Idaho Cleanup Project

CFD Modeling to Support Waste Sack Storage at INL

Bruce Kanirie
ICP Fire Marshal

Bruce Campbell
Vice President, DOE Services

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Fire Modeling

ARP Structural Enclosure

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Problem

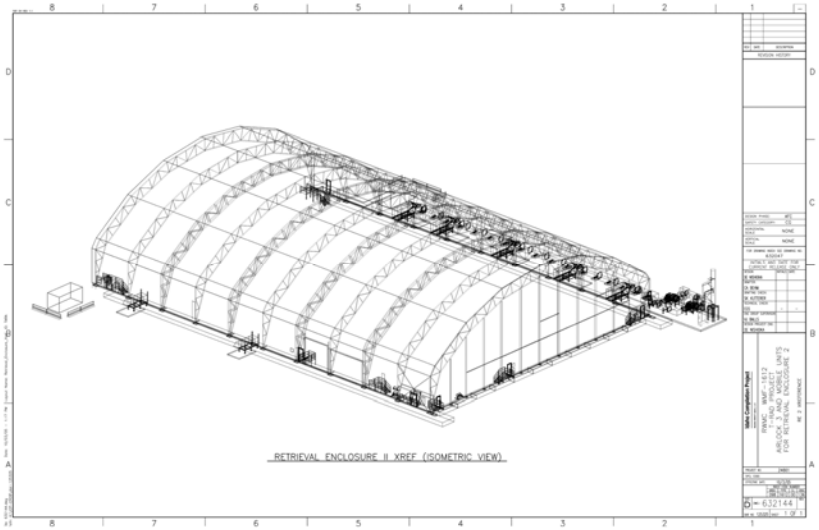
- The tents are provided with smoke detection systems (AnaLASER). The high ceiling heights and fabric structure of the tents pose a challenge for designing, installing, and maintaining a conventional smoke detection system. The ICP has installed what they believed to be an equivalent smoke detection system, but not in a listed configuration.

Problem

- HAI was asked to examine the effectiveness of the installed smoke detection system to detect fires within the containment tent. HAI used the Fire Dynamics Simulator (FDS) computational fluid dynamics (CFD) model, developed by the National Institute of Standard and Technology (NIST) to evaluate detection times of fires. The model was also used to determine the environmental conditions that exist during the simulated fires.

Tent

- The existing tent used by the ICP (more are to follow) is a large fabric structure with metal trusses for support. The containment tent is approximately 240 ft (73.5 m) long by 170 ft (52.1 m) wide. The tent has a semi-circle shaped cross section with the center being 58 ft (16.2 m) high and minimum sidewall height of 20 ft (6.1 m)



HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

HVAC

- An HVAC system is designed to provide a filtered discharge path for the air inside the tent. This system provides heated air in the winter. The air is filtered through five 4 ft x 4 ft HEPA exhaust points located along the north side of the tent. Air is supplied through two heater units (3 ft x 3 ft openings) along the south center and south west edges of the tent and from the waste repackaging area. Additional air is supplied from a radiological control access area and from infiltration from the tent.

Smoke Detection

- An air sampling type smoke detection system is installed in the tent. This air sampling system has six sampling ports located at each of the five exhaust points along the north wall. This is an unusual sampling configuration, thus the request for the modeling

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Basis for Analysis

- Smoldering Fire Scenarios

  The smoldering source fire is based on the standardized test fire used to test smoke detection systems in UL 268, *Standard for Smoke Detectors for Protective Signaling Systems*. While this standard defines how to run the test, it does not provide the necessary inputs needed to model the fire in FDS. In order to obtain these inputs, the test standard was run in a lab to measure the mass loss rate, smoke production rate, and power level of the source. Appendix A of the HAI report documents the experiments used to obtain the measurements.

Basis for Analysis

- Array Fire Scenario

  The array fire is based on the testing that was conducted to evaluate current and proposed waste staging configurations used in the tent. Fire hazards associates with the staging configurations were evaluated both in a small-scale (single sack) as well as large-scale (16 to 32 sacks in a 4 x 4 array). Both scales of testing were used to develop the fire curve used for this fire.

Basis for Analysis

- While the array sack test was able to provide details on fire spread and overall heat release rate data for the array as a whole, it was not able to provide details on how the individual sacks burned. For this data, the small scale tests results were used. The small scale sets showed that a single sack could burn for about five to ten minutes at 100-150 kW, but would die off rather rapidly after that time.

Design Approach

- Fire Dynamics Simulator (FDS)

  The Fire Dynamics Simulator (FDS) computational fluid dynamics program has been under development NIST Building Fire Research Laboratory (BFRL) for over a decade. The model is specifically designed with fire scenarios in mind and continues to be improved as its results have been verified. Various versions of the model have been applied to a number of outdoor and indoor fire scenarios. The indoor version is intended to handle isolated and spreading fires in human habitable spaces in the presence of obstacles such as furniture, overhead ceiling obstructions, and other structural members. Fuel properties and burning rates of a fire are user-defined. The user may select whether to have sprinklers decrease the fire severity, based on establish algorithms, or have sprinkler water spray affect only the properties of the smoke layer.

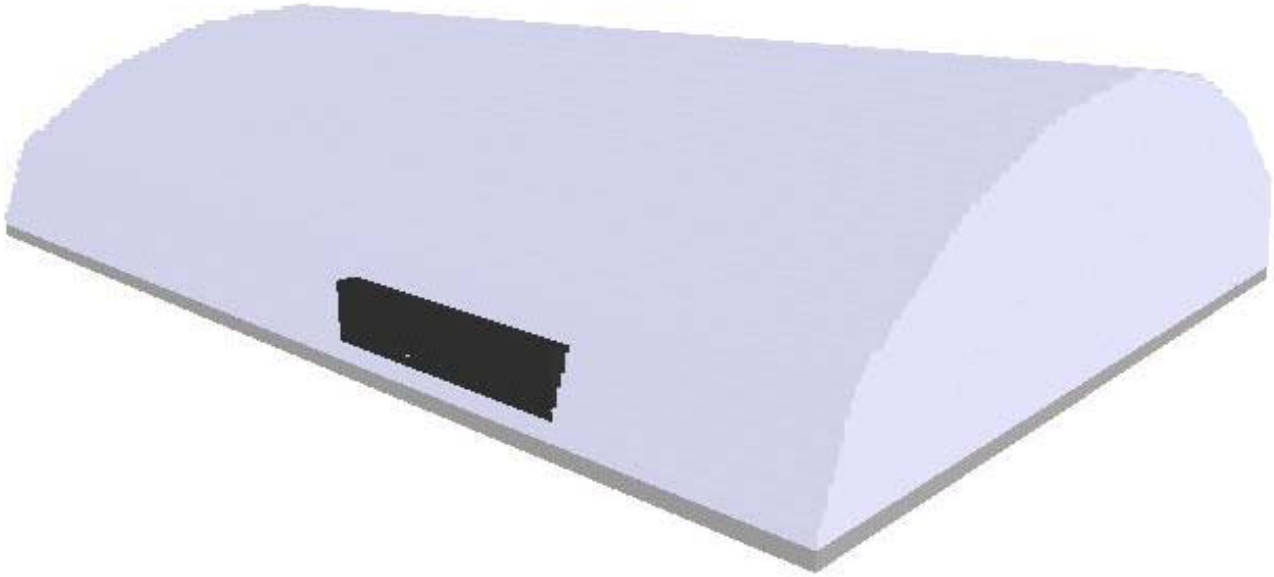
Model Construction

- The grid chosen to model the tent enclosure needed to be fine enough to resolve the smoke spread. The smallest dimension of these obstructions/openings was on the order of two feet.
- This would indicate that the grid cell size should be at least as small or smaller than this dimension. A grid cell spacing of two feet, while adequate for smoke transport away from the fire, required refinement (smaller grid cells) to resolve the turbulence in and around the fire. It was decided that a cell spacing of 1 ft cubed would better resolve the turbulence issue.
- This cell spacing was confirmed to be reasonable through several test runs. These test runs showed similar air flow patterns even when the grid cells were reduced to a 4 in cube.

Model Construction

- Once the grid cell spacing was chosen, the next step was to determine the computational domain. The large open space of the tent required that the entire tent structure be included in the domain.
- This created a computation domain composed of approximately 2,250,000 cells. While there were not any significant obstructions within the domain, the airflow patterns will affect the spread of smoke throughout the facility especially with the smoldering source fire.
- The major air flows into and out of the tent structure were included in the domain, based on measurements conducted on the system.

Model Construction



FDS Model Domain (Isometric View)

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Model Construction

- Analaser Detection Response
  - In order to evaluate the results of the fire modeling, the ability to predict the response of the detection system was required
  - The tent has an air sampling smoke detection system, which pulls air from various detection points to one central location for analysis of the smoke
  - The smoke concentration reported by the detection system is a sum of the various sampling locations
  - This concentration depends not only on how much air is sampled at each location, but also on how long it takes for the sampled air to reach the central location

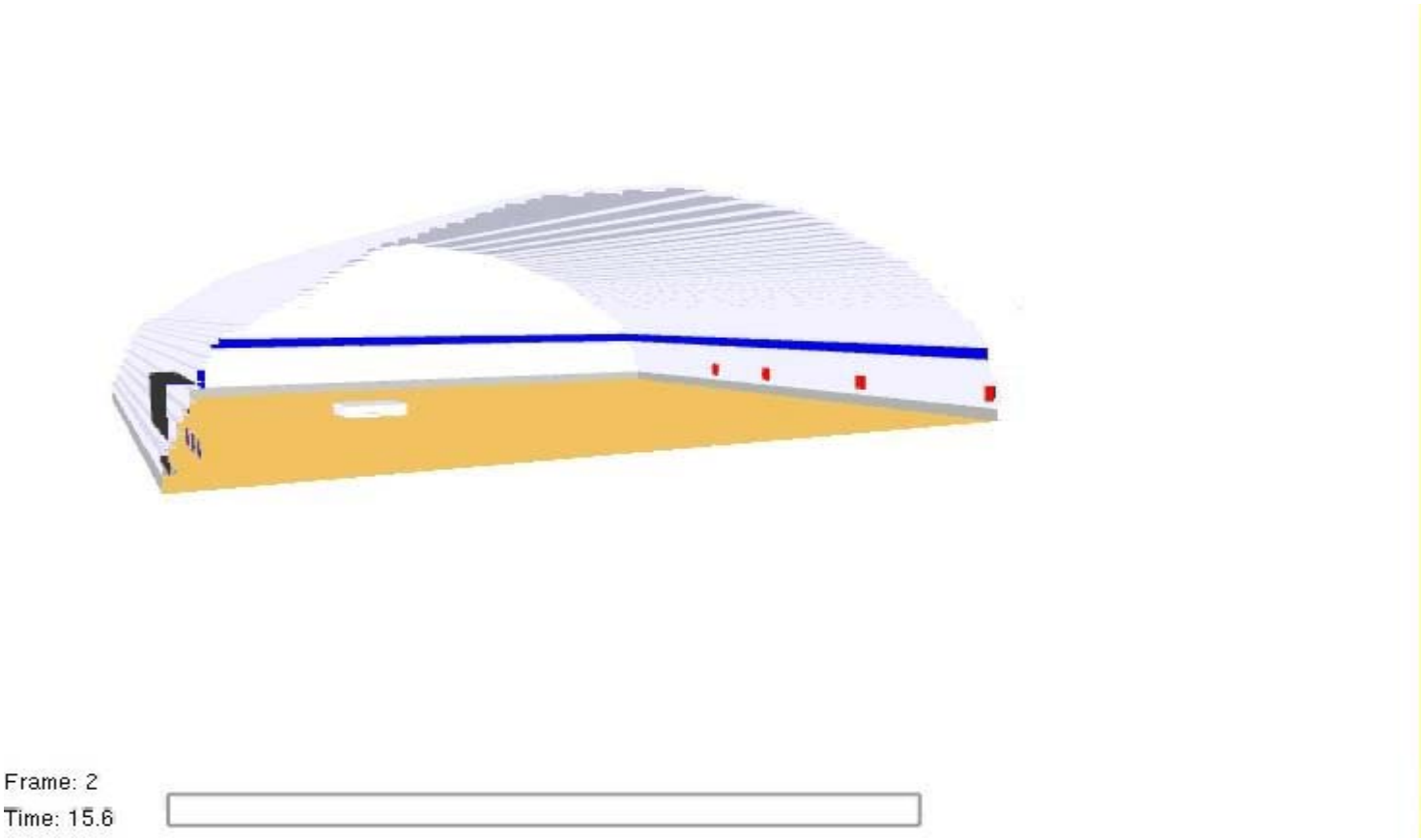
Smoldering Fire

- The results show a classical “layer driven” fire behavior
- A plume forms above the fire location. This plume impacts the ceiling and spread outward forming a layer at the ceiling level. As time progresses, the layer gets thicker and thicker until it reaches the floor
- The modeling showed the smoke concentration at different time points
- The results show the .06 %OBS/ft level was not met, this supported the results of field tests that were conducted
- The results show a high potential for stratification to occur with very minor temperature changes; there was very little change in temperature

Array Fires

- Like the smoldering fire, the modeling results for the array fire show a classical “layer driven” fire behavior. A plume forms and impacts the ceiling and spread outward forming a layer
- The layer gets thicker and thicker until it reaches the floor
- The maximum temperature across the centerline of the array reached about 131 F
- Since the ceiling is not constant across the tent area, the temperature at lower heights become important if the fire were to occur in an area of lower ceiling height. The lowest height of the ceiling that is not within 20 ft of the sides of the tent is 27.9 ft
- The peak ceiling temperatures reached about 176 F

Example of Output



HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Modeling Conclusions

- The modeling of the smoldering fire confirmed the field testing performed in the facility
- While the current set point of the smoke detection system is not low enough to cause an alarm, the system would be capable if the alarm level was reduced below 0.042 %OBS/ft.
- The exact alarm time would depend on what alarm level is chosen. If a conventional ceiling level detection system was installed, it would not be capable of detecting this fire
- The temperatures experienced with the smoldering fire make stratification a significant issue. This stratification makes ceiling level detection ineffective
- The currently installed Analaser detection system would not be affected by the stratification issue, since the stratified layer is drawn into the HEPA filters.

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Modeling Conclusions

- The modeling of the array fire confirmed that the smoke detection system as installed is capable of detecting this fire
- Detection occurs in approximately 7 minutes. This stands in contrast to a conventional ceiling level detection system which would not respond to this fire
- The environmental conditions within the space do not reach high temperatures. The peak temperatures experienced during the array fire tests indicate that temperatures do not exceed 176 F at the ceiling level
- In conclusion, the installed smoke detection system provides a superior level of protection to a conventional detection system. The environmental conditions that exist during the simulated fires kept the ceiling level gas temperatures below 176 F

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Conclusions

- Fire Testing
  - The soil placed on top of the sacks proved to be effective in limiting fire size even though localized waste exposure occurred
  - The existing waste staging configuration was shown to be acceptable and potential improvements were also identified
- CFD Modeling
  - The modeling of the smoldering fire confirmed the field testing performed in the facility
  - The installed smoke detection system provides a superior level of protection to a conventional detection system

HUGHES ASSOCIATES, INC.

CH2M•WG IDAHO, LLC

Acknowledgements

- Steve Additon, CWI, Nuclear Safety
- Bruce W Kanirie, CWI Fire Marshal
- Douglas Clark, P.E., CWI Fire Engineering
- Ed Budnick, P.E.,Vice President
  Hughes Associates, Inc.
- Craig Beyler, Technical Director, *Hughes Associates, Inc.*
- John Cutonilli, Engineer, *Hughes Associates, Inc.*