December 15, 2004

MEMORANDUM TO: Sunil Weerakkody, Chief
Fire Protection Engineering and Special Projects Section
Plant Systems Branch
Division of Systems Safety and Analysis

FROM: James Downs, Fire Protection Engineer //RA//
Fire Protection Engineering and Special Projects Section
Plant Systems Branch
Division of Systems Safety and Analysis

SUBJECT: SUMMARY OF NOVEMBER 2004 PUBLIC MEETING ON NUREG-1805

On Novmber 22, 2004 and November 23, 2004 the Fire Protection Engineering and Special Projects Section conducted a public meeting at NRC Headquarters on the applications of NUREG-1805, "Fire Dynamics Tools (FDT^{s}) - Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program". The meeting summary and the handouts provided on each day are attached. Please contact me if you require any additional information.

Attachments: Attachment 1: Meeting Summary
Attachment 2: Presentation Slides

Contact: James Downs, NRR/DSSA/SPLB
415-3194

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DATE	12/15 /04		12/17/04					

ATTACHMENT 1

Meeting Summary

The NRC staff and management conducted a Category II public meeting at NRC Headquarters in Rockville on November 22 & 23. The meeting, attended by roughly 60 individual stakeholders, was focused on the applications of NUREG-1805, “Fire Dynamics Tools (FDT^s) - Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program“. The goal of the meeting was to introduce stakeholders to the staff’s path forward on each of the primary focuses. Comments were heard at the meeting and are to be incorporated into the hardbound version of the document, expected to be published in January of 2005. As stated during the meeting, there was no intention to present or create new staff positions and individual opinions expressed by the staff may not have been the official NRC position.

NUREG-1805 will help agency inspectors perform quick, first-order calculations for potential fire scenarios, using principles of fire dynamics. The NRC inspectors will be able to use the analytical methods and computer spreadsheets to perform evaluations of credible fires that could cause critical damage to essential equipment necessary for post-fire safe-shutdown of the plants.

Draft NUREG-1805 was issued for public comments and technical reviews in June of 2003. Comments from interested stakeholders, and other technical reviewers have been taken into account in preparing the final report. An advanced copy of the final report was published and posted on November 12, 2004 on NRC's public website at: http://www.nrc.gov/site-help/new-content.html

During the two day workshop, the NRC staff provided detailed discussion on each of the FDT^s and its features. Each chapter was reviewed, and the fire dynamics behind each of the spreadsheets was explained. An advanced copy of the text (NUREG-1805) and working CD was provided. Many participants brought laptop computers to work the sample problems in Microsoft Excel along with the instructors.

Any technical questions regarding NUREG-1805 should be sent by an email to Naeem Iqbal or Mark Salley at nxi@nrc.gov or mxs3@nrc.gov, faxed to (301) 415-2300, or sent by regular mail to U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Mail Stop O11 A11, Washington, DC 20555-0001. Any questions concerning the November public meeting, or requests for the hardbound version, should be sent to James Downs at jrd2@nrc.gov.

ATTACHMENT 2

SLIDES FROM PRESENTATION

NOTE: THE SLIDE PRESENTATION DIRECTLY FROM NUREG-1805 IS NOT SHOWN HERE

FIRE DYNAMICS TOOLS (FDT^s)
NUREG-1805

Presentation at the Nuclear Regulatory Commission Headquarters
An Introduction to NUREG-1805 "Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program"
Rockville, Maryland, November 22 – 23, 2004

Mark Henry Salley, P.E.
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Office of Nuclear Regulatory Research

Naeem Iqbal
Fire Protection Engineer
Office of Nuclear Reactor Regulation

U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Acknowledgement

- **Publication Support:**
  - Paula Garrity, Gary Lauffer, Lionel Watkins, Guy Beltz, Monique King
- **Internal Stakeholders**
  - Engineers & Management of NRR, RES, Regions I, II, III, IV, ACRS
- **External Stakeholders**
  - ATF&E
  - Licensees
  - Professional Groups, EPRI, NEI, SFPE,
  - Fire Protection Professionals
  - University of Maryland

Presenters

- James Downs (NRR/SPLB)
- Matthew Yoder (NRR/DE/EMCB)
- Jason Dreisbach (NRR/PMAS/Professional Intern Program)
- Support:
  - Francisco Jogular-Billoch (SAIC/EPRI)

Overview- What is FDT^s?

- **FDT^s** are a series of Microsoft Excel® spreadsheets issued with **NUREG-1805, "Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program."**
- The primary goal of FDT^s was to be a training tool to teach NRC Fire Protection Inspectors an **Introduction to Fire Dynamics**.
- The secondary goal of FDT^s was to be used in plant inspections and support other programs that required Fire Dynamics knowledge such as, SDP and NFPA 805.

History

- Draft **NUREG-1805** (two volumes) was developed over a 3 year period working with NRC Fire Protection Inspectors and was published in June 2003 for public comments and technical review.
- FDT[s] are modeled after the U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF&E) Fire and Arson Certified Fire Investigation Program
- Selected a series of state-of-the-art **Fire Dynamics Correlations** from ***SFPE Handbook of Fire Protection Engineering***, ***NFPA Fire Protection Handbook***, and other relevant **Fire Dynamics** text.
  - Customized for nuclear power plants applications
  - Appropriate physical properties
- New spreadsheets were added as a part of the review.
- Final NUREG-1805 was published in November 2004. Case Bound copies are expected to be back from the printer in January 2005

Features of FDT[s]

- User-friendly, **Pre-Programmed** Microsoft Excel® based on **Fire Dynamics** equation/correlations.
  - Quick application of **Fire Dynamics** principles found in state-of-the-art ***Fire Protection Handbooks***
  - Spreadsheets are protected to **Prevent Tampering**
  - **Automatic Unit Conversion**
  - Related **Material Fire Properties Data** for materials commonly found in nuclear power plants listed within each spreadsheet
  - **Reduces Input Errors** from inaccurate manual entries by using **Pull-Down Menus** which allow the user to select material fire property data
  - Provides for quick iterations with easy data entry in the spreadsheets to provide first order Fire Dynamics estimates.
- Spreadsheets are available in English and SI Units.

New Features of FDT^s Based on Comments

- User Specified Value option was added in **Material Fire Properties Data** table.
- Input parameters information was modified to be more User Friendly.
- Calculate button was added in all spreadsheets.
- Additional information block was added for user to describe specific fire scenario being analyzed.
- Revision Log table was added to maintain spreadsheet version and issue date.

Future FDT^s Updates

Future updates, corrections, or new FDT^s spreadsheets will be posted on NRC's external website within the Fire Protection section at: http://www.nrc.gov/reactors/operating/ops-experience/fire-protection.html

FUNDAMENTALS OF FIRE DYNAMICS

ESTIMATING HOT GAS LAYER TEMPERATURE IN A COMPARTMENT FIRE

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Natural Ventilation Compartment Fire

$$\Delta T_g = 6.85\left[\frac{\dot{Q}^2}{\left(A_v\sqrt{h_v}\right)\left(A_T h_k\right)}\right]^{\frac{1}{3}}$$

Where:
ΔT_g = upper layer gas temperature rise above ambient $(T_g - T_a)$ (K)
$\dot{Q}$ = heat release rate of the fire (kW)
A_v = total area of ventilation opening(s) (m^2)
h_v = height of ventilation opening (m)
h_k = heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surfaces (m^2) excluding area of vent opening(s)

Thermally Thin Interior Lining

$$h_k = \frac{k}{\delta}$$

Thermally Thick Interior Lining

$$h_k = \sqrt{\frac{k\rho c}{t}}$$

Where:
h_k = heat transfer coefficient (kW/m^2-K)
ρ = density of the interior lining (kg/m^3)
c_p = thermal capacity of the interior lining (kJ/kg-K)
k = thermal conductivity of the interior lining (kW/m-K)
δ = thickness of the interior lining (m)
t = time (sec)

Challenges of Fundamental Fire Dynamics

- Mathematical
  - How do I do a cube root?
  - How do I do view factor algebra?
  - How do I handle multiple variables in an equation?
- Physical Properties
  - What is the heat transfer coefficient?
  - What is thermal capacity of concrete or gypsum?
  - What is thermal conductivity of concrete or gypsum?
- Fire Dynamics
  - Which equation do I use?
    - Thermally thin?
    - Thermally thick?

Regulatory Application of FDT^s^

- To support **Significance Determination Process (SDP)** to evaluate inspection findings required by the **ROP**.
  - Develop Credible Fire Scenario
- To evaluate the **Significance** of non-compliant fire protection issues.
  - Evaluate the Potential Fire Effects
- To support evaluation of fire protection exemption requests.
  - Evaluate Fire Severity and Adequate Protection
- Future use in **Risk-Informed Performance-Based Applications**.
  - NFPA 805 Rule

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NRC Reactor Oversight Process

- The primary objectives of the **Fire Protection Programs (FPPs)** at U.S. commercial nuclear power plants are to **Minimize** both the **Probability of Occurrence and Consequences of Fire**.
- To meet these objectives the FPPs for nuclear power plants are designed to provide reasonable assurance, through **Defense-in-Depth (DID)**, that a **fire will not prevent the performance of necessary safe-shutdown functions and that radioactive releases to the environment in the event of a fire will be minimized.**
- NRC ROP uses a **Risk-Informed** approach to evaluate the safety significance of inspection findings.
  - Need to understand **Fire Effects**

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NFPA 805 Rule

- NFPA 805 includes:
  - Maximum Expected Fire Scenarios (MEFS)
  - Limiting Fire Scenarios (LFS)
  - Potential Fire Scenarios
- NUREG-1805 provides a fundamental discussion of Fire Dynamics concepts that are necessary to understand requirements of NFPA 805.

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Evolution of Quantifying Fire Scenarios in Nuclear Power Plants

Past
- **Fire load** expressed in (BTU/ft^2) does not consider other factors which greatly affect the compartment fire intensity such as **Compartment Volume, Heat Transfer Characteristics of the Enclosure Boundaries, and Ventilation Openings**.

Present
- **FDT^s** is a training tool that can be used to teach **Fire Dynamics** and develop **First Order Fire Dynamics Evaluation** in actual commercial nuclear power plant applications.

Future
- **NFPA 805**, Performance Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants will use detailed **Fire Modeling Calculations**.

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Regional Inspector Training

- Training covered basic principles of **Fire Dynamics**, **Assumptions, Limitations**, and **Applications**.
  - NRC training lesson plans formed the draft text of NUREG-1805
- Quarterly training led by NRR staff **Fire Protection Engineers**. New spreadsheets were presented at each quarterly training session.
  - Regional Inspectors performed Beta evaluation
  - ATF&E also used in recent training with their inspectors
- Inspectors independently develop fire scenarios and solve realistic problems.

List of FDT^s Spreadsheets

- 02.1_Temperature_NV.xls
- 02.2_Temperature_FV.xls
- 02.3_Temperature_CC.xls
- 03_HRR_Flame_Height_Burning_Duration_Calculation.xls
- 04_Flame_Height_Calculations.xls
- 05.1_Heat_Flux_Calculations_Wind_Free.xls
- 05.2_Heat_Flux_Calculations_Wind.xls
- 05.3_Thermal_Radiation_From_Hydrocarbon_Fireballs.xls
- 06_Ignition_Time_Calculations.xls
- 07_Cable_HRR_Calculations.xls
- 08_Burning_Duration_Solid.xls
- 09_Plume_Temperature_Calculations.xls
- 10_Detector_Activation_Time.xls
- 13_Compartment_ Flashover_Calculations.xls
- 14_Compartment_Over_Pressure_Calculations.xls
- 15_Explosion_Claculations.xls
- 16_Battery_Room_Flammable_Gas_Conc.xls
- 17.1_FR_Beams_Columns_Substitution_Correlation.xls
- 17.2_FR_Beams_Columns_Quasi_Steady_State_Spray_Insulated.xls
- 17.3_FR_Beams_Columns_Quasi_Steady_State_Board_Insulated.xls
- 17.4_FR_Beams_Columns_Quasi_Steady_State_Uninsulated.xls
- 18_Visibility_Through_Smoke.xls

Summary

- By taking commonly available computer spreadsheet software (like Microsoft Excel®) and creating a series of computational spreadsheets, **Complex Concepts** like **Fire Dynamics** can be taught to inspectors and put into reliable **Field Application**.
- The use of the **FDT^s** further **Reduces Mathematical Complexities and Errors**, and promotes greater application of **Fire Science and Engineering** in **Field Use**.
- FDT^s complies necessary **Physical Material Properties** to perform fire dynamics calculation in one reference.
- **NUREG-1805** and **FDT^s** can make a positive impact in the NRC's **Fire Protection Inspection Program**, specifically **Risk-Informed** fire protection initiatives such as **SDP**, inspection of **Post-Fire Safe-Shutdown Circuits and NFPA 805**.

Evaluating Fire Scenarios Using FDT^s

- Example – 1

A pool fire scenario arises from a breach (leak or rupture) in an auxiliary cooling water pump oil tank. This event allows the fuel contents of the pump to spill and spread over the compartment floor. A 5 gallon, 9.0 ft^2 surface area spill of flammable liquid (lubricating oil) leads to consideration of a pool fire in a compartment with a concrete floor. The fuel is ignited and spreads rapidly over the surface, reaching steady burning almost instantly. Compute the HRR, burning duration, and flame height of the pool fire. The dimensions of the compartment are 15 ft wide x 15 ft deep x 10 ft height. A cable tray is located 8 ft above the pool fire. Determine whether the flame will impinge upon the cable tray. Assume instantaneous and complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.

- Example – 2

In one nuclear power plant, it was important to determine whether a fire involving a 4-gallon spill of lubricating oil from an auxiliary feed water (AFW) pump could cause damage to an unprotected electrical cable pull box and cable trays. The unprotected pull box and cable trays were located 10 ft and 8 ft above the AFW pump, respectively. The pump room had a floor area of 20 ft x 20 ft and a ceiling height of 15 ft with a vent opening of 5 ft x 15 ft. Compute the HRR, burning duration, and flame height of the pool fire with a diameter of 4 ft.
The lowest cable tray is located 8 ft above the pool. Determine whether flame will impinge upon the cable tray or cable pull box. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.

Evaluating Fire Scenarios Using FDTs

- Example – 3

A standby diesel generator (SBDG) room in a power plant has a 3-gallon spill of diesel fuel over a 1 ft^2 diked area. This event allows the diesel fuel to form a pool. The diesel is ignited and fire spreads rapidly over the surface, reaching steady burning almost instantly.
Compute the HRR, burning duration, and flame height of the pool fire. The dimensions of the compartment are 10 ft wide x 12 ft deep x 12 ft high. The cable tray is located 10 ft above the pool fire. Determine whether flame will impinge upon the cable tray. Also determine the minimum area required of the pool fire for the flame to impinge upon the cable tray. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by plant fire department or automatic suppression.

- Example – 4

Consider a compartment that is 10 ft wide x 15 ft long x 8 ft high ($w_c \times l_c \times h_c$) with a door that is 3 ft wide x 7 ft high ($w_v \times h_v$). The construction is essentially 0.5 ft thick gypsum board. The fire is constant with an HRR of 500 kW. Assume that the top of the vent is 8 ft. Compute the hot gas temperature in the compartment, as well as the smoke layer height at 2 minutes

- Example – 5

Consider a compartment that is 16 ft wide x 20 ft long x 12 ft high (($w_c \times l_c \times h_c$), with a vent opening that is 3 ft wide x 7 ft high ($w_v \times h_v$). The forced ventilation rate is 100 cfm. Calculate the hot gas layer temperature for a fire size of 700 kW at 2 minutes after ignition. The compartment boundaries are made of 1 ft thick concrete.

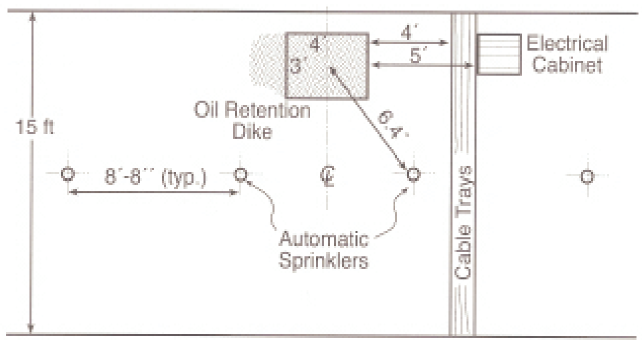
Evaluating Fire Scenarios Using FDTs

Example - 6
During a routine fire protection inspection, an NRC inspector discovers an significant oil leak in a station air compressor in an access corridor in the auxiliary building. This event allows the 10 gallons lube oil spill over a 12 ft^2 (1.12 m^2) oil retention dike. The dike is
located 1 ft (0.3048 m) from the wall. The unprotected cable trays are located 8 ft (2.45 m) above the floor, 4 ft (1.2 m) horizontally from the edge of the dike. A electrical cabinet is located 5 ft (1.52 m) horizontally from the edge of the dike.

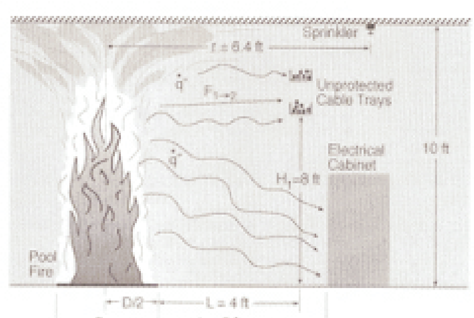
The corridor has a floor area of 30 x 15 ft (36.6 x 4.6 m), a ceiling height of 10 ft (3 m), and has two fire rated doors of 3 x 7 ft (0.914 x 2.15 m). The corridor has no forced ventilation system. The walls, ceiling, and floor are constructed of 1 ft thick concrete. The corridor has a smoke detection system and wet pipe sprinkler system. The nearest sprinkler is rated at 165 °F (74 °C) with a RTI of 235 $(m\text{-}sec)^{1/2}$ and is located 6.5 ft (1.98 m) from the center of the dike. The nearest smoke detector is 20.5 ft (6.25 m) from the center of the dike.

Determine if there is a credible fire hazard to the unprotected safety-related cable trays and electrical cabinet. (Assume no ventilation effects on the fire.)

Fire Scenario



Fire Scenario



Solution

ANALYSIS

Fire damage resulting from spills of flammable and combustible liquid fuels depend on the fuel type, the size and shape of the fire, the duration of the fire, its proximity to the target, and the thermal characteristics of the target. Combustible liquids that have relatively high flash points (e.g., lube oil or diesel fuel), require localized heating to ignite. However, once ignited, a pool fire rapidly spreads over the surface of the liquid spill. To perform an FHA, assume that the 20 gallons of lubricating oil spills into the diked area and is ignited by the failed compressor.

SPREADSHEETS (FDT^s) INFORMATION
Use the following FDT^s to determine:

- Heat flux to the target (electrical cabinet) Heat_Flux_Calculations_Wind_Free.xls (Click on Solid Flame 1)
- Heat flux to the target (cable trays) Heat_Flux_Calculations_Wind_Free.xls (Click on Solid Flame 2) Target above ground level
- Hot gas layer temperature in the corridor Temperature_NV.xls (Click on Temperature_NV Thermally Thick)
- Sprinkler activation time, $t_{activation}$ Detector_Activation_Time.xls (Click on Sprinkler)

Results

The summary results of FHA calculations are:

- Heat flux to the target (electrical cabinet) = 8.90 kW/m²
- Heat flux to the target (cable trays) = 16.40 kW/m²
- Hot gas layer temperature in the corridor = 450 °F (232 °C) doors open
- Hot gas layer temperature in the corridor = 545 °F (285 °C) one door open only
- Sprinkler activation time, $t_{activation}$ = 1.2 min

Heat fluxes to the electrical cabinet and cable trays are high enough to damage them. The FHA Calculation demonstrates that a pool fire with a 12 ft² dike area in a corridor could damage remote unprotected safety-related cable trays and electrical cabinets.

For this analysis the sprinkler system, if operable, should quickly activate and mitigate damage to the safety- related cable tray and electrical cabinet.

Conclusion

- NUREG-1805 provides a basic Introduction to Fire Dynamics for nuclear power plant applications.

- NUREG-1805 provides tools and methods that can be used in actual nuclear power plant Fire Hazard Analysis (FHA)

- The NRC conducted this public meeting on the NUREG-1805 on November 22 and 23, 2004, to share this information with all interested stakeholders. During these 2 days, NRC staff will make presentations, introducing FDT[s] and exercise their features. NRC thanks all interested stakeholders for attending this public meeting and furthering the understanding of fire-risk analysis.