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Jorman A. Koski[1] , Steven D. Wix[1], and David E. Beene, Jr.[2]

EXPERIMENTAL MEASUREMENT OF A SHIPBOARD FIRE ENVIRONMENT WITH SIMULATED RADIOACTIVE MATERIALS PACKAGES

REFERENCE: Koski, J. A., Wix, S. D., and Beene, D. E., Jr., "Experimental Measurement of a Shipboard Fire Environment with Simulated Radioactive Materials Packages", Very Large Scale Fires, ASTM STP 1336, N. R. Keltner, N. J. Alvares, and S. J. Grayson, Eds., American Society for Testing Materials, 1998.

ABSTRACT: Results from a series of eight test fires ranging in size from 2.2 to 18.8 MW conducted aboard the Coast Guard fire test ship *Mayo Lykes* at Mobile, Alabama are presented and discussed. Tests aboard the break-bulk type cargo ship consisted of heptane spray fires simulating engine room and galley fires, wood crib fires simulating cargo hold fires, and pool fires staged for comparison to land-based regulatory fire results. Primary instrumentation for the tests consisted of two pipe calorimeters that simulated a typical package shape for radioactive materials packages. The calorimeters were both located adjacent to the fires and on the opposite side of the cargo hold bulkhead nearest the fire. The calorimeters were constructed from 1.5 m length sections of nominal 2 foot diameter schedule 60 steel pipe. Type K thermocouples were attached at 12 locations on the circumference and ends of the calorimeter. Fire heat fluxes to the calorimeter surfaces were estimated with the use of the Sandia SODDIT inverse heat conduction code. Experimental results from all types of tests are discussed, and some comparisons are made between the environments found on the ship and those found in land-based pool fire tests.

KEYWORDS: Ship fires, calorimeters, radioactive materials shipments, cargo fires

The safety of land transport of radioactive materials packages has been studied for many years. For example the "modal studies" [1] conducted during the 1980s considered truck and rail shipment of radioactive cargoes. Sea shipments of such cargoes, on the other hand, have not been studied to the same level of detail. In an effort to increase the knowledge of the possible fire exposure that a package might receive during sea transport, a series of eight shipboard fire experiments have been conducted aboard an actual break-bulk cargo ship. The tests were intended to measure a range of possible fire exposures for packages on ships, and give some basis for comparison to fires specified in current safety regulations. This paper presents some key results from the tests. More detail in a report format, including plots of all data collected, is available in Reference [2].

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[1] Sandia National Laboratories, Transportation Systems Department, MS-0717, Albuquerque, NM 87185. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

[2] United States Coast Guard Research and Development Center, 1082 Shennecossett Road, Groton, CT 06340-6096

Sea shipments of hazardous materials are governed by the International Maritime Dangerous Goods (IMDG) code [3]. For radioactive materials packages, the Irradiated Nuclear Fuel (INF) regulations [4] and the International Atomic Energy Agency Safety Series 6 regulations [5] must also be followed. Together these regulations limit the types of fires that must be considered during sea shipments. For example, the IMDG code specifies that for break-bulk freighters, a watertight bulkhead must separate radioactive cargo from flammable cargo. Thus, the most likely fires on this type of ship are fires with flammable materials in adjacent holds such as engine rooms, galleys and crews quarters, and combustible cargo fires in the same ship hold.

The tests were conducted aboard the *Mayo Lykes*, a World War II Victory class cargo ship, maintained by the United States Coast Guard at Mobile, Alabama, specifically for the purpose of fire testing. Two holds, Holds 4 and 5, at the aft end of the ship were selected for the tests. Level 1 of these holds, immediately below the weather deck, was used for all fires and measurements. In all cases the fires were set in Hold 4. Steel pipe calorimeters representing simulated radioactive materials packages were placed in both Holds 4 and 5. Fires consisted of ignited heptane sprays impinging on the steel bulkhead between Holds 4 and 5, and wood crib fires representing combustible cargo fires. The general experimental arrangement is shown in Fig. 1.

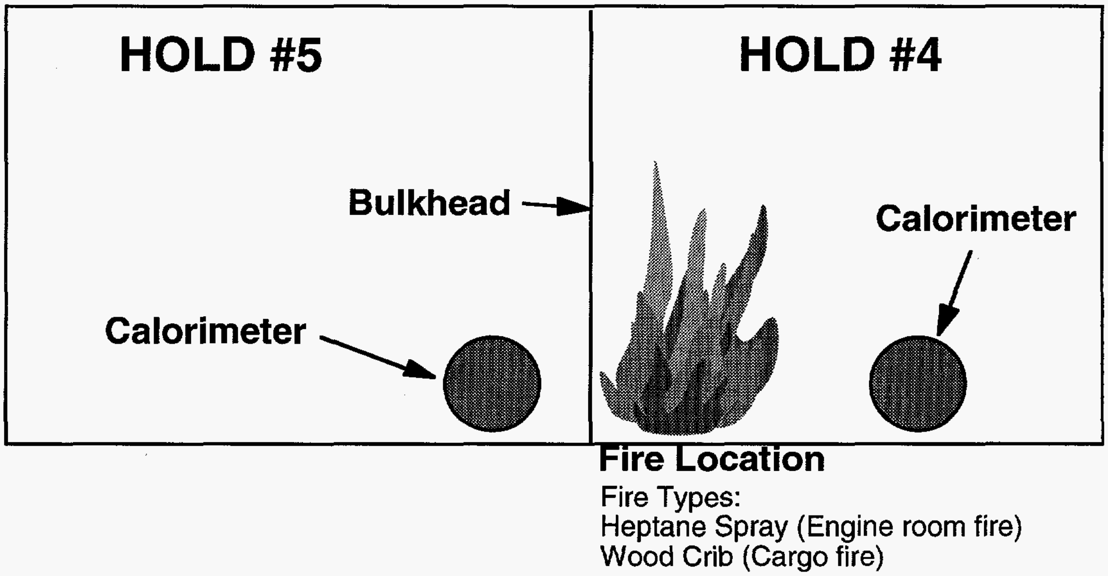

Fig. 1. Sketch of experimental configuration for heptane and wood crib fires.

Land based studies of fire accidents concentrate on the fully engulfing pool fire. This type of fire could occur, for example, if a truck transporting radioactive materials collided with a gasoline tanker truck with a resultant large gasoline spill. Packages for larger quantities of radioactive materials are designed and tested to withstand 30 minutes in a fully engulfing hydrocarbon fire. Filling a ship hold with flammable hydrocarbons with an adequate source of oxygen is a highly unlikely event, but for comparison to land based fires, a pool fire with a simulated package suspended over the pool was conducted as part ot the test series to determine if in-hold shipboard pool fires differed from those conducted on land.

A major purpose of the tests was to collect data useful in benchmarking fire calculations for ship fires. In a separate effort, the data collected are being compared to fire simulations made with the use of computational fluid dynamics.

For brevity, this paper will concentrate on the results obtained from the steel pipe calorimeters representing simulated radioactive materials packages. Results such as bulkhead and overhead tempertures, air temperatures in the holds, and flow probe measurements are included in [2]. Over 100 thermocouples, 12 flow probes, two radiometers, two video cameras, and an oxygen sensor were included in the test instrumentation.

TEST DESCRIPTION AND SEQUENCE

The sequence of eight fires conducted aboard the *Mayo Lykes* is shown in Table 1. A brief description of each type of fire and major fire characteristics follows. Hold 4 measures 17.6 m wide by 21 m long by 3.8 m high. Hold 5 dimensions are 17.6 m wide by 16 m long by 3.8 m high. For all tests the calorimeter in Hold 5 was located with its centerline 0.4 m above the deck and 2 m aft of the Hold 4-5 bulkhead. Detailed descriptions of the ship holds involved and instrumentation locations are included in [2].

To avoid potentially explosive conditions with the heptane spray and in-hold pool fires, adequate oxygen was supplied to Hold 4 via openings in the hull. Measurements indicate that oxygen levels in the vicinity of the fire were usually near normal atmospheric

Table 1. Fire Test Sequence

Test Number	Date, Time and Duration	Type of Test	Peak Thermal Power, MW
5037	9/12/95 2:09 PM CDT 60 Minutes	2 burner heptane spray test	2.2
5040	9/14/95 9:13 AM CDT 20 Minutes	Wood crib fire test with 17 L heptane accelerant	4.1
5041	9/14/95 12:21 PM CDT 60 Minutes	2 burner heptane spray test with diesel fuel in drip pans for smoke	2.2
5043	9/15/95 8:26 AM CDT 20 Minutes	Wood crib fire test with 17 L heptane accelerant	4.1
5045	11/13/95 12:02 PM CDT 60 Minutes	4 burner heptane spray test	5.6
5046	11/13/95 2:46 PM CDT 60 Minutes	4 burner heptane spray test with diesel fuel in drip pans for smoke	5.6
5048	11/14/95 3:09 PM CDT 27 Minutes	Diesel pool fire in Hold 4	15.7
5049	11/15/95 2:20 PM CDT 32 Minutes	Diesel pool fire on weather deck	18.8

content. In sealed shiphold fires at sea, oxygen would be more limited, leading to smoldering fires with even lower heat flux levels than experimentally measured. The experimental fires reported here represent conditions more typical of a fire that could occur during ship loading or unloading in port.

Heptane Spray Tests

The heptane spray fires were intended primarily to simulate a fire in an adjacent ship compartment. For the first series of tests heptane in a pressurized reservoir was fed through nominal 3/8 inch stainless steel tubing to two nozzles located in Hold 4. Stainless steel BETE model P54 fine atomization spray nozzles were used to create a 90° cone shaped fog spray that was manually ignited with a propane torch. The nozzles were located 0.91 m to either side of the hold centerline. The nozzles were located 1 m above the deck, 1 m from the bulkhead between Holds 4 and 5, and were aimed at the bulkhead at an angle of 45° above horizontal. The heat release of a spray nozzle was estimated by correcting the spray nozzle factor, k, in the equation

$$q = k\sqrt{\Delta p} \tag{1}$$

where q is the flow in m^3/s, k is the nozzle flow constant, and Δp is the pressure drop in Mpa. For heptane density rather than the water density data listed in the BETE catalog the factor k can be modified with the expression

$$k_{\text{heptane}} = k_{\text{water}}\sqrt{\rho_{\text{water}}/\rho_{\text{heptane}}} \tag{2}$$

where ρ is the density of the fluid. Since heptane is less dense than water, the nozzle flow increases by a factor of about 20 per cent above water flow for the fluid temperatures considered. Pressure drop from the reservoir to the nozzles was estimated with standard fluid pressure drop formulas for flows in piping. For the estimated 0.21 MPa pressure difference across the nozzle, a 0.024 kg/s mass flow rate results through each nozzle. For heptane with a heat of combustion of 44.6 MJ/kg, this gives a thermal output of each nozzle for full combustion of 1.1 MW. The two nozzle configuration doubles this to a total thermal output of the fire to 2.2 MW.

After inspecting the calorimeter results from the first series of two-burner heptane spray tests, a second series with larger nozzles in a four-burner arrangement were conducted. For these tests, in addition to the nozzle locations 0.91 m to each side of the ship centerline, nozzles were located 3.05 m to each side of the centerline. As with the two burner tests, nozzles were 1 m above the deck, 1 m from the Hold 4 and 5 bulkhead, and aimed at the bulkhead at an angle of 45° above horizontal. For the test, the larger BETE P66 nozzles were used with a 0.55 MPa pressure maintained at the fuel reservoir. This gives an estimated nozzle pressure difference of 0.17 MPa and a flow from each nozzle of 0.031 kg/s. This yields an estimated power release of 1.4 MW for each burner, and a total release of 5.6 MW total for all burners.

Wood Crib Fires

Wood cribs built from clear Douglas fir were used to simulate a cargo fire immediately adjacent to the radioactive cargo. The general arrangement for the crib fires is shown in Figure 2. The general wood crib design is based on UL Standard 711 [6], and is consistent with the size designated as 20-A in that standard. To estimate the heat release from the crib, equations were taken from Walton [7]. First the cross sectional area of the exposed surface, A_E, is calculated from the equation

$$A_E = 2nb^2[(2(l/b)+1)N - n(N-1)] \tag{3}$$

where b is the stick thickness in m, n is the number of sticks per layer, N is the number of layers and l is the length of the wood sticks. Since the wood used was rectangular in cross section, the stick thickness b was taken to be one-fourth of the perimeter dimension. The heat release rate is then obtained from the equation

$$\dot{q} = A_E E C b^{-0.5} \tag{4}$$

where $\dot{q}$ is the heat release rate in MW, A_E is the cross-sectional area from Equation (3) in m^2, E is the heat released from the combustion of pyrolysis products in kJ/kg, and C is an empirical constant for the mass of pyrolysis product produced per unit surface area and unit time in $kg/(m^{1.5}s)$. Walton suggests a C value of 0.65×10^{-3} $kg/(m^{1.5}s)$ for single cribs of Douglas fir. Application of these equations to the UL 711 size 20-A crib give a heat release of 2.4 MW. The UL standard also specifies that to initiate the fire, 17 L of heptane accelerant are to be ignited in a 1 m square pan under the crib. Observation of the experimental data indicated that this accelerant burned for about five minutes giving an experimental recession rate of 0.038 $kg/(m^2s)$, and a corresponding output of 1.7 MW. Combining the heat release of the wood crib and the heptane accelerant gives an initial thermal output of 4.1 MW for the first 5 minutes of the fire, then a steady heat release of 2.4 MW as the crib alone burns. Inspection of the data for the calorimeter in Hold 4 indicates that the wood crib heat release decreased rapidly 15 minutes after ignition indicating that most wood had burned.

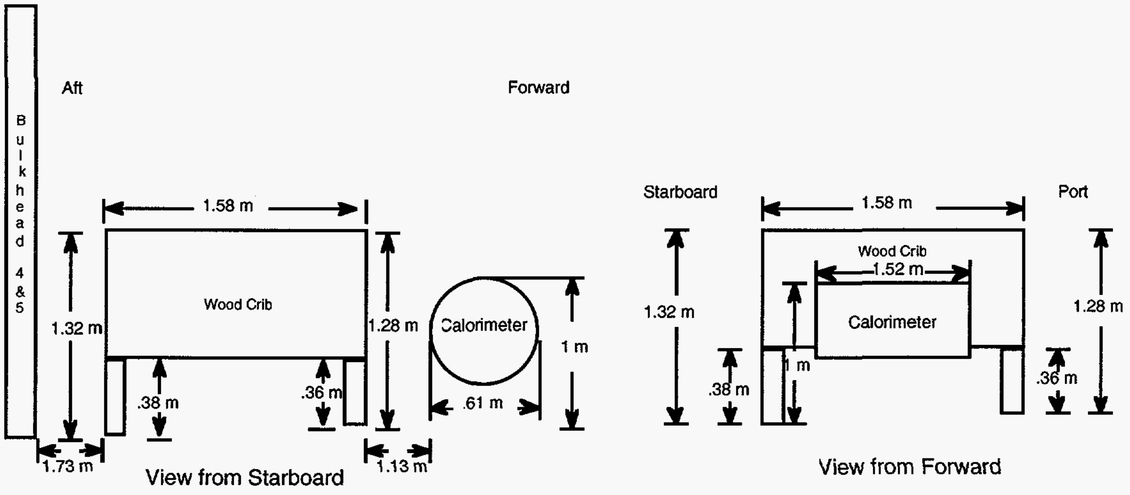

Fig. 2. Sketch of wood crib fire arrangement.

Pool Fires

For this test a 3 m x 3 m pool was constructed on the ship centerline at the aft end of Hold 4, and the steel pipe calorimeter moved to be centered above the pool in a manner consistent with land based regulatory testing. At the start of the burn, the bottom of the calorimeter was 1 m above the fuel surface. Because of its ready availability and usefulness for other purposes if not all the fuel was consumed, diesel fuel was selected for this test. The fuel was floated on a pool of water in the specially built containment area adjacent to the bulkhead between Holds 4 and 5. To avoid a possible explosion, openings in the hull provided adequate oxygen to the fire. In an actual shipboard fire, this free availability of oxygen is unlikely.

During the test a 7.6 cm depth out of a total depth of 13 cm of diesel fuel were burned before overhead temperatures exceeded the previously agreed upon maxiumum of 540°C at 24 minutes into the test. At 27 minutes the fire extinguishment with foam was complete. From this information a fuel recession rate of 0.0443 kg/m^2-s was calculated. With a typical diesel heat of combustion of 42.75 MJ/kg this leads to an average heat release of 15.7 MW during the test.

For the pool fires Directional Flame Thermometers (DFTs) based on a design from Burgess and Fry [8] were used to estimate the temperatures of the engulfing flames. These devices, resembling a vegetable can, have thin metal ends that rapidly approach flame temperatures. Thermocouples attached on the inside of the thin metal ends provide an estimate of flame temperatures in the direction that the end faces in the fire. The cans are filled with insulation to prevent internal heat transfer within the DFT.

For comparison to the in-hold fire test, a 3 m x 3 m pool was built on the weather deck of the *Mayo Lykes* on the port side amidships. The pool was constructed to closely follow the dimensions of the pool built in Hold 4. The calorimeter from Hold 5 was centered above the pool, 1 m above the fuel surface at the start of the test. A depth of 13 cm of diesel fuel gave a 32 minute burn, typical of a regulatory pool fire. Calculation of the recession rate for this fire led to an estimated average thermal output of 18.8 MW. A strong off-shore wind tended to lay the fire plume over, often diverting the flames from the calorimeter. This effect, which was visible in the data as highly variable heat fluxes to the calorimeter, is not typical of land based tests that are conducted when the wind is relatively calm.

PIPE CALORIMETER DESIGN

The pipe calorimeters that simulated the radioactive cargo packages were constructed from two 1.52 m lengths of nominal 2 foot diameter Schedule 60 carbon steel pipe with an outside diameter of 0.61 m and a wall thickness of 0.0244 m. Nominal 1 inch (0.0254 m) thick circular carbon steel plates were bolted to form the ends of the calorimeters. Thermocouples were fastened to the pipe interior and exterior surfaces with thin capacitance-welded Nichrome metal strips at the locations shown in Figure 3. Calorimeters located in Holds 4 and 5 were identical in construction, with the side containing the larger number of thermocouples facing the bulkhead between Holds 4 and 5. Type K thermocouples were attached in pairs with one interior and one exterior thermocouple at each location. This permitted measurement of the time history of the pipe wall temperature difference at 12 locations as shown in Fig. 3.

As discussed by Keltner and Moya [9], the temperatures measured by a thermocouple must be considered carefully. A surface thermocouple on the calorimeter, for example, when exposed to rapid changes in radiant energy levels, does not respond in the same manner as the steel substrate to which it is attached. Having less mass, the thermocouple bead responds more rapidly than the surface, and, under these rapid heating conditions, does not accurately represent the calorimeter surface temperature. The inverse heat conduction program interprets this rapid increase in the bead temperature as the

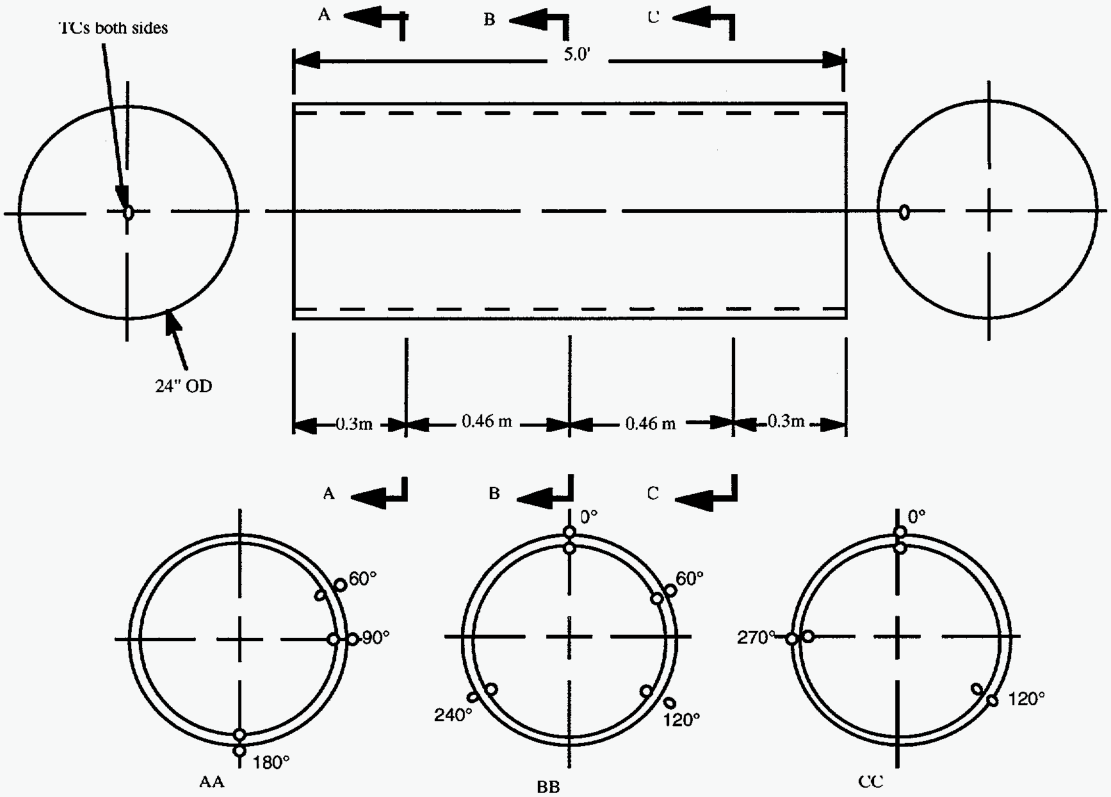

Fig. 3. Calorimeter arrangement with thermocouple locations.

temperature of the steel surface of the calorimeter. The result is an estimated peak in the heat transfer that is significantly higher than when the inside thermocouple alone is used for the data analysis. Where the heating rate is slow, as is the case for the calorimeter located in the adjacent Hold 5, little effect is noticed whether only the inside or both inside and outside thermocouples are used. For the cases in Hold 4 with wood cribs and pool fires in the immediate proximity of the calorimeter, only the inside thermocouple response is typically used to predict heat flux and calorimeter surface temperatures since these estimates do not exhibit the errors that occur during rapid surface heating.

After attachment of the thermocouples, the calorimeter interiors were packed with commercial Kaowool insulation material with a nominal density of 8 pounds per cubic foot (128 kg/m^3) to provide an insulated boundary condition for data analysis. The insulation also blocked thermal radiation and convection heat transfer inside the calorimeter cavity that would require the complicated interior geometry to be analyzed as part of the data reduction.

Absorbed heat fluxes to the calorimeter were determined with the use of the Sandia One-Dimensional Direct and Inverse Thermal (SODDIT) computer code [10]. This code can be used to solve inverse heat conduction problems, i.e., rather than solving for the temperatures of an object given the boundary conditions, this code estimates the heat flux boundary conditions given object temperatures. As the name implies, the code assumes a one-dimensional geometry for cylinders, spheres or plates. This approach provides good estimates of the surface heat transfer as long as local peaking of the flux profiles does not produce significant two- or three-dimensional heat transfer near the peak.

As a test of the calorimeter's potential to record accurately the absorbed heat fluxes, a computer simulation under controlled conditions was conducted. First the Topaz2D [11] finite-element computer code was used to generate simulated two-dimensional test data for the calorimeter. The geometry chosen for the test consisted of a circular pipe cross section with a view of a flat, infinite hot wall. With a radiation heat transfer boundary condition, this leads to a peaked heat flux distribution on the side of the calorimeter facing the hot wall. The temperatures calculated by Topaz2D for the inside surface of the calorimeter for this geometry were then treated as pseudo-experimental data in the one-dimensional SODDIT code. The comparison between the Topaz2D heat flux values calculated at the calorimeter surface and the SODDIT predictions at three different times is shown in Fig. 4. Initially, the heat flux is accurately predicted as shown by the small overprediction of the heat flux at one minute in Fig. 4. As time progresses, the SODDIT predictions start to predict peak values lower than the calculated Topaz2D heat fluxes and higher values than Topaz2D at points away from the peak. At 30 minutes, SODDIT predicts about 87 per cent of the Topaz2D peak heat flux, while at 60 minutes, about 80 per cent of the Topaz2D peak flux is predicted. The gradual decrease of the predicted values with time is probably due to the circumferential component of thermal conduction in the pipe wall that is included in the Topaz2D model, but neglected by the one-dimensional SODDIT code. For these experiments, this level of measurement accuracy is considered adequate, but all heat flux data presented should be viewed with these effects in mind.

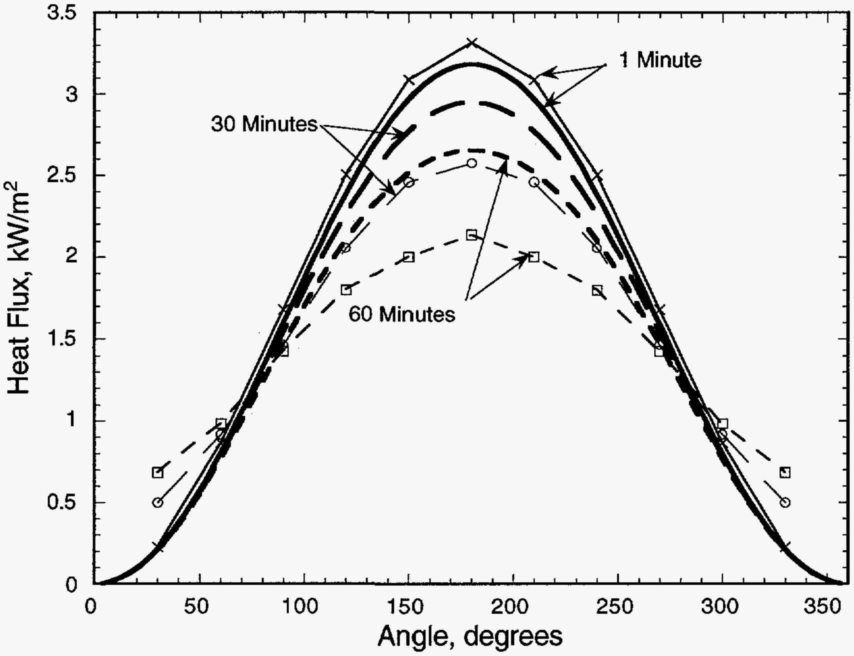

Fig. 4 Topaz2D calculations compared to SODDIT results. SODDIT results are lighter lines with symbols.

Another consideration in analysis of calorimeter data is the size of the time step used for the numerical SODDIT calculations. If the time step is too small, the magnitude of the signal noise is comparable to the magnitude of the temperature change, and the code has difficulty separating signal from noise. If the time step is too large, the unconditionally stable implicit time stepping algorithm used by SODDIT loses accuracy giving poor heat flux predictions. For the calorimeters used for these experiments, a 30 s time step proved a good compromise between these two extremes.

EXPERIMENTAL RESULTS

Heptane Spray Fires

Temperature and heat flux results for the first four-burner heptane spray test designated test 5045 are given in Figs. 5, 6, and 7. These results are typical of the one-hour four-burner heptane spray fires conducted. For these tests the calorimeter located in the adjacent compartment, Hold 5, was heated about 25°C during the one hour duration of the test as shown in Fig. 5. SODDIT, with use of both inside and outside thermocouples at each angular position shows maximum heat fluxes of about 0.8 kW/m^2 on the side of the calorimeter facing the hot bulkhead between Holds 4 and 5 (see Fig. 6). Fig. 7 shows the angular distribution of the heat flux around the circumference of the calorimeter 30 minutes after ignition.

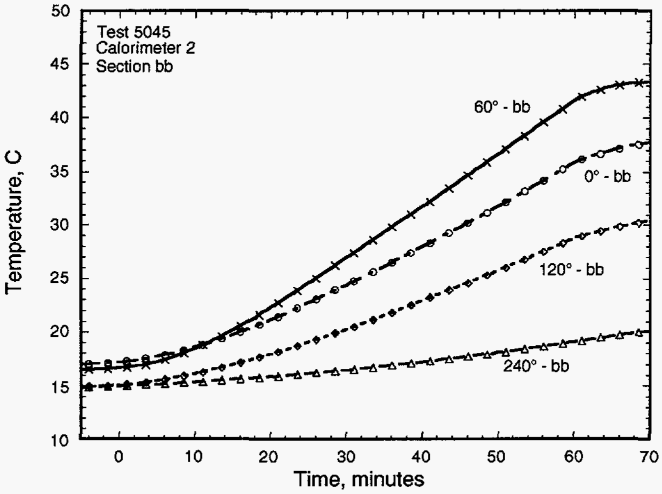

Fig. 5. Exterior temperatures at center of calorimeter in Hold 5 during four burner heptane test.

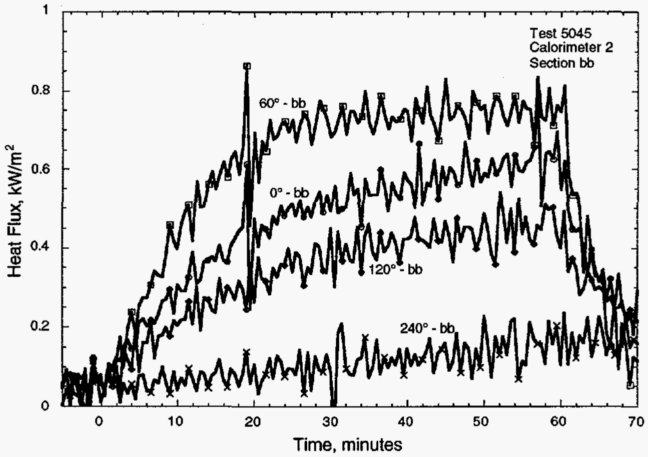

Figure 6. Estimated heat fluxes to calorimeter in Hold 5 during four-burner heptane test.

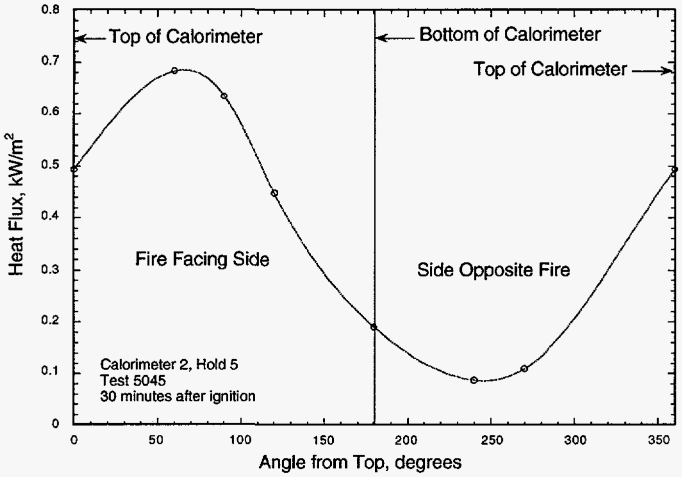

Fig. 7. Heat flux distribution around calorimeter in Hold 5 30 minutes after ignition during four-burner heptane spray test.

Wood Crib Fires

Results for the calorimeter located immediately adjacent to the burning wood crib for the first wood crib test designated as Test 5040 are shown in Figs. 8, 9, 10, and 11. During this test the calorimeter increased in temperature about 200°C. The initial rapid temperature increase at the start of the test is caused by the heptane accelerant used to start the fire. This initial transient results in an initial peak of about 25 kW/m^2 on the calorimeter surface (see Fig. 9) as estimated with SODDIT with the use of the interior thermocouples only. Angular distributions of the heat flux at 4 and 20 minutes after ignition are shown in Figs. 10 and 11.

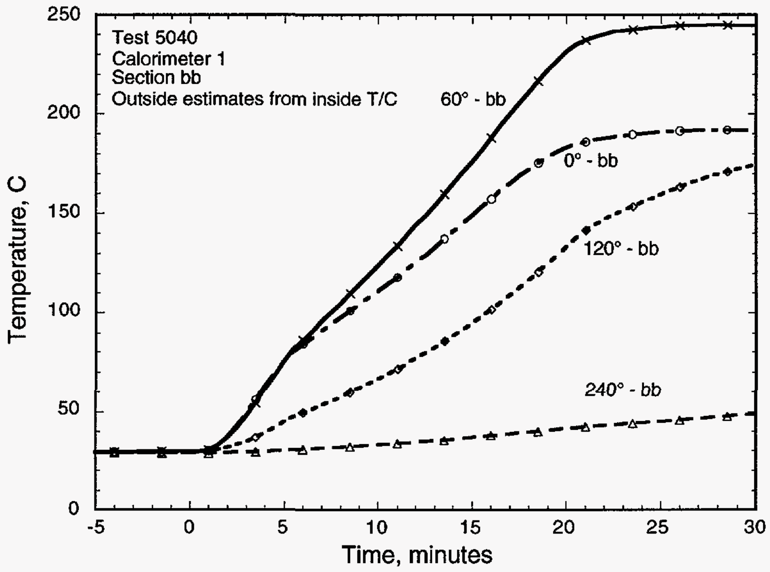

Fig. 8. Temperatures at outside of calorimeter in Hold 4 during wood crib fire test. Temperatures are estimated from inside thermocouple data with use of the SODDIT code.

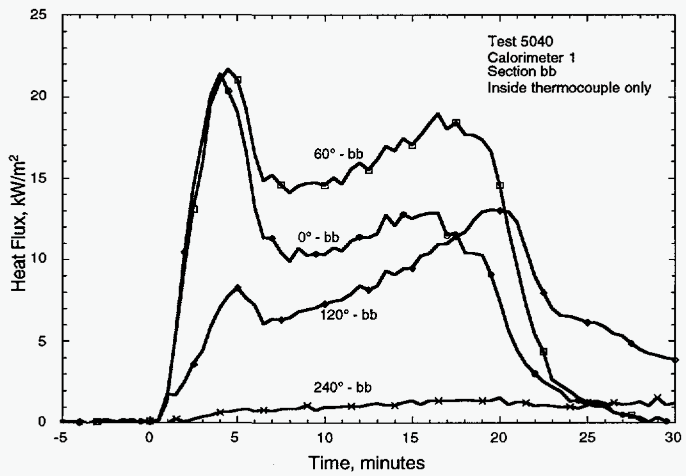

Fig. 9. Heat fluxes estimated by SODDIT code for calorimeter in Hold 4 during wood crib fire test. The initial peak is caused by the heptane fire accelerant.

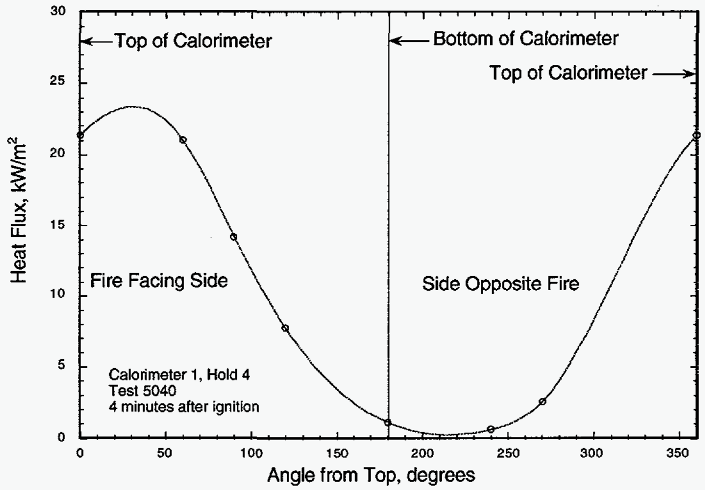

Fig. 10. Heat flux distribution around calorimeter 4 minutes after ignition during wood crib fire test.

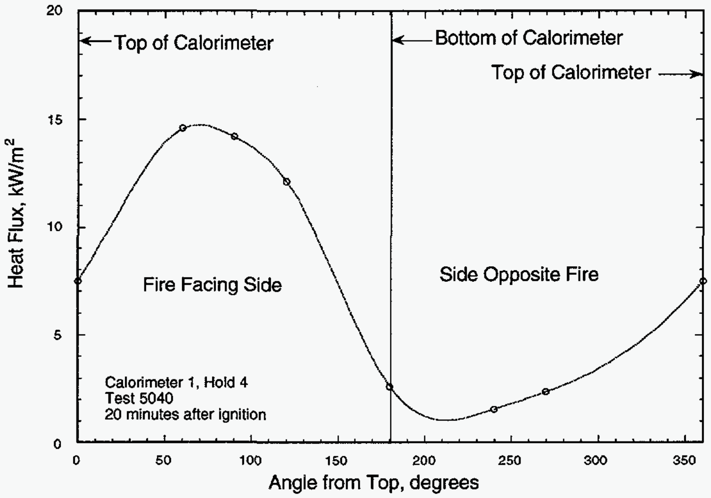

Fig. 11. Heat flux distribution around calorimeter 20 minutes after ignition during wood crib fire test.

Pool Fires

For the in-hold pool fire, the calorimeter was completely engulfed by the pool fire flames. Near the end of this test, cables strung on the deck above the fire hold were damaged, resulting in erratic data swings. As shown in Fig. 12, calorimeter temperature increases of 700 to 800°C were measured during the test. SODDIT calculated brief initial heat flux values between 150 and 200 kW/m^2 for this test as shown in Fig. 13. Directional Flame Thermometers located in the fire zone recorded temperatures between 900 and 1100°C during the fire as shown in Fig. 14. The heat fluxes to the calorimeter in Hold 5 adjacent to the fire compartment remain at about the 1 kW/m^2 level as shown in Fig. 15. At about 24 minutes, a decision to extinguish the fire was made to avoid damaging the deck immediately above the fire zone.

Because the on-deck outdoor pool fire was conducted during a strong wind, these data are not directly comparable to typical regulatory outdoor pool fires conducted under low wind conditions. For this reason, these data are not presented here. A complete summary of the data is provided in [2].

CONCLUSIONS

The fire tests yielded several results that tend to confirm the beliefs held prior to testing. First, the overall heat flux level in typical adjacent-hold and combustible-cargo ship fires is considerably below the initial 65 kW/m^2 heat flux levels implied by regulations such as Safety Series 6 [5]. Even for the in-hold pool fire, initial heat flux levels are comparable to values measured in land-based regulatory fires [12]. For Hold 5, adjacent to the fire hold, the heat fluxes to the calorimeter never exceeded 1.5 kW/m^2, even with the large 15.7 MW pool fire near the Hold 4-5 bulkhead in Hold 4.

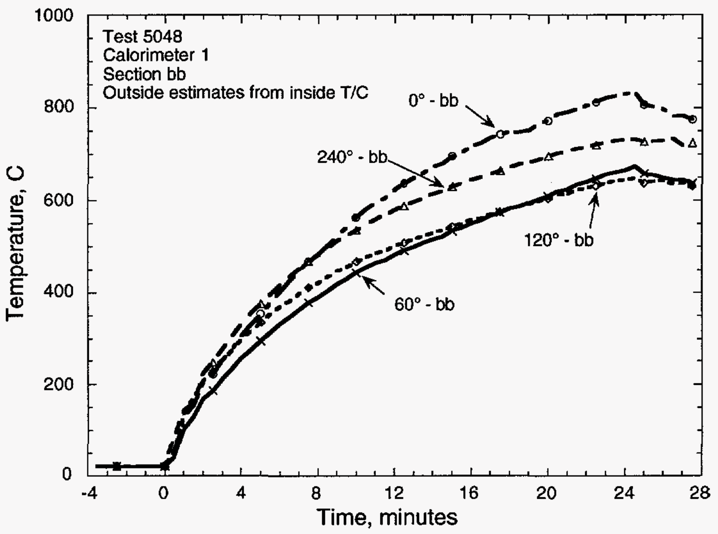

Fig. 12. Estimated surface temperatures from SODDIT for calorimeter located in fully engulfing in-hold pool fire.

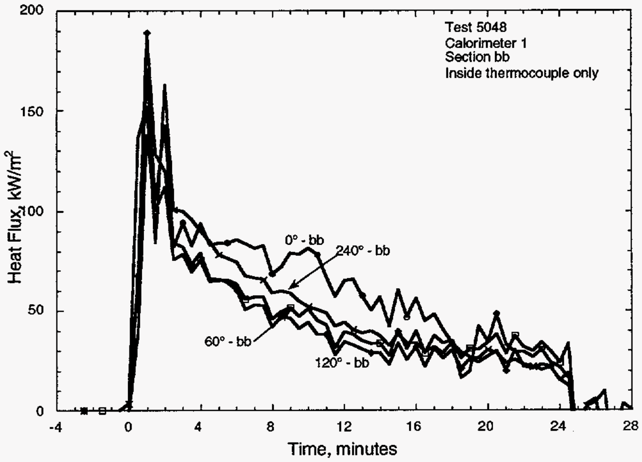

Fig. 13. Estimated heat fluxes to calorimeter located in pool fire in Hold 4.

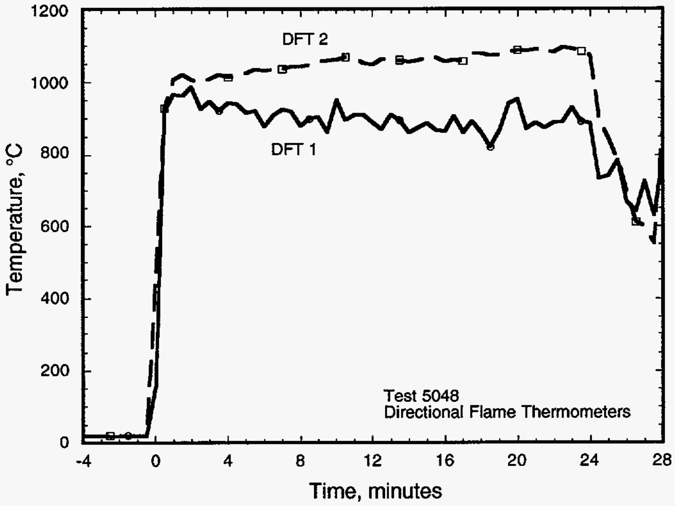

Fig. 14. Directional flame thermometer temperatures for pool fire in Hold 4.

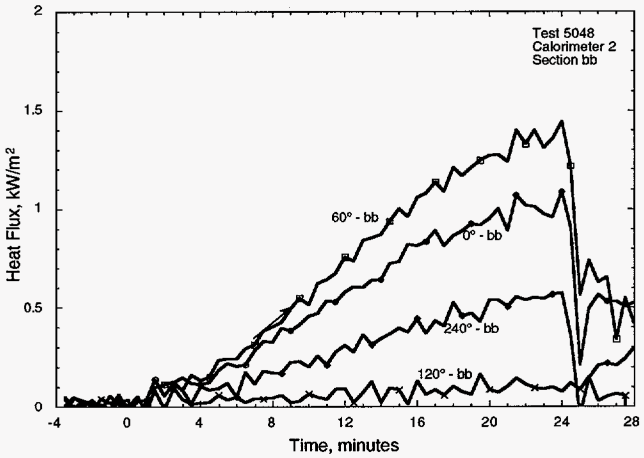

Fig. 15 Estimated heat fluxes to calorimeter in Hold 5 during pool fire in Hold 4.

For both the heptane spray and wood crib fires, analysis of the calorimeter heat flux plots shows that the absorbed heat fluxes are much higher on the side facing the fire. This indicates that thermal radiation is the dominant heat transfer mechanism since convection would lead to a more uniform heating with hot gases flowing around the entire circumference of the calorimeter. Accurate fire simulations with computer models will aid in determining the partitioning of the heat transfer mechanisms involved.

Steel cargo holds typically do not contain the combustible carpets, wall coverings and other easily combustible materials such as furniture and paper that lead to the flashover conditions typical of building fires on land. At the flashover point, room temperatures and thermal radiation combine to ignite simultaneously most combustible materials in the room. This condition was not observed for any of the tests conducted. The calorimeter measurements of heat fluxes, coupled with ignition models, could be used to estimate the time required for spread of a ship-hold fire from one combustible cargo to another.

Inspection of the estimated heat transfer plots for Holds 4 and 5 shows some rapid fluctuations in the estimated heat flux values, especially for Hold 5. Since the heat fluxes to the calorimeter in Hold 5 are generally much lower than the values for the calorimeter in Hold 4, any noise in the Hold 5 data are displayed as proportionately larger variations on the heat flux signal than occur for Hold 4 data. Although the SODDIT code permits multiple time point analyses that smooth the results, the decision was made to display the single time point analysis results to enable a better understanding of the signal-to-noise ratios involved in the data analysis.

Analysis of the data does not indicate that shipboard fires are likely to lead to increased heat transfer when compared to land based regulatory fires. In general, the heat transfer seems to be lower than for the fully engulfing pool fire considered for land based accidents. This leads to the consideration of the duration of shipboard fires, a study that may be better based on historical data or engineering analysis than on experiment.

These experimental results are primarily intended to serve as a means of confirming and refining analytical heat transfer models of shipboard fires. No general conclusions regarding the adequacy or inadequacy of regulatory tests as applied to the shipboard fire environment can be drawn directly from the tests. Any risk assessment model of fires must also include the probabilities of initiating events, as well as details of crew response and allowances for use of fire suppression systems.

The testing here applies primarily to the break-bulk freighters typically used to transport radioactive materials. The work does not apply to container ships, where the IMDG rules differ from those applied to break-bulk ships. Further investigations are in progress to assess typical fire conditions aboard container cargo ships.

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