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Validation of CFAST Software for the Hanford Site

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Fluor Hanford
P.O. Box 1000
Richland, Washington

Contractor for the U.S. Department of Energy
Richland Operations Office under Contract DE-AC06-96RL13200

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SB Ailes Fluor Hanford

June 2004

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Fluor Hanford
P.O. Box 1000
Richland, Washington

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Consolidated Model of Fire Growth and Smoke Transport (CFAST)

Qualification Report

On April 7, 2004 Hanford's Waste Management organization initiated a draft site report (Occurrence Report RL- -PHMC- -General-2004-0001) that a Potential Inadequacy in the Safety Analysis (PISA) had been determined to exist due to issues involving the validation and/or verification of CFAST software used to develop documents supporting the safety basis. In response to the PISA, each Hanford Project Organization instituted a USQ review and performed a safety review.

This report documents the results of an analysis performed to determine if sufficient verification and validation test data exist to support the use of the CFAST code for Safety Analysis at the Hanford Site. The analysis also identifies critical features, capabilities and interfaces to be validated for Hanford Site applications. The report is prepared in response to the Fluor Hanford Evaluation of the PISA (FH-0401116).

BACKGROUND:

The CFAST computer software tool is a fire modeling application developed by the National Institute of Standards and Technology that is capable of predicting the environment in a multi-compartment structure subjected to a fire. It uses an iterative, zone-based approach to calculate the time-evolving distribution of smoke and fire gases, and the temperature throughout a building during a user-specified fire. The program provides a broadly accepted approach to modeling fire growth and the spread of smoke and toxic gases, and has been demonstrated through extensive research to make reasonably good predictions.

The Department of Energy (DOE) has designated the CFAST computer code as an appropriate tool for use in preparation of a Documented Safety Analysis (DSA). DOE report DOE-EH-4.2.1.4-Interim-CFAST, *The CFAST Computer Code Application Guidance for DOE Documented Safety Analysis*, sanctioned the use of two National Institute of Standards and Technology (NIST) supported versions of this code, CFAST 3.1.7 and CFAST 5.0.1.

However, the Defense Nuclear Facility Safety Board (DNFSB), in Recommendation 2002-1, determined that there was no evidence that DOE had established software quality assurance requirements for CFAST and several other codes used for safety analysis. TECH-25 noted that a formal SQA plan has not been documented for CFAST and that the Verification and Validation Status of the code is not consistent with industry standards.

In response to the DNFSB Recommendation 2002-1, DOE issued a Software Quality Assurance (SQA) Implementation Plan that identified specific actions to resolve the identified SQA Program weaknesses. Commitment 4.2.1.3 of that Implementation Plan included a CFAST Gap Analysis which was released in January of 2004. The CFAST Gap Analysis Interim Report identified several deficiencies in the level of design, test and user documentation, user training, and problem reporting.

VALIDATION APPROACH:

The Fluor Hanford (FH) Evaluation of the PISA (FH-0401116) identified several versions of CFAST that were used in the site safety hazards analysis. For example, CFAST v2.0.1 was used for the Reference Fire Hazard Analysis at 327 Bldg. (HNF-SD-HT-FHA-003), and CFAST v4.0.1 was used for the fire analysis at WRAP (HNF-SD-W026-FHA-001).

In order to determine the validation approach, a review of CFAST applications at the Hanford Site was performed to identify critical characteristics for validation. Appendix A lists the facilities, the Fire Hazard Analysis document, the analysis performed using CFAST, and the consequence based on that analysis. The following facilities used CFAST for part of their fire hazard analysis:

- 100-K Area
- 212N
- 224-B
- 324 Bldg.
- 327 Bldg.
- B-Plant
- Canister Storage Building (CSB)
- Central Waste Complex (CWC)
- Cold Vacuum Drying Facility (CVDF)
- Plutonium Finishing Plant (PFP)
- PUREX
- REDOX
- T-Plant
- Waste Encapsulation and Storage Facility (WESF)
- Waste Receiving and Processing Facility (WRAP)

The FH evaluation also identified how CFAST was used to support the safety basis. The parameters determined by CFAST included predictions of four primary fire events:

- upper layer temperature,
- ventilation limit,
- radiant ignition, and
- flashover.

In all cases, the CFAST zone model was used to draw conclusions about structural steel failure and flashover in a compartment. These conclusions were critical in determining the impact of the postulated hazards analysis on building integrity, fire propagation, and radionuclide containment.

Understanding the fire hazard analyses conducted was important in determining what level of test data would be required to validate CFAST for Hanford Site use.

THEORETICAL BASIS:

Because no formal Verification and Validation Report exists for CFAST, the validation approach relied heavily on test data and research available in peer-reviewed journals. Unfortunately, much of the research that is available did not identify the specific CFAST version used. Understanding the theoretical basis for the CFAST model is important to be able to draw conclusions for the validity of newer versions. For example, CFAST versions 2.0.1, 3.0, 3.1, 3.1.4, 3.1.6, 3.1.7 and 4.0.1 were used at Hanford. Appendix B provides a description of the CFAST development history for each of these versions.

CFAST is a member of a class of models referred to as zone or finite element models. This means that each room is divided into a small number of volumes (called zones), each of which is assumed to be internally uniform. That is, the temperature and smoke and gas concentrations within each zone are *assumed* to be exactly the same at every point. In CFAST, each room is divided into two layers which represent the upper and lower parts of the room, conditions within a room can only vary from floor to ceiling, and not horizontally. This assumption is based on experimental observations that in a fire, room conditions do stratify into two distinct layers.

Fire modeling involves an interdisciplinary consideration of physics, chemistry, fluid mechanics, and heat transfer. In some areas, fundamental laws (conservation of mass, energy, and momentum) can be used, whereas in others empirical correlations or even "educated guesses" must be employed to bridge gaps in existing knowledge. The necessary approximations required by operational practicality result in the introduction of uncertainties in the results. The user should understand the inherent assumptions and limitations of the programs, and use these programs judiciously – including sensitivity analyses for the ranges of values for key parameters – in order to make estimates of these uncertainties. This assumption places some limitations on the model as shown in Table 1.

Table 1 - Identified Limitations Of CFAST

Limitation	Effects
Only one internal ambient state is permitted.	May lead to minor errors in predictions if there are large initial temperature differences among the compartments.
Compartments must be rectilinear.	Heat transfer via conduction and radiation will not be correct for surfaces which are not rectangular. Approximation methods that minimize this limitation are provided in Hoover et al., 2000.
Ceiling, floor and walls are each limited to a single set of thermo-physical properties.	Approximations must be made if the ceiling, floor or walls are composed of multiple regions having different properties.
Compartments have only one wrap-around wall, not individual surfaces.	May lead to significant errors if there are large differences in the properties of walls. Work-around methods have been devised in Hoover et al., 2000.
User-specified fire histories are required.	The user must know (or be able to accurately estimate), in advance, the development of the fire.

A detailed description of assumptions and limitations inherent in developing a zone model are described in the CFAST Technical Reference Manual (NISTTN1299).

VALIDATION RESULTS

The approach used to demonstrate the validity of the CFAST application for Fire Hazards Analysis was based on identifying test data available for earlier versions and then comparing the record of code changes for the version used at Hanford in order to determine if test data were complete. This section of the report will provide an overview of the test data available for the major changes to CFAST.

CFAST v1.2.1

A Theoretical Reference Manual is not available for versions prior to 1.6, although a User's Guide does exist[1]. Without the Reference Manual, there is no direct data on validation of CFAST v1.2.1. However, several publications are available that document the validation of intermediate versions of the code. The first clear reference in the literature to the CFAST Model Validation is found in a Fire Safety Journal publication by Richard D. Peacock[2]. This study, "Verification of a Model of Fire and Smoke Transport", compares the model prediction of a fire in a room with real-scale fire experiments.

The report compared the validity of CFAST version 1.2.1 for the following parameters:

- upper and lower layer gas temperature,
- layer interface position,
- gas species concentration,
- fire pyrolysis and heat release rate,
- room pressure, and
- vent flow.

The real-scale fire tests selected included the following:

- a single-room test using upholstered furniture as the burning item
- a single-room test using furniture as the fire source and adding a wall burning
- a three-room configuration with steady-state gas burner fires
- multiple-room configuration with larger and time-varying gas burner fires in a room-cooridor configuration
- elevated zone (seven-story hotel) with and without stairwell pressurization

Peak fire sizes included up to 3 MW with a total building volume of 140,000m^3.

For all the tests, times to peak values and times to 100 degrees C predicted by the model averaged within 25 seconds of experimentally measured values. In general the upper layer temperature and interface position predicted by the model was somewhat higher than the experimental measurements. Conversely, the lower layer temperature was somewhat lower for the model than for the experiments. Presuming conservation of energy, these three observations are consistent. A higher interface position gives rise to a smaller upper volume within a room. With the same enthalpy in a smaller upper volume, higher temperature predictions would result.

The report also determined that CFAST heat release and fire pyrolysis rates were excellent, within 5% of experimental values for the single-room and three-room with corridor tests. A comparison of measured versus predicted pressures found reasonable agreement in the data. However, the model underpredicted flow through openings due to the fact that the flow calculation is affected by flow damping in the model.

CFAST v1.4 (2/1/92)

No user manual or theoretical manual exists for version 1.4, however, there is good evidence that the improvements made in v1.4 are documented in a Fire Safety Journal article by W.W. Jones[3].
The report, "Improvement in Prediction Smoke Movement in Compartmented Structures" describes improvements made to model vertical flow and mechanical ventilation. As shown in Appendix B, version 1.4 was modified to add vertical flow and mechanical ventilation and improve the radiation transport scheme.

The Jones report documents the theoretical basis for the changes, defines the predictive equations, derives the equations for a two-layer model, and provides a comparison of the various types of flow that can occur in a building. The report concludes that the 4-wall model is a significantly better simulation of radiation flux when different wall materials are used as boundaries for the ceiling, walls and floor. However, the report is limited to theoretical predictions and parameter sensitivity studies and does not validate the model against experimental or empirical data. Although such studies are not relevant to a strict validation of the model, they do serve a useful purpose in demonstrating how reliable the model is over its operational range.

CFAST v2.0.1

A comprehensive study reported by Alvord[4] in NIST IR 5705 compared three CFAST versions through the use of a documented set of test files. This study used 107 CFAST input files using CFAST versions 1.4, 1.6.4, and 2.0.1. The test cases were a large sample of disparate scenarios that tested many different parts of the fire model. The test method served as an excellent regression test to determine the impact of changes between the code versions. However, the Alvord report did not attempt to quantify the differences in the predictions of the critical parameters.

CFAST v3.1

Extensive model validation experiments are available for version 3.0 and later of CFAST. In addition, a comprehensive Theoretical Manual (NIST TN 1299[5]) exists for this version. The Theoretical Reference Manual provides five validation test problems developed to demonstrate acceptable software performance. In addition to the validation problems, the manual provides an extensive description of CFAST research comparing previous model predictions with experimental data.

Most importantly, the test problems were identical to those run for version 1.2.1. This allows a comparison of how changes in the model have affected its ability to predict layer temperature and interface position, heat release and fire pyrolysis rate, pressure and vent flow. A comparison of the v1.2.1 results with the v3.1 results determined that they were identical. This comparison, demonstrated that the code changes since version 1.2.1 had not adversely affected the model predictions.

Further research conducted in 1996 through 1998 further validated the model for more complex fire environments. JL Bailey[6] and W.W. Jones[7] reported the results of an enhancement to v3.0 to account for conductive heat transfer through metal decks and bulkheads aboard ship. The studies compared the results of the new model with real-scale fire tests conducted aboard the ex-USS Shadwell, the U.S. Navy's Research and Development Damage Control Platform. The Shadwell experimental data used for the model validation were part of the Internal Ship Conflagration Control (ISCC) Program. Reproducibility in the experimental data was excellent, as was the comparison between the model-predicted, and experimentally determined compartment temperatures. The comparison did indicate that during the early stages of the fire, the far-side temperatures were under predicted. This was also reported by Bailey[6] with the conclusion that the under-prediction was indicative of a heat capacity which is too high and conductivity which is too low.

In addition to actual experimental data, extensive research has been conducted to understand the physics of complex fire models. A list of relevant studies are provided in Appendix C. These studies systematically evaluated the effect of discrete model changes on fire growth predictions. Such studies by Quintiere[8] and Babrauskas[9] considered the effect of room openings on fire plume entrainment and wire and cable reaction to fire tests. This research demonstrates that the zone model concept adequately covers a wide variety of phenomena and are well suited to investigating most effects of fires in buildings. The caveat is that when detailed information about a flow field or temperature distribution is needed, use of a more detailed model as provided by computational fluid dynamics is required. For most other situations, though, the ability to model whole building systems provides a level of detail that is sufficient.

Sensitivity analyses performed by Peacock et.al.[10], studied how changes in model parameters affected the results generated by the CFAST model. Model predictions may be sensitive to uncertainties in input data, to the level of rigor employed in modeling the relevant physics and chemistry, and to the accuracy of the numerical treatment. The purpose of the sensitivity analysis was to determine:

- the important variables in the model
- the computationally valid range of values for each input variable, and
- the sensitivity of output variables to variations in input data.

The sensitivity analysis considered the sensitivity of the model to small and large changes in input parameters, and evaluating the sensitivity of the output to changes in a single parameter value. For example, Peacock[10] demonstrated that the heat release rate had much more of an effect on the peak temperature than vent width. This research also demonstrated that other model inputs, including room volume and vent size have lesser effects on a range of predicted outputs. The sensitivity analysis demonstrated that CFAST v3.1 can provide excellent model predictions over a wide range of simple and complex applications.

Paul A. Reneke et.al.[11], demonstrated that an examination of comparisons of CFAST predictions with experimental data support the conclusion that CFAST is generally capable of producing good predictions for gas layer temperature, interface height, and boundary temperature. The study also demonstrated the important role of heat release rate estimates and expert judgement in the selection of input data as well as the evaluation of the model runs. The CFAST model usually predicted upper layer temperatures which were higher than the experimental results, though the difference was typically less than 50 degrees C. The high upper layer predictions in part were attributed to the method for calculating heat losses through the compartment boundaries. Reneke[11] reported that the high upper layer predictions in part may have been caused by the method of calculation of heat losses through the compartment boundaries. In addition, experimental results showed that heat release rates varied with ventilation configurations by as much as a factor of 3. This research indicated that the wide practice of using free burn heat release rate data in compartment fire predictions can result in over prediction of compartment fire conditions.

Finally, a Verification Test Report for CFAST 3.1.6 was published by the Westinghouse Safety Management Solutions LLC in March of 2002. The test report, WSRC-TR-2001-00405[12], described the primary verification exercise used to check the functionality of CFAST and its user interface program, FAST. The verification test included comparison of CFAST/FAST predictions based on the first scenario from the recently completed benchmark exercise from the *International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications*. The test problem was a relatively simple baseline that could be easily replicated for verification of initial installation of the FAST code. Selection of this problem also provided a verifiable baseline that could be compared to other user results.

The sample problem modeled a relatively small fire in a large room with a closed door. The target was a single power cable with a diameter of 50 mm located at the bottom left corner of a cable tray. The input parameters, which were presented in the Benchmark Exercise, were provided as an input file by Dr. Monideep Dey, NIST/NRC. The input data file was reconstructed for the verification effort.

The problem provided predictions of room temperature, ventilation through a narrow gap, oxygen consumption and target heat flux. Table 2 provides a list of capabilities that were evaluated by the verification test. The sample problem did not address oxygen limited fires or post-flashover fires.

Table 2-- FAST Capabilities and priority for their evaluation

Parameter	Validation Importance	Priority for Validation
Upper layer temperature	High	1
Horizontal opening ventilation	High	2
Fire curve database	High	3
Vertical opening ventilation	High	4
Lower layer temperature	High	5
Thermophysical data base	High	6
Oxygen content	High	7
Target temperature	Medium	8
Target heat flux	Medium	9
Fans (forced convection)	Medium	10

The test compared the output provided by NIST with the output from the WSRC verification effort. Most of the parameters evaluated had a relative difference of less than 0.01 percent, which was considered acceptable. The parameters Ambient Target (1), Floor Target (1) and Target (2) were not verified due an ambiguity regarding their specifications. Furthermore, the parameters for N2, CO2, CO, HCN, HCl, TUHC, and OD were not verified, as the production of these species were held to zero and thus not considered in the simulation. Some variation was identified for the following parameters:

- Pressure
- Target Convection
- Lower Inflow
- Lower Outflow

The parameters listed in Table 2 were verified for a specific sample problem involving a fire that did not approach flashover conditions. In most cases, the normalized (percentage) difference between the test case and the base case was below 0.01 percent. The largest difference was 1.56 percent, which was for the room gage pressure. This large normalized error, and most of the other large normalized errors, were due to the fact that the calculated parameter was so small (i.e., division by a value close to zero). In terms of the applications for which the CFAST model will be used, such errors are considered negligible.

CFAST v4.0.1

Floyd[13] provide a detailed comparison of CFAST predictions compared with real-scale fire tests at the Heiss-Dampf Reactor (HDR) facility in Germany. From 1984 to 1991 a total of four fire test series divided into seven fire test groups were performed inside the HDR facility. The fire tests consisted of the T51 series consisting of eleven propane gas tests and three wood crib tests, the T52 series consisting of four hydrocarbon oil pool tests, the E41 series with ten hydrocarbon oil pool tests, and the E42 series consisting of three cable fire tests.

In the described tests, Floyd[13] determined that CFAST made good predictions of near-field temperature and gas concentration. However, the model results showed a number of non-physical behaviors in the form of discontinuities in temperatures and gas-concentrations near the start and the end of the fire. As a steady-state combustion process, well supplied with oxygen, sudden sharp increases and decreases in these quantities did not occur as expected. The observed phenomena appeared to be related to shifts in the layer height prediction, which drove the temperature and mass flow solver.

For the T51 test, the upper layer temperature was overpredicted consistently by 150 °C. However, this was within 17 % of the measured value. The model did show a sudden increase in rate of temperature rise during the last five minutes of the fire, which resulted in an overprediction of 30 %. During this period, the layer height shifted 0.75 m toward the ceiling. The CFAST lower layer temperature predictions were well within the range of the measured data, however, the post fire cooldown was not matched as well in the lower layer as it was for the upper layer.

The upper layer predictions exceeded the measured data by a maximum deviation of 23 °C. Even though the model showed reasonable deviations, the trends shown were not entirely reasonable. The model reached its peak temperatures at 50 minutes into the fire whereas the data did not peak until 60 minutes. However, the temperature discontinuities seen in vertical flowpath were not seen in the velocity profiles.

For the T51 test Gas Concentration Predictions tracked quite well with the data for the first 50 minutes of the fire, within 10 %. However, in the last ten minutes of the fire the predicted concentration dropped rapidly until it was almost 6 v/o (volume percent or mole fraction) below the data. Although the model predicted a partial recovery in the post-fire oxygen concentration, it did not come close to predicting the near complete recovery in oxygen concentration as indicated by the data.

The model made good predictions for both the upper and lower layer for carbon dioxide concentration. In the upper layer they were within 16 to 30% of the measured data, except for the sharp increase in concentration seen during the last ten minutes of the fire. In the lower layer, the model did not show a rise in CO_2 concentration until 45 minutes into the fire. At this point the predictions all rose quickly to match the trend of the measured data only offset by 0.5 v/o (volume percent).

For Test Case 52 the CFAST model predicted gas concentrations, near-field and dome velocities, and dome temperatures well. However, far-field temperatures and velocity predictions continued to be conservative (e.g. high). And in the far-field, temperature predictions showed unphysical behavior. For example, upper layer temperatures showed no increase for 8 minutes while the lower layer saw a 10 °C. At 8 minutes the upper layer jumped instantly to the same temperature as the lower layer followed by a decrease in the lower layer temperature.

CFAST over predicted the volume average temperature substantially in the fire level hatch upper layer temperatures. However, the post cool fire cool-down was well predicted. During the first five minutes of the fire the lower layer predictions exceeded the upper layer predictions. After this point the predicted layer height decreased rapidly and the lower layer predictions were well within the measured data; however, the layer height at this point was below the measured data locations.

In the upper layer, CFAST velocity predictions were near the average of the data during the fire. However, after the fire the model showed an instantaneous drop to zero, the data clearly indicated that a small region of the upper doorway still had a substantial outward flow of 1 m/s at 60 minutes. In the lower layer, the model overpredicted the velocity by greater than 75 %. Also, during the post-fire cooldown the model predicted a small outward flow whereas the data indicated that a small inward flow still existed in the lower layer. CFAST predictions for velocities leaving the fire room level and entering the dome were about 50% below the measured velocities. However, since the upward flow did not actually occupy the whole hatch, the CFAST predictions were correct in terms of mass flow.

The CFAST prediction for oxygen up until the peak of the fire was excellent as compared with measured oxygen concentration. However, after this point in time the predictions and the data diverge. After the fuel addition starts, the CFAST prediction slowly decreased to 8 volume percent. Unfortunately, CFAST did not successfully predict the oxygen concentration in the fire room during the fire. The data, however, showed a quick recovery to the original concentration after the fire was terminated, followed by a slow decrease of 2 volume percent as the global circulation loop mixed with the oxygen-depleted atmosphere deposited in the dome throughout the facility. In addition, the code did not predict the CO2 concentration well.

In general, gas concentrations, near-field and dome velocities, and dome temperatures were well predicted by CFAST models. Far-field temperatures and velocities were not well predicted, however, CFAST predictions in these regions were conservative.

One of the major changes in v4.0.1 was the addition of a Corridor Flow submodel to more accurately predict the flow of smoke down a corridor which has an impact on fire protection issues such as detection and escape time. Bailey[14] reported the results of a comparison of CFAST v4.0.1 model predictions against real-scale experiment data conducted on board the ex-USS SHADWELL. Both the original model and the enhanced model predicted that the hot gases from the Fire Compartment would enter the passageway outside the fire source location at 18 seconds. This was expected because the differences between the models occur after this point. The enhanced model provided a more realistic prediction of the delay that occured as the ceiling jet traveled down the passageway. At the point the ceiling jet entered the passageway, there was a sharp increase in temperature prediction that closely matched the experimental data. The predicted temperature for the new submodel agreed remarkably well with the experimental data until the ceiling jet reached the end of the corridor 48 seconds from ignition.

VALIDATION SUMMARY:

The test data described in this report demonstrate that an examination of comparisons of CFAST predictions with experimental data support the conclusion that CFAST is generally capable of producing good predictions for gas layer temperature, interface height, and boundary temperature. The CFAST model usually predicted upper layer temperatures which were higher than the experimental results, though the difference was typically less than 50 degrees C. The discrepancy in high upper layer predictions in part were attributed to the method for calculating heat losses through the compartment boundaries. The data also demonstrated the important role of heat release rate estimates and expert judgement in the section of input data as well as the evaluation of the model runs.

The new submodel incorporated in version 4.0.1 has improved the ability of CFAST to predict flow of smoke down a corridor. However, the review of the validation data and research data available in the open literature demonstrated that far-field mass flows, temperature changes, and the propagation of gas species are not well predicted by CFAST. What is clear, however, is that CFAST is a robust performance-based code system. Hand calculations are not going to have the precision to analyze an entire structure, and field modeling methods are currently computationally too expensive to model multiple fire scenarios in large structures for long periods of time or to model very large, complex, structures in their entirety.

The review of validation results demonstrated that although weaknesses were identified in gas propagation and far-field mass flows, these parameters are not critical to the fire hazard analyzes performed at Hanford. And although far-field temperatures were often overpredicted by CFAST, these results are conservative from a fire hazard viewpoint and did not adversely affect the safety basis for the facilities under study.

The level of theoretical basis, user and test documentation available for version 3.x is far superior to earlier versions. In addition, updates to v3.1.7 have been developed to resolve errors in the dimensioning of the solver workspace. Although v4.0.1 has implemented a new submodel to handle transport down a passageway, no technical reference manual or user manual exists for this version. Because there is a large volume of analyses and experience with version 3.1.7, extensive user and technical reference manuals are available, and a formal validation test has been documented for version 3.1.6, it is recommended that version 3.1.7 be used to support fire hazard analysis.

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Appendix A

FACILITY	FHA REFERENCE	EVENT DESCRIPTION	CURRENT CONSEQUENCES
CWC	HNF-12206, 6.1.1.3/4.01	Large Truck Fire, 10MW	Building breached, various modes of waste container failures
WRAP	HNF-SD-W026-FHA-001 .	Diesel Fire in TRUPACT Bay	Some structural damage,
WRAP	HNF-SD-W026-FHA-001,	Supercompactor Fire; 18MW	roof and structural failure
WRAP	HNF-SD-W026-FHA-001 .	49L forklift fire	No structural damage
WRAP	HNF-SD-W026-FHA-001	49L forklift fire + wooden boxes	No structural damage
WRAP	HNF-SD-W026-FHA-001	49L forklift fire + 870 lbs HDPE	Flashover: roof and structural failure
T Plant	HNF-SD-CP-FHA-002	Medium Fire: 5.6MW	Flashover with HEPA failure
T Plant	HNF-SD-CP-FHA-002	Large Vehicle Fire, 88 MW	No impact if pallet separation >1.5m
T Plant	HNF-SD-CP-FHA-002	Medium Vehicle Fire; 6.4MW	Flashover does not occur
T Plant	HNF-SD-CP-FHA-002	Small Fire; 2706T Greenhouse	All MAR burned
WESF	HNF-SD-WM-FHA-019	Truckport Fire	Truckport structure, FSS failure
WESF	HNF-SD-WM-FHA-019	Hot Cell Fire; 7.5MW	contamination in all hot cells
CSB	HNF-SD-SNF-FHA-002	crane hydraulic fluid fire, MHM shield/bumper fire	structural damage to building, MCO
CVDF	HNF-SD-SNF-FHA-003	Transporter fire in bay	structural damage to building
K Basins	HNF-SD-SNF-FHA-001	Diesel Fire in transfer bay	structural damage to building
REDOX	Appendix C of BHI-01142	Product Receiver cage fire	Minor environmental release
B Plant	Appendix C of HNF-14804	canyon fire	Minor release to the environment
324 Bldg.	HNF-SD-HT-FHA-002	Large fire in a hot-cell	Low release of radiological inventory
327 Bldg.	HNF-SD-HT-FHA-003	Liquid pool fire, Hot-Cell fire.	Low consequences without controls.
212N	BHI-01192	burning of the decking and wooden features of the building.	minor release to environment
PUREX	CP-14977	N Cell fire	Fire does propagate throughout the canyon
224-B	Appendix B of CP-18179	fire involving the entire building	Minor release to the environment

Appendix B

Code Revision History

Changes for Version 5.1.1 (May 1, 2004)

- Corrected error in the HCR (hydrogen/carbon ratio) calculation. It introduced about a 6% error into the pyroloysis calculation.

Changes for Version 5.1.0 (March 1, 2004)

- The oxygen calculation was changed to an oxygen to carbon ratio instead of an oxygen to fuel ratio.

Changes for Version 5.0.1 (May 7, 2003)

- Flow was not being reported correctly in some cases. The calculation was correct, but the output from cfast (/rf) was not updated when a vent opening decreased to zero.
- The vertical flow calculation has been fixed. The symptom is that it the pressure in a compartment connected by VVENT was never updated.

Changes for Version 5.0 (11/1/2001)

- The number of points in a time history has been increased.
- Fix a printout error: the size of the fire was reported incorrectly in some cases.
- The workspace for the solver was not dimensioned correctly, so CFAST could not do 30 compartments. This has been fixed.

Changes for 4.0.1 (3/1/00)

- This release runs as an application under the Windows series of operating systems.
- New phenomena: horizontal heat conduction (wall/wall) (HHEAT), horizontal smoke flow in corridors (HALL), variable geometry for compartments (ROOMA, ROOMH).
- Fonts must be in the "font" directory off the "bin" folder.

Changes for Version 3.1.7 (10/1/01)

- The workspace for the solver was not dimensioned correctly, so CFAST could not do 30 compartments. This has been fixed.

Changes for 3.1.6 (11/01/99)

- Add "constrained/with flashover" to FAST as a fire type

Changes for 3.1.5 (04/01/99)

- Build is included, along with sample files and documentation
- Reportss has been fixed to include target temperatures in the output

Changes for 3.1.4 (07/01/98)

- Fix compatibility between FAST and CFAST. The history files were not compatible

Changes for 3.1.3 (04/01/98)

- Fix fonts for FAST (remove wddraw from an explicit include in fast and fastlite)
- Spreadsheet output - data file naming error
- Incorrect entrainment when the fire is in the upper layer (dofire) (variables not defined)
- Eliminate heat conduction thru the ceiling/floor connection to the outside (nputp)

Changes for version 3.1.2 (01/01/98)
- Fix boundary condition for vertical flow to the outside

Changes for version 3.1.1 (10/01/97)
- Fix font interface for metawindows.
- Removed O(n**2) data structures (about 40 arrays)
- Added a non-rectangular room option - roomhgt, roomarea are the key words
- Fixed wind - wind now applies to vents rather than rooms (couldn't do from vs back)
  - effect of wind was zero for ground floor rooms. wind induced pressure rise is now calculated at the average of the floor and ceiling elevation
- Initialize inside and outside pressure and temperature to the same lapse rate
- Output warning for excessive number of small time steps
- Add BLACK option to have atmosphere behave as a blackbody
  Note: reworking SHAFT option to use only 3 equations per room
- Modify hybrid code to conform to new les heat loss algorithm

Changes for version 3.0 (01/03/96)
- Totally new user interface for CEdit.
- Add flame height calculation to report
- Add flame spread algorithm
- New module, reportss, which uses the same format as report, but puts the output into a spread sheet (ascii delimited text) output format
- New phenomena added: ceiling - floor heat transfer for intercompartment heat transfer, CFAST keyword CFCON.
- New phenomena added: ceiling - heat transfer to targets. Program calculation of object Temperature and impinging heat fluxes can be printed. CFAST keyword is TARGET
- Added reporting option for wall and target heat flux printout. New output options are /r:winfstp. W is now wall and target heat fluxes and P is now wall temperature profiles.
- Improved stability of mechanical ventilation routines so that solution converges over a wider range of input values.
- Add <esc> option to CPlot (for script files, primarily)

Modules in the release

cfast (main model)
fast (gui data editor)
cplot (plotting package)
report report utility
reportss utility to generate spread sheet format
reportg graphics playback utility
bintoasc convert binary history files to ascii text files
compare compare two separate cfast runs (using ascii text files)
compinfo summarize output from compare

Changes to version 2.1.1/H1.2 (01/01/95)
- Fixed CFAST so that optional ceiling jet calculation would not take into account lower wall surfaces. Too much energy was lost through the lower wall.
- Corrected EXITT and SURVIVAL to access the layer interface height correctly.
  Prior to this fix, layer depth was always zero, making smoke detection inoperable.

- Fixed several formatting issues in CEDIT. Some large number were written such that CEDIT generated data files could not be read by CEDIT/CFAST.
- Fixed thermal properties in several example data files to be consistent with current THERMAL.DF file.

Changes to version 2.0.1/H1.2 (07/01/94)
- Corrected write of vertical vent information to .DAT file in CEDIT. For large vent area, old format would merge two fields together resulting in read errors with the model.
- Tightened differential equation solver tolerences to correct calculated species concentrations for one test case. This may make the model run slower when conditions are rapidly changing, but the answers should be more correct.
- Corrected interaction between fire size and plume entrainment.

Changes to version 2.0.1 (2/13/94)
- Corrected flow through horizontal openings (VVENT). In some test cases (where significant flow occurred from upper room to lower room), model would calculate extremely low temperatures in the lower room.
- Corrected species mass balance. For very large fires in small rooms, species mass fractions would not sum to unity when fire became oxygen limited.
- Printed output file is now placed in the data subdirectory along with the input data file.

Changes to version 2.0 (August 23, 1993)
- Code restructured for future addition of a flame spread model.
- Consolidated calculation of hazardous conditions (and colors for plotting of them).
- Added a new THERMAL.DF file taken from Incorpera and DeWitt.
- New conduction routine.
- New convection routine. Use Watcom Fortran compiler.
- Printout routine has been totally rewritten to provide additional information with a consistent format.

CFAST version 1.6.2 (December 1, 1992)
- A faster initialization routine, selection rules for vertical flow, use Pharlap memory expander, supports more display drivers, bug fixes. Mechanical ventilation is tightly coupled with vertical and horizontal flow routines.

CFAST version 1.5 (June, 1, 1992)
- Added object specification (heat loss, ...), a more robust ODE solver (DASSL), restructured code to include physical interface routines for each physical phenomenon, CEdit support for all modelling features.

CFAST version 1.4 (February 1, 1992)
- Added multiple fires, history file compression, extended memory, vertical flow, multiwall radiation model, distributed mechanical ventilation ducts, ceiling jet and 3D positioning of fires.
- Increased number of compartments to 15.

CFAST version 1.0 (May 1, 1990)
- An amalgam of FAST 18.5 and CCFM -- functionally equivalent to FAST. Same physics as FAST, but more modular like CCFM.

Appendix C

List of available CFAST research data

- Calculating Flame Spread on Horizontal and Vertical Surfaces.
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