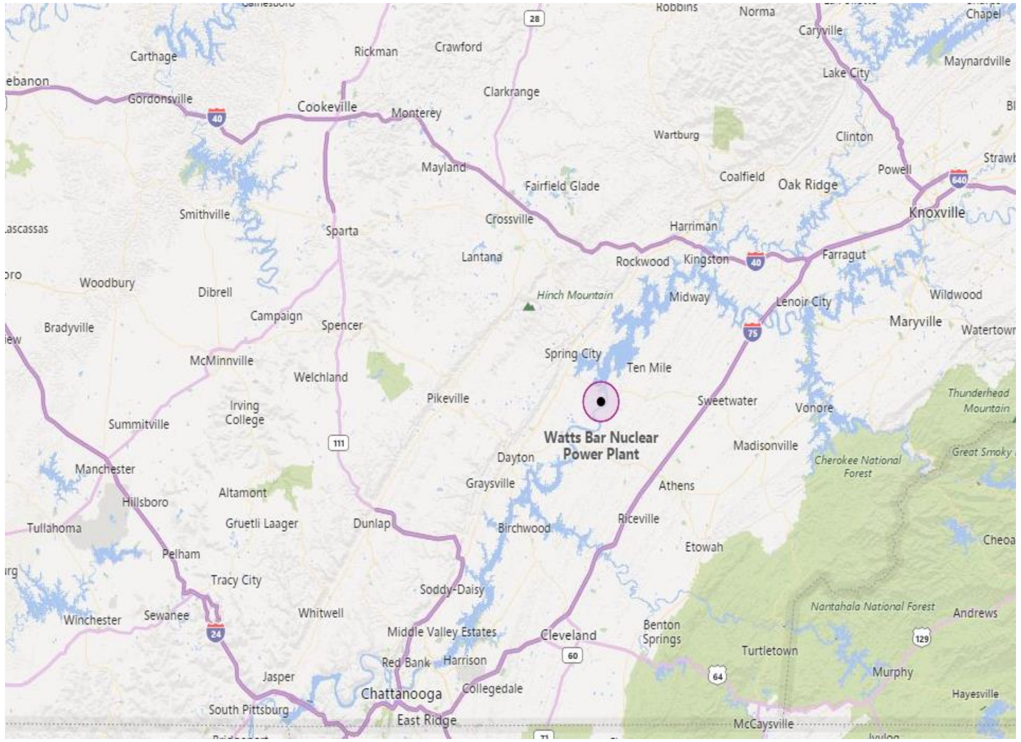
Humidity: 83%

Pressure: 29.53 in

Wind speed: 16.1 mph

Building Structure and Site

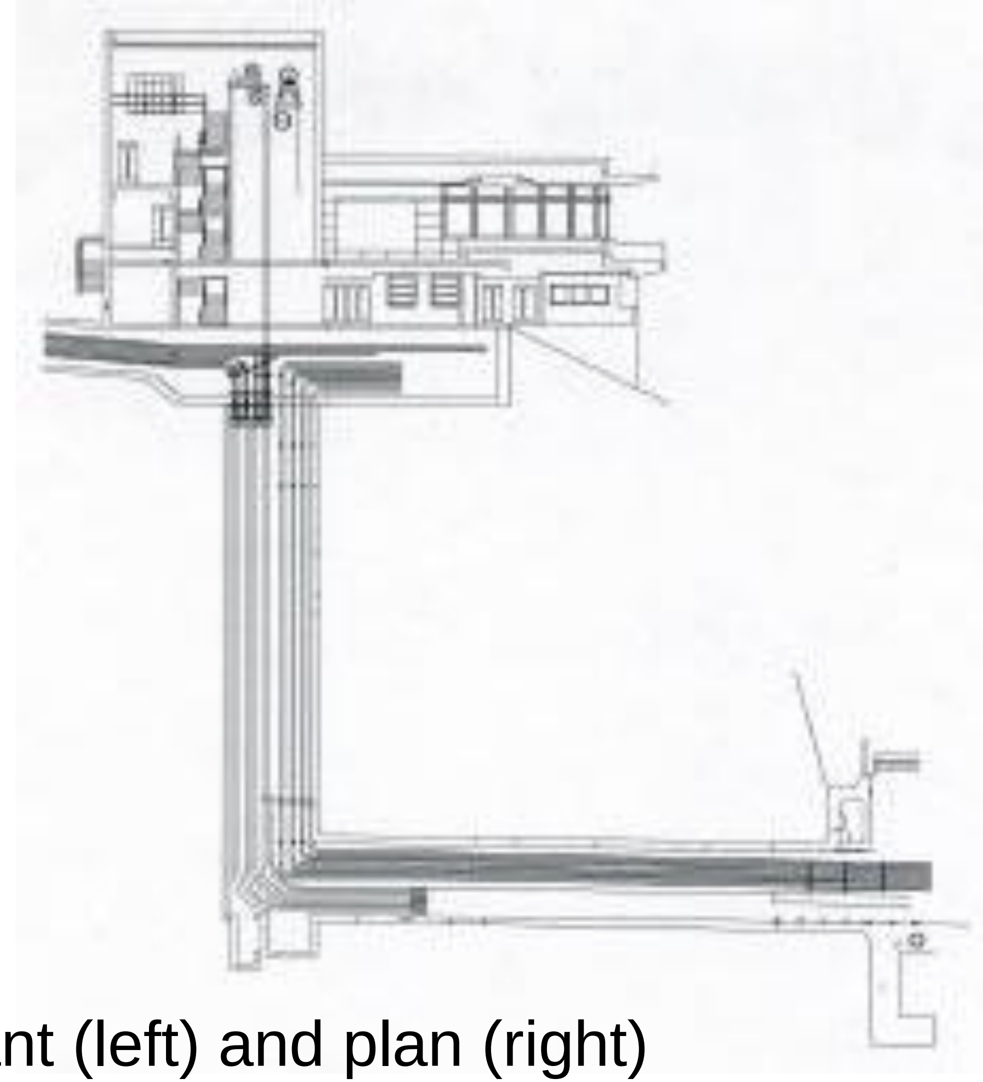
- Located halfway between Knoxville and Chattanooga on Tennessee River
- Opened in 1942
- Originally constructed to provide power to ORNL, flood control
- Later used backup power and cooling water for WBN reactors
- Not in compliance with National Fire, Building, and Electrical Codes



Power Generation

- Uses five 30,000 kW turbines
- Power fed through wiring from the turbines, up a 120 foot vertical shaft
- Seven of the 440 VAC cables along this run are copper clad with butyl rubber
- Control Room is located at top level above the spreading and terminal levels

Power Generation



Watts Bar Hydroelectric Plant (left) and plan (right)

Accident Investigation Team And Purpose

Coordinated investigation by:

- TVA Serious Accident Investigation Team
- Tennessee Valley Authority Police
- TVA Office of the Inspector General
- Bureau of ATF
- Knox County Sheriff's Department

Purpose:

- Rule out sabotage as the cause of the fire

Timeline of Events

- 8:15 am – Phase-phase ground fault on two 480 VAC cables in vertical shaft
- 8:24 am – First trip detected
- 8:30 am – 911 calls being received
- 8:31 am – WBN dispatched firefighters
- 8:35 am – Wolf Creek and Spring City FD arrive
- 9:10 am – Water supply established

Timeline of Events (Con't)

- 9:11 am – Initial entry made with thermal imaging camera and 1¾ line
- 9:35 am – Second entry with two 1½ lines
- 10:00 am – WBN firefighters ventilated control room with 1¾ line
- 10:47 am – SQN firefighters arrive and relieve WBN firefighters

Timeline of Events (Con’t)

- 11:50 am – Entry made to terminal room, exited at 12:05 am
- 12:50 am – Entry made to open hatch to cable shaft
- 1:20 pm – Entry made to cable spreading room, exited at 1:40 pm
- 1:42 pm – Fire reported extinguished

Materials First Ignited

<u>440 VAC Rubber Cable properties as provided by U.S. TVA and the U.S. Nuclear Regulatory Commission (NRC)</u>:

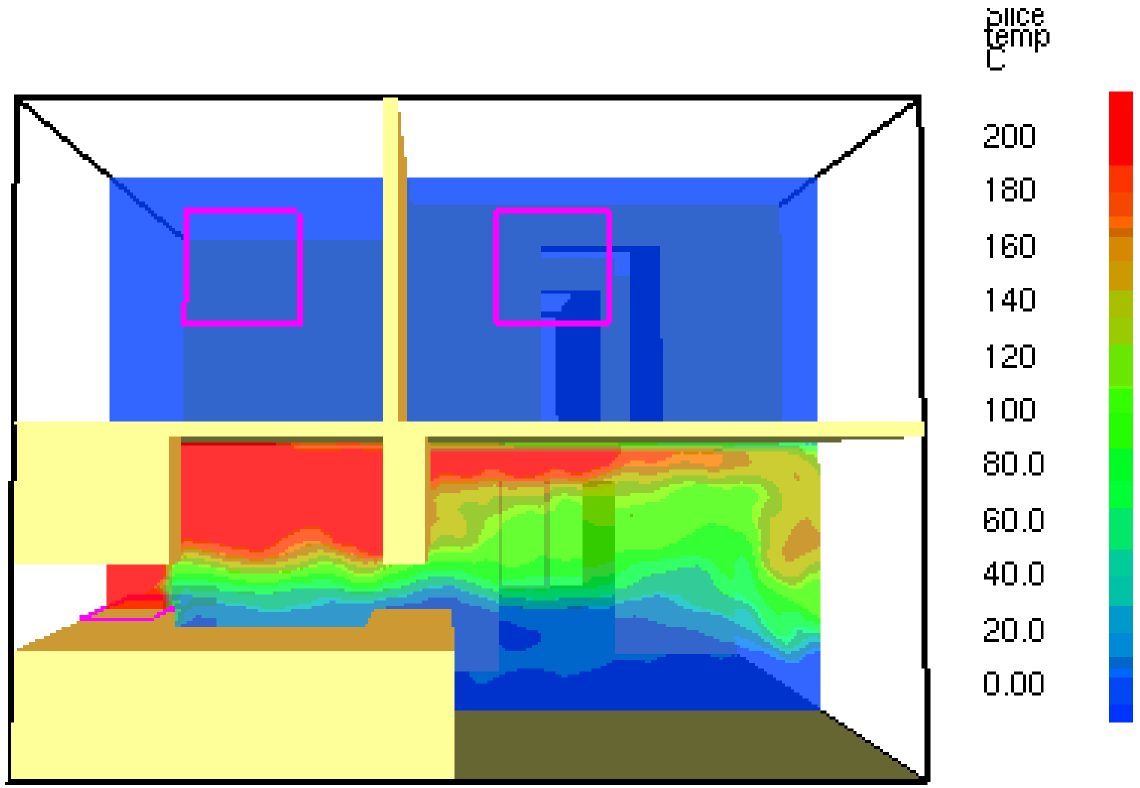
Weight	1.022 kg/m
Length (upper half of shaft)	15.24 m
Circumference	0.1207 m
Mass	93 kg
Surface area	11 m^2
Mass loss rate	26.7 $g/s\text{-}m^2$
Heat of combustion	44,000 kJ/kg
Peak heat release rate	1,175 kW/m^2
Heat release	25,900 kW

Time to Ignition

	Rubber	PVC	Wood
Heat Flux	Seconds	Seconds	Seconds
5	**954.5**	**1529.8**	**952.5**
10	**238.6**	**382.4**	**238.1**
15	**106.1**	**170.0**	**105.8**
20	**59.7**	**95.6**	**59.5**
30	**26.5**	**42.5**	**26.5**
40	**14.9**	**23.9**	**14.9**
50	**9.5**	**15.3**	**9.5**

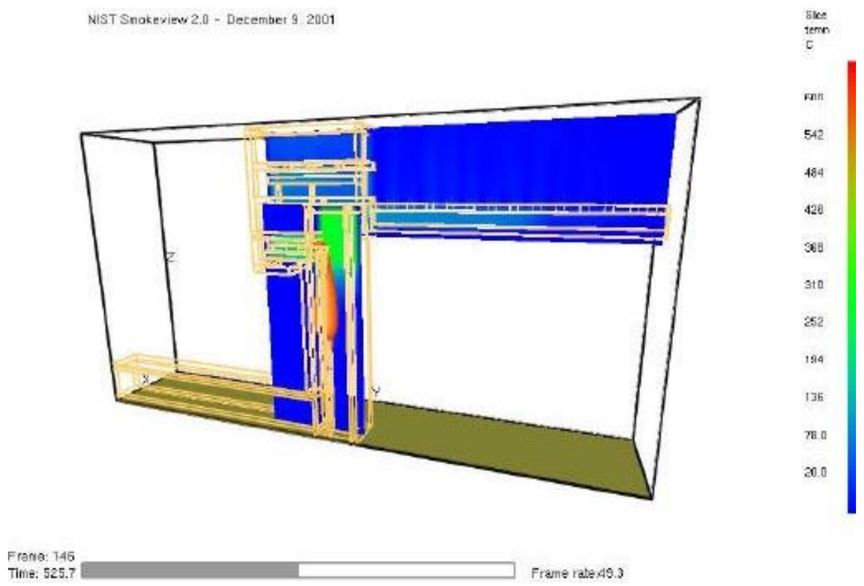
What is Computer Fire Modeling

- Application of sound engineering principles to emulate the impact of fires, not the fire itself
- Uses probabilistic, deterministic, and mathematical approaches
- Effective tool in Fire Protection Engineering

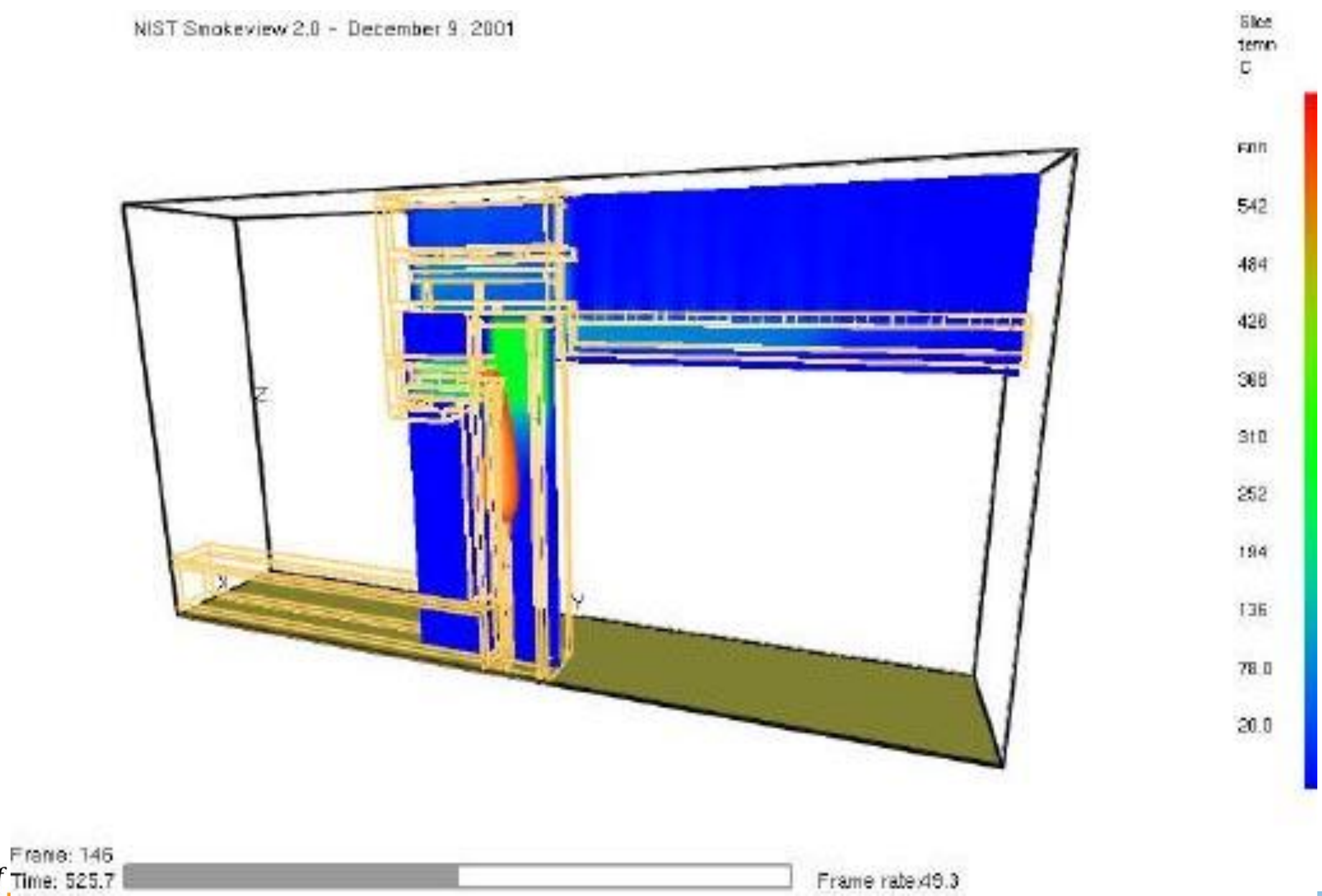


TVA’s Watts Bar Hydroelectric Fire Model

- NIST FDS Fire Model
- Refocused the investigation to the correct deck
- Explained many fire phenomena, including fire patterns, smoke movement

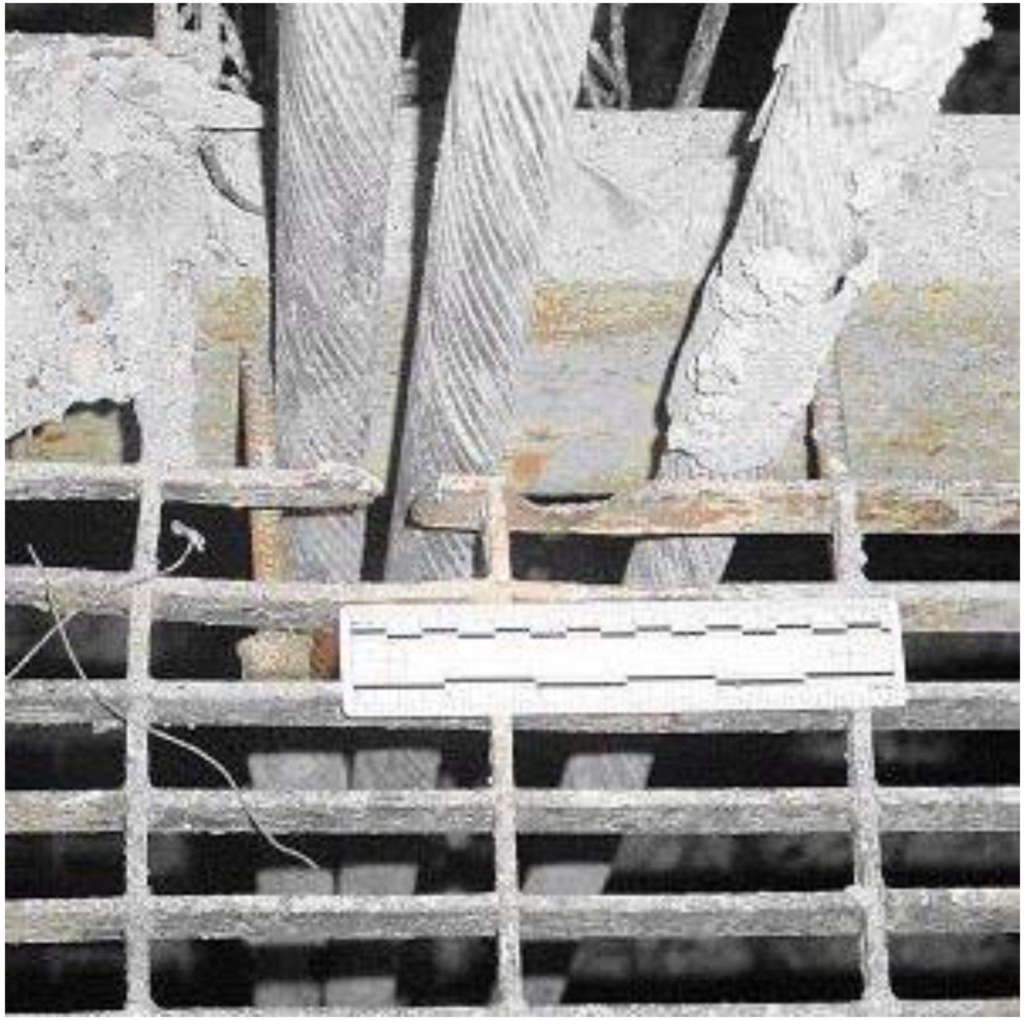


TVA's Watts Bar Hydroelectric Fire Model

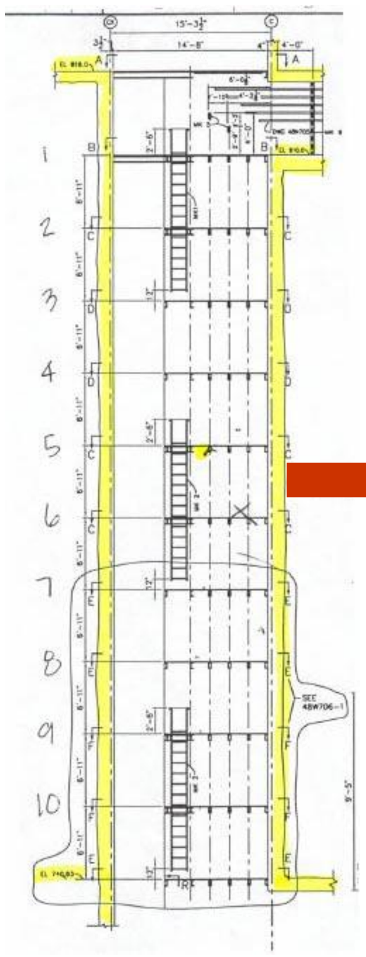


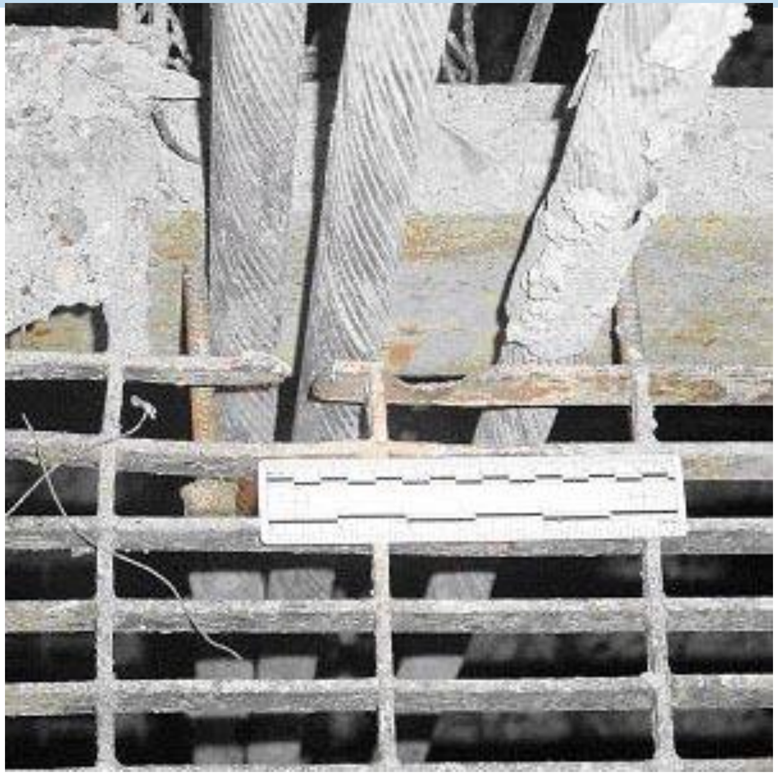
TVA's Watts Bar Hydroelectric Fire

- Fire started midway down a vertical cable shaft
- Involved an electrical short of a butyl rubber 440 VAC cable contacting against a steel decking



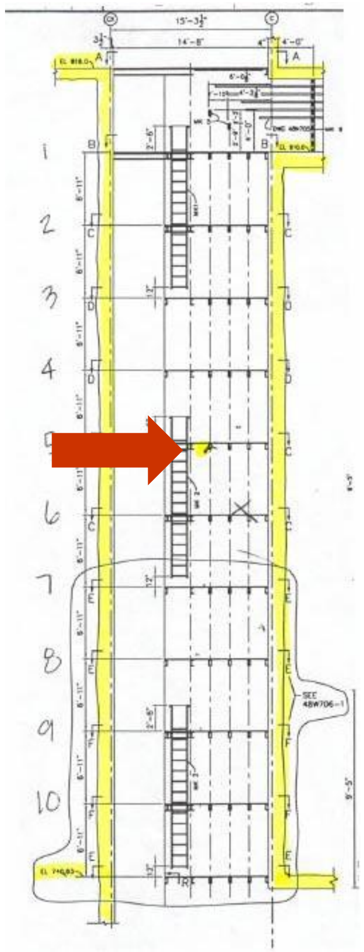
Area of Origin

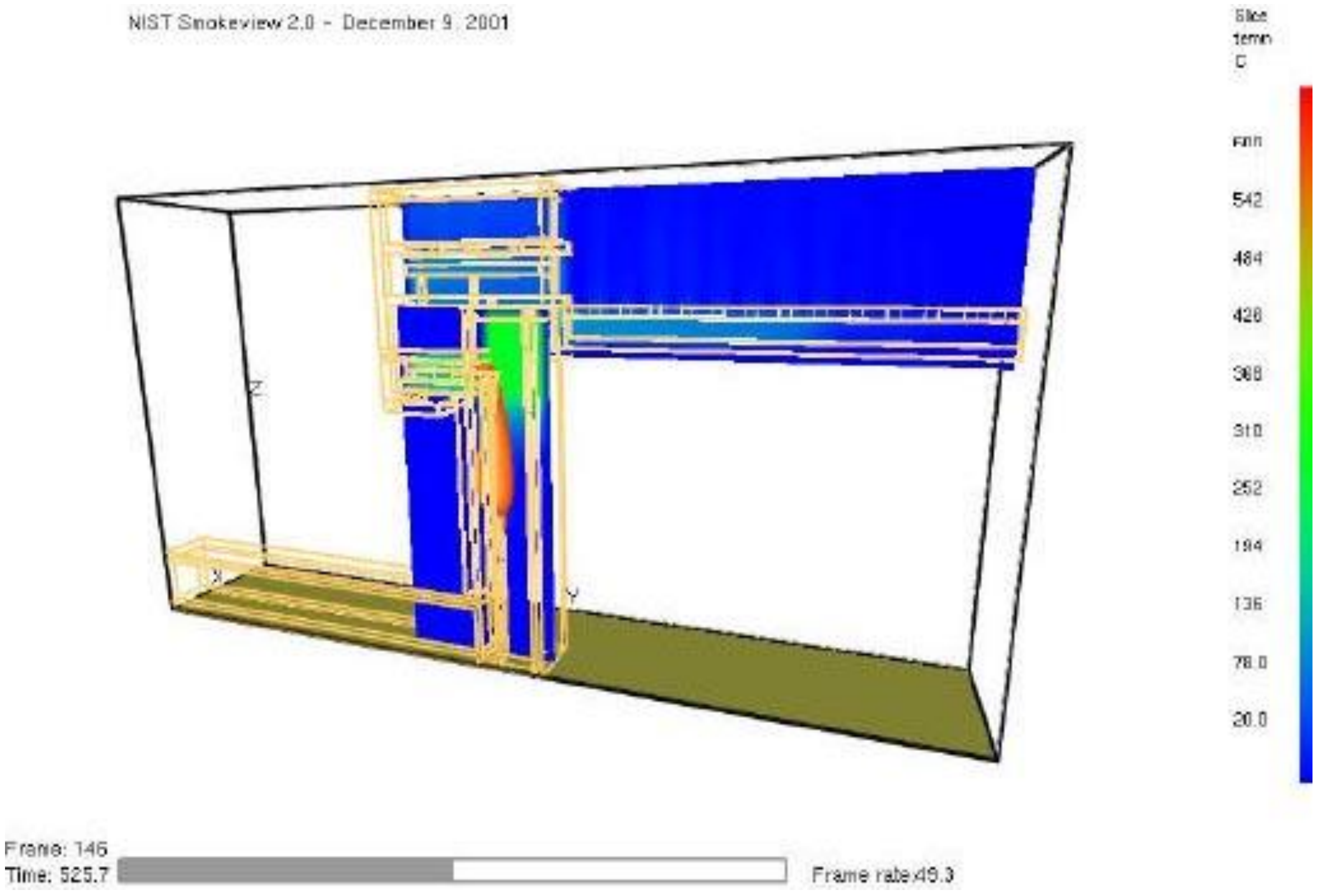




Point of origin (left), evidence of electrical arcing (middle), and suspect cable (right)

Area of Fire Origin as Predicted and Confirmed





TVA’s Watts Bar Hydroelectric Fire

- Investigation revealed complex fire pattern and spalling damage
- Some damage was inconsistent with existing fire investigation experience
- Computer fire modeling demonstrated its effective use in the investigation

UT Graduate Certificate Program and Concentration in Fire Protection Engineering

Courses Offered:

- **ECE 563 Introduction To Fire Protection Engineering (3)**
- **ECE 564 Enclosure Fire Dynamics (3)**
- **ECE 567 Forensic Engineering (3)**
- **ECE 575 High Performance Computer Modeling And Visualization (3)**

Courses available to select undergraduates with approval of advisor and certificate program coordinator

FIRE PROTECTION ENGINEERS
2012 SALARIES

Median USA total compensation is

$113,748

UP 2.9% since 2010

Fire Protection Engineers earned raises of 3% in 2011

Median Annual Income by Experience

- Entry-level $70,000
- Mid-level $96,200
- Senior-level $128,600

Professional Engineers have salary benefits. PE's earn 21% more annually.

- NON-PE $99,000
- PE $119,500

Total Annual Compensation by Industry Sector

- Consulting $62,400 – $150,000
- Insurance $115,000 – $182,500
- Fire Service $92,100 – $112,500
- Government $67,464 – $140,134

SFPE

Society of Fire Protection Engineers
www.sfpe.org

*The survey polled 745 professionals practicing in the profession of fire protection engineering worldwide. Income data is based on earnings in 2011.

QUESTIONS, COMMENTS, ENCOURAGEMENT?

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