DESIGN OF AN EXPERIMENT TO MEASURE FIRE EXPOSURE OF PACKAGES ABOARD CONTAINER CARGO SHIPS

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SUMMARY

The test described in this paper is intended to measure the typical accident environment for a radioactive materials package in a fire aboard a container cargo ship. A stack of nine used standard cargo containers will be variously loaded with empty packages, simulated packages and combustible cargo and placed over a large hydrocarbon pool fire of one hour duration. Fire environments, both inside and outside the containers, typical of on-deck stowage will be measured as well as the potential for container-to-container fire spread. With the use of the inverse heat conduction calculations, the local heat transfer to the simulated packages can be estimated from thermocouple data. Data recorded will also provide information on fire durations in each container, fire intensity and container-to-container fire spread characteristics.

INTRODUCTION

For cargo in standard International Standards Organization (ISO) containers carried aboard either container ships or other ships fitted for permanent storage of containers, the International Maritime Dangerous Goods (IMDG) Code, 1992, does not require a bulkhead to be located between radioactive materials and flammable materials. The table in Section 15.1.16 of the IMDG code specifies that radioactive materials be "separated from" flammable liquids. For one closed and one open container on a container ship, the table in Section 15.3.2 of the code specifies that "separated from" means either one container space distance apart on deck, or one container space or a bulkhead separation under deck. The rules thus permit transporting both flammable liquids and radioactive materials in the same hold of the container ship as long as one of the cargoes is in a closed container and at least one container space intervenes.

For purposes of discussion of the consequences of the IMDG rules, consider the newer container ship designs that have no weather deck, where containers are stacked in open holds, typically up to 13 containers deep. Under these conditions, flammable liquids can be transported in cylindrical tanks with an external frame for lifting that conforms to ISO standards. If one of

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the cylindrical tanks were to leak or rupture, the flammable contents could drain to the bottom of the hold. If ignition of the flammable liquid were to occur, then flames could surround the stacks of shipping containers in the hold. Typically, the bottoms of the holds would be pitched for drainage and have sufficient space between the deck and the container to distribute any liquid such as rain fall as it moves toward the bilge. Sloshing caused by the rocking of the ship would also tend to spread the fuel around the bottom of the hold. Thus, the open cargo hold design could lead to higher heat fluxes than ship designs with closed cargo holds because the closed hold limits the oxygen availability to the fire which in turn limits the combustion process.

Shipping containers for radioactive materials meet relevant standards such as Title 10, Code of Federal Regulations, Part 71 (10CFR71) in the U.S. or International Atomic Energy Agency Safety Series 6, 1990 for international shipments. Containers for larger type B quantities of radioactive materials must be capable of surviving, without release of contents, a 30 minute fully engulfing pool fire typical of accidents that might occur during land transport. Fire conditions on containerized cargo ships probably differ significantly from the large, intense pool fires that are concerns for land transport. Comparison of the container ship fire environment to regulatory fires will aid risk analysts planning for the sea transport of hazardous materials. Some measure of the additional protection offered by the standard cargo shipping container surrounding the radioactive material package would also be useful.

On June 2, 1973, the container ship *Sea Witch* collided with the tanker *Esso Brussels* in New York harbor. The resulting container cargo fires have often been identified as among the worst to occur. Questions as to the actual temperatures and heat transfer in and among the containers during this type of fire have been raised when shipments of hazardous cargoes are studied.

Sandia National Laboratories in Albuquerque, New Mexico plans to conduct fire tests at the United States Coast Guard Fire and Safety Test Detachment located at Mobile, Alabama. A fire with simulated cargoes in standard International Standards Organization (ISO) shipping containers will be used to assess the fire environment to which radioactive material cargoes on container ships are likely to be exposed. The test will consist of setting a fire in the existing pool fire facility on Little Sand Island and then monitoring the response of stacked ISO containers with simulated cargoes above the burning pool, as shown in Figure 1.

EXPERIMENTAL OBJECTIVE

The main objective of the experiment is to measure temperatures and heat transfer for containerized cargoes of simulated radioactive materials in a configuration typical of on-deck stowage. The on-deck environment is expected to be more severe than below-deck stowage because of the ready availability of oxygen to support combustion. The experimental results will be provided in the form of citable references for use in future documents such as Environmental Impact Statements and Environmental Assessments for particular shipments or shipping campaigns. An additional objective of the experiments is quantify typical container fire conditions and to provide a comparison between the fully engulfing open pool fire associated with land transport accidents and the hold fires typical of marine transport. Inherent characteristics of containers during fires will also be noted, where container design could affect fire size, duration, or spread.

TECHNICAL APPROACH

A three-by-three array of 6 m long International Standards Organization (ISO) containers of various types will be exposed to a large jet fuel (type JP-8) pool fire at the existing15 m x 15 m

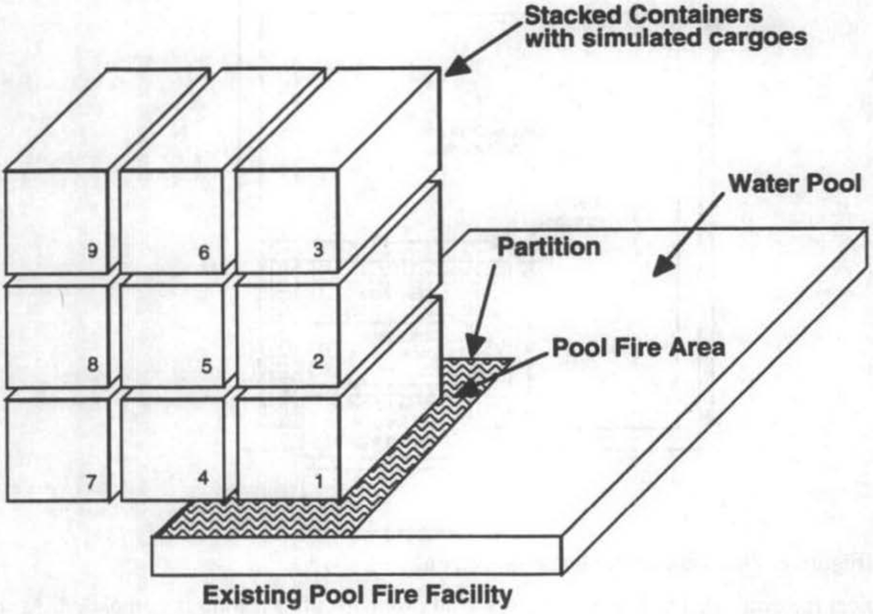

Figure 1. Schematic of fire test arrangement.

pool on Little Sand Island as shown in Figures 1 and 2. The containers, used commercial units purchased for testing purposes, will represent a typical on-deck array of steel containers. The array will be placed with container-to-container spacing typical of sea transport conditions on container ships. One stack of containers will be directly located over the fire to measure that fire environment, one stack will straddle the edge of the pool, while the final stack will be adjacent to the fire to enable measurement of possible container-to-container fire spread. The interior of the containers will be instrumented and loaded with simulated combustible cargo such as newspapers, scrap lumber, and cardboard boxes. Three of the containers will house steel pipe calorimeters for measurement of heat transfer and to simulate a radioactive material shipment. After the pool fire burns out at approximately one hour, the container array will be monitored for at least 24 hours to determine if the combustible cargoes and containers continue to propagate the fire to adjacent containers. To conserve the amount of fuel needed for each test a welded partition will be used to limit burning area to a 6 m x 10 m section of the existing 15 m x 15 m pool width.

TEST PARAMETERS

The test will be conducted at the U.S. Coast Guard Fire and Safety Test Detachment facility on Little Sand Island in Mobile, Alabama. The tests will consist of igniting a premeasured depth of JP-8 fuel estimated to produce a one-hour burn and letting the pool fire proceed to completion.

The test will allow measurements of long term thermal effects inside the containers. Table 1 shows the cargo manifest for individual containers during the tests. The numbers are consistent with the container locations shown in Figure 1. Simulated combustible cargoes were chosen to

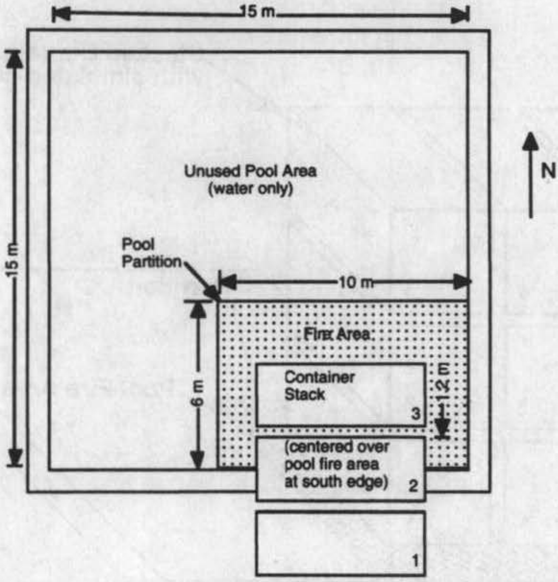

Figure 2. Plan view of fire test arrangement

be typical materials that will not create disposal problems after testing is completed. Arrangement of cargo in the containers was determined based on several criteria. First, each container with a simulated or unused radioactive materials package should be immediately adjacent to containers with combustible cargo, and the simulated and actual packages should also be close to the pool fire. Combustible cargoes should be distributed to permit determination of fire spread among containers both near and away from the pool fire. In addition, containers with real or simulated radioactive materials packages should not be located immediately above of beside another container with radioactive materials packages.

INSTRUMENTATION

Exact instrumentation locations with data channel and cable identifications will be listed in an instrumentation index compiled prior to and during installation. The following is a general guide to the intended instrumentation.

Calorimeters

The calorimeters simulating a radioactive material shipment will be provided by Sandia and will be constructed in two configurations. A single stainless steel calorimeter located in Container 6 will be constructed from 0.762 m diameter, 6 mm wall thickness (nominal 30 inch diameter, 0.25 inch wall), Type 304L stainless steel as shown in Figure 3. The calorimeter will be instrumented with 15 Type K sheathed thermocouples with 1.5 mm (0.063) inch outside diameter placed as shown in Figure 3. To block internal thermal radiation, portions of the interior of the calorimeter will be insulated with commercial insulation. The exterior of the calorimeter will be coated with Pyromark flat black or similar paint to enhance surface absorptance. Thermocouples will be placed to allow the surface distribution of the heat transfer to the container to be estimated through the methods of inverse heat conduction. The surface absorptance of the calorimeter and its coating will be determined by measurements of similar surfaces measured at Sandia.

TABLE 1. Cargo Manifest

Container Number	Cargo	Instrumentation
1	Baled cardboard boxes (1300 kg)	Thermocouples
2	55 gallon drums, pipe calorimeter, containers, etc.	Temperature labels, thermocouples, pipe calorimeter
3	Newspapers stacked at various locations (2600 kg)	Steel pipe calorimeter, thermocouples
4	Scrap lumber from pallet (1000 kg)	Thermocouples
5	Stacked newspaper bales (2300 kg)	Thermocouples
6	Simulated cask	Stainless steel tube calorimeter, thermocouples
7	Newspapers stacked on side facing fire (600 kg)	Thermocouples
8	Newspapers stacked on side facing fire (600 kg)	Thermocouples
9	Newspapers stacked on side facing fire (600 kg)	Thermocouples

Two additional calorimeters located in Containers 2 and 3 will be constructed from schedule 60 mild steel pipe 0.61 m (24 inches) outside diameter by 1.5 m long The end plates are made of 25 mm thick steel plate. These calorimeters will also be instrumented with 12 Type K sheathed thermocouples with 1.5 mm (0.063 inch) outside diameter each mounted on the pipe interior as shown in Figure 4.

Other Instrumentation

The walls of each ISO container will be instrumented with 7 thermocouples as shown in Figure 5. The exact location (height, spacing) and placement of the thermocouples will be determined during test setup. For ISO Containers 1, 2, 4 and 5, additional thermocouples on rakes may also be used to measure interior temperatures and determine if ignition of the cargo near the center of the container has occurred.

To determine approximate flame temperatures outside the containers two directional flame thermometers (DFTs) will be installed over the pool. These devices will be field located during test installation, with locations chosen both between containers and at the outside edge of the container stack. During each test a record of wind direction and speed will be maintained by the Coast Guard.

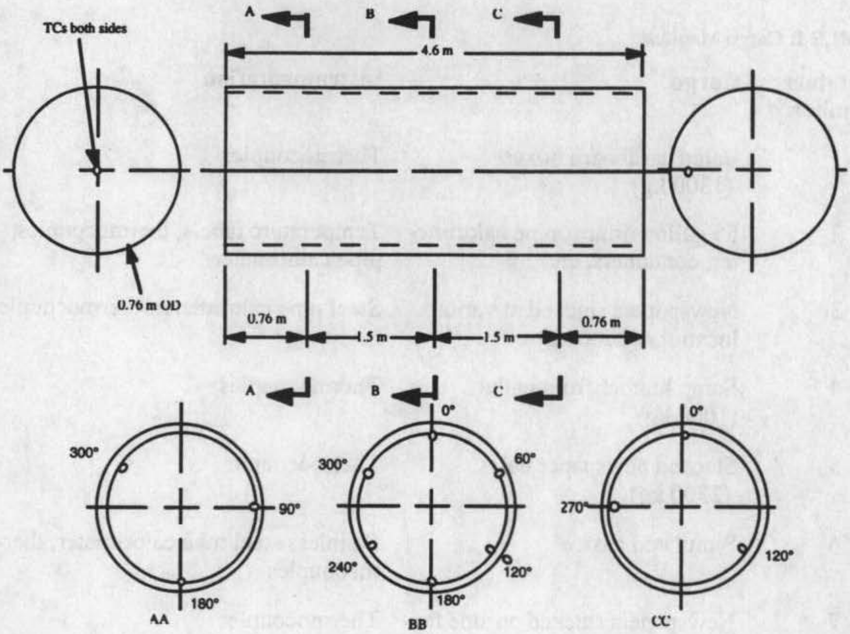

Figure 3. Thermocouple arrangement for large, stainless steel calorimeter.

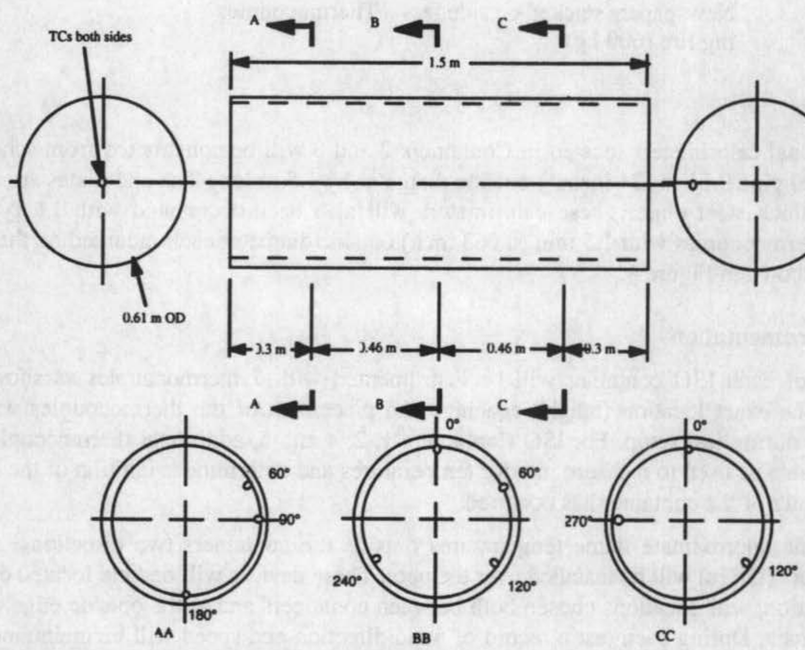

Figure 4. Thermocouple arrangement for carbon steel calorimeters.

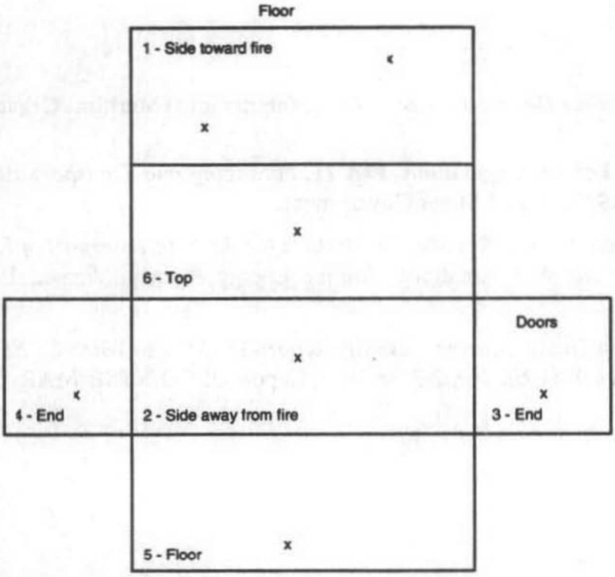

Figure 5. Location of thermocouples for determining ISO container wall temperatures. Figure represents flattened fold-out of container, with locations for thermocouples denoted with "x."

The data acquisition system will be located in an air-conditioned cabin located on Little Sand Island at least 100 feet from the pool. The data acquisition system has a total capacity of 200 channels, and is based on Hewlett-Packard data loggers and computer work stations. Data sampling intervals will be adjusted following the initial one hour pool fire to permit the recording of data for at least 24 hours.

Two video cameras will be used during these tests. One camera will be located on the deck of a nearby ship, and a second at ground level with a good view of the container stack. The locations of these cameras are to be field determined to obtain information about the fires and potential fire propagation.

CONCLUSIONS

The test should provide a basis for determining the additional protection offered to a radioactive materials package by a standard ISO shipping container. Typical temperatures and heat fluxes will be measured and used to guide studies into the safety of such shipments. Data obtained will also be of use in determining exposures for other types of hazardous cargos, and in determining the general nature of container ship fires where fires may travel from container to container in a sequential manner. Data from the test will be provided in a detailed report citable for environmental studies, and in papers summarizing key findings.

The test should also provide guidance for computer modeling efforts of container fire scenarios such as occurred during the *Sea Witch* accident in 1973. The test will provide benchmark data against which computer models can be calibrated prior to analysis of additional fire scenarios.

As of this writing, the test has been successfully completed, and preliminary data analysis is in progress. Papers and reports will document the results as time permits.

REFERENCES

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