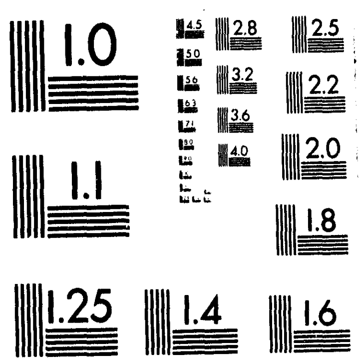
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Modeling of HDR Oil and Cable Fire Tests[1]

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ABSTRACT

This paper summarizes the calculations performed at Sandia National Laboratories using the COMPBRN fire model for the Heiss Dampf Reaktor (HDR) tests E41.7 and E42.2. A Sandia modified version of COMPBRN III was used for the calculations. Test E41.7 was an oil pool fire, and test E42.2 was a cable fire. Both tests were conducted inside a small room within the HDR containment. Calculations were also performed for test E41.7 with the Notre Dame Fire Model. Hot gas layer temperatures and other relevant results are presented. Comparison with experimental data is made, where possible. A brief discussion on the problems encountered in the application of fire models to nuclear power plant fire modeling is also included.

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1. Background

The German government has conducted fire tests in a decommissioned nuclear reactor (HDR). The HDR fire tests represent a unique contribution to the existing large-scale fire test database. These tests are the only fire tests that have been conducted inside an actual nuclear reactor containment building. The tests have investigated realistic fires in a complex, inter-connected facility with high forced ventilation. An international cooperative effort is underway to model these tests using the latest fire models available.

Sandia has been involved in this program as technical consultants to the United States Nuclear Regulatory Commission (NRC). As part of this program, fire modeling calculations have been conducted for HDR tests E41.7 and E42.2. Test E41.7 was an oil pool fire. Test E42.2 was a polyvinylchloride (PVC) cable fire. For test E41.7, both the COMPBRN III fire model [1] and the Notre Dame Fire Model (NDFM) were utilized. Only COMPBRN III was applied to the E42.2 test.

The goal of this work was to perform blind post-test calculations with COMPBRN III to generate results for later comparison to the test data. This paper summarizes the details concerning the inputs, models, and results of the calculations.

2. Fire Models

2.1 COMPBRN Model

For our calculations, the COMPBRN III fire model [1] (as modified for the Fire Risk Scoping Study [2]) has been applied to the E41.7 and E42.2 tests. COMPBRN is a one-room zone model that calculates the hot gas layer (HGL) temperature and HGL height based on a simple mass and energy balance, and radiative and convective heat transfer to objects in the fire room (with subsequent ignition and burning), as shown in Figure 1. Each object (such as a cable tray) can be discretized into smaller elements for the calculation of heat flux, temperature, ignition (based on surface temperature), and burning (based on correlations). COMPBRN III will model both surface-controlled and ventilation-controlled burning.

COMPBRN III accounts for forced ventilation effects on the fire, and can also model an opening such as a door. However, it is not capable of modeling the effect of opening a door once the calculations have begun. Thermal radiation from the ceiling, HGL, and walls can all be modeled if so desired. More details of the models and submodels in COMBRN III can be found in references [1] and [3].

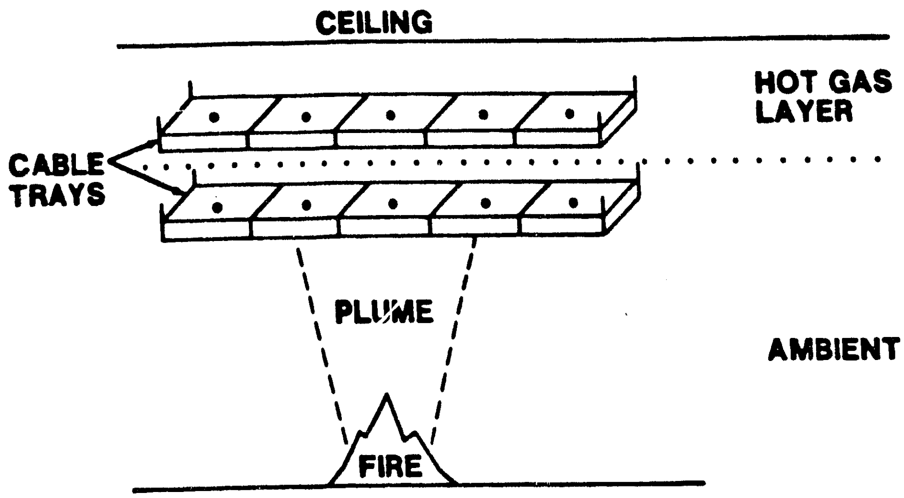

Figure 1: COMPBRN III Fire Model

2.2 Notre Dame Fire Model

Along with the COMPBRN zone model calculations, field model calculations were also performed for the E41.7 test. The model used is the University of Notre Dame Fire Model, developed by Professor K. T. Yang and colleagues. This fire model is a research tool that has been under development since the mid-1970s, and has been used to simulate many different fires (see for example, [4-7]). The calculations discussed herein were performed by Professor Yang and his colleagues at the University of Notre Dame.

The NDFM is a fully transient, 3-D finite difference field model of the fire environment, and is an appropriate model for simulating the transient development of the fire. An HDR-specific version of the NDFM was developed and used in the present study. This version accomodates full compressibility, turbulence, wall losses, surface-to-surface and surface-to-flame radiation exchange, and the specific geometries dealing with the elevated fuel bed and the ventilation inlet and outlet. Gas radiation is neglected, and the combustion heat release rate must be prescribed due to lack of a combustion model.

For the NDFM calculations, the facility is divided into a number of finite control volumes. The governing partial differential equations for the heat, mass, and momentum transfer are solved within each volume in the calculation domain at every time step, using a finite difference algorithm. Wall losses are calculated using a 1-D unsteady conduction algorithm with a prescribed exterior convection coefficient. An algebraic turbulence model is utilized which incorporates stratification effects.

The NDFM was not applied to the E42.2 test. The large uncertainties regarding HRR from burning cable insulation precluded using a CPU-intensive transport model such as the NDFM for this calculation.

3. E41.7 Test

3.1 E41.7 Test Specification

The details of the test specification for test E41.7 are contained in the problem specification report [8]. Test E41.7 was an oil pool fire test with high forced ventilation at the 1500 level of the HDR containment building. The ventilation rate for the fire room was specified as 30 air changes per hour (ACH) for the first 15 minutes of the test. During this time period, the doors to the fire room were closed. After 15 minutes, the doors were opened and the ventilation rate was reduced to 10 ACH. Our focus herein is only on the first 15 minutes.

The fire room has a volume of 100 m^3 (approximate ceiling height of 4.7 m, and floor area of 22 m^2). The floor and side walls are made of concrete. The side walls are protected with Alsiflex mats (2.5 cm thick).The ceiling is protected with Promatec (5.0 cm thick). The material properties can be found in the problem specification report [8].

The fuel was burned in a 2 m^2 trough located near the center of the fire room. The initial fuel loading was 40 liters of Shell SOLT oil. This fuel has a density of 0.756 kg/l and a calorific value of 42,500 kJ/kg. When the initial fuel load was consumed, oil was supplied at a rate of 0.12 kg/s.

3.2 E41.7 COMPBRN Inputs and Assumptions

Some preliminary calculations must be performed to determine appropriate input parameters. The ventilation rate of 30 ACH corresponds to 0.85 m^3/hr into the fire room. The amount of fuel initially is 30.2 kg. For conduction into the walls, floor, and ceiling, the composite layers are converted into an equivalent thickness of Alsiflex by ratioing the thermal diffusivities of the materials (including concrete). Thus, the walls are represented by 27.5 cm of Alsiflex, the ceiling by 10.5 cm of Alsiflex, and the floor by 62.5 cm of Alsiflex. The thermal diffusivity of all surfaces was varied over the range 1.5 - 2.0E-6 m^2/s. The absorptivity of all surfaces was varied from 0.7-0.9 with little impact on the results.

SOLT oil is assumed to behave similarly to kerosene fuel. An efficiency of 70-80% was assumed for the burning process. Half of the energy released in the combustion process was assumed to be in the form of thermal radiation (since these flames are sooty). A surface-controlled burning rate of 0.039 kg/m^2s was used based on information in the SFPE handbook [9]. This burning rate was considered to have a heat flux augmentation factor of 1.3E-6 kg/m^2J, which is related to the inverse of the latent heat of vaporization (0.77 kJ/g).

Fire Room Assumptions

- The fire room (out to the doors) is modeled as a single square room of dimensions 4.69 m high x 4.66 m wide x 4.66 m long.
- The ceiling is assumed to be: 4.66 m wide x 4.66m long x 0.105 m thick of Alsiflex. Four walls of the fire room are modeled out to the doors (the doors are modeled as closed). All of these walls are 4.69 m high. The total surface area of the walls is 87 m^2.
- The properties of Alsiflex are assumed to be: density = 130 kg/m^3, specific heat = 1000 J/kg/K, and thermal conductivity = 0.25 W/m/K.
- The forced ventilation flow is assumed to enter below the HGL. All of the outflow is assumed to exit from the HGL. The convective heat transfer coefficient for heat transfer from the HGL to the ceiling is assumed to be 10 W/m^2. The thermal radiation absorption coefficient for the HGL is assumed to be 1.3 m^{-1}.
- An initial temperature of 300 K was assumed for all surfaces, and a time step of 60 seconds was used for all calculations.

3.3 E41.7 NDFM Input and Assumptions

The geometric model of the HDR fire room used in the NDFM E41.7 calculations is sketched in Figure 2. Note that the fire room consists of a larger room (in which there was a pool of fuel) and

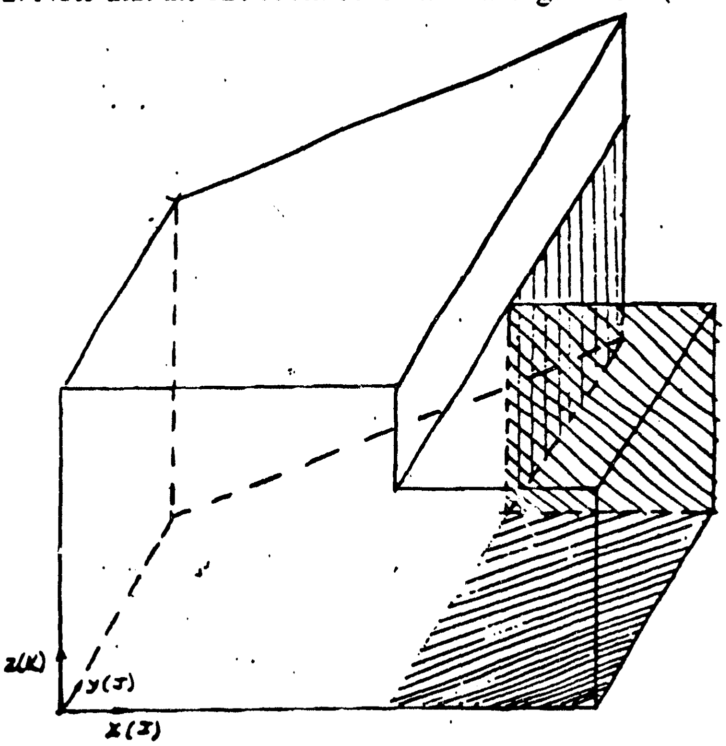

Figure 2: NDFM E41.7 Geometric Model

a smaller room (alcove) that was directly attached. The alcove had doors on the end of it that led to the rest of the containment, but these doors were assumed to be closed. For the model, the ventilation air was introduced into the fire room through a square hole at the actual location of the ventilation inlet in the HDR fire room. This is near the origin in Figure 2. The ventilation rate was maintained at a constant value of 0.85 m^3/s.

The calculation domain was divided into cubical cells measuring 0.273 m on each side. The uniform grid used was 28x24x19 cells (IxJxK). The wall emissivity was assumed to be 0.9, and a coefficient of heat transfer at the exterior wall and ceiling surfaces of the fire room was taken to be 85 W/m^2K. The fraction of flame energy radiated away from the flame was assumed to be 0.9. This is consistent with measurements from large, sooty hydrocarbon pool fires [10]. Other physical properties were based on those given in the design specification report [8].

The heat release rate(HRR), in megawatts (MW), was assumed to vary with time (t) according to the following relationship:

$$HRR = 1.9625\, t, \text{ for } 0 < t < 2 \text{ minutes,}$$
$$HRR = 1.17\, t + 1.30, \text{ for } 2 < t < 4 \text{ minutes}$$

This relationship was based on the COMPBRN results. The average heat release rate using this relationship is approximately 3.4 MW.

3.4 E41.7 COMPBRN Results

COMPBRN calculation were performed for the ranges of parameters specified above. The size of the fire (MW) is calculated to be very large relative to the volume of the fire room. This agrees with the observation during the test that most of the room was filled with flames (i.e., a fireball). Consequently, the surfaces of the fire room heat up to very high temperatures very quickly in the calculations. As a result, the COMPBRN calculations become unstable within 4 - 7 minutes from the beginning of the fire. This is due to the manner in which COMPBRN models the radiative heat input into a surface. Therefore, the calculations could not be carried out for long times.

Only the case with a surface emissivity of 0.7, an efficiency of 70%, and a thermal diffusivity of 2.0E-6 m^2/s will be discussed. These input parameters were believed to be the most reasonable for the cases that were run.

The COMPBRN results are shown in Table 1 for the first 4 minutes of the calculation. The COMPBRN-calculated mass loss rate agrees quite well with the measured values over the first 2 minutes. The COMPBRN-calculated values are lower by about 20%. Note that there is some discrepancy in the test data at time equal to zero. It is not clear why the test data shows 0.11 kg/s as the mass loss rate before ignition occurs. At 3 minutes, COMPBRN calculates a mass loss rate of 0.1535 kg/s. This is about 50% larger than the measured value. The reason for this result is two-fold. First, the COMPBRN quasi-steady HGL model over-predicts the early rate of transient HGL development, and hence, radiative feedback. Second, COMPBRN assumes that the air entrained by the fire is not diminished in oxygen concentration. In the actual test, some depletion of the oxygen may have been occurring, as evidenced by the monotonic decrease in the measured mass loss rate. By 4 minutes, COMPBRN predicts that the fire has become limited by the amount of oxygen available (ventilation controlled burning). It no longer burns at a rate solely dependent on the amount of fuel surface area (surface controlled burning). The mass loss rate drops substantially at this time as a result.

The initial pool fire has a COMPBRN-calculated heat release rate(HRR) of approximately 2.8 MW. During the initial pool fire burning, COMPBRN calculates that the surrounding surfaces heat

Table 1: COMPBRN Results for E41.7 Test

Time (minutes)	Calculated Mass Loss Rate (kg/s)	Measured Mass Loss Rate (kg/s)	Calculated Fire HRR (MW)	Calculated HGL Temp (K)	Measured HGL Temp (K) CT5204
0	0	.11	0	300	293
1	.09	.11	2.8	815	450
2	.09	.11	2.8	962	750
3	.1535	.10	4.6	1135	873
4	.03	.10	0.9	1138	925

up quickly and provide substantial radiative feedback to the fuel pool. Consequently, the fire HRR begins to climb very quickly over the next few minutes. After 3 minutes, the HRR is calculated to be 4.6 MW. By 4 minutes, the fire has become ventilation controlled, and the COMPBRN-calculated HRR then drops to just under 1 MW.

As shown in Table 1, the COMPBRN-calculated HGL temperatures rise to a high level very early in the calculation. This result is, again, an artifact of the quasi-steady nature of COMPBRN, in which it is always assumed that the HGL has reached a steady-state. Obviously, this assumption will be in error during the first few minutes of a fire, when the HGL is developing rapidly. From the 2 minute mark and afterward, the calculated HGL temperatures are within 250 K of the measured values. This is reasonable in view of the quasi-steady nature of COMPBRN. By the 3 minute mark, the HGL temperatures have reached 1135 K. These very high temperatures result in very large radiative heat fluxes back to the fuel pool, and to the walls and ceiling. As a result, the COMPBRN model becomes unstable after the 4 minute mark and does not produce a solution.

The COMPBRN results reflect several of the shortcomings of the model, as discussed above. However, COMBPRN was not designed to handle very large, rapidly developing fires in small rooms. These results should be viewed in this regard.

3.5 E41.7 NDFM Results

The E41.7 calculations with the NDFM were performed on an IBM RISC 6000 machine. The time steps used were between 0.05 and 0.001 seconds. The total estimated CPU time required to model 4 minutes of the fire was about 50 hours. Because of the large CPU time requirements, only a single set of calculations was performed with the NDFM for the E42.2 test. As a result, there was no 'adjustment of parameters' used to obtain the following results.

To begin the NDFM calculations, the model was run with the ventilation turned on, but with no fire load (zero HRR) until a steady-state flow was achieved in the room. Then the fire was assumed to start (time equal to zero in the plots). Calculations were only carried out until 4 minutes was reached, since the COMPBRN results were being used to provide a basis for estimating the HRR for the NDFM calculations.

With a field model such as the NDFM, the HGL is described by many nodes. A rough description of the physical location of each point of interest is given below. A more detailed description can be found in the problem specification report [8].

Thermocouple number 5204 (CT5204) was located directly above the fuel pool, just below the ceiling. The calculated results for this thermocouple are in very good agreement with the measured values, as shown in Figure 3. The slight difference in the shape of the calculated and measured curves could be due to a difference in the rate of heat release used for the calculations, as compared to the test. This agreement is very good, considering the uncertainty in the HRR values and profiles used in the NDFM calculations.

Thermocouple number 5246 (CT5246) was located near the closed doors in the alcove, in the vicinity of the ceiling. Figure 4 indicates reasonable agreement between the calculated and measured gas temperatures at this location, with the calculated results underpredicting the test data by about 100 C. The trends in the two curves are very similar, although the calculated temperatures rise more slowly. A possible reason for this discrepancy is that some outflow may have occurred in the test in the vicinity of the doors, whereas the calculations assume a perfectly leak-tight boundary. Leakage around the doors in the test would have resulted in a larger flow of hot gases into this otherwise 'dead' corner, thereby increasing the local gas temperature.

Thermocouples 5290 and 5294 were located close to the junction of the main room and alcove. CT5290 was very close to the floor, and CT5294 was very close to the ceiling. For CT5290 (floor), there is excellent agreement during the first 2.5 minutes of the test, as shown in Figure 5. Both the NDFM calculations and the test measurements indicate that the HGL has not descended to this location yet. However, by the 3 minute mark the NDFM results indicate that the HGL has indeed descended almost to the floor, while the test results indicate otherwise. If there is some cold air infiltration near the base of the doors, a fresh supply of cold air would be drawn into the fire room right over CT5290, thus keeping it close to ambient temperature. However, the calculations assume zero infiltration around the closed doors, which allows the HGL to descend more quickly. This would explain the discrepancy between the calculated and measured results during the 3 - 4 minute time frame.

Thermocouple 5294 was located directly above CT5290, but very near the ceiling. Excellent agreement between the calculated and the measured HGL temperatures can be seen in Figure 6. The calculated temperatures are within approximately 25 C of the measured values over the 4 minute time period, reaching a maximum value of about 550 C.

In general, the NDFM results show very good agreement with the measured temperatures. Discrepancies between the calculations and the measurements are explainable in terms of gas

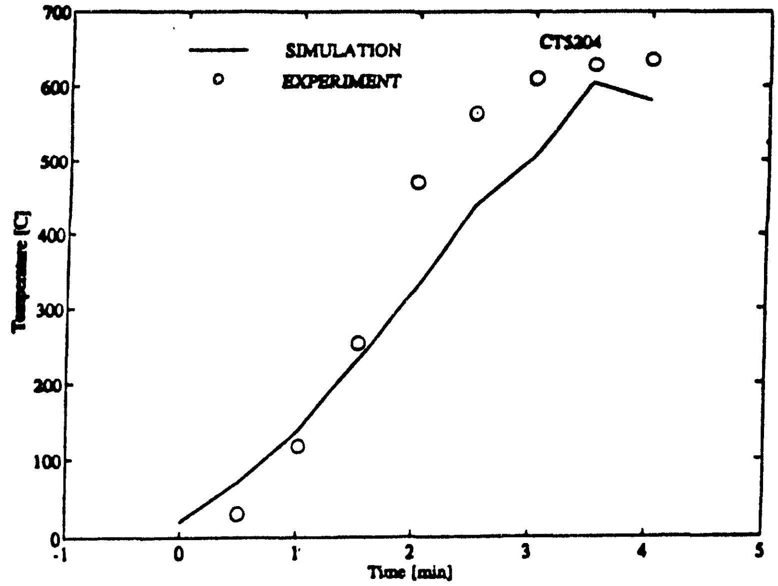

Figure 3: E41.7 CT5204 Temperature (Solid=NDFM, Dash=Data)

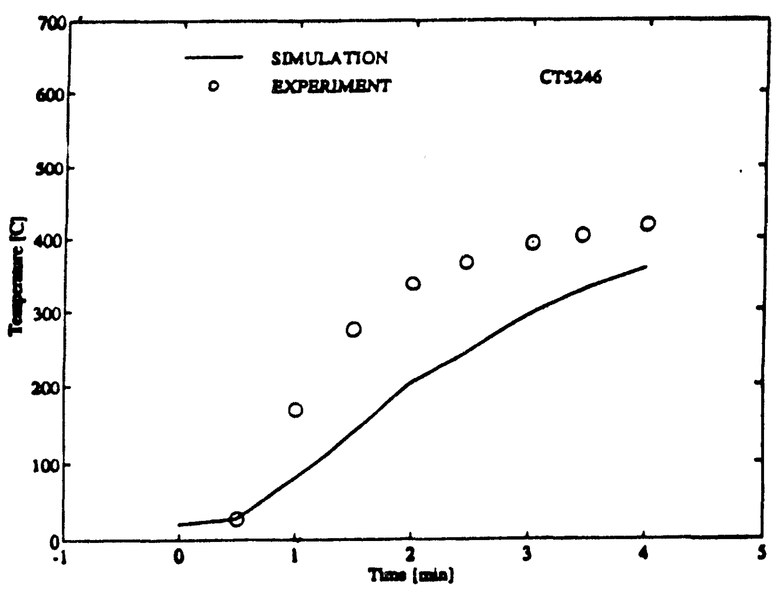

Figure 4: E41.7 CT5246 Temperature (Solid=NDFM, Dash=Data)

leakage around the doors. Since only one calculation was performed with the NDFM (no adjustment of parameters), such good agreement was not expected.

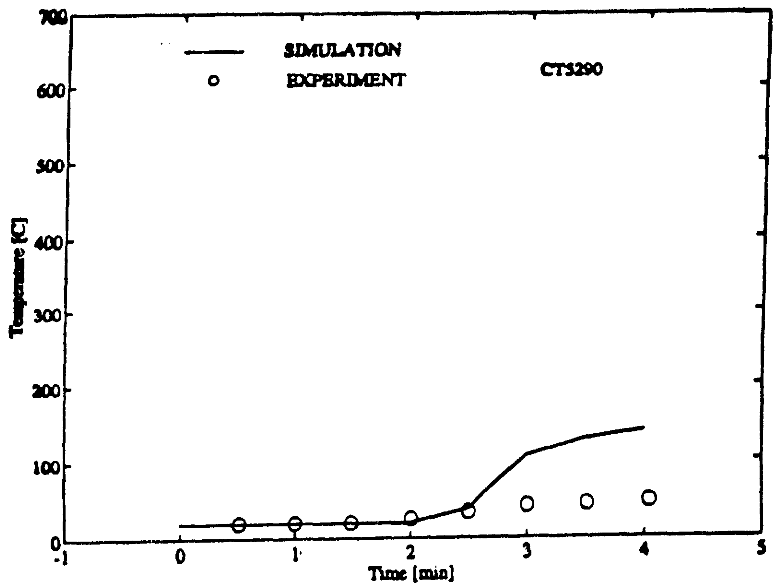

Figure 5: E41.7 CT5290 Temperature (Solid=NDFM, Dash=Data)

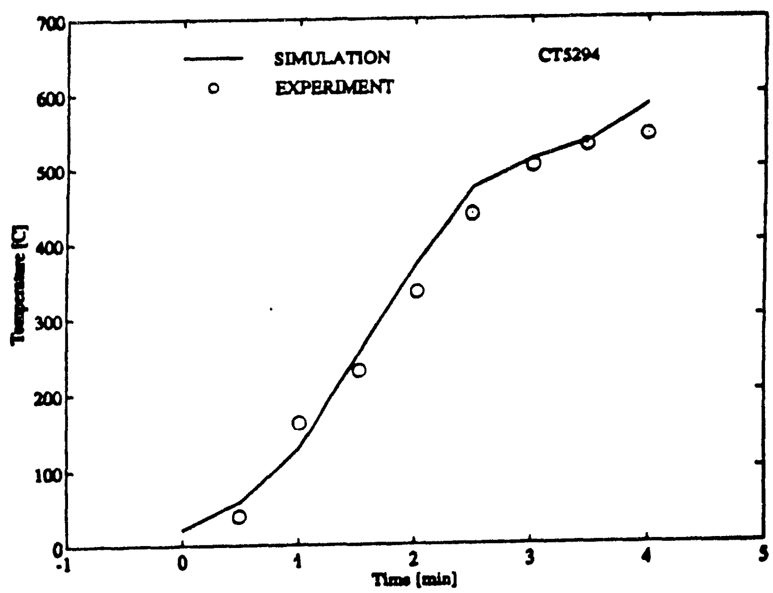

Figure 6: E41.7 CT5294 Temperature (Solid=NDFM, Dash=Data)

4. E42.2 Test Calculations

4.1 E42.2 Test Specification

The details of the test specification for test E42.2 are contained in the problem specification report [11]. Test E42.2 was a cable fire test with high forced ventilation at the 1500 level of the HDR containment building. The fire room was the same room used for the E41.7 test, so many of those specifications apply to this calculation as well. However, cable trays were added to the fire room to provide a source of combustible material (Figure 7). The ventilation rate for the fire room was specified as 1700 m^3/hr for the first 22 minutes of the test. During the first 9 minutes of this time period, the doors to the fire room were closed. After 9 minutes, one of the doors was opened for the remainder of the test. The material properties can be found in the problem specification report [11], along with the details of the PVC cable tray fuel loading.

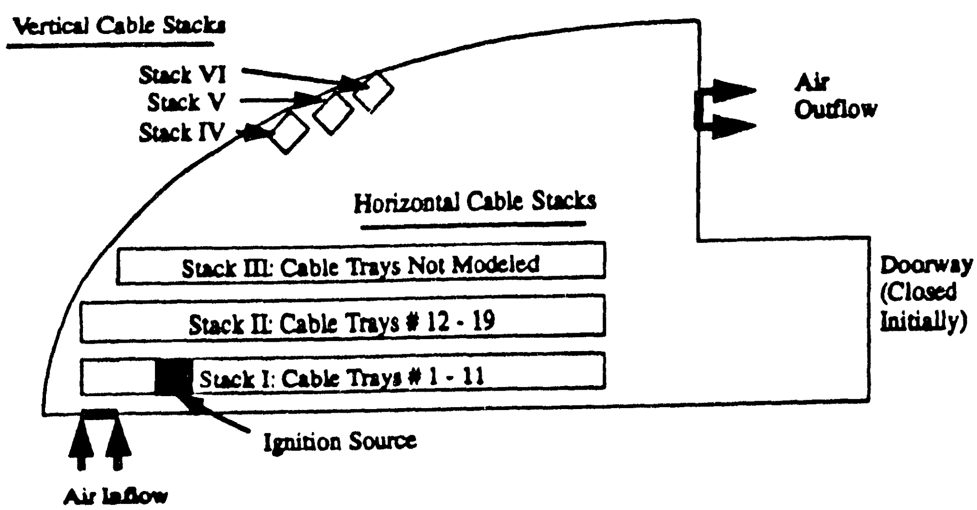

Figure 7: E42.2 Cable Tray Layout in Fire Room

4.2 E42.2 COMPBRN Input and Assumptions

The important assumptions relevant to the COMPBRN E42.2 input deck will now be stated. Only differences from the E41.7 input and assumptions will be mentioned.

Fire Room Assumptions

- Six walls of the fire room are modeled out to the doors (the doors are not included in the calculation). All of these walls are 4.69 m high. The total surface area of the walls is 97.4 m^2.

Of this, 82.8 m^2 is modeled as 0.275 m thick Alsiflex, with the remainder modeled as 0.4 m thick Alsiflex. The (x,y,z) coordinates of the wall centroids are given in the input deck, and correspond directly to the locations of the wall centroids shown in the specification report.

- The properties of Alsiflex are assumed to be: density = 130 kg/m^3, specific heat = 1000 J/kg/K, thermal conductivity = 0.1 W/m/K, and an absorptivity of 0.9.
- The forced ventilation rate used is 0.472 m^3/s. An initial temperature of 290 K was assumed for the walls, ceiling, and all cable trays.

Cable Tray Assumptions

- The cable trays that are covered with Alsiflex mats are not modeled in this simulation.
- Properties assumed for the cables are: density = 1715 kg/m^3, specific heat = 1045 J/kg/K, thermal conductivity = 0.092 W/m/K, and an absorptivity of 0.9.
- All eleven cable trays of Rack I are modeled. Each cable tray is 4 m long x 0.3 m wide, and has a thickness of 0.015 m. The cable thickness is chosen to represent a typical radius of one cable for calculation of ignition. Each of the cable trays is divided into 4 equal longitudinal sections, 1 m in length, for modeling.
- The cable trays are loaded with an amount of cable roughly equivalent to that specified in the specification report [11].
- In Rack II, trays 12 - 19 are all modeled in a similar fashion to those of Rack I. Only cable trays 12 and 13 were allowed to absorb energy from the fire and the HGL. The remainder of the trays in Rack II were covered with Alsiflex.
- No cables in Rack III are modeled, since most of them were consumed in previous tests.
- Rack IV is modeled as a single cable tray, 4.5 m long x 0.3 m wide x 0.015 m thick. It is divided into 4 equal longitudinal sections, 1.1 m each.
- Racks V and VI are not modeled because they are covered with Alsiflex.
- There was no radiation shielding of any of the participating cable trays from the hot gas layer. Because of the manner in which COMPBRN models shielding, it is not possible to prohibit thermal radiation to a tray from the hot gas layer without also prohibiting convective heat transfer from the hot gas layer.
- In terms of radiative heat transfer from one burning cable tray to another non-burning tray, this was only permitted if the non-burning tray was immediately above or below the burning tray, or off to one side of the burning tray. Trays that were above or below the burning tray, but shielded by an intervening cable tray, were not permitted to receive thermal radiation from the burning tray.
- The convective heat transfer coefficient for cable trays in the flames is assumed to be 23 W/m^2K.

Combustion Assumptions

- The heat of combustion for the cables was assumed to be 17 MJ/kg (at the upper end of what was measured and reported [11]). Calculations with 12 MJ/kg did not result in ignition of the surrounding trays. Burning parameters representative of PVC cable are used, and assumes the burn rate (kg/s per m^2 of cable surface) is equal to a constant (A) plus the product of another constant (B) multiplied by the incident heat flux (q") to the cable tray (in W/m^2). Or, mathematically, the burn rate = A + Bq", where A = 0.022 kg/s/m^2, and B = 0.186×10^{-6} kg/J.

- The combustion efficiency for the cable combustion is assumed to be 0.9 for these calculations. This number is very high compared to typical combustion efficiencies for cables burning in a large, open room. However, previous experience with COMPBRN III [2] has demonstrated the necessity of using a high efficiency for cable fires, to obtain reasonable flame temperatures.
- An ignition temperature of 450 C is assumed for the PVC cables. This value is consistent with the lower limit of Sandia test data on PVC cable. The results are greatly dependent on this parameter.
- The fire is started by igniting element 2 of cable tray 5 in Rack I. This element has a length of 1m, and is located in accordance with the pilot fire in the specification report.
- A buoyant plume entrainment coefficient of 0.0 is used, as recommended in the COMPBRN manual for a room with no open doorway.

A time step of 60 seconds was used for the calculations.

4.3 E42.2 COMPBRN Results

Because the COMPBRN III fire model is a zone model, the results of interest to us are the hot gas layer temperatures as a function of time, the fire heat release rate, the cable mass loss rate, and the length of time to ignition of the various cable trays. Unfortunately, COMPBRN does not allow one to simulate the case where a room is initially isolated, and then the doors are opened at a later time. Therefore, the calculations were not carried out for times greater than 9 minutes.

The mass loss rate as a function of time is shown in Figure 8. COMPBRN III significantly

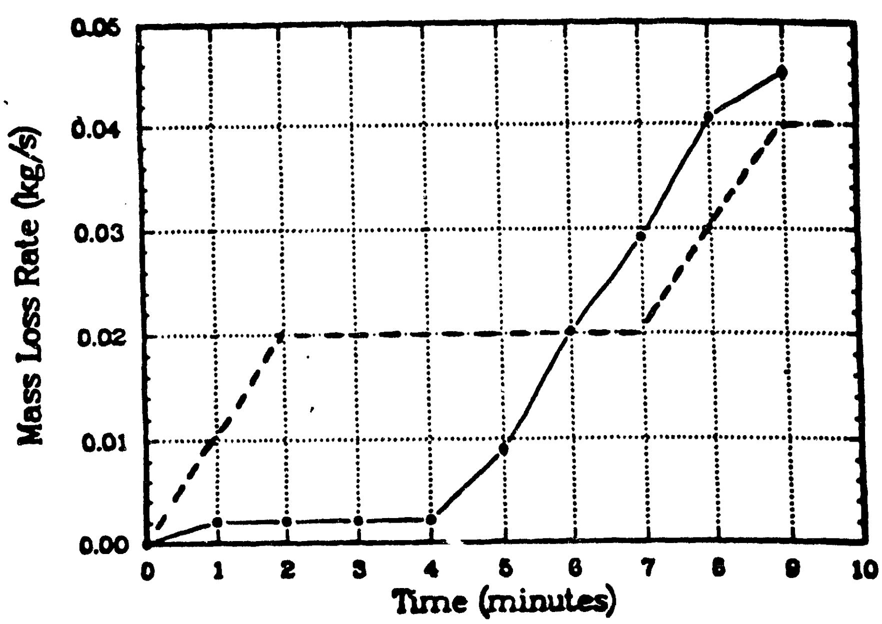

Figure 8: E42.2 Mass Loss Rate (Solid=COMPBRN, Dash=Data)

underpredicts the mass loss rate during the first 5 minutes of the test. The calculations indicate that there is very little flame spread during this time. The non-burning cables are pre-heating, but have not reached the ignition temperature. COMPBRN III does a reasonable job of predicting the cable mass loss rate during the 6 - 9 minute time frame, and slightly overpredicts the mass loss rate from the cable trays. The calculated and experimental results have the same slope during this period.

The calculated fire power output is shown in Figure 9. The fire size approaches 0.7 MW at the 9 minute mark.

The HGL temperatures are shown in Figure 10. The COMPBRN III results greatly underpredict the temperatures measured with thermocouple 5298 during the first 5 minutes of the test. This result is expected based on the large difference in mass loss rates between the calculated and measured values. However, it is interesting to note that COMPBRN calculates a HGL temperature of 405 C at the 9 minute mark, which agrees very well with the measured value of 440 C.

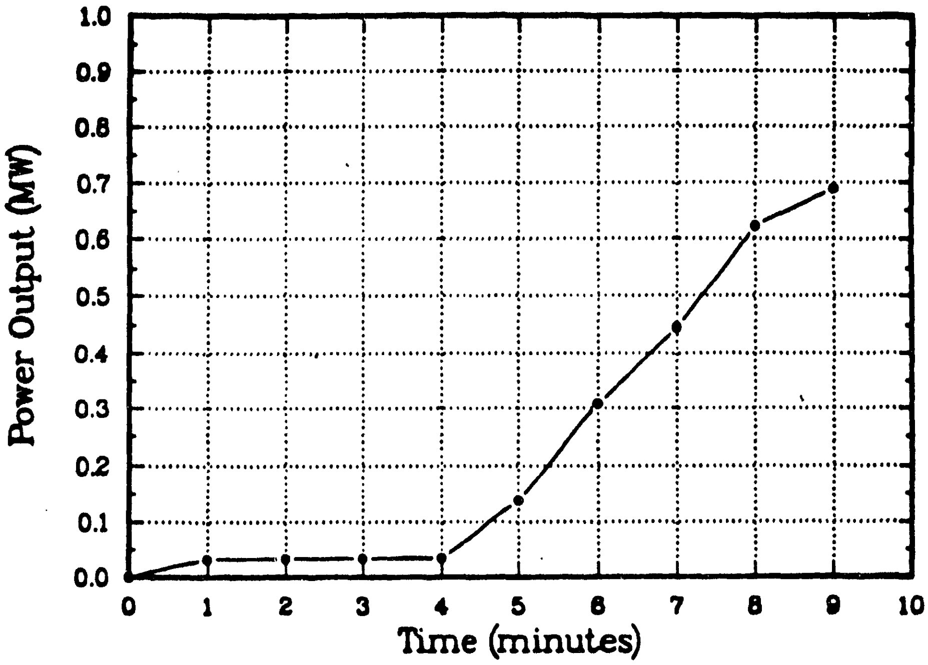

Figure 9: E42.2 Fire Power Output (COMPBRN)

In Table 2, the time at which each cable tray ignites is shown (in minutes). For cable trays which have not ignited by the 9 minute mark, the surface temperature of the cable trays is shown (in degrees Kelvin) at 9 minutes. Note that since each tray was divided into 4 segments in the COMPBRN model, the time/temperature is given for each of the 4 segments. From this table, we can deduce the following sequence of cable tray ignition and fire growth. One quarter of tray 5 of rack I is the only cable tray that burns during the first 4 minutes of the fire. At 4 minutes, the quarter of trays 2, 3, and 4 of rack I that are directly above the burning quarter of tray 5 also ignite. At 6 minutes, the quarter of tray 1 of rack I that is directly above the burning quarter of tray 2 ignites. From 6 to 9 minutes, no new ignitions occur. However, at 9 minutes much of the remaining cable insulation ignites, or is very close to ignition. At 9 minutes, 2 quarters (out of the remaining 3 quarters) of trays 1-5 ignite, so that 75% of these trays are burning or have been burned. Additionally, 3 quarters of cable tray 20 of rack IV have ignited at the 9 minute mark, and all of the remaining cable insulation is seen to be within 50 C of the assumed ignition temperature.

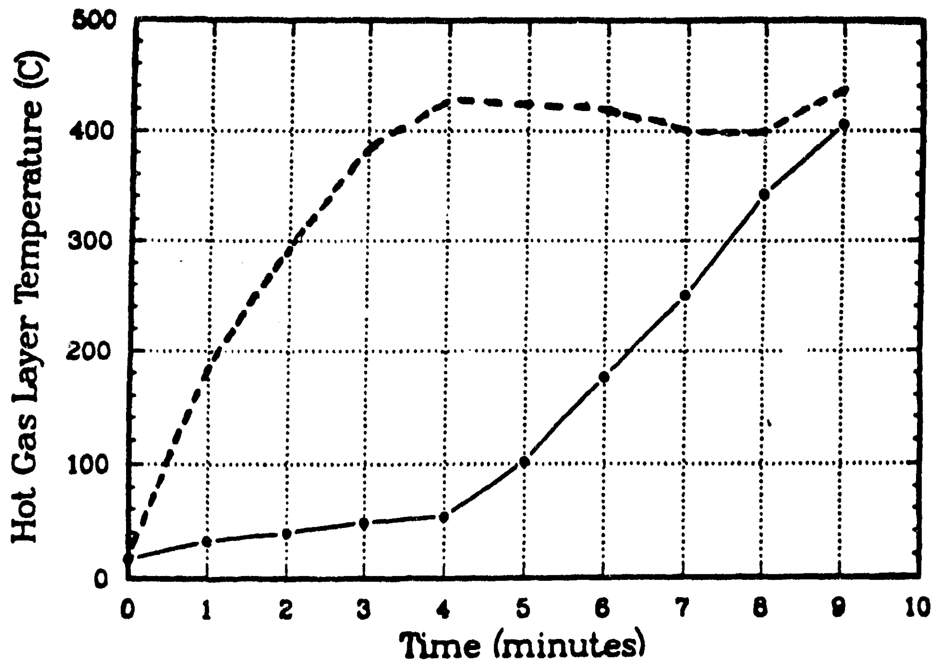

Figure 10: E42.2 HGL Temperatures (Solid=COMPBRN, Dash=Data)

Table 2: Cable Tray ignition/Temperature

Rack #	I[a]					II		IV
Cable Tray #	1	2	3	4	5	12	13	20
Segment 1	9 min	9 min	9 min	9 min	9 min	718 K	716 K	707 K
Segment 2	6 min	4 min	4 min	4 min	0 min	722 K	715 K	9 min
Segment 3	9 min	9 min	9 min	9 min	9 min	696 K	695 K	9 min
Segment 4	705 K	706 K	701 K	695 K	688 K	677 K	677 K	9 min

a. Numbers indicate the time at which the cable tray segment ignited, or the surface temperature of the cable tray at 9 minutes (if no ignition has occurred). An ignition temperature of 723 K was assumed for the calculations.

As seen in Table 2, a radical change in the fire environment is predicted by COMPBRN III at the 9 minute mark. All of the combustible cable insulation is either burning or within 50 C of the ignition temperature. It appears that the fire room is very close to the flash-over point. Unfortunately, no longer times could be modeled due to the limitations of COMPBRN III (the test specification indicated that the doors would be opened at this time in the test).

The results shown in Table 2 are in reasonable agreement with regard to the observed timing of cable tray ignition in the tests. The test results indicate that all of the trays directly above the initial burning tray ignited within 2 minutes of the first tray, whereas the calculated results indicate 4 minutes (or more) is required to ignite any of these trays. This partly explains the large differences in calculated and measured cable tray mass loss rate during the early part of the test. This may also be a result of the relatively long time step used in the COMPBRN calculations (1 minute).

It should be noted that the above results are a strong function of the PVC heat of combustion, ignition temperature, PVC thickness used, discretization of the cable trays, and combustion efficiency assumed.

5. Fire Modeling Difficulties

It is prudent to include a few words regarding the difficulties encountered in application of fire models to simulate nuclear power plant fires. Fire models have advanced greatly over the past decade due to a number of research and development activities by many researchers around the world. Tremendous progress can be seen if one compares the state-of-the-art in fire modeling with that of 10 years past. Some of the results presented in this study (and others at this conference) attest to the fact that fire models can be used to obtain results which agree reasonably well (and sometimes very well) with experimental data. As a consequence, there is a tendency for many of us to view fire modeling results with great confidence.

Unfortunately, there are many unknowns that enter into the application of a fire model to a particular problem. Many assumptions must be made, and poorly-known combustion parameters must be entered. As a result, the output of a fire model is **highly** dependent on the experience/judgement of the user. The results of any fire model should be viewed with great caution, and taking into account the model used (inherent assumptions, input parameters and modeling assumptions required), the validation of the model (range of application, weak areas), and the experience of the user (with modeling of fires in general, and with the specific model in question).

To illustrate this fact, the results obtained with COMPBRN III for test E42.2 varied all the way from the prediction of no ignition of adjacent cable trays after 9 minutes into the test, to the prediction of active burning of all cable trays less than 5 minutes into the test. The following is an incomplete list of the assumptions and parameters upon which the fire model results are greatly dependent. The intent of generating this list is to target areas where caution and experience are necessary in using fire models, and to target areas for future research.

- Geometric details, such as soffit heights, leakage around doors/windows
- Grid and time-step dependency of results
- Changes in geometry/boundary conditions/ventilation resulting from the fire environment
- Ventilation connections to adjacent areas
- Determination of the onset of ventilation-controlled burning
- Burning rate under ventilation-controlled conditions
- Burning models for liquid and solid fuels, including cable tray fire propagation
- Ignition criteria for solid fuels not well understood
- Combustion properties and combustion efficiency are poorly quantified
- Flame radiative fraction, soot production
- Validation of models against experimental data is not straightforward

The above list illustrates that there are many areas where the experience/judgement of the user will greatly influence the fire model results. It would seem that many of these problem areas could be circumvented by hard-wiring default values for them into a fire model. Unfortunately, the dependence of critical parameters and assumptions on the scale and type of a fire preclude the hard-wiring of many default values into any particular model. Thus, the experience/judgement of the user is of critical importance to the results obtained. This dependence of fire model results upon the users experience/judgement greatly complicates the comparison of fire modeling results, even when the same model has been employed by different users. The comparison of fire model results is, of course, even less straightforward when different models have been employed by different users.

The above comments are not meant to detract from the tremendous advances in fire modeling, or the usefulness of fire models. Fire models are very useful and much needed tools, but they are also very easy to misuse. The results should always be viewed with caution, and with regard to the experience of the person who generated them.

6. Conclusions

The Sandia calculations for HDR tests E41.7 and test E42.2 have been discussed. Resuts were obtained using both the COMPBRN III code and the NDFM. E41.7 results with COMPBRN III showed reasonable agreement with test data: the mass loss rate agreed well during the 0 - 2 minute time frame, and the HGL temperatures showed reasonable agreement later during the 2 - 4 minute time frame. However, the quasi-steady assumptions in COMPBRN III lead to very high HGL temperatures early in the test. These lead to large radiative feedback to the fuel pool, walls, and ceiling. As a result, the HRR is overpredicted during the 2 - 4 minute time frame, and the calculations cannot be carried out beyond the 4 minute mark due to instabilities in the code.

E41.7 calculations conducted with the NDFM showed very good agreement with thermocouple test data. This agreement is very surprising in view of the fact that the HRR was estimated based on COMPBRN results, and only a single set of calculations was performed with the NDFM (no adjusting of parameters to fit the data). Discrepancies between the calculated and measured results are explainable in terms of air leakage around the closed doors.

E42.2 calculations conducted with COMPBRN III differ significantly from the test results during the early portion (first 6 minutes) of the test. The time required to ignite the cable trays directly above the initially burning tray is calculated to be 4 minutes, whereas the trays ignited within 1 - 2 minutes in the test. As a result, the COMPBRN-calculated mass loss rate and HGL temperature is lower than measured during the first 6 minutes of the test. However, by the 9 minute mark, the mass burning rate and the HGL temperature are in good agreement with the measured values.

As seen in the results of this study, fire models can be employed to obtain reasonable (and sometimes very good) agreement with experiment. However, the output of a fire model is also shown to be highly dependent on the experience/judgement of the user. As a consequence, the results of any fire model should be viewed with caution, and taking into account the model used (inherent assumptions, input parameters and modeling assumptions required), the validation of the model (range of application, weak areas), and the experience of the user (with modeling of fires in general, and with the specific model in question).

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