Pool Fire Testing at AEE Winfrith

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INTRODUCTION

The thermal assessment of transport flasks has been carried out for many years at AEE Winfrith, an establishment of the UKAEA, by theoretical modelling and by the experimental measurement of temperatures under normal transport. In 1986 our capabilities were significantly enhanced by the building of a Pool Fire Test Facility in which packages could be tested and fundamental research into heat transfer in pool fires carried out. This paper describes the facility and the instruments and techniques which have been developed and presents some of our findings.

THE POOL FIRE TEST FACILITY

The Pool Fire Test Facility (PFTF) consists of a shallow pool, 9.5 m long and 6.5 m wide which is partly filled with water (Figure 1). The pool is constructed from concrete and is strong enough to hold a flask weighing 100 tons. The walls are lined with bricks to protect the concrete from the fire. The fuel, normally kerosene, is floated on top of the water. Either the whole pool may be used or the fire may be restricted to any desired area by means of a simple steel bund. Water can flow under the bund to replace the fuel as it burns during the fire, thereby keeping the surface of the fuel at a fairly constant level. To date the fires have neither been extinguished nor fed with fuel during the fire. The duration of the fire has therefore been governed solely by the initial quantity of fuel pumped into the bund.

The instrumentation in the fire consists mainly of thermocouples. Their cables are passed down into the cool water so that as little length as possible passes through the fire. They then pass out through a culvert into an insulated isothermal junction box. Cables run from this junction box to a nearby control cabin where a portable data logger is housed. The data channels are scanned typically every 15 seconds and, in addition to the temperature data, wind speed and direction are also recorded.

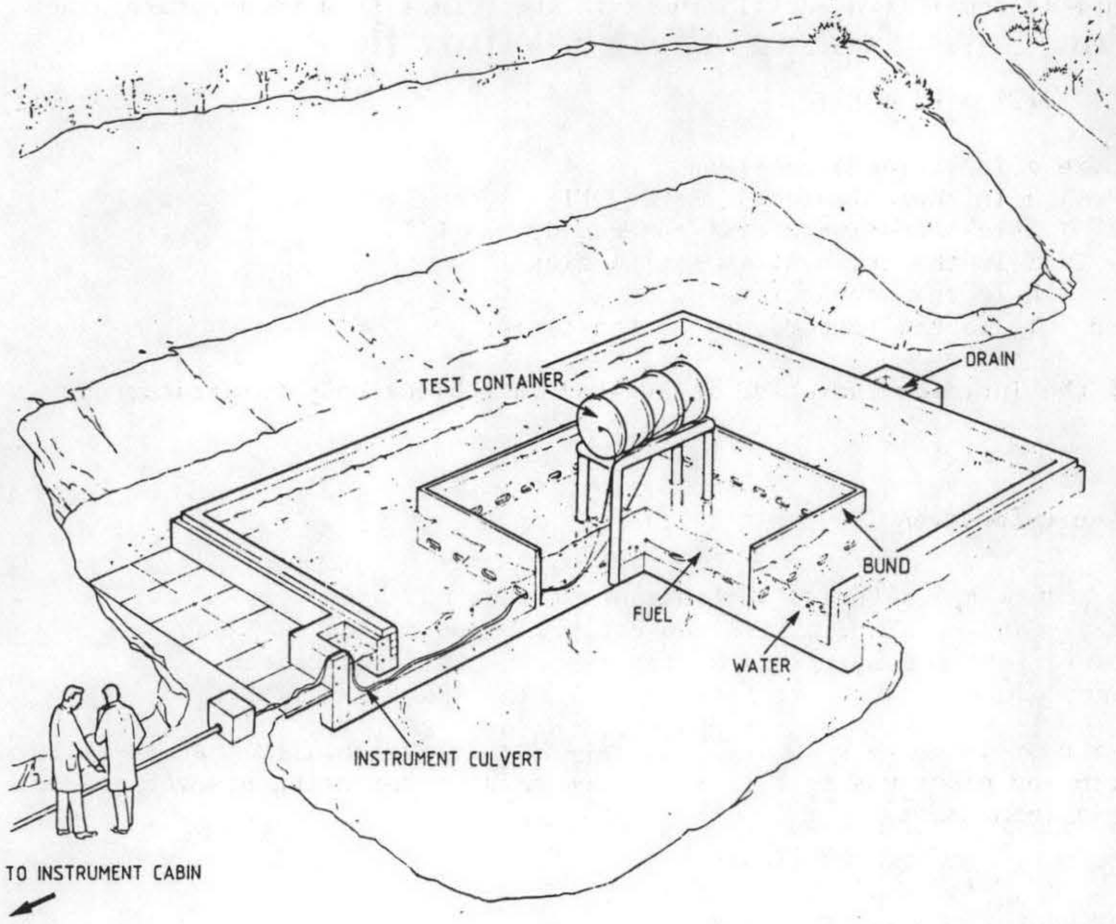

FIGURE 1 THE POOL FIRE TEST FACILITY

DIRECTIONAL FLAME THERMOMETERS

Since heat transfer in a pool fire is generally dominated by radiation the temperature of a bare thermocouple will relate to the local radiative flux rather than the local gas temperature. Furthermore, since the end of the thermocouple is a complex shape and the radiative flux is, in general, a function of direction, the temperature measured by the thermocouple would be expected to be some undetermined, complex function of this radiative flux and the measurement made from the thermocouple therefore meaningless.

Given the inadequacy of bare thermocouples a new instrument named a Directional Flame Thermometer (DFT) was designed and built. This instrument consists of a thermocouple bonded firmly to the back of a thin stainless steel plate, 20 mm square. The plate is mounted in a box with its front face exposed and its rear face insulated.

The thermocouple measures the temperature of the thin plate which rapidly comes into equilibrium with the flames at a temperature given by:

$$\sigma\varepsilon T^4 = \varepsilon I + h\ (T_f - T) \qquad (1)$$

where σ is Stefan's constant
ε is the emissivity of the DFT
T is the temperature measured by the DFT
I is the incident radiation flux
h is the convection coefficient
and T_f is the temperature of the flames

If the incident radiation is equated to a black body temperature by

$$I = \sigma T_b{}^4 \qquad (2)$$

then this gives

$$(3) \quad T^4 = T_b{}^4 + \frac{h}{\sigma\varepsilon}\ (T_f - T)$$

The convection term on the RHS is generally far smaller than the first term and hence may be ignored or compensated for using assumed values. This then leaves

$$T = T_b \qquad (4)$$

ie, the temperature measured by the DFT corresponds to the black body temperature equivalent to the radiation incident upon its face. Note that the measured temperature is independent of the emissivity of the DFT.

At the centre of a pool fire of reasonable size the radiation flux is relatively uniform in all directions and hence the temperature measured is independent of the orientation of the DFT. This temperature is also that which is measured by a bare thermocouple (Figure 2). Near the edge of the fire however the radiation flux is very different in the inward facing and outward facing directions and the temperature measured by a bare thermocouple lies somewhere between that measured by an inward facing and an outward facing DFT (Figure 3).

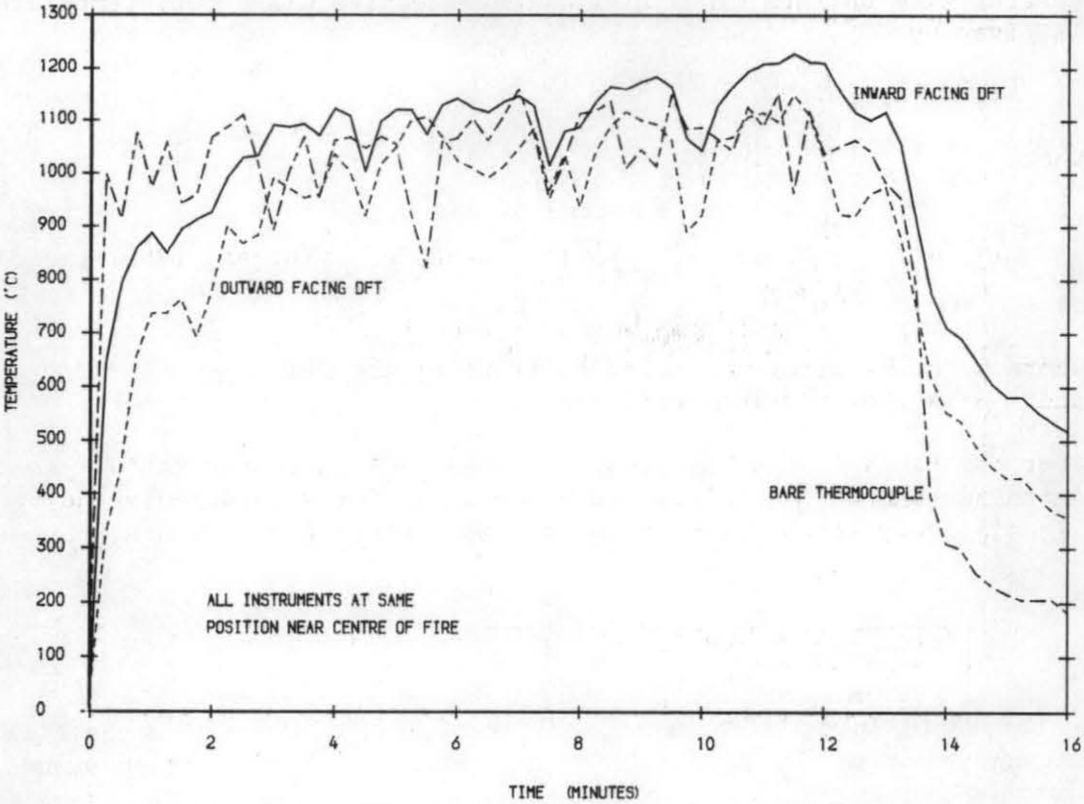

FIGURE 2 MEASURED FLAME TEMPERATURES NEAR CENTRE OF FIRE

MEASUREMENT OF FLAME THICKNESS

The NUREG (1978) regulations for the transportation of plutonium by air specify a fire test in which the flame thickness on all sides of the package must be at least 1 m. It is therefore necessary to be able to measure the flame thickness. A measurement of flame thickness is also useful even when not a regulatory requirement.

At Winfrith a technique for measuring flame thickness has been developed based on DFTs. A row of DFTs are placed on each side of the test object, facing outwards, at 0.5 m intervals. Thus a 2 m range can be covered using 5 DFTs. The data from all the DFTs are recorded typically every 15 seconds during the fire. The data from each line of DTFs at each scan is then processed to determine the flame thickness in the following manner.

A cut off limit is set below which the DFT is slow to respond and therefore prone to error. This limit is generally taken as 600°C. Starting from the outermost DFT and moving inwards the measured temperatures are inspected until a value above this limit is found. This places the edge of the flame a short distance in front of this

DFT. This distance is estimated by assuming that the flame is a grey emitter with uniform properties. The effective black body temperature is given by

$$T_b{}^4 = \varepsilon_f T_f{}^4$$

where

$$\varepsilon_f = 1 - \int_0^{\pi/2} \sin 2\theta . \exp(-\mu x \sec\theta)\, d\theta \quad \text{(Burgess 1986)}$$

where x is the flame thickness in front of the DFT
and μ is the emission coefficient.

Over the range of x of interest (0-0.5 m) $T_b{}^4$ increases rapidly as x increases and so the calculated value of x, for a measured value of T_b, is relatively insensitive to the assumed values for T_f and μ.

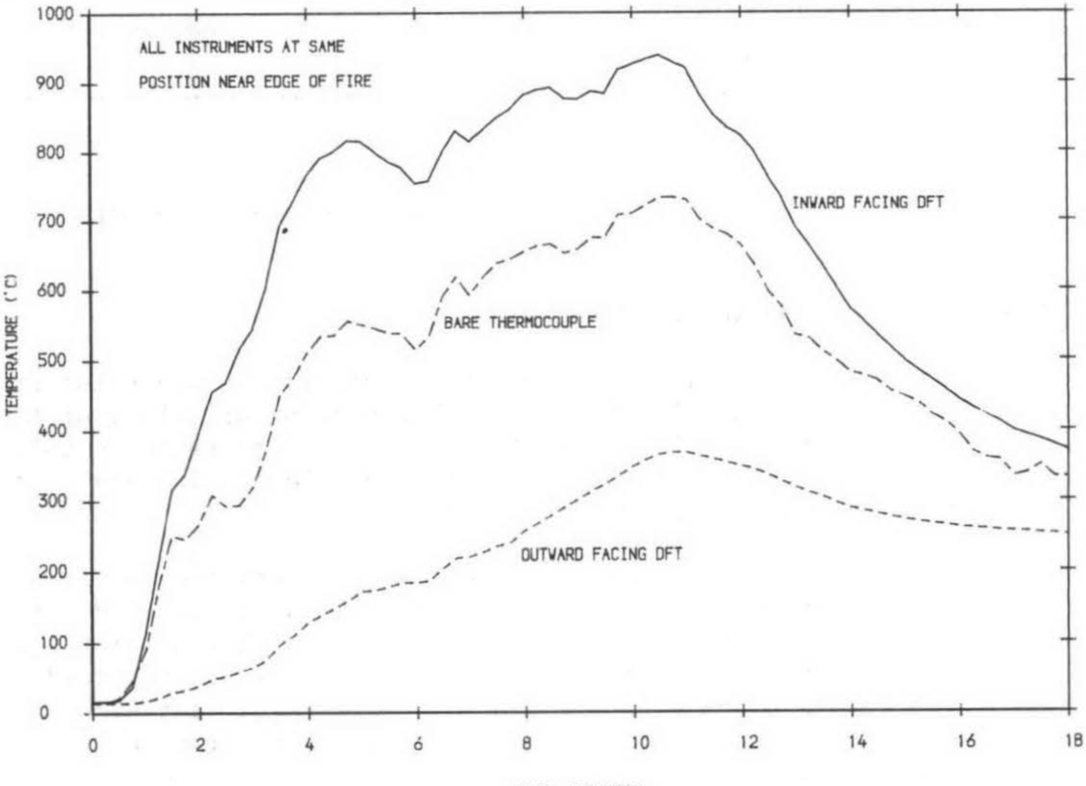

FIGURE 3 EFFECT OF DIRECTION UPON MEASURED FLAME TEMPERATURE

FLAME UNIFORMITY

A major part of the programme to date has been concerned with developing a capability for producing a good fire test with reasonably even flame cover which will demonstrably satisfy the IAEA regulations (Safety Series No 6, 1985). Previous work by other authors frequently stated that the flame cover was non-uniform due to wind. This experience was also apparently repeated in our tests with an open pool fire. Some tests however were performed under conditions of extremely light or zero wind and the non-uniformity of flame cover still occurred. This is demonstrated in Figure 4 where the radiation heat flux incident on each face of a test package is shown for a test carried out on a still day. These measurements were made using DFTs.

It is thought that the test package itself is large enough to affect the flames, generating a chimney effect whereby the flames pass preferentially up one side of the package and suck the flames under the package from the other side. Given that the package and test geometry is generally symmetrical the dominant side will be selected by any external influence. In most cases this will be any wind present, even when light. Thus the natural non-uniformity of the open pool fire upon a large package may often be attributed incorrectly to being due to this wind.

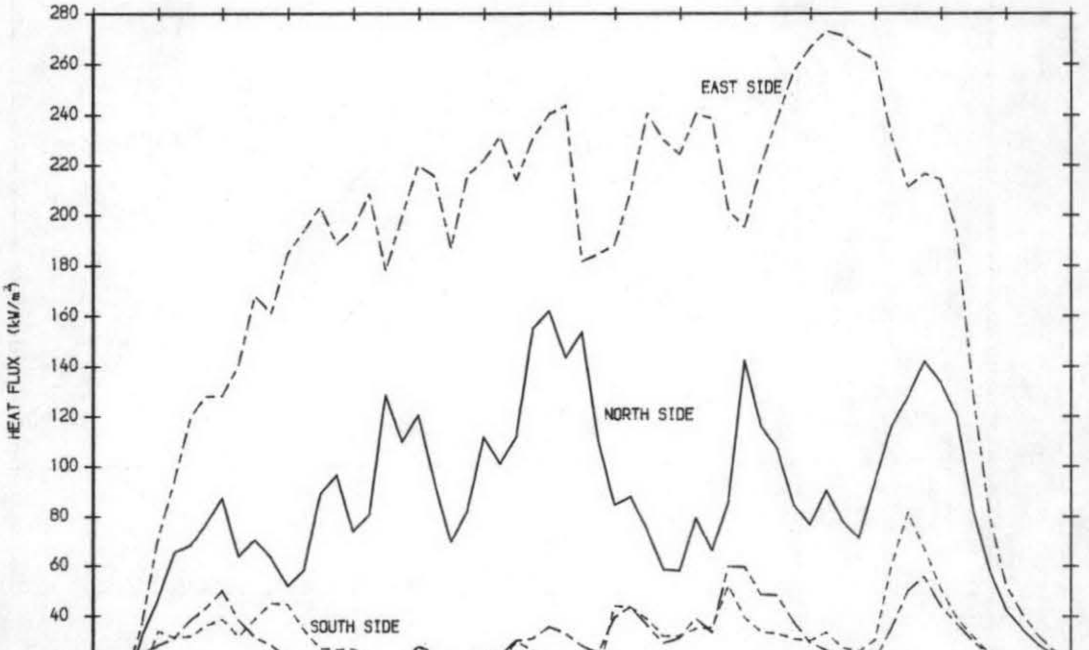

FIGURE 4 RADIATION FLUX UPON TEST CONTANER ON CALM DAY

FLAME GUIDES

Different arrangements of flame guides have been tested with the objective of finding an arrangement which ensures a more uniform flame cover without changing the nature of a pool fire or being obtrusive. The most suitable arrangement found consists of two short walls, extending from the surface of the fuel up to the base of the package, crossing over under the package. This cross-over wall can be constructed from thin sheets of steel and extends about 0.5 m beyond the package in each direction. The effect that these flame guides have upon the uniformity of flame cover is shown in Figure 5 which shows the radiant heat flux incident upon each side of a package when the flame guides are used. With good flame cover all round the package the flame guides are hardly visible and so the test still appears to be an open pool fire.

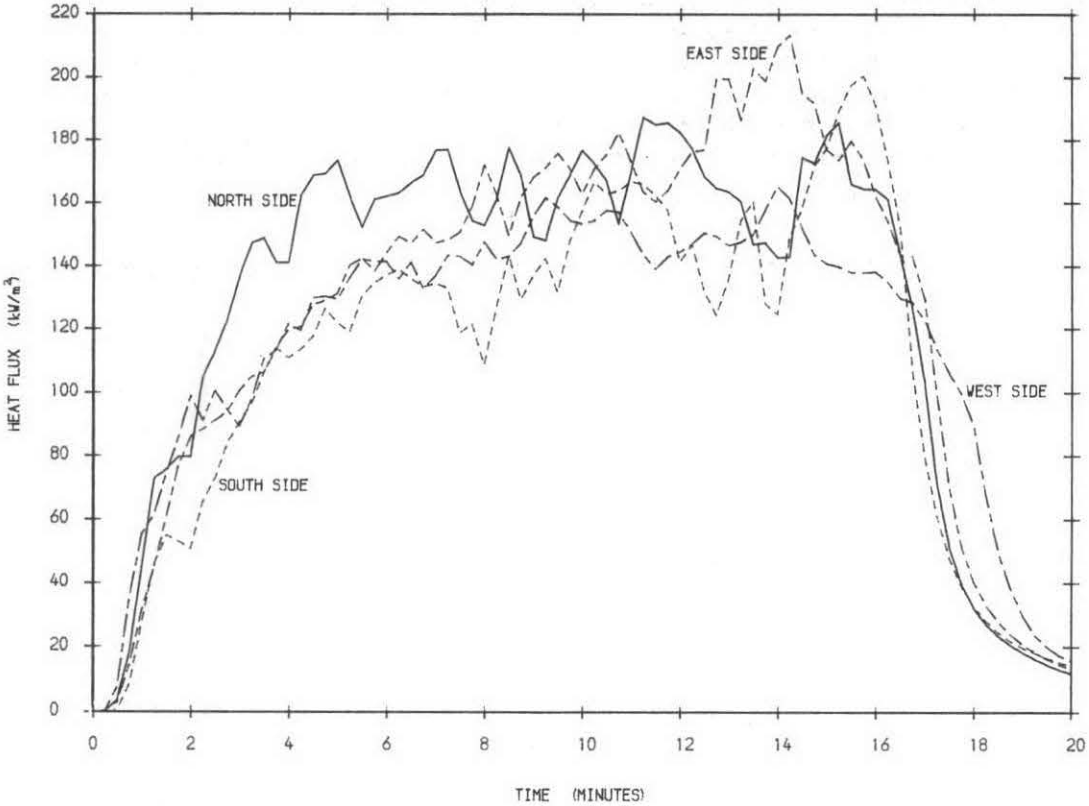

FIGURE 5 RADIATION FLUX UPON TEST CONTANER WITH FLAME GUIDES

FUTURE PROGRAMME

In our future programme the effects of varying the height of the package above the pool and the size of the pool will be investigated. Tests on a range of fin geometries are also planned to enable validation of theoretical models. Accurate measurements of heat flux will also be made to enable the flux into a surface to be compared against the radiant heat flux incident upon it. This will enable the effect of any soot deposition on the surface to be determined. If deposited, soot may act as an insulating layer significantly reducing the heat flux into the package.

REFERENCES

BURGESS, M. H., "Heat Transfer Boundary Conditions in Pool Fires", IAEA-SM-286/75P (PATRAM '86).

IAEA Regulations for the Safe Transport of Radioactive Material, Safety Series No 6 (1985).

Qualification Criteria to Certify a Package for Air Transport of Plutonium, US Nuclear Regulatory Commission, Washington DC, PB 287303 (1978).