APPENDIX 13C

Pool Fire Analysis

POOL FIRE ANALYSIS

For Jet A1 pool fires, the distance to potential lethality is well approximated by the extent of the flame envelope. For unconfined pool fires this is reasonably approximated by the pool radius. For confined (bunded) pool fires the distance to potential lethality takes into account the extent of predicted flame drag in the wind; this is because the edge of the pool is well defined and a well developed and stable fire is expected to form. Lethality is not expected beyond the flame envelope [3].

13C.1 Pool Fire Modelling

ESR, model pool fire hazards using the PFIRE2 code [18] which was developed by ESR and has been used since 1991. The models used in PFIRE2 are similar, but not identical, to the recently developed POOLFIRE6 model. The PFIRE2 model, including recent modifications to include flame sag for tank head fires has been used for thermal radiation and flame drag calculations for the tanks [3].

The flame shape used in modelling the thermal radiation flux from a pool fire is typically based on the assumption of a circular pool. PFIRE2 uses a skewed elliptical prism to represent the flame surface, as shown in **Figure 13.15**, allowing for flame tilt and drag in the wind. Other pool fire codes, e.g. POOL, POOLFIRE5, POOLFIRE6, Shell's FRED, and BP's Cirrus codes adopt a similar geometry, including both flame tilt and drag. It is now common practice to adopt a two zone representation as in PFIRE2, which includes; a lower, clear, flame and an upper, smoky, flame. For large diameter Jet A1 pool fires, clear flame height is predicted to be very short or non-existent, consistent with the work of Considine [3].

The flame drag correlation used in PFIRE2 and also recommended in the recent HSE review is that developed by Moorhouse and the flame sag (for tank head fires) is taken as for POOLFIRE6 [3].

Unconfined pool fire and its smoke impact are included in the consequence analysis.

13C.2 Thermal Radiation Impact Criteria

An estimate of the probability of fatality can be made on the basis of a thermal dose. One of the most commonly used expressions for this is the Eisenberg probit [25]. Other relationships exist but the Eisenberg probit provides one of the more conservative estimates. A difficult question is always how to evaluate the exposure time. In some cases it is reasonable to integrate the dose received when moving away from the fire. For this assessment it is assumed that the worst case scenario is that an individual has to pass the entire diameter of the bund or tank head fire (either at ground level below the highway or at elevation on the highway) in order to escape.

For this assessment it is required that two potential scenarios are considered for any event:

1. If the highway is unblocked and the traffic can move freely, then a member of the public using the highway will remain in their car and will only be exposed for a short period of time, as they drive past. It is thought that this will be the case for highway users for the majority of the time (approximately 90%). When the traffic is moving freely it has been estimated that the traffic will travel at a moderate 45mph or approximately 20ms^{-1}.
2. If the highway is blocked (i.e. because of traffic jams or if the bridge is damaged) then a member of the public using the highway will have to vacate their car and walk from the affected area. In this case the exposure duration will be fairly long, but this accounts for only a minority of the time (approximately 10%). It has been assumed that a brisk walking speed can be taken as 2ms^{-1}.

At the existing Airport Fuel Tank Farm, the dimension of a contained bund fire is ~170m, whilst the dimensions of a tank head fire for the large and small tanks are 39m and 27.5m respectively. For case 1, where the incident can be travelled past by car, a typical exposure time would be approximately 8.5 seconds for a bund fire and either 1.9 or 1.4 seconds for a tank head fire. For case 2, assuming an escape speed by foot of 2ms^{-1}, the exposure times would be greatly increased to around 85 seconds for a bund fire and either 19 or 14 seconds for a tank head fire.

For the new extension facility the bund fire dimension is ~100m and the tank head fire would be 34m in diameter, so for case 1, passing the incident by car, a typical exposure time would be around 5 seconds for a bund fire and 1.7 seconds for a tank head fire. For case 2 these exposure times would increase to 50 seconds for a bund fire and 17 seconds for a tank head fire. It should be noted that all of these exposure times will be for individuals at a distance of approximately 100m from the edge of the pool (bund and tank head) fires, as it is the assessment of the risk from these types of fire to people on the highway that is required.

10kWm^{-2} is the surface emissive power of large Jet A1 fires [26], so the thermal flux outside the flame envelope will always be less than this and will reduce as someone moves away from the fire. Jet A1 pool fires are also predicted to take a significant time to develop [3], and during this time much lower thermal radiation levels would be experienced outside the pool.

It is only for the 'escape by foot' cases described above, that the thermal radiation effects from a bund fire have any potential impact. This is because thermal radiation is usually expressed as a thermal dose, which is dependent on the duration of exposure. For case 1, when the fire is passed by car, the duration of exposure is only a few seconds, which results in a negligible thermal dose. In this case it is only the effects of the flame envelope resulting from the fires which could pose any risk to the highway users (see **Section 13C.3** for flame envelope dimensions). For case 2, which only accounts for 10% of highway usage, it is necessary to consider the effects of the thermal radiation, as the duration of exposure can be over one minute.

For the bund fires the thermal radiation exposure to someone outside the developed flame envelope would therefore be predicted to be lower than 10 kWm^{-2} for 85 seconds at the existing facility or 50 seconds at the new extension facility when escaping by foot (case 2). The highway is approximately 100m from the edge of the bunds at the existing and new extension facilities. At these sort of distances the thermal radiation levels from the bund fires will fall to approximately 4kWm^{-2} (using PFIRE2 [18]). Thermal radiation exposure is usually expressed as a thermal dose; 4 kWm^{-2} for 85 seconds gives a thermal dose of 540(kWm^{-2})$^{4/3}$s and 4kWm^{-2} for 50 seconds gives a thermal dose of 317(kWm^{-2})$^{4/3}$s. The Eisenberg probit gives a nominal fatality probability of <0.1% for this thermal dose, i.e. fatality is predicted to be very unlikely even for upper exposure levels predicted.

The UK HSE defines a dangerous dose as that which would cause severe distress to all persons suffering it and could result in highly susceptible people being killed. The dangerous dose of thermal radiation for average members of society is given as 1000(kWm^{-2})$^{4/3}$s [13]. The exposure predicted here is significantly below this dangerous dose level, so no fatalities would be expected for people located in the vicinity of the highway from a bund fire at either the new extension or existing facilities, when escaping by foot.

As the tank head fires are much smaller in width than the bund fires and hence involve shorter exposure durations (due to their reduced dimensions), the thermal dose resulting from these events will be of negligible effect to individuals on the highway when attempting to escape on foot an event occurring at the Airport Fuel Tank Farm. Therefore it is only necessary to assess the impact upon the highway from the tank head fires flame envelopes (see **Section 13C.3**).

13C.3 Smoke Plume Impact

The combustion products of aviation fuel include carbon dioxide, nitrogen oxides and sulphur oxides. Incomplete combustion will generate thick black smoke and potentially hazardous gases including carbon monoxide. In the case of fire involving heavier hydrocarbons such as Jet A1 and for large diameter tank/bund fires, smoke production is high. However smoke from such fires is buoyant and does not tend to seriously impact people on the ground in the open air; as was found to be the case in the recent Buncefield tank farm fire [30].

Smoke plume rise was considered in the PAFF report [3], and the ESR PFIRE2 code [18] was used to assess the smoke envelope produced. The PFIRE2 code includes correlations for both flame drag and flame tilt and has therefore been used to assess the smoke envelope from potential fires at the Airport Fuel Tank Farm. The following fires are considered and results for potential smoke impact distances provided in **Table 13C-1** and **Figure 13.16**.

Table 13C-1: Smoke Impact Distances

Scenario		**Pool Fire Diameter (m)**	**Fire Height (roof or wall) (m)**	**Distance to Boundary Fence (m)**
TANK HEAD FIRE	Small tank (existing)	27.5	20.0	26.0
	Large tank (existing)	39.0	20.0	26.0
	Tank (new extension)	34.0	20.0	22.5
BUND FIRE (not inc. EVA road)	Existing	172.0	1.0	16.0
	New extension	96.0	2.0	12.5

Figure 13.16 also features a plot of the cross section of the Hong Kong Link Road where section B-B refers to cross-section B-B noted in **Figure 13.2** (the point where the highway is closest to the AFTF). It is clearly shown that the smoke envelopes do not impinge on the highway, when considering the cases of the tanks in closest proximity to the highway.

The nearest smoke envelope to the highway relates to the large (existing) bund fires in a wind speed of 10ms^{-1} (making the cautious assumption that the 5 ≤10ms^{-1} category will represent 10ms^{-1}) , which occurs just over 42% of the time but only just over 5% of the time towards the Hong Kong Link Road.

A tank head fire is predicted to occur with a frequency of 1.2x10^{-4}/yr per tank (see **Section** Error! Reference source not found.) whilst a bund fire is predicted to occur with a frequency of 1.2x10^{-5}/yr per bund (see **Section** Error! Reference source not found.). In order for the bund fire to impact upon the bridge it is necessary for the wind to blow from the North or North-West, as this will carry the smoke towards the Hong Kong Link Road from the tank farm.

Bund fire impacts with a wind directed towards the highway therefore have a maximum impact frequency in the worst case direction (2 sectors N and NW, of 20.88%) of 2.5x10^{-6}/yr based on the wind rose in **Appendix 13D**, whilst a tank head fire would have a maximum impact frequency of 2.5x10^{-5}/yr under these conditions.

Unconfined pool fires, will produce smoke and this will tend to raise clear of anyone outside the pool area. For unconfined pool fires, the hazard to life is dominated by the flame over the pool itself since the smoke hazard would only be transitory as the pool spreads and drains away – direct impingement by the flame above the pool would have an immediate effect and is the basis of the hazard range for unconfined pools in this assessment. Confined pool fires, including tank head fires, may last many hours or days, generating a continuous smoke plume and are also much more likely to occur at the Airport Fuel Tank Farm facilities.