A collaborative project between BlueScope Steel Limited and the Bushfire CRC

RESEARCH INTO THE PERFORMANCE OF WATER TANKS IN BUSHFIRE
-Bushfire CRC Project D1

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by

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1. Introduction

The performance of water storage tanks during unplanned bushfire events is of significant interest to agencies and the general community. Past bushfire investigations have shown that the mains water supply is not reliable during and especially after the fire front has past a given region. In many cases water storage devices are relied upon for fire suppression activities by agencies and community members. This investigation was undertaken to understand the performance of common water storage tanks under the effects of bushfire impact of varying intensities.

2. Key outputs

Metal water tanks

The metal spiral tank maintained structural integrity through all fire exposures, minor leaks where observed only after structural exposure tests involving 30 minute flame immersion.

Conventional metal tanks maintained structural integrity through all fire exposures.
For the flame emersion and structure simulations small leaks with a low rate of water loss from some of the seams was observed. The total rate of water loss for all leaks in any given experiment was below 2 litres per minute.

Internal plastic linings of both types of metal tanks were observed to degrade and delaminate in the region above the water line in areas where fire immersion occurred. This detached material either remained buoyant or sunk to the bottom of the tank. Although unlikely it may be possible for this detached material to hamper water evacuation. Consideration to tank outlet design and location would eliminate this potential problem. Visible degradation of the internal liner of these thanks in the region below the water line was evident after the 30 minute flame immersion, with water loss below 2 litres per minute.

Plastic water tanks

During leaf litter exposure the polyethylene tanks showed some involvement in the combustion process. This combustion remained localised and persisted for up to 22 minutes with a relatively small amount of leaf litter. If significantly high levels of leaf litter were present loss of integrity of the tank may occur.

During higher level exposures the tank portion above the waterline melted and was involved in flaming combustion. Below the waterline, surface flames were observed and in the more intense exposures the tank wall swelled under the static pressure load of the water due to softening of the outer surface of the plastic. This distortion was greater in tanks filled to a higher percentage of their design capacity and for tanks where more of the tanks wall thickness was consumed or softened by flame combustion. In a number of cases this distortion led to catastrophic rupture at the swollen tank section. It is concluded from the range of exposures that polyethylene tanks with minimal ground fuel accumulation around the tank and at least a 30m clearance from forest fuels and other stored combustible materials (including other combustible water tanks and dwellings) are likely to maintain structural integrity during a fire event.

Any combustible element or adjacent structure could present a risk to the tank by providing continued radiation exposure which extends the period of surface flaming and can lead to catastrophic failure. The example of catastrophic failure of a 30,000 liter 15 year old tank filled to 100% capacity from a flame and radiation exposure likely from a moderate forest fire with no additional heavy fuels around the tank provides an important observation as to polyethylene tank performance.

In each case, larger capacity tanks that were filled close to their full capacity failed sooner. For experiments involving high radiation or flame contact, the tank portion above the water line became involved in combustion to the point that an adjacent house may be threatened by these flames.

3. Objectives of the study

The objective of this research was to investigate the relative performance of different types of water tanks to bushfire and infrastructure interaction conditions. This experimental program provides an insight into the failure modes and levels of performance of a selection of common and new water tank types.

4. Review on water tank use in bushfire prone areas

A review of regulatory documents has been performed to assess the recommendations for use of water tanks in bushfire prone areas. Also various post-bushfire survey data have been reviewed to further qualify the behaviour of water tanks in bushfires. These review outcomes are provided below.

4.1. Recommendations and/or limitations for use of water tanks in bushfire prone areas

Various governmental documents have been reviewed:

4.1.1. AS3959 – Building in Bushfire Prone areas

The current version of AS 3959 building in bushfire prone area standard does not refer to the design and use of water tanks in bushfire prone area (Australian Standard, 1999).

4.1.2. COAG Bushfire Enquiry

The COAG report provides no specific recommendations for water supply or tank provision for private dwellings (Ellis, 2004).

4.1.3. Fire Agency Comments

Some fire agencies refer to the importance of water supply in bushfire prone areas in the broader planning context. Some general recommendations can be found on different documents generated by the fire service to protect your house. They consider the amount of water needed and the importance of maintaining this supply throughout the fire event.

In "make your property safe from bush" (from CFA http://www.cfa.vic.gov.au/residents/living/protectyourproperty.htm) water tanks are mentioned: "*Mains water supply may not be a reliable source during a fire as the water pressure may drop. Make sure that you have access to adequate water supplies, such as tanks, dams, swimming pools or water reserves*."

The NSW RFS developed a document to help environmental planning and assessment (s.79BA Business Rules - NSW Rural Fire Service & planning NSW, 2001). The business rules provided in the document cover a range of issues, from general matters such as the process of handling referred applications, to specific cases where experience has shown difficulties in interpreting or applying the provisions of Planning for Bush Fire Protection (PBP). One of the sections in the document is related to water supply. Water supply is an important aspect of fire fighting effectiveness.

Four situations are addressed in the document:

- *Unreliable reticulated water supply: "where property is connected to a reticulated water supply and the water supply is known to be unreliable, and the dwelling may be subject to bushfire attack then a tank with a capacity of 5,000* *litres for a dedicated fire fighting supply shall be provided. A 65mm Storz fitting and ball or gate valve shall be installed in the tank"*

- *No reticulated water supply available. "Where no reticulated supply is available then a minimum 10,000 litres dedicated water supply is to be provided. Sufficient water is required to fill 3 fire fighting tankers."*
- *Dual occupancy and no reticulated water. "When a detached dual occupancy building is proposed in an area where no reticulated water supply is available then a minimum 22,000 litres dedicated water supply is to be provided (i.e. 10,000L for each dwelling). This amount can be amalgamated and stored in a single tank that is accessible for both dwellings. However, provision must be made for maintenance of the tank and access to the tank."*
- *Dedicated water supply. "Dedicated water supply is to be stored in a fire resistant or heat shielded tank and fitted with a ball valve and a 65mm storz fitting. They must also draw from the base of the tank. If on a stand then the stand itself should be of a fire resistant construction."*

ACT Emergency services Authority in "preparing your home" (http://www.esa.act.gov.au/fire_safety/preparation.html) mentions the importance of water supply: *"Ideally you would install a tank specifically for fire fighting purposes. Tanks vary in size from 1000 to 20,000 litres and come in a variety of materials including galvanised iron, concrete, fibreglass and polyethylene. " …" A petrol, diesel or electric powered pump will be necessary if you need to draw water from an independent water supply such as a tank or swimming pool."*

In Western Australia the homeowner's Bushfire Survival Manual edited by FESA give some recommendation for water supply (FESA, 2001). For home protection the manual recommend to have a minimum of 1000 litres and for a sprinkler system to have about 15,000 litres plus a further supply for house protection. It is recommended to protect the metal tank stand. The reserve water supply needs to be on gravity feed, unless a diesel or petrol pump is used to maintain the water pressure. Plastic water pipes should be avoided as they are likely to melt.

4.1.4. AFAC Position Paper

The position paper on community safety and evacuation during bushfire (AFAC, 2001) mentioned that *"Residents in or near areas that may be threatened by bushfires should be encouraged to make plans in relation to how they will manage their safety when a bushfire occurs some of their consideration should be:…Alternative water supply…"*

4.1.5. Council Policy

The Blue Mountains city council provides the following advice on the website http://www.bmcc.nsw.gov.au/

"Water pressure is often depleted during a bushfire as a result of excessive demand. It is sometimes advisable to provide a static water supply on the site such as a pool, dam or tank together with a petrol or diesel pump.

***10,000 litres** is considered to be an adequate static water supply for a building the size of a typical dwelling. An individual assessment may be necessary for a larger building or a situation where a sprinkler system is to be employed.*
***Elevated** water storage tanks will need to be protected, particularly if they are supported by timber framed construction.*
***Fit tanks with a 65mm diameter outlet** and a 65-38mm stortz reduction fitting together with line and standpipe for bushfire vehicle access. In addition to the 65mm outlet, the supply pipe to the sprinkler system should be provided with a 19mm outlet for the connection and use of a garden hose in bushfire conditions.*
***Protect** the water supply system from the effects of radiant heat."*

4.2. Findings from post bushfire surveys

To better understand the issues surrounding house loss during bushfire, CSIRO has performed survey at the rural/ urban interface following significant fire events (From Ash Wednesday to recent surveys in the Eyre Peninsula) (Ramsay, McArthur et al. 1995) (Leonard and Blanchi 2005). The data collected include details of the extent of damage in the fire, extensive information on the structure of house, site details, description of surroundings, and details of the action of residents and fire fighters during the event. The surrounding environments such as garden design and different types of outbuildings (mainly garages and sheds but in some case water tanks) play an important role in the house's chances of survival.

Some information has been collected on water tanks mainly in the post bushfire surveys conducted in rural areas. Damage to water tanks has been assessed from the data collected during the Eyre Peninsula survey (see Table 1) and from photo analysis (see Figure 1, Figure 2).

Table 1 Degree of damage of water tank (data collected during Eyre Peninsula survey)

	Metal	Polyethylene	Concrete
Untouched	8	2	4
Superficial	3	0	1
Light	0	0	0
Medium damage	0	2	1
Heavy damage	0	0	0
Destroyed	0	3	0
Degree of damage not mentioned	1	1	1

The findings from post bushfire surveys show different kinds of impact on tanks (see Figure 1 and 2).

Figure 1 Example of water tank damaged, Eyre Peninsula

Figure 2 Example of metal water tank withstanding adjacent structure fire, Eyre Peninsula.

5. Methodology full scale experiment

The performance of a range of water tanks were tested with a Bushfire Flame Front Simulator, which allows repeatable exposures of these elements at varying levels.

5.1. Experimental performance objective

Two main aspects were evaluated:
- The ability to maintain integrity and water supply. Water access is a key element for fire-fighting bushfire.
- The potential of water tank to burn and support flame spread that might affect surrounding objects. The radiant heat and flame produce by the water tank burning can impact on windows (causing breakage) or on other potentially combustible material.

5.2. Water tanks investigated

A series of 25 tests were carried out on 10 different types of tanks of various shapes and material. The diameter of the tanks varied from 4000mm for the largest to 1340mm for the smallest. Both plastic (polyethylene) and metal tanks were tested (see Table 2). The tanks were filled with water to different levels (2/3 full or full).

Table 2 Type of tank investigated

Tank description	Size (mm or l)	Test number
Tank 1 – COLORBOND R AQUAPLATE R Steel (mist green)	h:1250, d:3030	Test 1, 2, 3
Tank 6 - Polyethylene (beige)	h:1570, d:2450	Test 4, 5, 6
Tank 3 – COLORBOND R AQUAPLATE R Steel (mist green)	h:2470, d:1480	Test 7, 8, 9, 10, 11
Tank 5 – Spiral wound galvanised AQUAPLATE R steel	h:1830, d:1830	Test 7, 8, 9, 10, 11
Tank 2 – COLORBOND R AQUAPLATE R Steel, oval shape	h:1540, w:1150, l:2350	Test 12, 13, 14
Tank 4 - Polyethylene (green)	h:1800, d:1340	Test 12, 13, 14
Tank 7 - COLORBOND R AQUAPLATE R Steel	h:3000, d:2100	Test 15, 16, 17
Tank 8 – Nylex Polyethylene (black)	h:2400, d:2400 9000 litre	Test 18, 19, 20, 21
Tank 9 - ZINCALUME R steel bladder type tank	h:2180, d:4.68 37500l	Test 22, 23, 24
Tank 10 - Polyethylene (black - used tank)	h:2500, d:4000 30000l	Test 25, 26

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5.3. Experimental apparatus

The experimental apparatus used to assess the performance of water tank is described in the following sections.

5.3.1. Bushfire flame front simulator

A Bushfire flame front simulator has been constructed in the open at the NSW Rural Fire Service Hot Fire Training Facility south of Mogo, NSW to allow repeatable testing of different materials in bushfire burn over conditions. The bushfire flame front simulator is designed to recreate actual bushfire flame characteristics (e.g. flame temperature profiles and radiant heat flux) using an array of liquid propane burners.

Liquid propane is stored in an 8,000-litre tank permanently installed at the facility. The tank is pressurised by regulated nitrogen to avoid reduction in flow that occurs when the natural vapour pressure of propane is used as a propellant. Safety features fitted to the supply include over-pressure valves and overflow valves.

The pressurised propane is then piped to the simulator grid in a buried 75 mm internal diameter pipe, a distance of approximately 30 metres.

The burner grid consists of 5 separate stages to simulate fire front approach, burnover and continued advancement. However for this project only the fire front approach was of interest so only two stages, pre-radiation burners and on side immersion burner stages, were used Figure B2. This simulates the fire burning up to a fuel controlled house site where the fire front is unable to burn through the site with a high intensity. The water tanks were set up over the top of the unused burner stages. The two burner stages operated as follows:

The pre-radiation stage was arranged in a line of 4 sets of 3 burners at a distance of 5 m from the Northeast facing the water tank(s). This stage simulates the radiant heat exposure from an approaching fire front. Each set of 3 burners could individually be turned on and off via solenoid valves and the burner flow could be controlled via control valves.

On-side immersion stage burners were arranged in 3 rows of 6 burners set back at 350mm, 1.85m and 3.35m from the north east. During a burn this phase could only be turned on or off. The flow rate could be controlled by fitting differently sized calibrated jets to the burners. When simulating lower fire intensities with shorter flame depths the jets at the rear most rows may be blanked off. The total heat release rate can be estimated by summing the calibrated jets used.

The angle and height of the simulator's flames approaching the water tank was influenced by the ambient wind conditions. Thus, there was a degree of uncontrolled variation in flame angle accordingly to the wind gusts and lulls. For these experiments the simulator was intended to be used to conduct experiments under the North-easterly sea breeze with wind speeds at 2-5 metres height in the open of approximately 2-4 km/h. These relatively light breezes are considered to represent the attenuated forest wind under the canopy and to recreate flame angles similar to actual forest fire flames for the appropriate fire line intensity (Leonard, 2003).

While effort was made to accurately simulate critical aspects of a bushfire, there remain fundamental assumptions and limitations associated with attempting to simulate a moving fire on a stationary grid and the use of propane gas to simulate bushfire flames.

5.3.2. Experimental set-up

The experimental set up allows us to test one tank or two small tanks in the same experiment. The experimental set-up for the testing of single water tanks is shown in Annexe B. The water tank was placed at 50 mm from the first row of burners and centred in front of the grid masts, which were located in a row in the middle of the fire grid.

The experimental set-up for two tanks is shown in Annexe B. The tanks were placed so that the distance between the tanks and the distance to the extent of the fire grid were the same. This means that the centre to centre distance varies depending on the diameter of the different tanks.

5.3.3. Instrumentation

The instrumentation used for the experimental set up is presented in the following section for further details see Annexe B.

Temperature measurement

Temperatures were measured using 1.5 mm Type ‘K’ MIMS thermocouples. Each thermocouple was identified by a separate thermocouple number as shown in Annexe B.

Each tank was equipped with 24 thermocouples. The positions of all thermocouples are shown in Annexe B. Air and surface temperatures were measured at the bottom, centre and top of the tank. Measurements are taken in the front, sides, and back of the tank as well as inside the tank (water and air temperature). Steel reinforcing mesh or poles were placed on the sides of the tank to support these thermocouples.

Heat flux measurement

Heat flux was measured using Medtherm water-cooled Schmidt Boelter total heat flux meters with a sensing range of 0 to 100 kW/m^2. The total heat flux measured consisted of both radiant and convective heat.

Three or four heat flux meters were mounted beside the tank on masts facing horizontally towards the fire, also at right angles to the to fire front in the horizontal and vertical (skyward) plane.

On the top of the tank one heat flux meters was mounted horizontally and another one was mounted vertically. This was used to monitor the heat flux output of the bushfire flame front simulator as well as measure the effects of radiation feedback the tank surface receives. For these heat flux meters, radiant heat was the predominant component measured during pre-radiation exposure however during total flame emersion convective heat was the principal component.

All cables and cooling lines external lines were protected by placing them in silicon coated mineral fibre insulated sheathing or in steel downpipe sections or they were buried underneath sand.

Data acquisition

All thermocouples and radiometers locations are detailed in Annexe B, and were logged at 5-second intervals via a Datataker 505 data logger with up to three expansion modules. The data logger and expansion modules were placed in a steel fireproof box located inside the simulated residential building. The data logger had a battery power supply, which was recharged between tests. An RS232 communications link was created by a radio modem transducer connected to the logger and a matching receiver connected to a monitoring computer at the Control area. This allowed for real time observation of data. Data was simultaneously recorded on to the data logger's internal memory card and the PC in the control area to minimise the potential for data loss.

Weather measurement

A range of information relating to climatic conditions was collected prior to and during all experiments. An Oregon WMR112U Cable Free Weather Station and sensors was used to collect weather data and forward it to a base station positioned in the control room, which then logged the information directed to a PC. Data was collected by the sensors at a rate of three recordings per second and logged in the computer data base once a minute. Each record in the data base is an average of the 180 recordings taken in that minute.

Wind speed was measured and recorded in meters per second and the wind direction is displayed as a value between 0º and 359º (Degrees). 0º representing North, 90º representing East, 180º South and 270º West.

This information, in particular the information relating to wind direction and speed, was used to determine appropriate test windows. A North Easterly direction was favoured for testing, which is represented as 45º, although testing was carried out under a range of wind conditions.

Weather conditions over the testing window varied as compared to recent years. Generally the wind conditions are dominated by a local thermally driven sea breeze. This local thermal system produces strong North East winds in the afternoons of warmer days.

Where data is unavailable from this system weather data from the local Moruya Airport has been obtained.

This year, 2005, a warmer open ocean current moved further down and closer to the coast. It would appear this increase in sea surface temperature and a slightly lower than average land temperature reduced the frequency and strength of the traditional thermal driven North East sea breeze.

Audio-visual recording
A minimum of two digital video cameras were used to record each test. Digital still pictures before during and after each experiment were also taken and were time stamped for appropriate visual recreation of the exposures.

5.4. Exposure conditions

The exposure conditions proposed have been adapted from the draft for public comment Australian Standard (revision of AS 3959-1999) (DR 03182, April 2003) and from “A Guide for Councils, Planners, Fire Authorities, Developers and Home Owners” (NSW Rural Fire Service & planning NSW, December 2001).

The water tank are exposed to ember attack, radiation and flame commencing with low category of bushfire attack and with progressive increase in the category to medium, high and extreme, culminating with flame attack. At every stage detailed observations have been made as to the propensity of water tanks to:

- Ignite;
- Loose their integrity; and
- Act as mechanisms for spreading flame;

5.4.1. Leaf litter exposure

This simulated an attack from burning embers or accumulated leaf litter. Eucalypt leaf litter consisting of leaves and small twigs was conditioned at 40°C and 20% RH until contact moisture content. For each exposure approximately 100 litres of leaf litter was spread along the base of the water tank. This leaf litter was then ignited using a portable propane burner. The burners of the bushfire flame front simulator were not used for leaf litter exposure experiments. The experiment was ceased when significant combustion or involvement of the water tank ceased. Leaf litter exposures were not conducted on metal water tank as no involvement of the material would be possible.

5.4.2. Bushfire passage pre-radiation exposure

This level of exposure represents a radiation profile typical of an advancing bushfire that does not reach a point of direct flame contact occurring on a fire danger day of FDI 40 and fuel load of 15t/ha with sufficient clearing to avoid direct flame contact. The pre-radiation burner stage of the bushfire flame front simulator was then controlled so that the following heat flux measurement readings on the top of the tank were achieved.

- 5 kW/m^2 for 3 minutes
- 10 kW/m^2 for a further 2 minutes
- 30 kW/m^2 for a further 2 minutes
- 10 kW/m^2 for a further 1 minute
- 5 kW/m^2 for a further 1 minute and then the burners were turned off

The flame immersion burner stage was not used. The flow rate of the pre-radiation burner stage was manually controlled in response to real time heat flux readings.

5.4.3. Bushfire passage flame immersion exposure

This level of exposure represents a bushfire occurring on a high fire danger day of FDI 40 and fuel load of 15t/ha including a flame immersion from a flame front of 10MW/m fire line intensity (flame heights typically 5m). This involved use of the pre-radiation stage similarly as for the pre-radiation exposure. The flame immersion stage was also used as follows:

- 5 kW/m^2 Pre-radiation stage only for 3 minutes
- 10 kW/m^2 Pre-radiation stage only for a further 2 minutes
- 30 kW/m^2 Pre-radiation stage only for a further 2 minutes
- Flame immersion stage on for a further 11 seconds
- Flame immersion stage is turned off but takes a further 40 seconds for all gas to burn out of lines for this stage of grid.
- 5 kW/m^2 pre-radiation stage for a further 2 minutes and then the burners were turned off

5.4.4. Structural fire exposure

This level of exposure was designed to simulate a worst case structural fire exposure. It is a full continuous flame immersion with fire line intensity of 5MW/m (flame height 2 - 2.5 metres) for a period of 30 minutes. The flame immersion stage of the bushfire flame front simulator was turned on for 30 minutes. No leaf litter was used.

6. Results and discussion

Results are summarised in the following Tables (see Table 3, 4, 5 and 6). All measurements are plotted in Annex A and photos of significant occurrences are given in Annex C. The results of each experiment are discussed in the following sections.

Table 3 Summary of experiment observations

Experiment **Type of water tank**	**Leaf litter**	**Leaf litter** **+ pre-radiation**	**Simulation bushfire passage**	**Simulation structure fire**
Tank 1 – COLORBOND R AQUAPLATE R Steel (mist green)		Experiment 1 Scorches, no damage to the structure	Experiment 2 Scorches and leak from seams	Experiment 3 More scorches, more leaking
Tank 6 - Polyethylene (beige)	Experiment 4 Small scorches no damage	Experiment 5 Tank melted and deformed to the level of water Leak from the base	Experiment 6 Further melting and leaking Integrity of structure maintain	
Tank 3 – COLORBOND R AQUAPLATE R Steel (mist green)		Experiment 7, 8 Scorches above the level of water	Experiment 9, 10 Scorches above and below water level Leak from the seams	Experiment 11 Front completely scorched Leaking increased
Tank 5 – Spiral wound metal galvanised		Experiment 7, 8 No damages	Experiment 9,10 Blackened	Experiment 11 Scorches, no leaking
Tank 2 - COLORBOND R AQUAPLATE R Steel, oval shape		Experiment 12 Scorches on top and along sealant	Experiment 13 More scorches Plastic vent burning Leak from seams	Experiment 14 Further scorches and leaks from seams
Tank 4 - Polyethylene (green)		Experiment 12 Top of tank melted and deformed to the level of water	Experiment 13 Front surface become involved in flame Leak from a hole at the bottom	Experiment 14 The tank unzip and collapse on itself
Tank 7 - Spiral wound galvanised AQUAPLATE R steel		Experiment 15 No damage	Experiment 16 Front of the tank is blackened	Experiment 17 Front face scorches without leak. Liner located above contained water melted, minor leaks.
Tank 8 – Nylex Polyethylene (black)	Experiment 18 Small ignition, no damage	Experiment 19 Front surface became involved in flame Top of the tank melted above the water level	Experiment 20 More melting of the tank above the water level, Integrity of tank is not threatened	Experiment 21 Tank unzip, empty itself and melted down
Tank 9 - ZINCALUME R steel bladder type tank		Experiment 22 Evacuation pipe slightly burnt	Experiment 23 Evacuation pipe burned down, Leak from the four joins (front, sides, back), Water flowing over the top of bladder	Experiment 24 More leaking from the top of the tank Bladder is damaged Tank maintains its integrity
Tank 10 - Polyethylene (black - used tank)		Experiment 25 Front surface became involved in flame Tank bulge a the bottom Leak from the top due to tank deformation	Experiment 26 Tank deformation increased Tank still burning after burner are turned off, 1m flames from top of tank. Tank unzip and empty itself	

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Table 4 Summary of Pre radiation exposure measurement

Type of water tank	Test	Radiant heat flux (kw/m^2)	Temp. Front surface Bottom (deg C)	Temp. Front surface Top (deg C)	Temp front Bottom (deg C)	Temp front Top (deg C)	Temp inside the tank (deg C)	Water temp inside tank (deg C)
Tank 1 – COLORBOND R AQUAPLATE R Steel (mist green)	1	80	280	415	330	275	102	13.5
Tank 6 - Polyethylene (beige)	5	25 (mast 1)	590	400	460	370	71	46
Tank 3 – COLORBOND R AQUAPLATE R Steel (mist green)	7	15	92	220	60	78	94	44
Tank 5 – Spiral wound galvanised AQUAPLATE R steel	7	15	90	130	92	68	62	50
Tank 2 – COLORBOND R AQUAPLATE R Steel, oval shape	12	56	228	208	186	171	90	13
Tank 4 - Polyethylene (green)	12	41	147	146	107	160	39	20
Tank 7 - COLORBOND R AQUAPLATE R Steel	15	29	121	66	186	183	27	17
Tank 8 - Polyethylene (black)	19	133 (peak) average 40	206	723	306	282	146	90
Tank 9 - ZINCALUME R steel bladder type tank	22	53	113	204	143	189	53	23
Tank 10 - Polyethylene (black - used tank)	25	80	279	650	530	462	350	17

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Table 5 Summary of bushfire passage exposure measurements

Type of water tank	**Test**	Radiant heat flux (kw/m2)	Temp. Front surface Bottom (deg C)	Temp. Front surface Top (deg C)	Temp front Bottom (deg C)	Temp front Top (deg C)	Temp inside the tank (deg C)	Water temp inside tank (deg C)
Tank 1 – COLORBOND R AQUAPLATE R Steel (mist green)	2	90	280	473	443	670	170	18
Tank 6 - Polyethylene (beige)	6	110 (mast 1)	25	486	482	483	NA	NA
Tank 3 – COLORBOND R AQUAPLATE R Steel (mist green)	10	98	463	508	858	606	221	36
Tank 5 – Spiral wound galvanised AQUAPLATE R steel	10	106	353	609	835	728	NA	NA
Tank 2 – COLORBOND R AQUAPLATE R Steel, oval shape	13	56 (higher on mast)	367	496	638	631	395	11
Tank 4 - Polyethylene (green)	13	100 (higher on mast)	162	146	284	508	63	20
Tank 7 - COLORBOND R AQUAPLATE R Steel	16	49	232	137	386	338	42	18
Tank 8 – Nylex Polyethylene (black)	20	>100	510	168	714	860	879	60
Tank 9 - ZINCALUME R steel bladder type tank	23	>100	137	501	635	803	203	20
Tank 10 - Polyethylene (black - used tank)	26	>100	744	101	603	514	33.8	26

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Table 6 Summary of structural fire exposure measurements

Type of water tank	**Test**	Radiant heat flux (kw/m2)	Temp. Front surface Bottom (deg C)	Temp. Front surface Top (deg C)	Temp front Bottom (deg C)	Temp front Top (deg C)	Temp inside the tank (deg C)	Water temp inside tank (deg C)
Tank 1 – COLORBOND R AQUAPLATE R Steel (mist green)	3	NA	452	543	745	559	546	21
Tank 3 – COLORBOND R AQUAPLATE R Steel (mist green)	11	NA	869	545	916	606	224	48
Tank 5 – Spiral wound galvanised AQUAPLATE R steel	11	NA	534	575	728	685	182	NA
Tank 2 – COLORBOND R AQUAPLATE R Steel, oval shape	14	NA	157	192	265	311	51	NA
Tank 4 Polyethylene dark green	14	NA	86	142	376	385	208	73
Tank 7 - COLORBOND R AQUAPLATE R Steel	17	NA	888	734	NA	1005	275	20
Tank 8 – Nylex Polyethylene (black)	21	NA	717	1039	877	975	803	20
Tank 9 - ZINCALUME R steel bladder type tank	24	NA	357	344	1010	890	234	25

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6.1. *Metal tank with polymer coating (mist green) Experiments 1, 2, 3*

Specifications: Tank 1 – COLORBOND ® AQUAPLATE ® steel. Conventional metal tank design with polymer coated inner and silicone mastic seals between sheets, tank dimensions:

- Height 1270mm,
- diameter 3050mm,
- 9000 litres capacity
- 70% fill level

6.1.1. Experiment 1 - leaf litter & pre-radiation

The experiment was a leaf litter and pre-radiation exposure (see Figure 3).

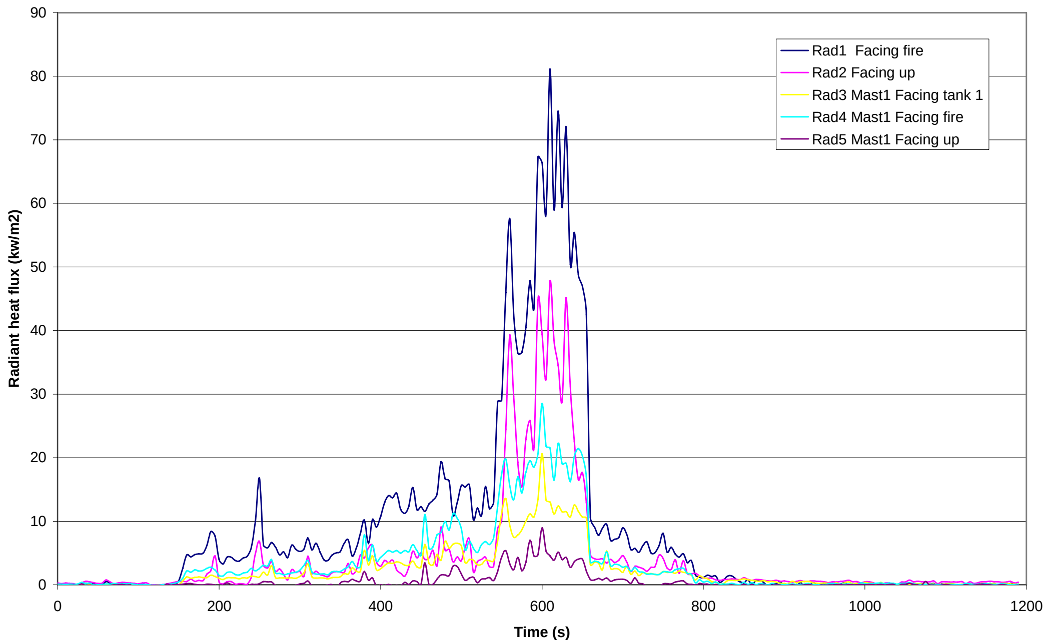

Figure 3 Experiment 1 – Radiant heat flux - Tank1 Colorbond Metal (mist green)

At the start of the test leaf litter was ignited along the base of the tank. Most of the leaf litter flamed and then smouldered. However the smouldering ceased as the leaf litter burnt out after 8 minutes. At 2 minutes the burners were turned on, at 10 minutes after the start of the experiment smoke was released from the top of the tank, the smoke decreased when the pre-radiation stage burners were turned off. Figure 3 shows that a heat flux greater than the target 40 kW/m^2 was achieved.

The surface of the tank was scorched, the polymer coating on the inside of the tank above the waterline is heat affected. The tank maintained its ability to hold water during and after the exposure (see Figure 4). This figure and the surface temperatures measured illustrates how these water tanks are more heat effected above the water level than below it due to the body of water acting as a heat sink.

Figure 4 Experiment 1 - Leaf litter ignited and pre-radiation on metal coated water tank

6.1.2. Experiment 2 - bushfire passage exposure

Heat flux measurements for experiment 2 are given in Figure 5.

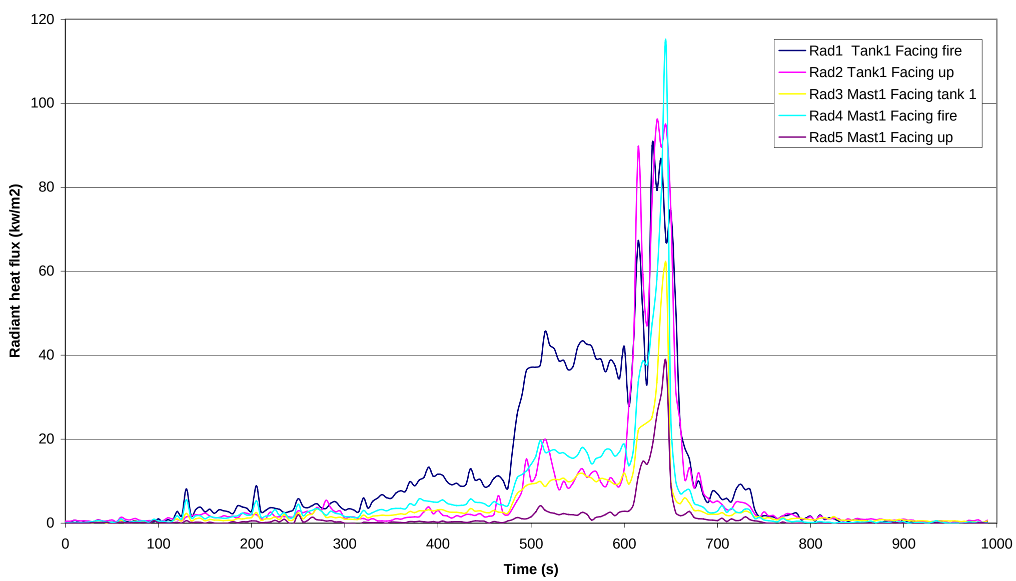

Figure 5 Experiment 2 – Radiant heat flux - Tank1 Colorbond Metal (mist green)

The surface of the tank shows heat effected regions below the waterline where silicone mastic was used to seal metal panel intersections. There are small leaks from some of these seams (see Figure 6). However the rate of leakage was very slow. Front surface temperatures in this region were in excess of 280°C.

Figure 6 Experiment 2 - Leaf litter ignited and flame immersion exposure, small leaks from the seams

6.1.3. Experiment 3 - structure exposure

Heat flux meters facing the fire were removed for structural fire exposures to prevent instrument damage.

The front face of the tank became heat affected; the paint is burnt and cracked (see Figure 7). The leaking from the seams has increased and is less than 2 litres per minute.

Figure 7 Experiment 3 - Structure exposure on metal coated tank

The tank was able to supply water from its outlet after this series of exposures, thus maintaining its ability to supply water for suppression activities, there was no point during theses experiments where the tank support flame spread.

6.2. Polyethylene water tank. Experiments 4, 5, 6

Specifications: Tank 6 – polyethylene tank with the following dimensions:

- Height 1570mm,
- Diameter 2450mm,
- 68% fill level

6.2.1. Experiment 4 - leaf litter

The flaming of the litter caused a few scorches on the bottom of the tank (see Figure 8). No leaks were observed and the integrity of the tank was maintained. Some consumption and melting of polyethylene around the base of the tank was observed but appeared to be insufficient to cause a weakening of the tank or leaking.

Figure 8 Experiment 4 - Leaf litter exposure on polyethylene tank

6.2.2. Experiment 5 - Leaf litter & radiation exposure

The measured radiant heat exposure for experiment 5 is shown in Figure 9.

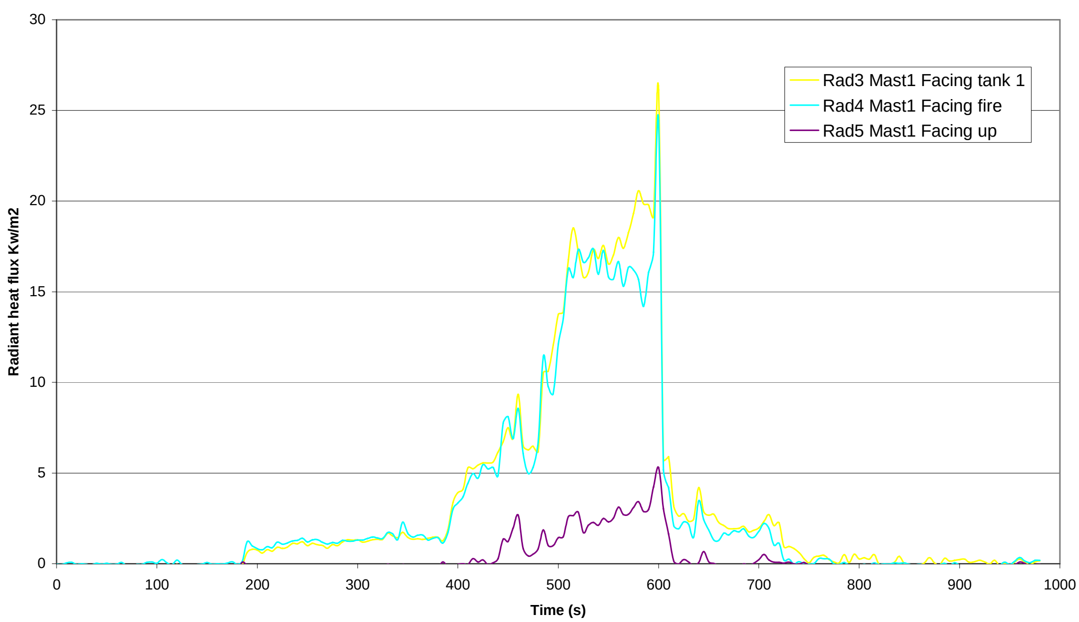

Figure 9 Experiment 5 - Radiant heat flux - Tank 6 Polyethylene water tank (beige)

Smouldering on the front face of the tank is observed during early stage of radiation exposure. The bottom front began flaming after 7:00 and by 7:30 the entire front surface of the tank was involved in flame (sees Figure 10). Flaming decreased at about 8:00 and ceased as burners are turned off. Temperatures of approximately 150°C were measured at the front exterior surface both above and below the water level just prior to flaming at these points. The experiment concluded with the top of the tank melted and deformed to the level of water, small flame still persisting on the top of the tank. There was water leaking out of the base of the tank at approximately 3 litres per minute, these leaks occurred at points where the tank had softened and expanded around its base by approximately 150 mm and contacted the instrument support rigging. Figure 11 below shows this extent of damage and leaking.

Figure 10 Experiment 5 - Pre-radiation exposure on polyethylene tank

Figure 11 Experiment 5 - Pre-radiation exposure on polyethylene tank (note water stream from the base of the tank)

6.2.3. Experiment 6 - Bushfire passage exposure

From the bushfire passage exposure further melting and propagation of leaks without complete structure failure was observed. In the front face the outer surface below the level of water had softened and yielded further (see Figure 12). Although the tank still held water it was severely damaged and would require replacement.

Figure 12 Experiment 6 - Structure exposure on polyethylene tank

6.3. Metal with polymer coating and metal spiral tank – Experiments 7, 8, 9, 10, 11

Two tank types were tested in these experiments. Tank specifications are provided below:
Tank 3 - COLORBOND ® AQUAPLATE ® steel, mist green with the following dimension:

- height 2470mm
- diameter 1480mm
- 71% fill

Tank 5 - Spiral wound galvanised AQUAPLATE ® steel rainwater tank

- height 1830 mm
- diameter 1830mm
- 72% fill

6.3.1. Experiment 7 and 8 – Leaf litter & pre radiation exposure

Radiant heat flux for the tank 3 and 5 are presented in the graph below (see Figure 13)

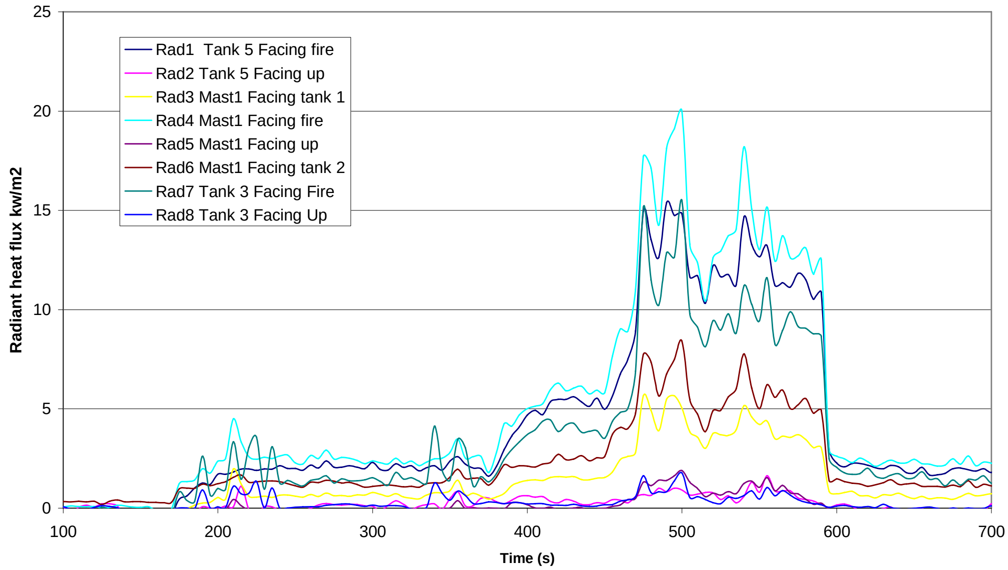

Figure 13 Experiment 7 – Radiant heat flux – Tank 3 Colorbond Metal (mist green) and Tank 5 Spiral wound metal galvanised

Tank 3 was scorched above the water level. Sealants along the seams had softened and degrade above the level of water. Tank 5 showed no damage for this experiment. Neither tanks leaked during the experiments.

6.3.2. Experiments 9 and 10 - Bushfire passage exposure.

These exposures were performed simultaneously Tank 3 had further scorching on the paint (see Figure 14). The sealant along the seams was scorched above and below the level of water where flame contact occurred. Some water was leaking from the seams at an estimated rate of 0.2 litres per minute (see Figure 15).

Tank 5 is blackened above the waterline but show signs of leakage (see Figure 14).

Figure 14 Experiment 9 - Pre-radiation and flame exposure on metal tank

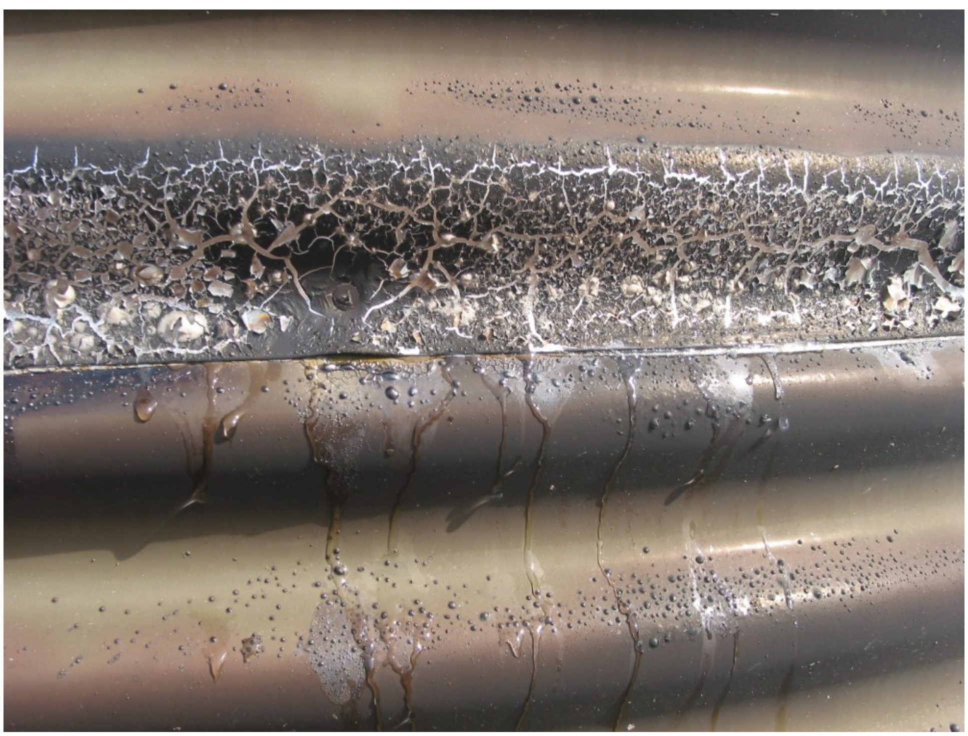

Figure 15 Experiment 9 - Leak from seams

6.3.3. Experiment 11 - Structure exposure

The front face of tank 3 was completely scorched. The leakage had increased to approximately 0.3 litres per minute.

Tank 5 shows further scorches but no leaks are observed. The exterior surface temperature at the top surface of these tanks reached approximately 500°C for both tanks. Investigation of the inside of the tank showed that the tanks internal polymeric coating was intact below the waterline, above the water line the coating had thermally degraded and some of this degraded material was resting on the bottom of the tank (see Figure 16). This material did not seem to inhibit the draining of the tank, however it may be seen as an advantage to include an outlet strainer to prevent outlet clogging if these exposure conditions are considered to be a significant risk.

Figure 16 Internal polymeric coating damage above water level

6.4. Metal Spiral and polyethylene tank – Experiments 12, 13, 14

Two tanks were involved in these experiments:

Tank 2 – COLORBOND ® AQUAPLATE ® steel oval shape, tank dimensions:

- height 1540mm
- width 1150mm
- length 2350 mm
- 100% fill

Tank 4 – Green polyethylene tank, with the following dimensions:

- height 1800mm
- diameter 1340mm
- 100% fill

6.4.1. Experiment 12 – Pre - radiation exposure

Levels of radiant heat are shown on the graph below for the two tanks (see Figure 17).

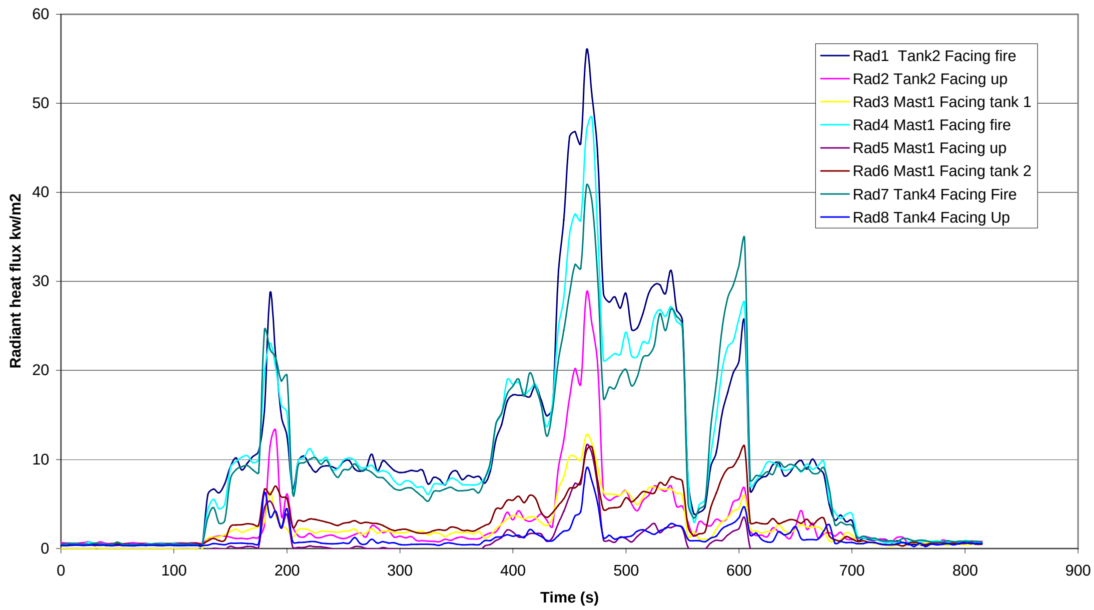

Figure 17 Experiment 12 – Radiant heat flux – Tank 2 Colorbond Metal, oval shape and Tank 4 Polyethylene dark green

After 4 minutes and 30 seconds white smoke became visible from the metal tank (white plastic coating). After 6 minutes and 48 seconds smoke rose out of the polyethylene tank (dark green), and the top of the tank started to melt (see Figure 18). At 9:30 the pre-radiation burners were turned off and the experiment ceased. Tank 4 leaked from the melted region at the top of the tank and bulged slightly at the base at the front face. Tank 2 did not leak.

Figure 18 Experiment 12 - Pre-radiation exposure on polyethylene and metal tank

6.4.2. Experiment 13 - Bushfire passage exposure

Levels of radiant heat for this exposure are shown on the graph below for the two tanks (see Figure 19).

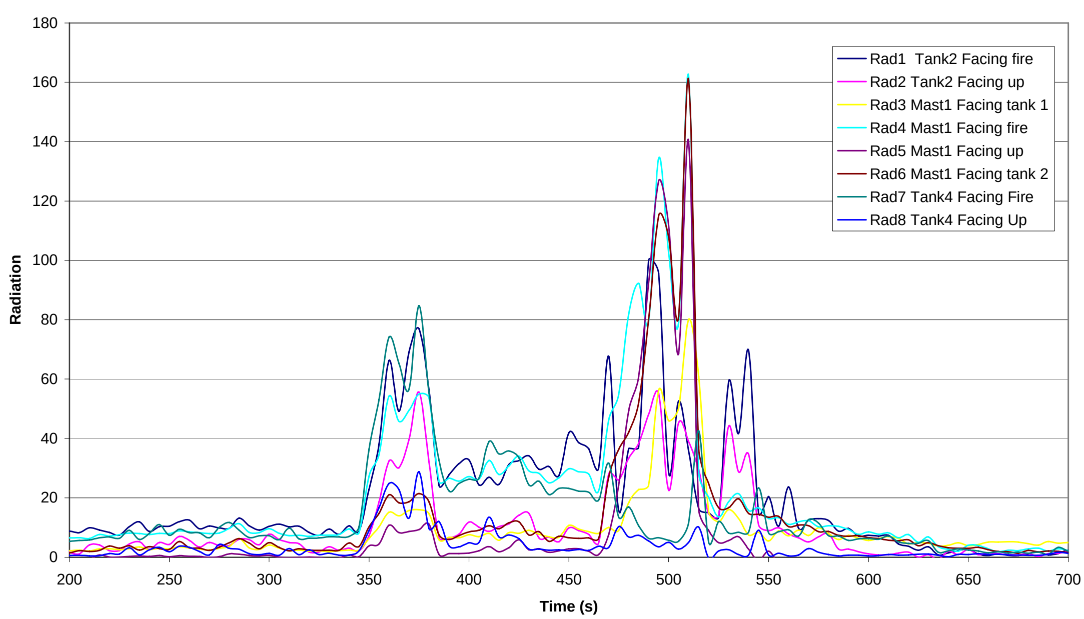

Figure 19 Experiment 13 - Radiant heat flux - Tank 2 Colorbond Metal, oval shape and Polyethylene dark green

The plastic vent on top of tank 2 started to burn after 7 minutes and 30 seconds, which generated heavy smoke. Paint was scorched and cracked. Small leaks appeared from some of the seams.

8 minutes after the beginning of the test the front surface of tank 4 become involved in flame. After 9 minutes and 5 seconds the plastic tank started to leak water from a hole on the South-East side, 0.5 meters up (¼ of the bottom of the tank) (see Figure 20). This leak is estimate to be 5 litres per minute.

Figure 20 Experiment 13 - pre-radiation and flame exposure

6.4.3. Experiment 14 - Structure exposure

During the structural fire exposure further scorches and leakage from seams appeared on the metal tank, leakage was considered to be less than 0.3 litres per minute.
Tank 4 failed when a small hole rapidly propagated releasing all water (unzipped) at 2 minutes after the start of the test (see Figure 21). The tank then collapse on itself (see Figure 22). The test was terminated shortly after tank 4 ruptured.

Figure 21 Experiment 14 - Structure exposure on polyethylene and metal tank

Figure 22 Experiment 14 - Structure exposure on polyethylene and metal tank

6.5. Metal spiral water tank – Experiments 15, 16, 17

This series of experiments involved the following tank type:

Tank 7 – COLORBOND ® AQUAPLATE ® steel, spiral wound metal galvanised

- height 3000mm
- diameter 2100mm
- 100% fill

6.5.1. Experiment 15 – Pre-radiation exposure

Levels of radiant heat for this exposure are shown on the graph below (see Figure 23).

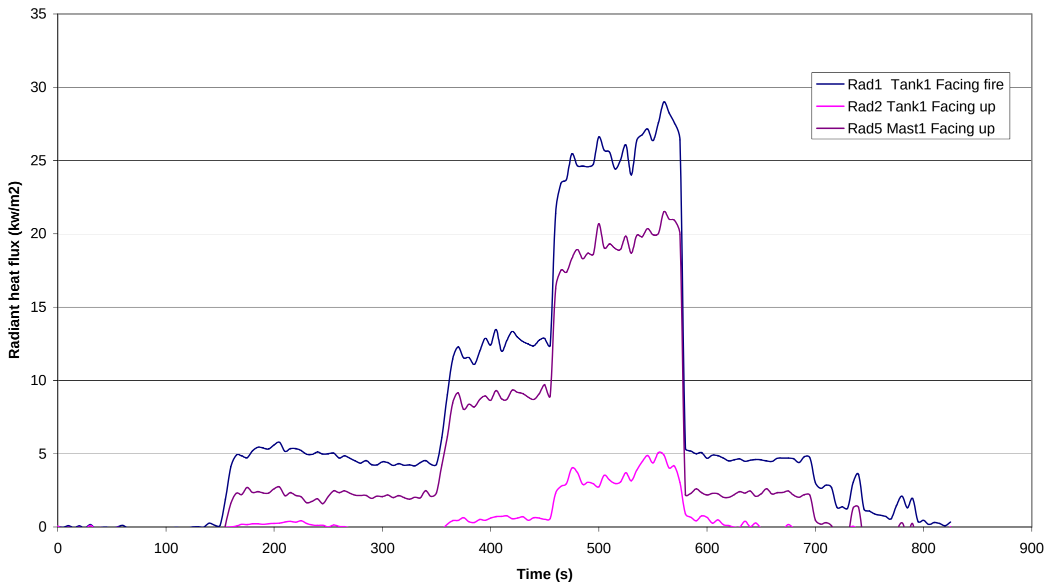

Figure 23 Experiment 15 - Radiant heat flux - Tank 7 Spiral wound metal galvanised

There is no damage of the metal spiral water tank resulting from the pre-radiation exposure.

6.5.2. Experiment 16 - Bushfire passage exposure

Levels of radiant heat for this exposure are shown on the graph below (see Figure 24).

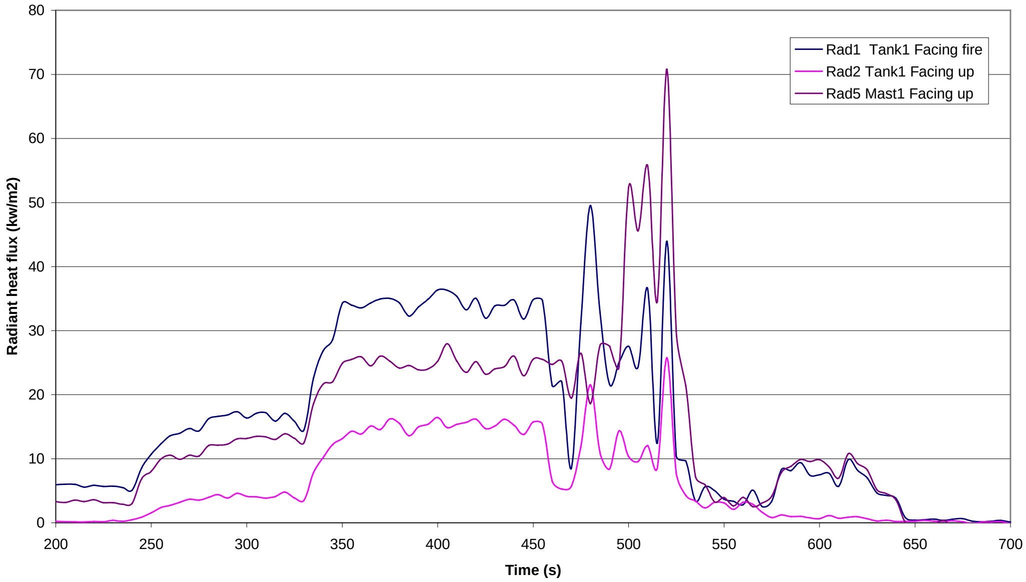

Figure 24 Experiment 16 – Radiant heat flux – Tank 7 Spiral wound metal galvanised

The front face of the tank was blackened with no apparent leaks or loss of integrity.

Figure 25 Experiment 16 – Radiant heat flux – Tank 7 Spiral wound metal galvanised

6.5.3. Experiment 17 - Structure exposure

The front face of the tank was scorched, with minor leaks of approximately 0.3 litres per minute (see Figure 27). The liner inside the tank is melted and damaged above the water line with some de-lamination having occurring below the waterline also (see Figure 26).

Figure 26 Liner inside tank 7

Figure 27 Experiment 17- Structure exposure on metal spiral tank

6.6. Polyethylene water tank – Experiments 18, 19, 20, 21

This series of experiments were performed on Tank 8 being a Nylex black polyethylene tank with the following specifications:

- 2400mm Diameter
- 2400mm height
- 9000 litre
- 90% fill

6.6.1. Experiment 18 - Leaf litter exposure

Leaf litter was ignited at the base of the tank. There was a small flame developed on the surface of the plastic from the litter ignited (5-10mm depth).

No penetration of the tank occurred and polyethylene tank material became involved in a number of areas around the tanks base, the flame persisted around the tank base for 23:30 (see Figure 28). It is interesting to speculate whether different weather conditions could allow these small flames to persist longer and cause some tank leakage.

Figure 28 Experiment 18 - Leaf litter ignited exposure on polyethylene tank

6.6.2. Experiment 19 - Pre-radiation exposure

Figure 29 Experiment 19 – Radiant heat flux – Tank 8 Polyethylene black

Small flames started from the bottom of the tank and then spread to involve the entire front of the tank by 7 minutes (see Figure 29 and 30). The flames on the front reduced to small flames around the top rim of the tank when the burners were reduced. The top of the tank above the water level melted in part and drooped to the waterline (see figure 31). There was no significant leakage of water.

Figure 30 Experiment 19 - pre-radiation exposure

Figure 31 Experiment 19 - pre-radiation exposure

6.6.3. Experiment 20 - Bushfire passage exposure

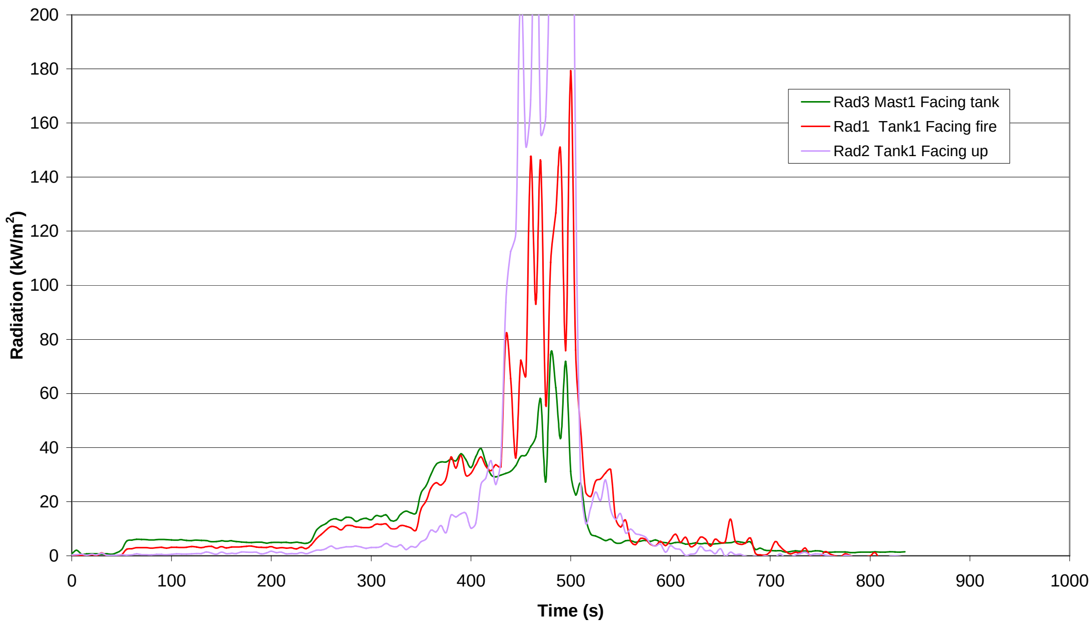

Figure 32 Experiment 20 – Radiant heat flux – Tank 8 Polyethylene black

Levels of radiant heat for this exposure are shown on the Figure 32. Six minutes after the beginning of the exposure the front surface of the tank was well alight (see Figure 33).

Figure 33 Experiment 20 - Polyethylene tank

After the burners were shut off the flames reduced to small flames around the top edges of the tank. There was more melting of the top of the tank above the water level (see Figure 34) Water was flowing from around the melted rim of the tank extinguishing much of the surface combustion. The base of the tank had significant bulging and appeared to be close to structural failure.

Figure 34 Experiment 20 – Pre-radiation and flame exposure on polyethylene tank

6.6.4. Experiment 21 - Structure exposure

Two minutes after the beginning of the structural exposure the tank unzipped and emptied completely (see Figure 35).

Figure 35 Experiment 21polyethylene tank at two minutes into tests

6.7. Bladder water tank – Experiments 22, 23, 24

This series of experiments were performed on a Pioneer water tank, ZINCALUME ® steel bladder tank with Aqualiner® with the following specifications:

- 2.18m height
- 4.68m diameter
- volume 37500l
- 100% fill

6.7.1. Experiment 22 – Pre-radiation exposure

Heat flux measurements for experiment 22 are shown in Figure 36

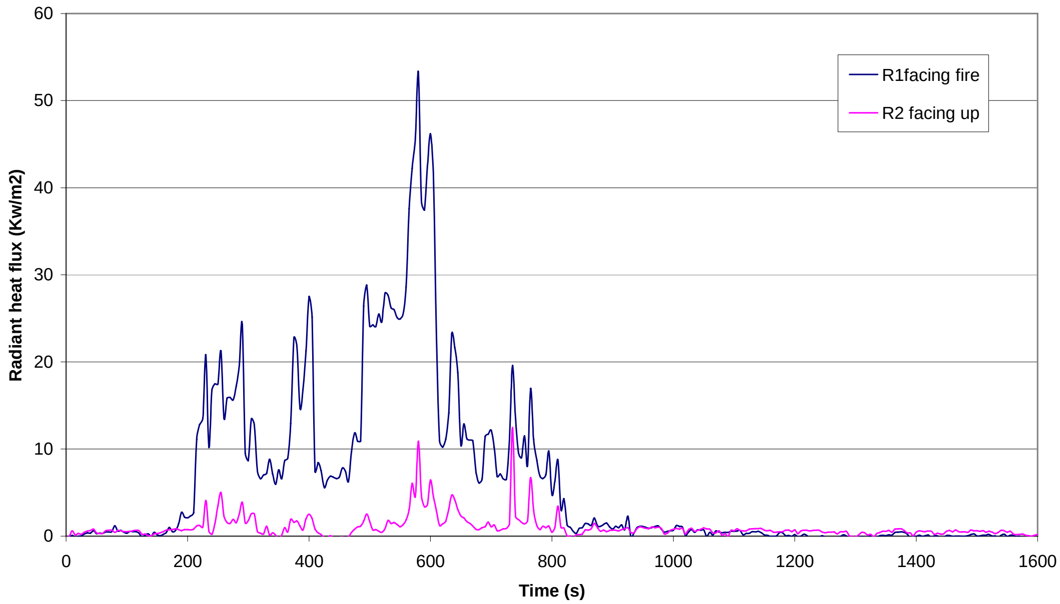

Figure 36 Experiment 22 – Radiant heat flux – Tank 9 Bladder tank

Seven minutes after beginning of the exposure white smoke was visible from the top of the tank. The PVC overflow pipe was also distorted at this point but would not have failed to operate. The smoke reduced when the burners were turned off. No water loss was evident from the tank.

6.7.2. Experiment 23 - Bushfire passage exposure

Measured heat flux for experiment 23 is shown in Figure 37.

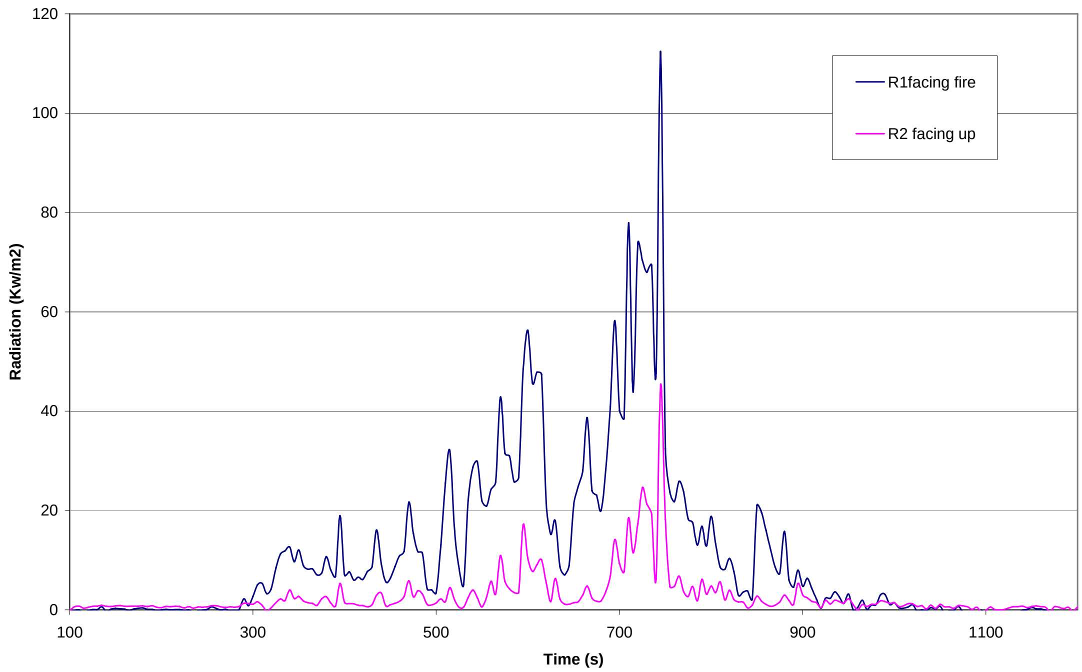

Figure 37 Experiment 23 – Radiant heat flux – Tank 9 Bladder tank

Smoke was produced from the front of the tank during the pre-radiation period. 7minutes after the start of the experiment the PVC overflow pipe on the exterior began burning. The pipe burned along its entire length until the pipe collapsed.

Leaks were observed from the top opening where the overflow pipe penetrated the tank. Leakage was observed at the horizontal metal join between the top and bottom tank sheet metal sections at the mid height of the tank. The four vertical joints (front, sides and back) where also leaking. The attachment of the bladder to the tank (screwed around the inside top rim of the tank) had failed at the front of the tank where the exposure had been most intense. The bladder had melted and come away from some of the screw mounting points. Where the bladder attachment had failed the bladder had slumped down to the water surface allowing water to slowly flow over the top of the bladder. This water then flowed between the bladder and the sheet metal shell and leaked out from the joints mentioned above (see Figure 38). Water loss from the tank is estimated at 3 litres per minute. The external surface temperature at the front top rim of the tank, near the location of bladder attachment exceeded 500°C during the exposure.

Figure 38 Experiment 23 – pre-radiation exposure on Bladder tank

6.7.3. Experiment 24 - Structure exposure

Structure exposure caused more leaking on the front of the tank (see Figure 39). The tank maintained its integrity. After the 30 minute exposure the bladder had sustained more damage. More of the bladder had become detached from the top rim and small holes were observed in the bladder material in the middle front where contact with the hot sheet metal had caused melting of the bladder. The metal sheets were blackened (see Figure 39). Water loss was estimated at 12 litres per minute.

Figure 39 Experiment 24 - pre-radiation and flame immersion on Bladder tank

6.8. *Polyethylene (used) tank – Experiments 25, 26*

Tank 10 used for this series of experiments was a black Polyethylene tank which has had a service life of 12 years prior to being used in this experiment. Some slight bulging around the base is obvious and appears to be consistent with a tank of this age. The following dimensions are relevant for the tank:

- height 2500mm
- diameter 4000mm
- 30000 litre capacity
- 100% fill

6.8.1. Experiment 25 - Pre-radiation exposure

Heat flux measurements for experiment 25 are shown in Figure 40

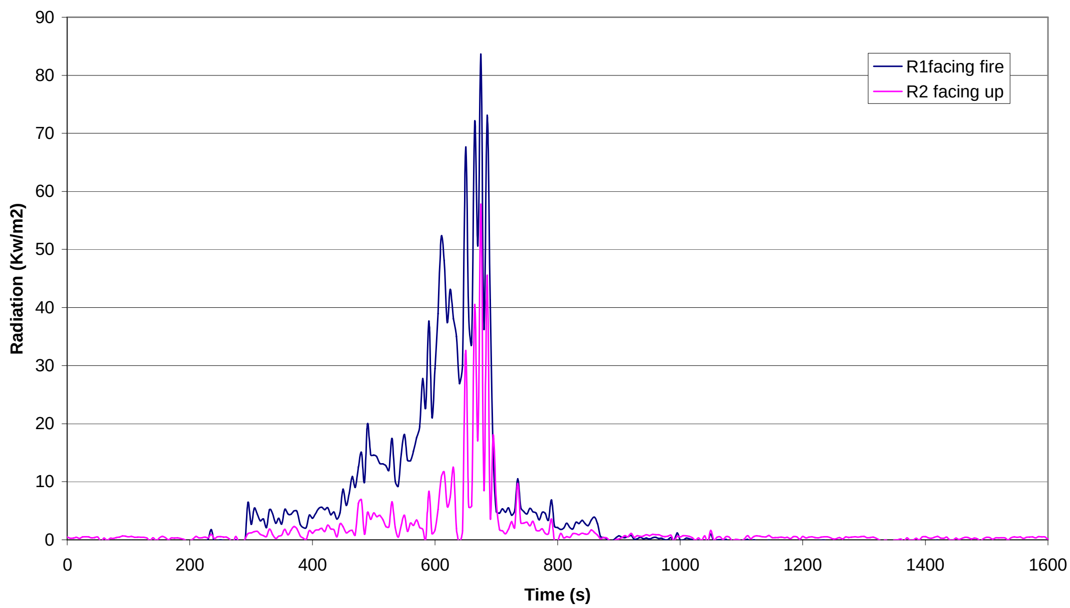

Figure 40 Experiment 25 – Radiant heat flux – Tank 10 Used polyethylene tank (black)

Smoke was observed from the burning leaf litter. After 8 minutes from the start of test the front of the tank was involved in flame from the middle to the top, 40 seconds later the entire front of the tank is involved in flame. 9 minutes after the start of test the tank showed some deformation at the bottom (slightly bulged). The flames on the front of the tank reduced when the burners were turned off (see Figure 41), after 9minutes and 45 seconds the flaming ceased on the front surface. Flames were still observed on the edge and top of the tank. After 12 minutes significant leaks appeared from the top of the tank as the tank leant over towards the bulging side. This leakage occurred because the tank walls and top were manufactured as 2 separate mouldings and were screwed together resulting in a non-watertight joint. As the tank bulged and leant over the front rim of the tank and dipped below the water level.

Figure 41 Experiment 25 - Leaf litter and pre-radiation exposure on used polyethylene tank

6.8.2. Experiment 26 - Bushfire passage exposure

Heat flux measurements for experiment 26 are shown in Figure 42

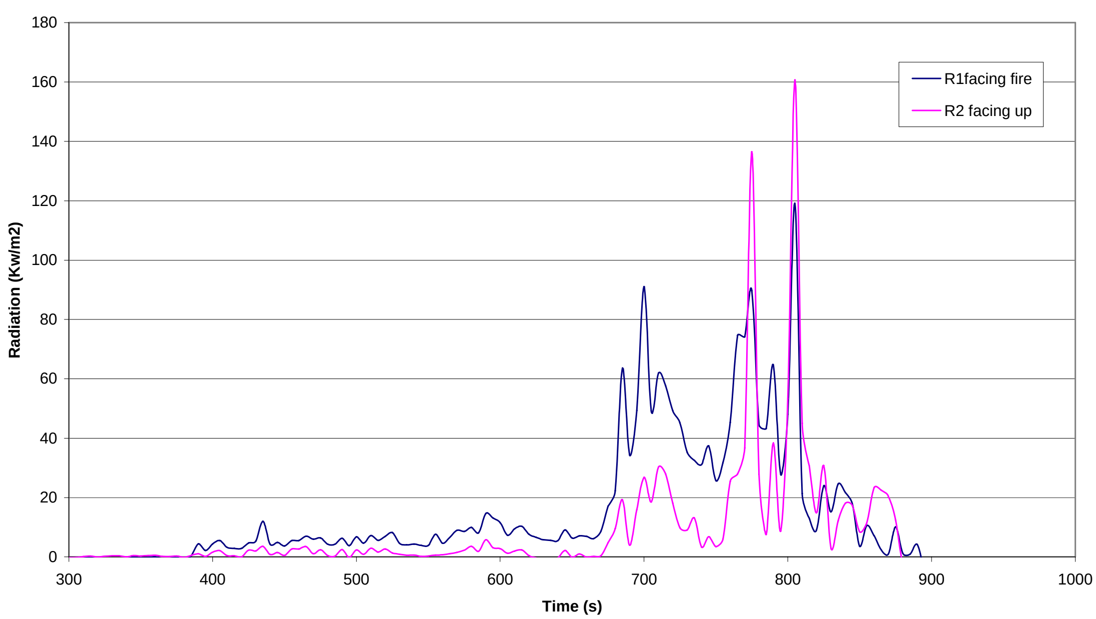

Figure 42 Experiment 26 – Radiant heat flux – Tank 10 Used polyethylene tank (black)

The deformation of the tank increased during the early part of the bushfire passage exposure. 5:30 into the test the front surface of the tank was fully involved in flame. The flame spread on the side and the top of the tank. During the flame exposure, 7minutes after the start of the test, the top of the tank was fully involved in flame producing heavy black smoke (see Figure 43).
8 minutes into the exposure the tank was still heavily burning mainly from the top, at 8:20 the tank unzipped from the lower half or the tank and emptied itself, see Figure 43.

Figure 43 Experiment 26 - Pre-radiation and flame exposure on used polyethylene tank

7. Conclusion

The performances of different types of water tanks are summarize in the tables 3, 4, 5 and 6.

The metal spiral tank maintained structural integrity through all fire exposures, minor leaks where observed during experiment 17 only after structural exposure tests involving 30minute flame immersion.

Conventional metal tanks maintained structural integrity through all fire exposures. For the flame immersion and structure simulations small leaks with a low rate of water loss from some of the seams was observed due to failure of the sealants used. The total rate of water loss for all leaks in any given experiment was below 2 litres per minute.
The bladder tank maintained structural integrity but sustained some leaks after bushfire flame exposure and structural exposures. The bladder was damaged with failure of the attachment to the top front of the tank rim and formation of small holes due to melting where in contact with hot sheet metal at the front of the tank. The leaking would not significantly affect its capacity to be used for fire-fighting during the bushfire event.

Internal polymer linings of both types of metal tanks were observed to degrade and delaminate in the region above the water line in areas where fire immersion occurred. This detached material either remained buoyant or sunk to the bottom of the tank. Although unlikely, it may be possible for this detached material to hamper water evacuation, consideration to tank outlet design and location would eliminate this potential problem.

For leaf litter exposure the polyethylene tanks showed some involvement in the combustion process. In the worst case limited combustion ceased after 23 minute with no leakage occurring, persistence flame support for this period of time suggests that higher initial leaf litter loads may present a risk for water loss from the tank (experiment 18). Leaf litter exposure experiments on polyethylene water tank demonstrate they are unlikely to ignite and spread flame under this kind of exposure. Care should be taken not to allow large amounts of leaf litter or especial any heavy combustible fuels around the base of the tank.

Under radiation and flame exposures all polyethylene tanks walls swelled under the static pressure load of the water. This distortion was greater in tanks filled to a higher percentage of their design capacity. The greater the thermal exposure more evident the swelling was as the tank wall was softened and/or consumed by flame combustion. The advanced stage of this bulging effect is an eventual unzipping of the tank wall. In some exposures the polyethylene tanks survived each exposure and in some case they did not. It appears that the older and larger the tank the more likely it is to fail at a lower thermal exposure. Also the high percentage fill the tank has during the exposure the more likely it is to fail under a given thermal exposure. It is also evident that any long term combustion that occurs against or near the tank could cause persistent flaming combustion of the tank wall leading to certain failure, even if the combustion is relatively small.

Radiation and ember exposures on polyethylene water tank show a significant degree of damage however all tanks maintained enough integrity to hold water. For many radiation exposures the tank portion above the waterline melted and was involved in flaming combustion. Flaming of the surface below the waterline was often observed. This flaming would cease as the radiation exposure was reduced.

Bushfire passage exposures of polyethylene tanks resulted in extensive flaming and melting as described for pre-radiation exposures. Below the waterline surface flames were observed and often the tank wall swelled under the static pressure load of the water. This distortion was greater in tanks filled to a higher percentage of their design capacity and for tanks where more of the tanks wall thickness was consumed or softened by flame combustion. This resulted in catastrophic rupture for the large used polyethylene tank 10 only.

All Structural fire exposures of polyethylene tanks resulted in catastrophic rupture.
It is clear from the range of exposures that polyethylene tanks with minimal ground fuel accumulation around the tank and at least a 30m clearance from forest fuels and other stored combustible materials including other combustible water tanks and dwellings are likely to maintain structural integrity during a fire event. Any combustible element or adjacent structure could present a risk to the tank by providing continued radiation exposure which extends the period of surface flaming which is likely to lead to catastrophic failure.

In each case larger capacity tanks, that were filled close to their full capacity failed sooner.

8. References

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http://www.bmcc.nsw.gov.au/
http://www.cfa.vic.gov.au/

9. Annexe A Graphs

Pre-radiation exposure

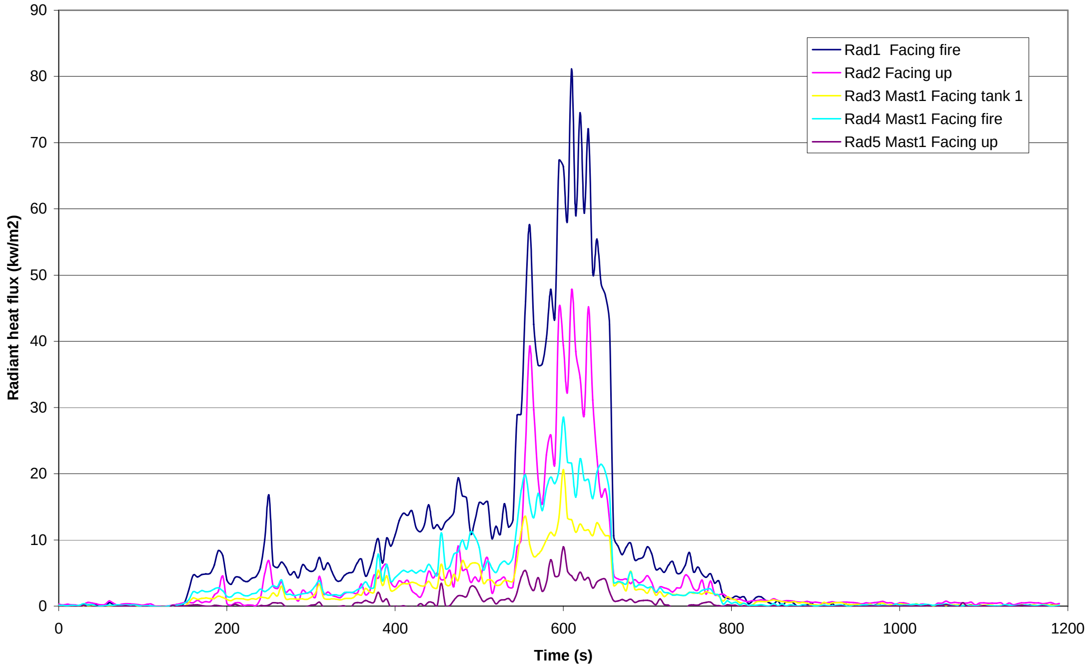

Figure A 1 Experiment 1 – Radiant heat flux - Tank1 Colorbond Metal (mist green)

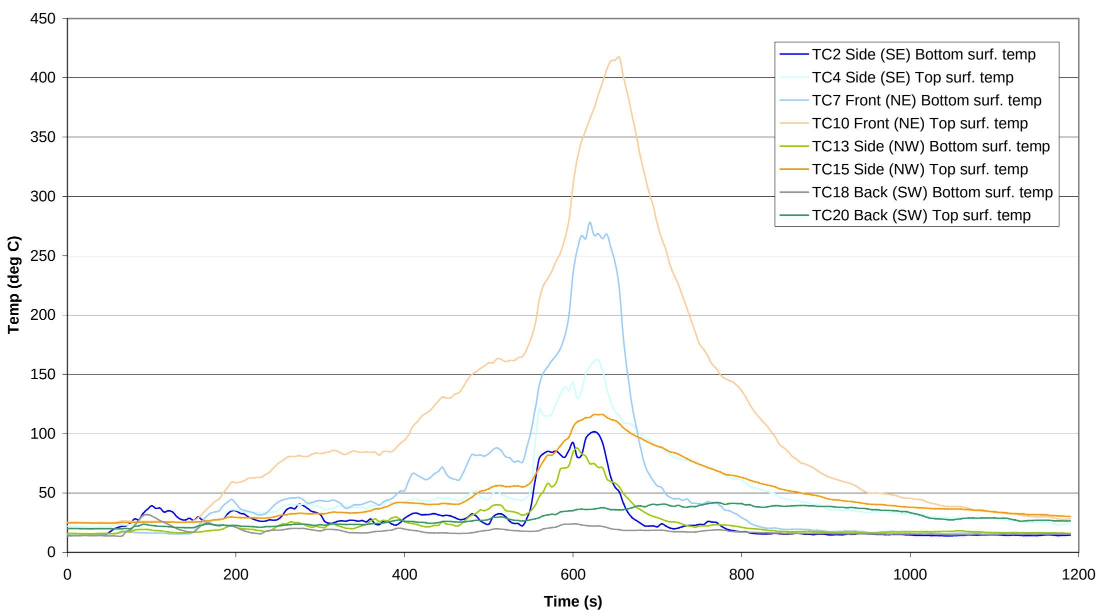

Figure A 2 Experiment 1 – Surface temperature – Tank1 Colorbond Metal (mist green)

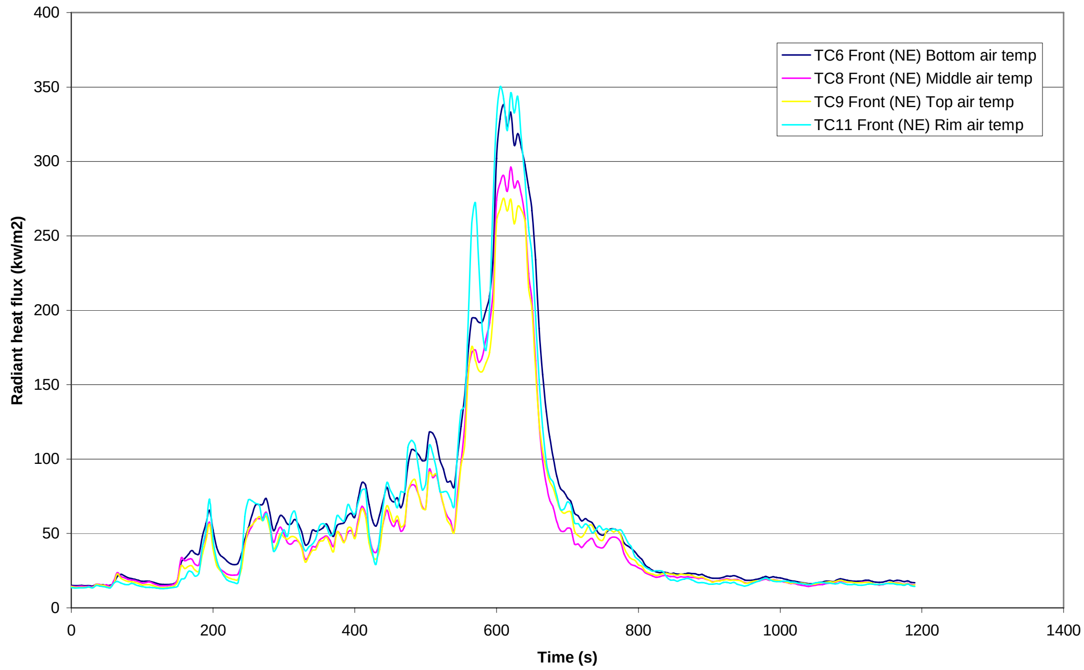

Figure A 3 Experiment 1 – Front temperature - Tank1 Colorbond Metal (mist green)

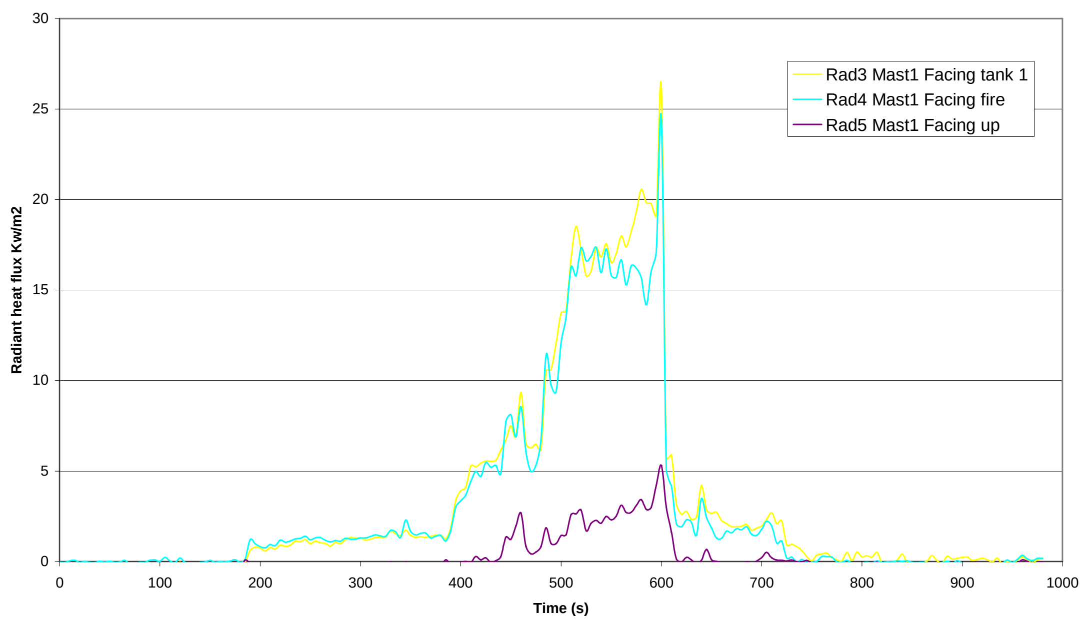

Figure A 4 Experiment 5 – Radiant heat flux - Tank 6 Polyethylene water tank (beige)

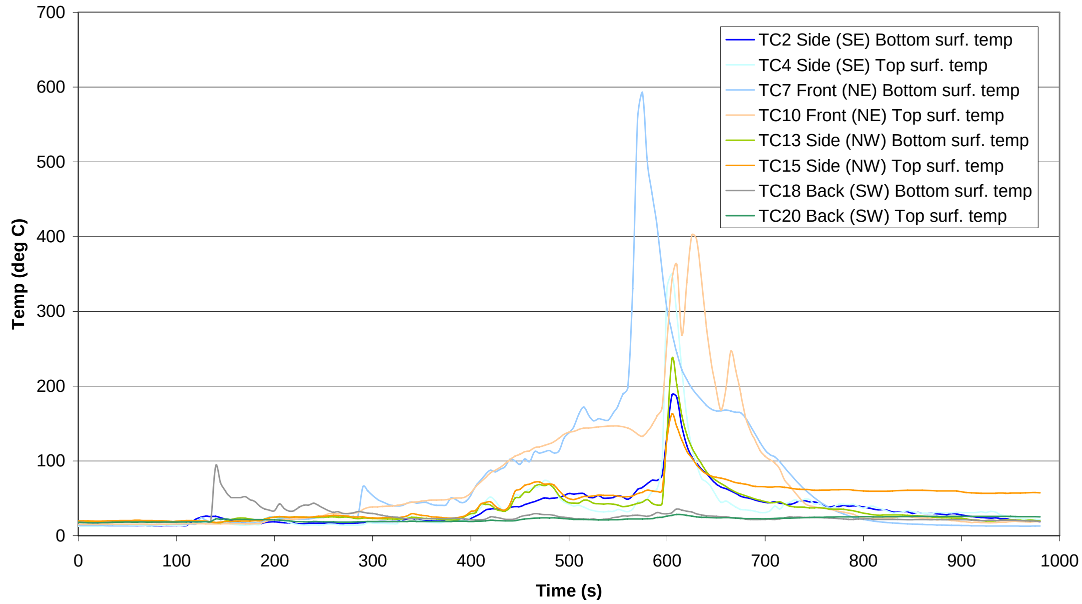

Figure A 5 Experiment 5 – Surface temperature – Tank 6 Polyethylene water tank (beige)

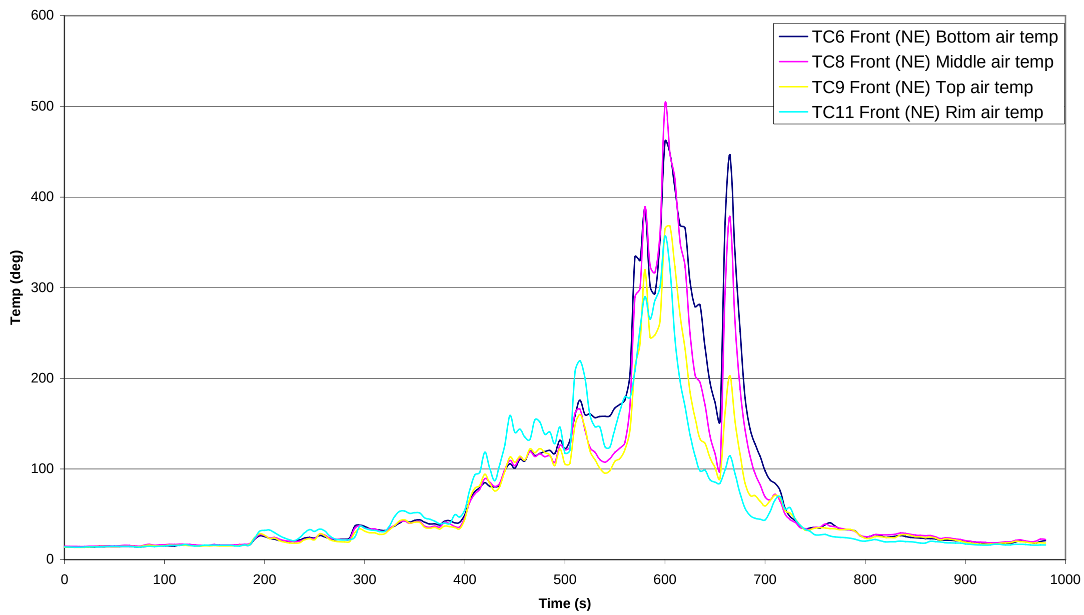

Figure A 6 Experiment 5 – Front temperature - Tank 6 Polyethylene water tank (beige)

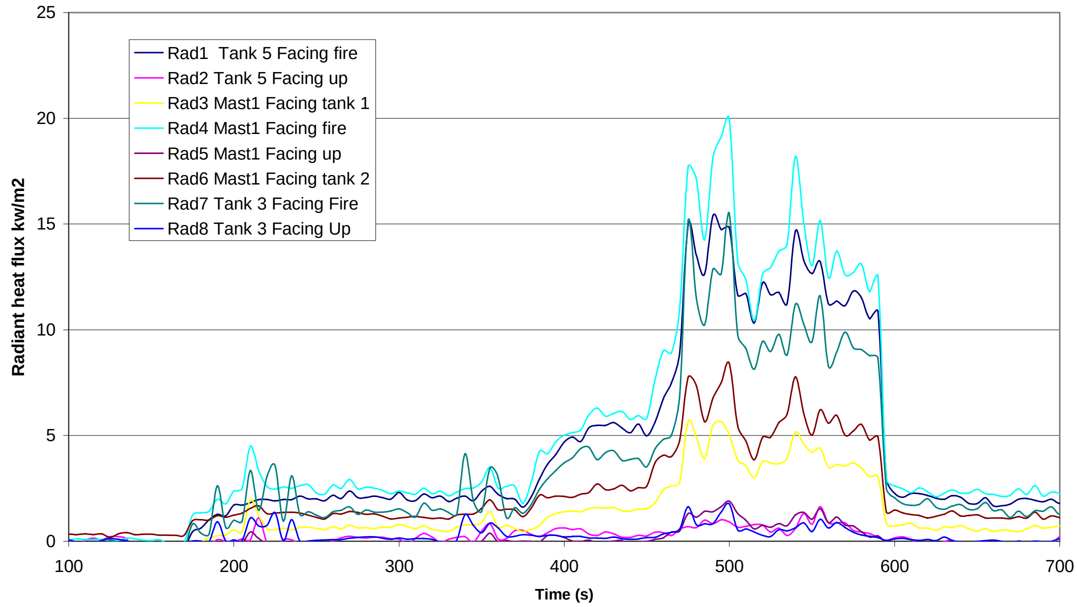

Figure A 7 Experiment 7 – Radiant heat flux – Tank 3 Colorbond Metal (mist green) and Tank 5 Spiral wound metal galvanised

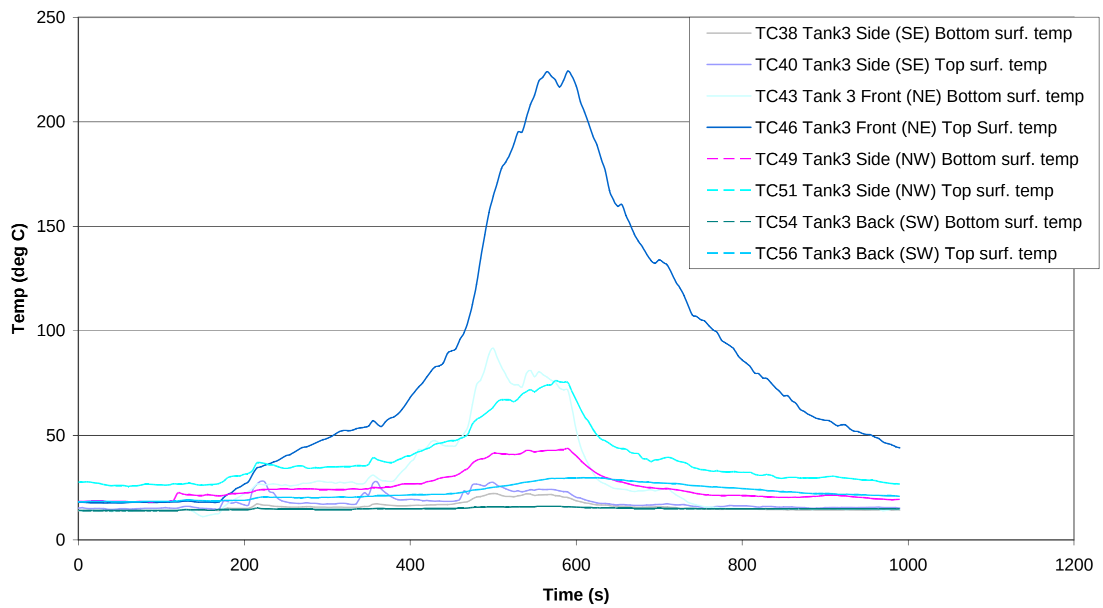

Figure A 8 Experiment 7 – Surface temperature – Tank 3 Colorbond Metal (mist green)

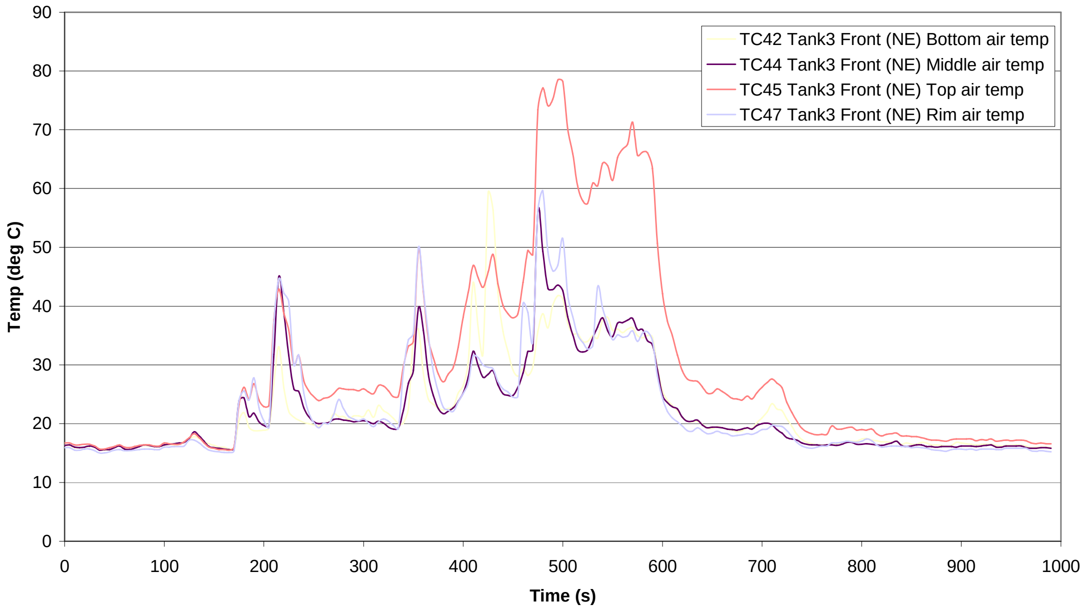

Figure A 9 Experiment 7 – Front temperature - Tank 3 Colorbond Metal (mist green)

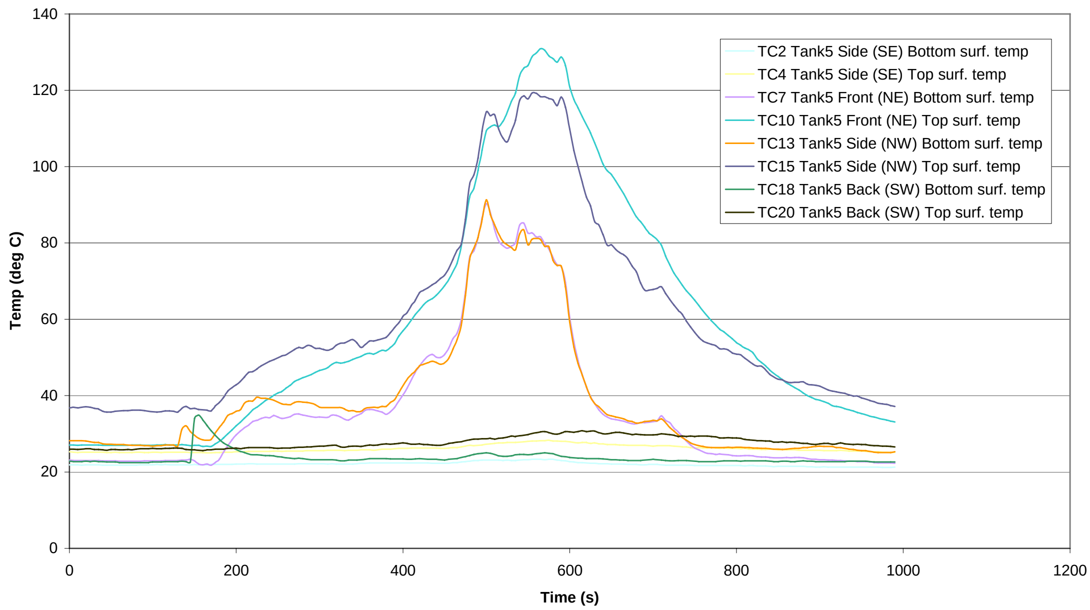

Figure A 10 Experiment 7 – Surface temperature – Tank 5 Spiral wound metal galvanised

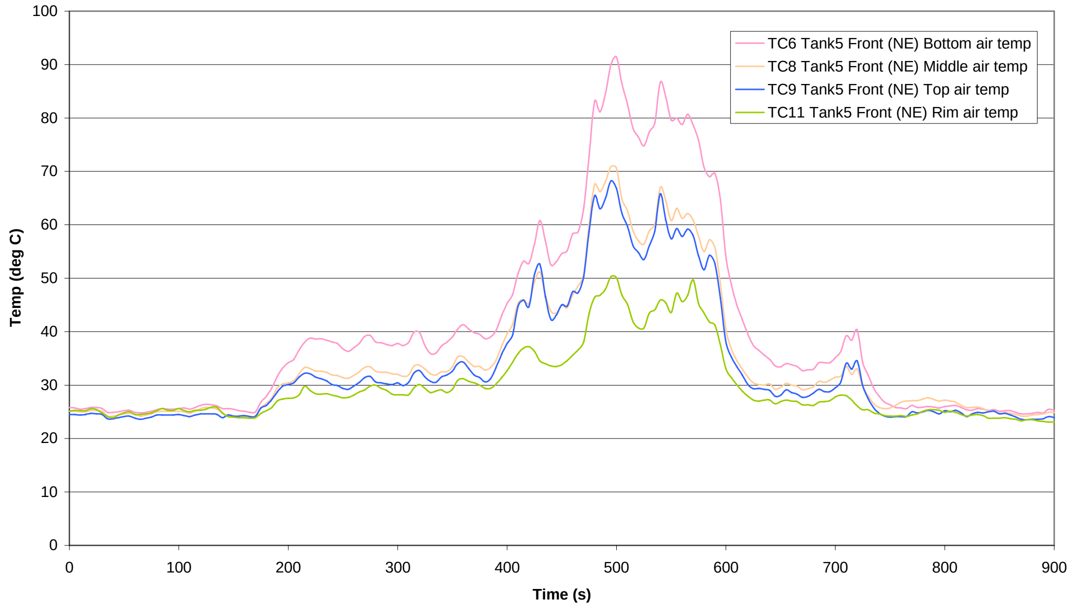

Figure A 11 Experiment 7 – Front temperature - Tank 5 Spiral wound metal galvanised

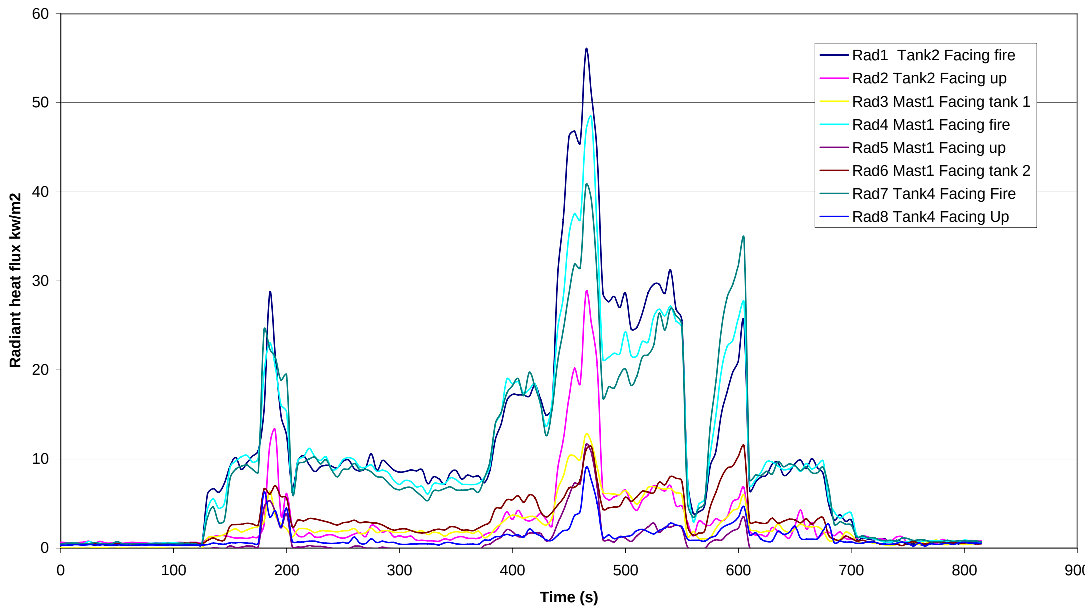

Figure A 12 Experiment 12 – Radiant heat flux – Tank 2 Colorbond Metal, oval shape and Tank 4 Polyethylene dark green

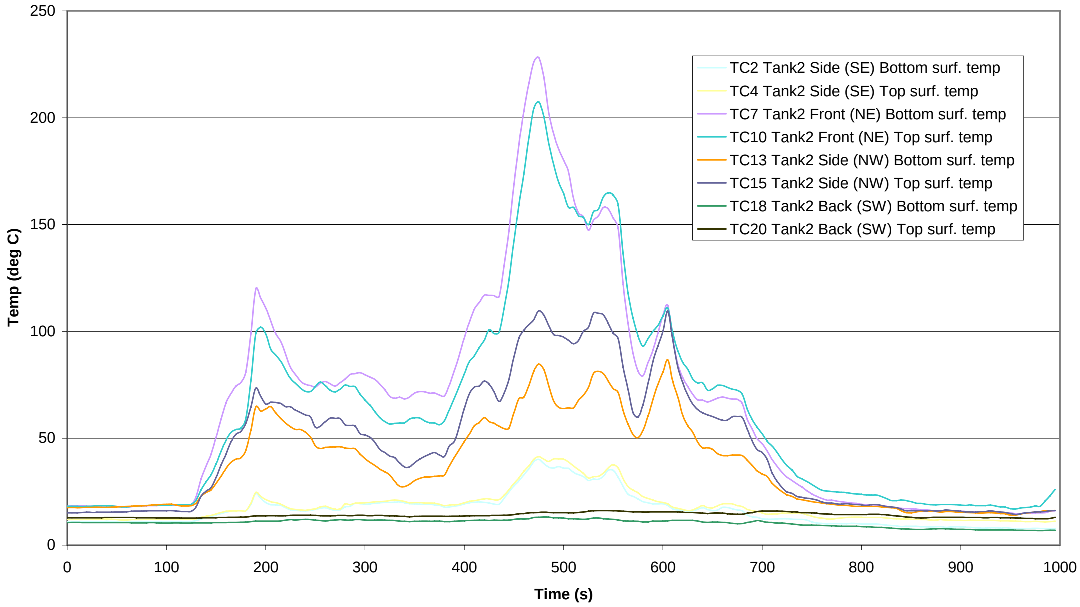

Figure A 13 Experiment 12 – Surface temperature – Tank 2 Colorbond Metal, oval shape

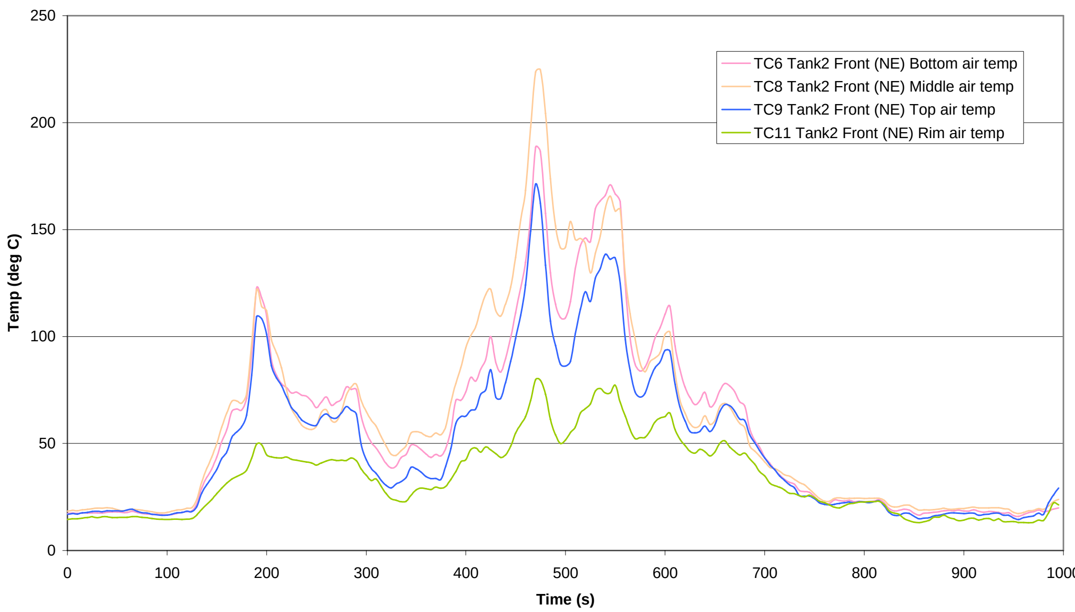

Figure A 14 Experiment 12 – Front temperature - Tank 2 Colorbond Metal, oval shape

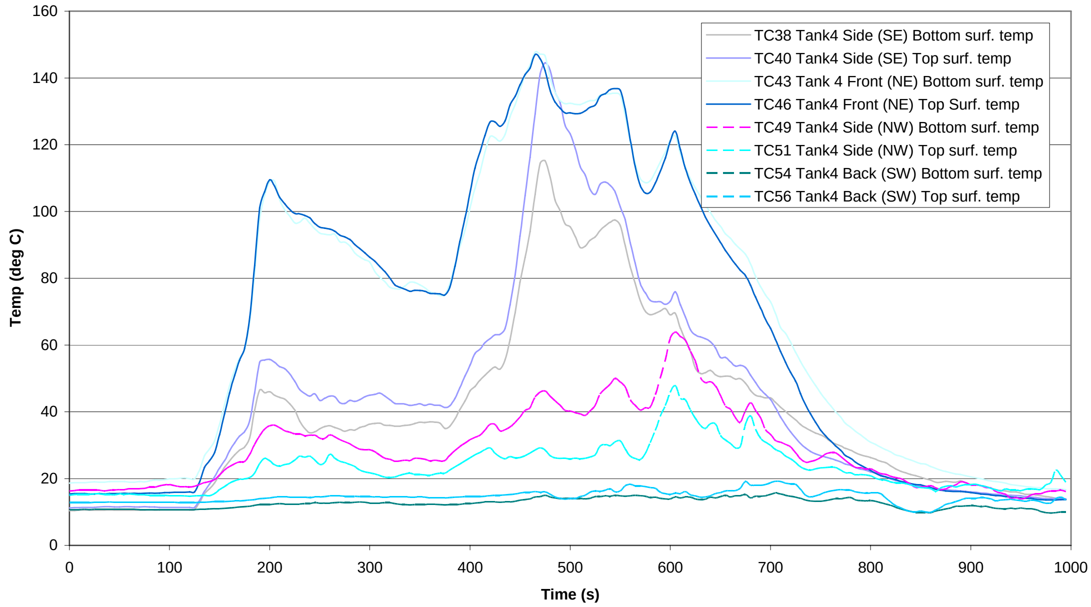

Figure A 15 Experiment 12 – Surface temperature – Tank 4 Polyethylene dark green

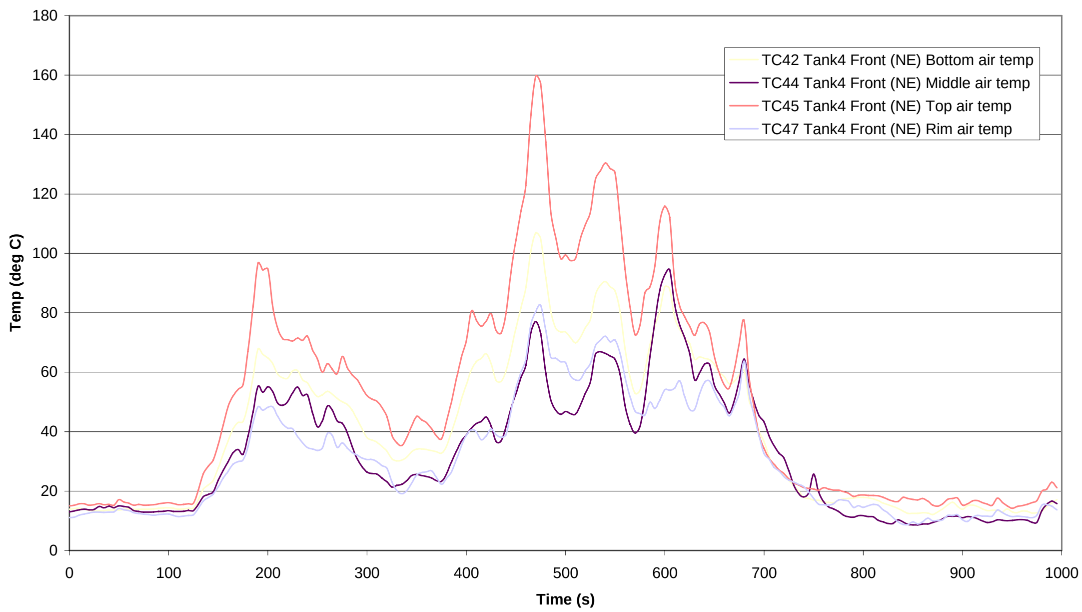

Figure A 16 Experiment 12 – Front temperature - Tank 4 Polyethylene dark green

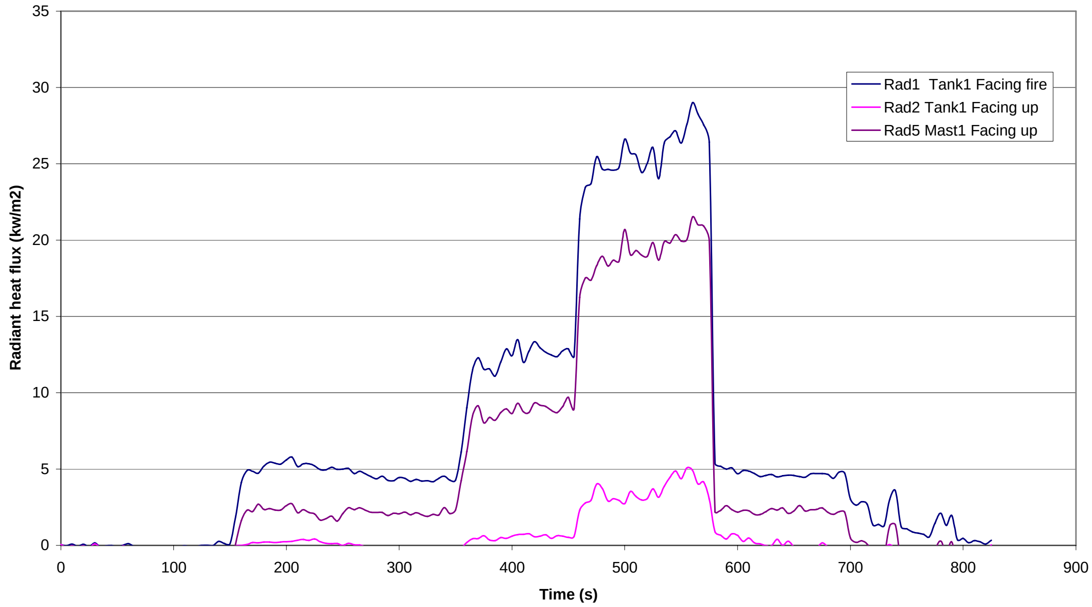

Figure A 17 Experiment 15 – Radiant heat flux – Tank 7 Spiral wound metal galvanised

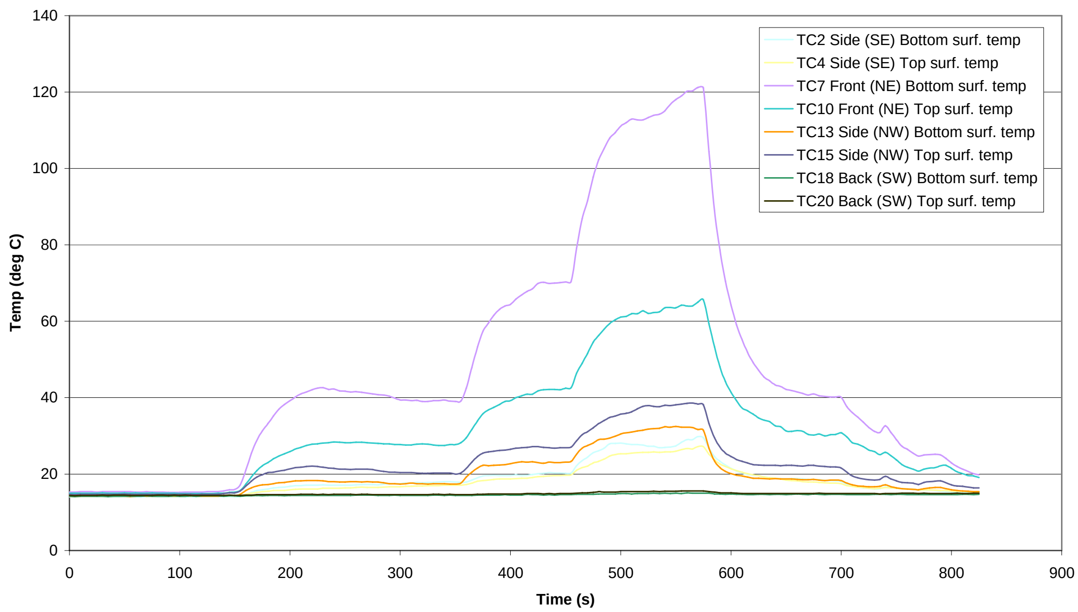

Figure A 18 Experiment 15 – Surface temperature – Tank 7 Spiral wound metal galvanised

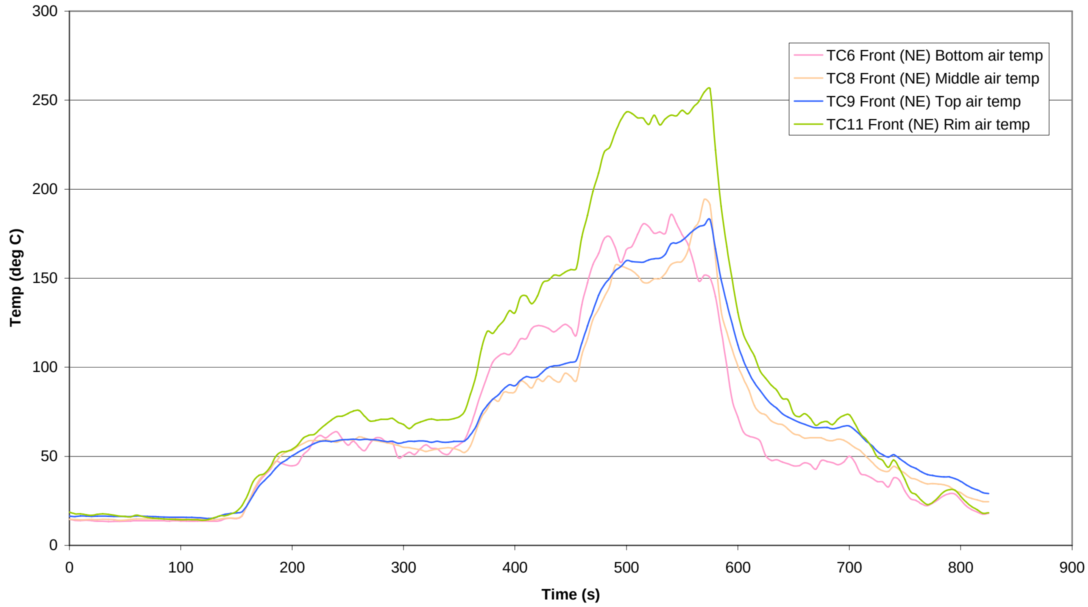

Figure A 19 Experiment 15 – Front temperature - Tank 7 Spiral wound metal galvanised

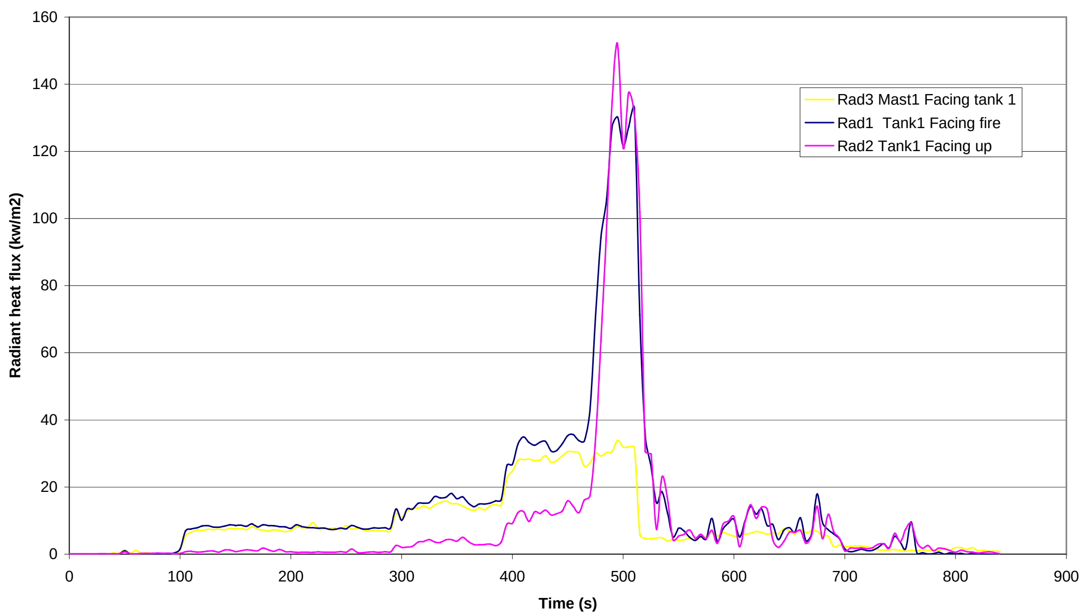

Figure A 20 Experiment 19 – Radiant heat flux – Tank 8 Polyethylene black

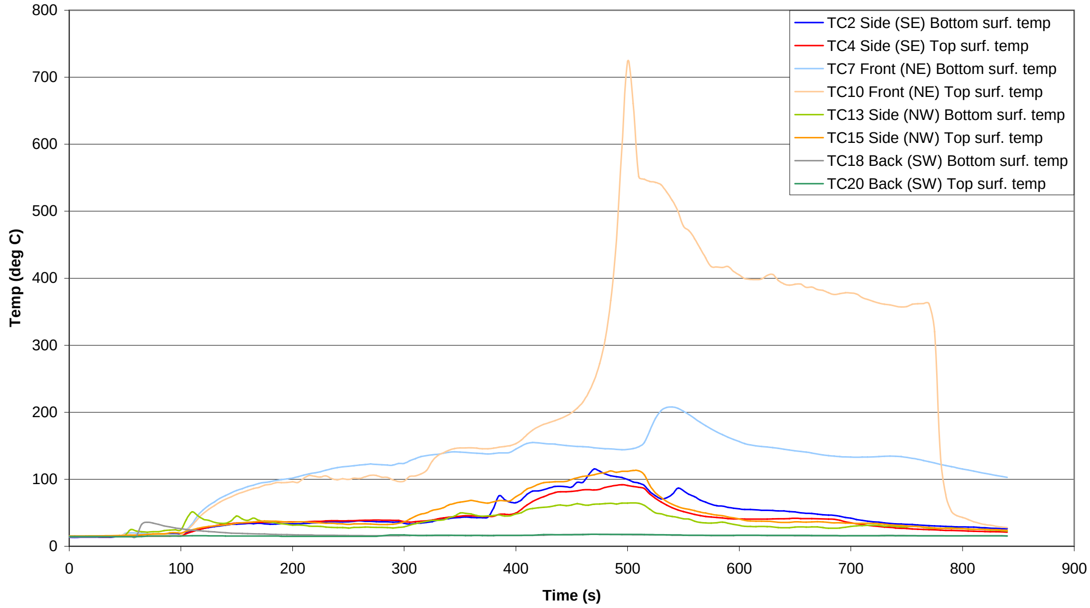

Figure A 21 Experiment 19 – Surface temperature – Tank 8 Polyethylene black

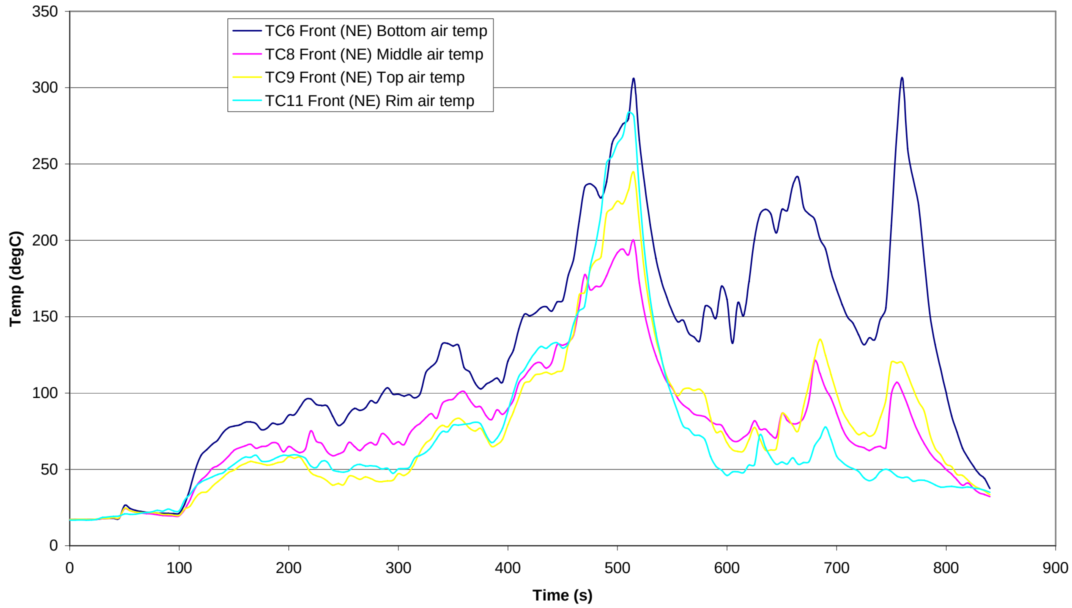

Figure A 22 Experiment 19 – Front temperature - Tank 8 Polyethylene black

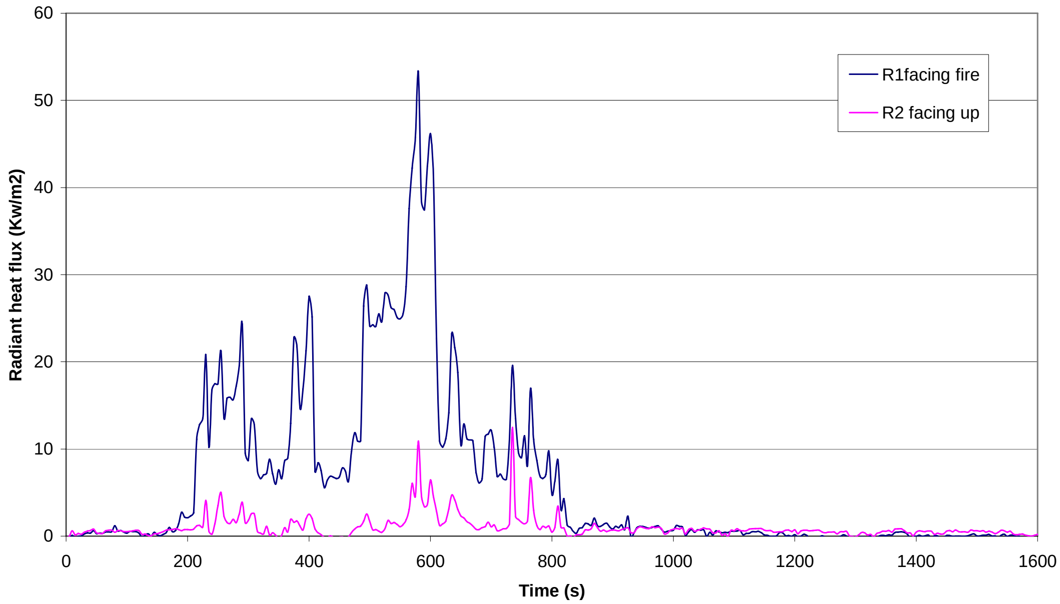

Figure A 23 Experiment 22 – Radiant heat flux – Tank 9 Bladder tank

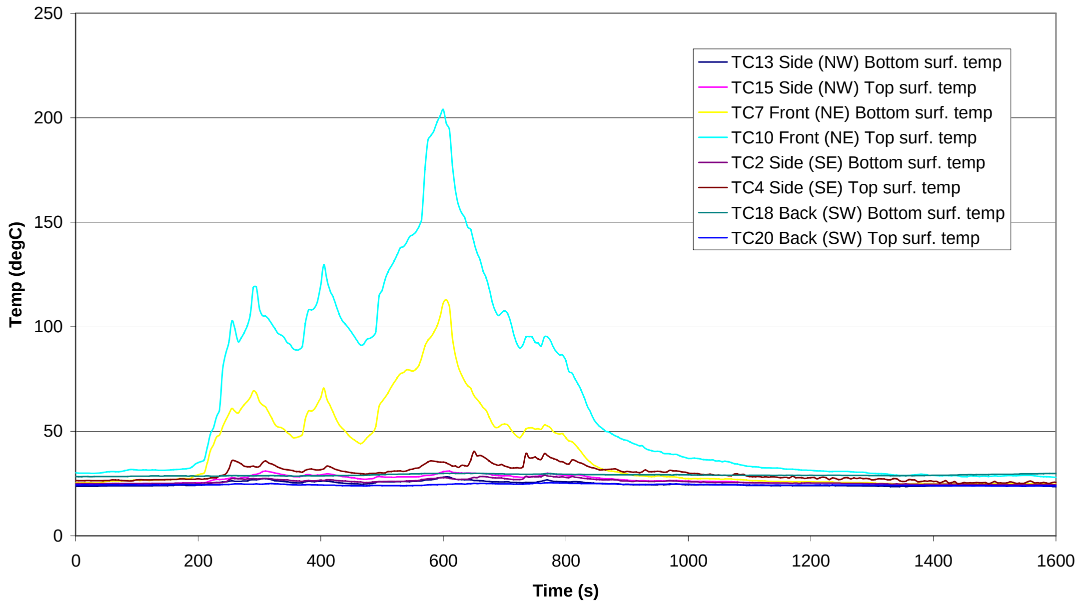

Figure A 24 Experiment 22 – Surface temperature – Tank 9 Bladder tank

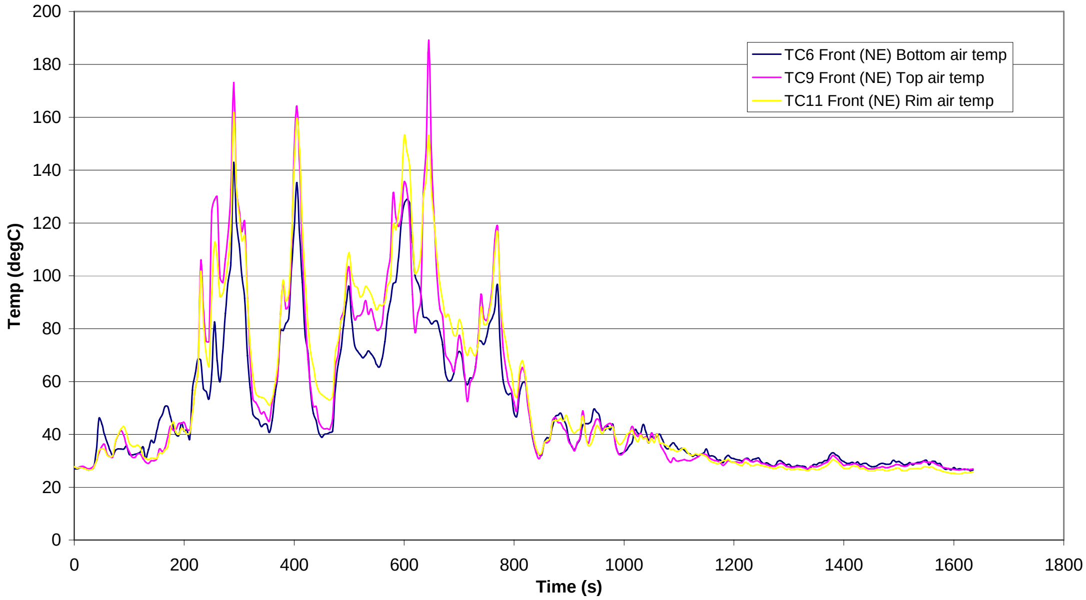

Figure A 25 Experiment 22 – Front temperature - Tank 9 Bladder tank

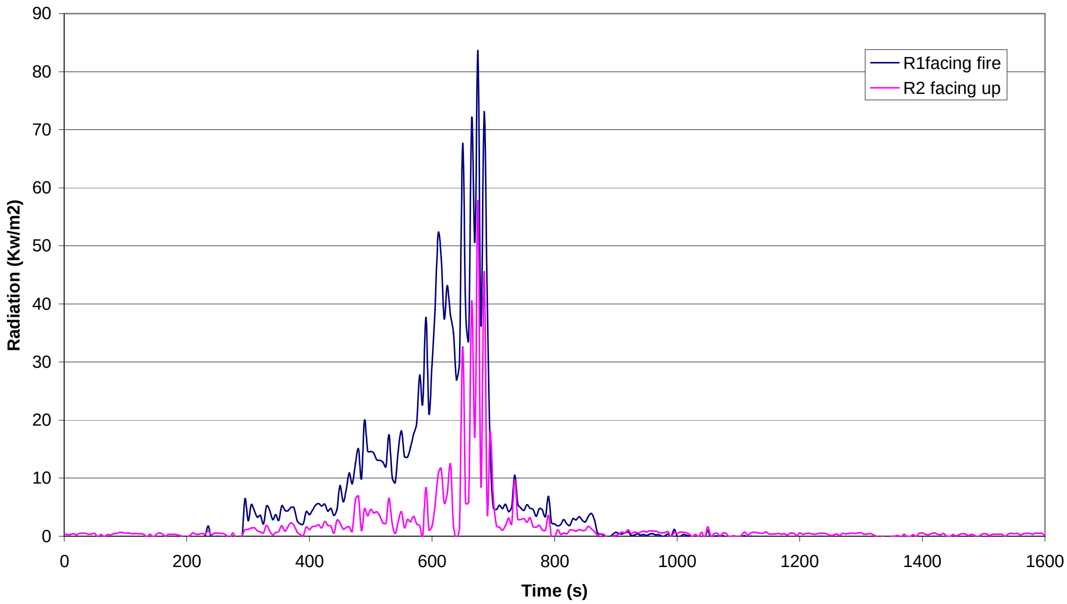

Figure A 26 Experiment 25 – Radiant heat flux – Tank 10 Used polyethylene tank (black)

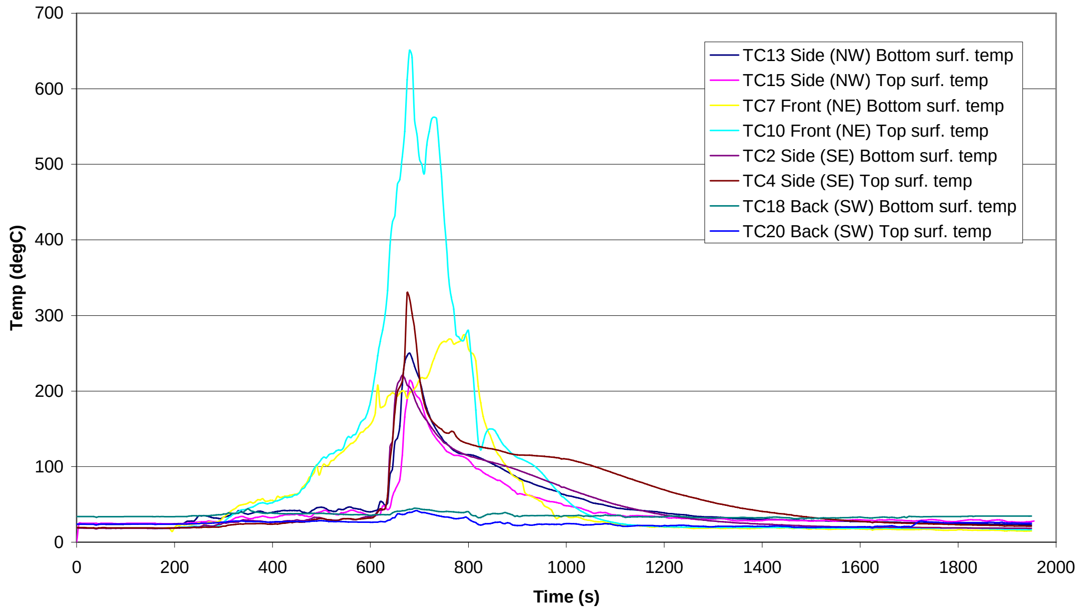

Figure A 27 Experiment 25 – Surface temperature – Tank 10 Used polyethylene tank (black)

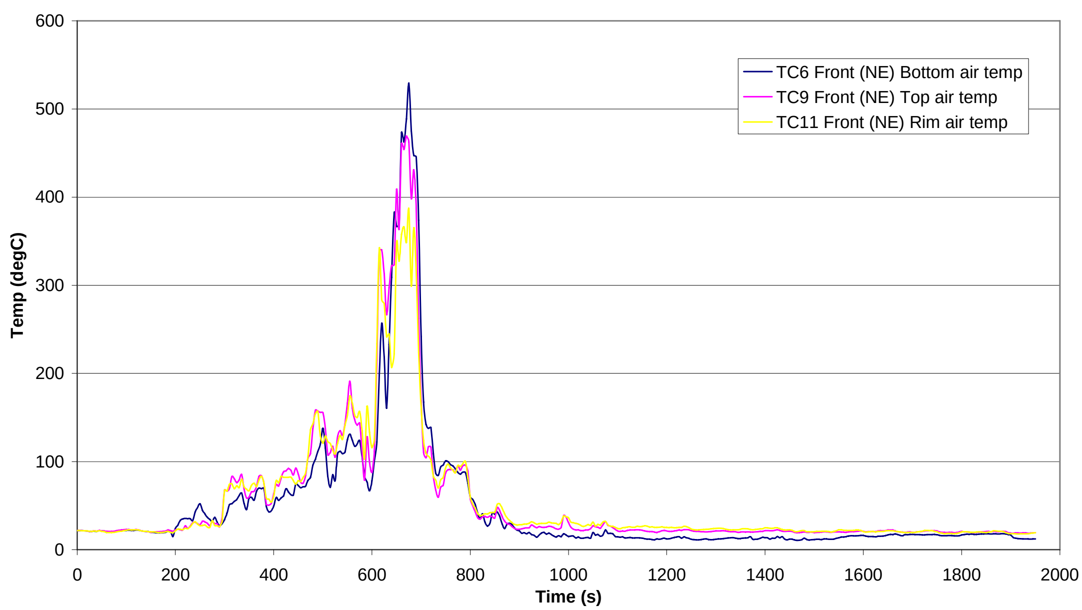

Figure A 28 Experiment 25 – Front temperature - Tank 10 Used polyethylene tank (black)

9.1. Pre-radiation flame immersion

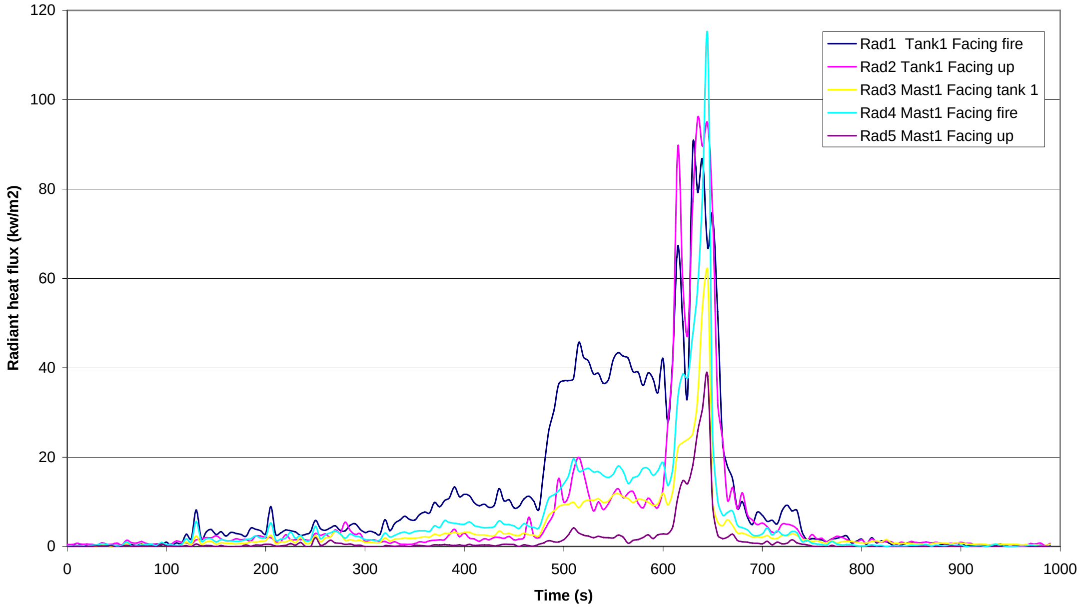

Figure A 29 Experiment 2 – Radiant heat flux - Tank1 Colorbond Metal (mist green)

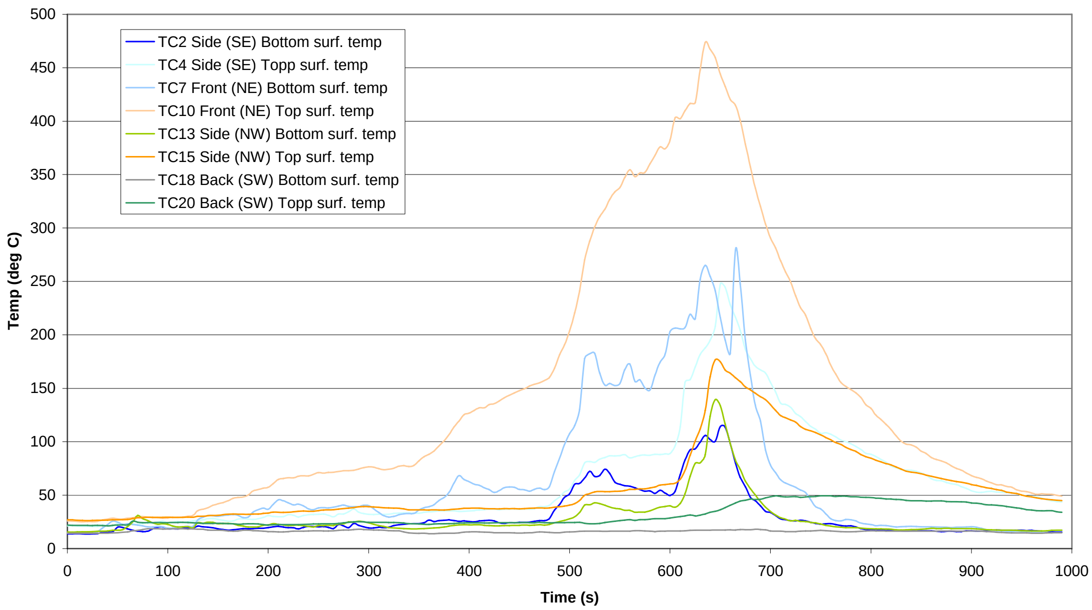

Figure A 30 Experiment 2 – Surface temperature – Tank1 Colorbond Metal (mist green)

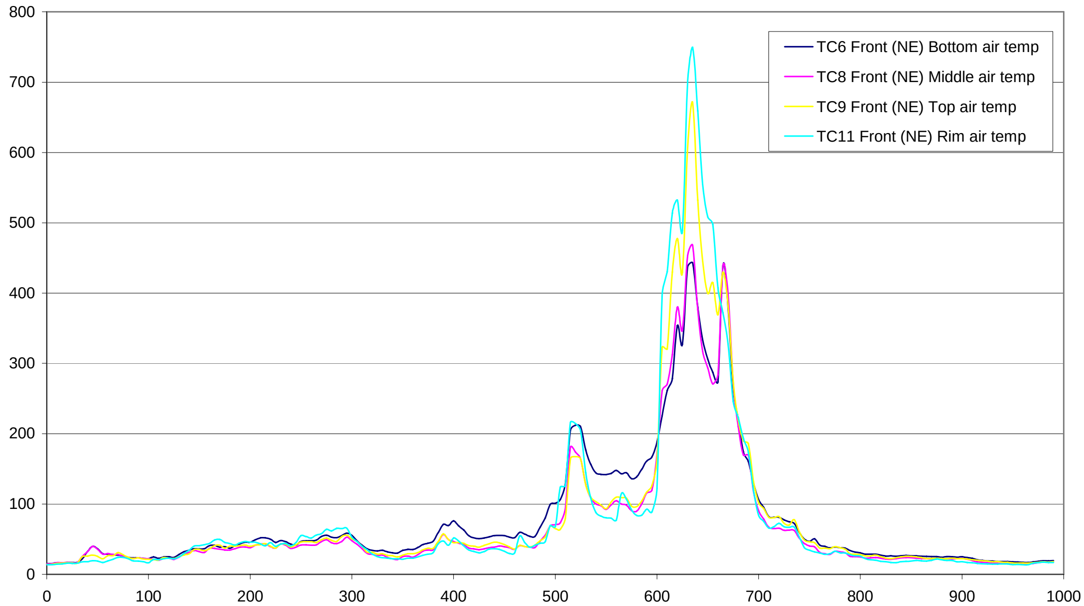

Figure A 31 Experiment 2 – Front temperature - Tank1 Colorbond Metal (mist green)

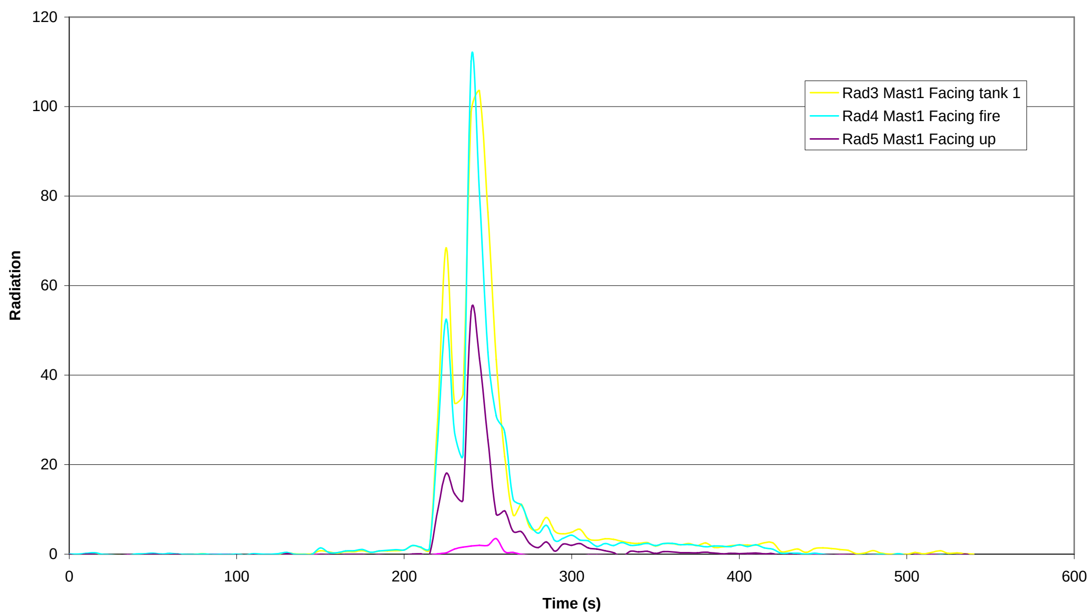

Figure A 32 Experiment 6 – Radiant heat flux - Tank 6 Polyethylene water tank (beige)

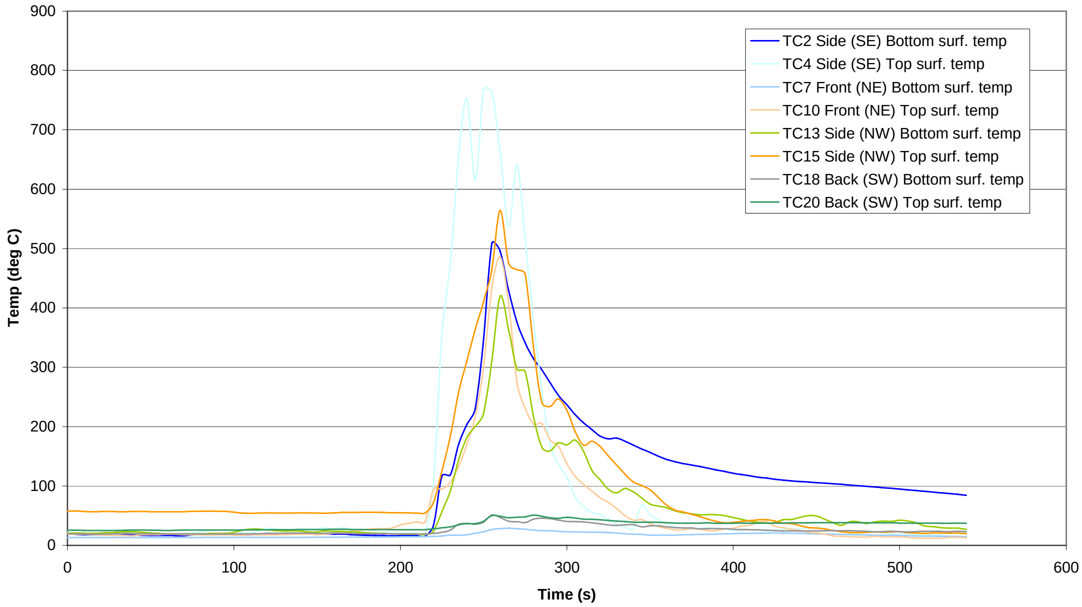

Figure A 33 Experiment 6 – Surface temperature – Tank 6 Polyethylene water tank (beige)

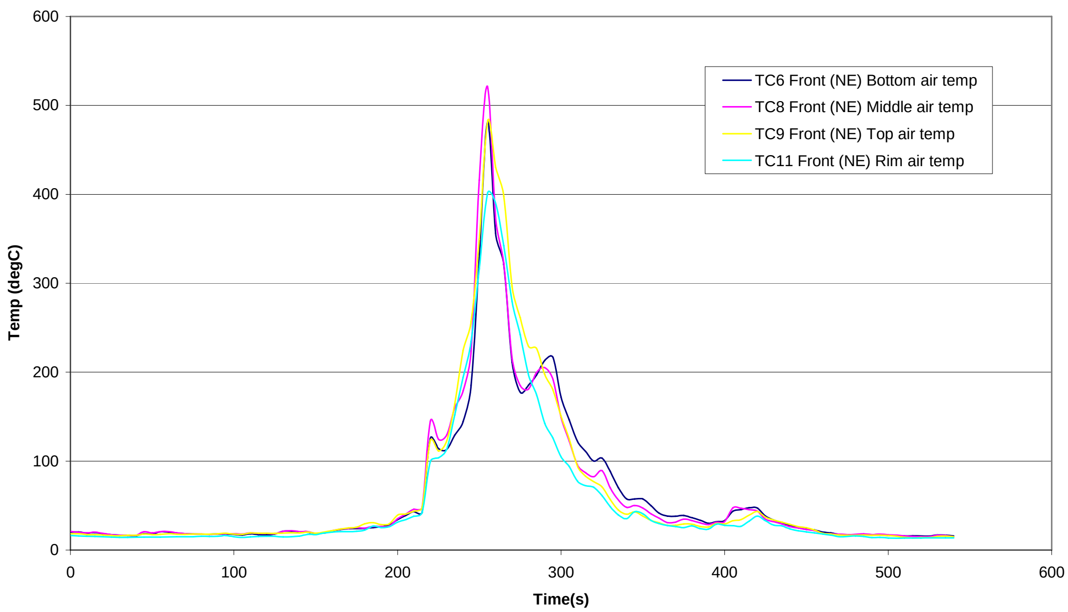

Figure A 34 Experiment 6 – Front temperature - Tank 6 Polyethylene water tank (beige)

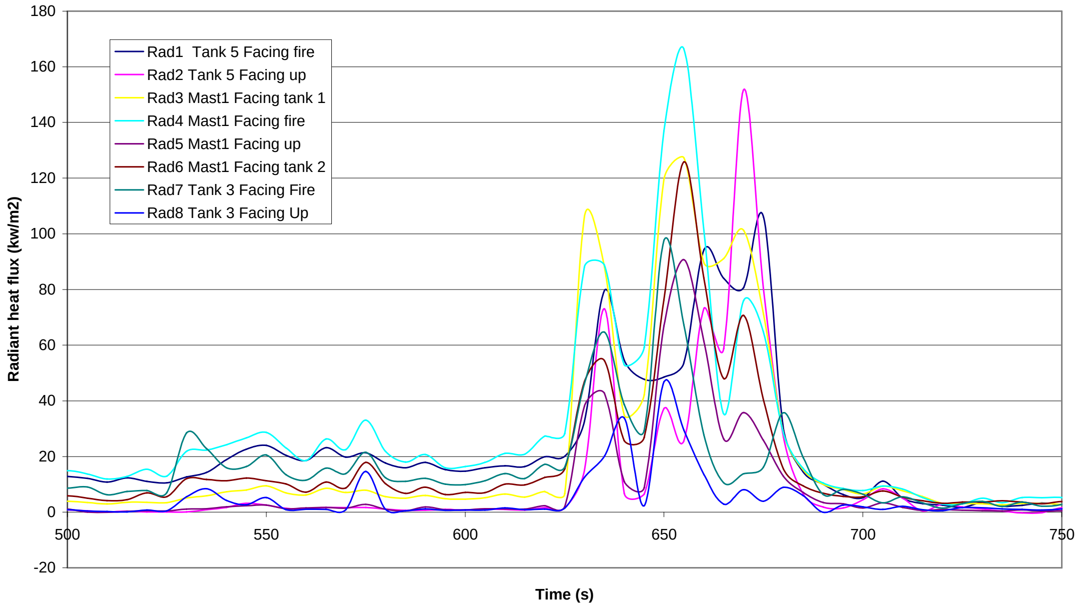

Figure A 35 Experiment 10 – Radiant heat flux – Tank 3 Colorbond Metal (mist green) and Tank 5 Spiral wound metal galvanised

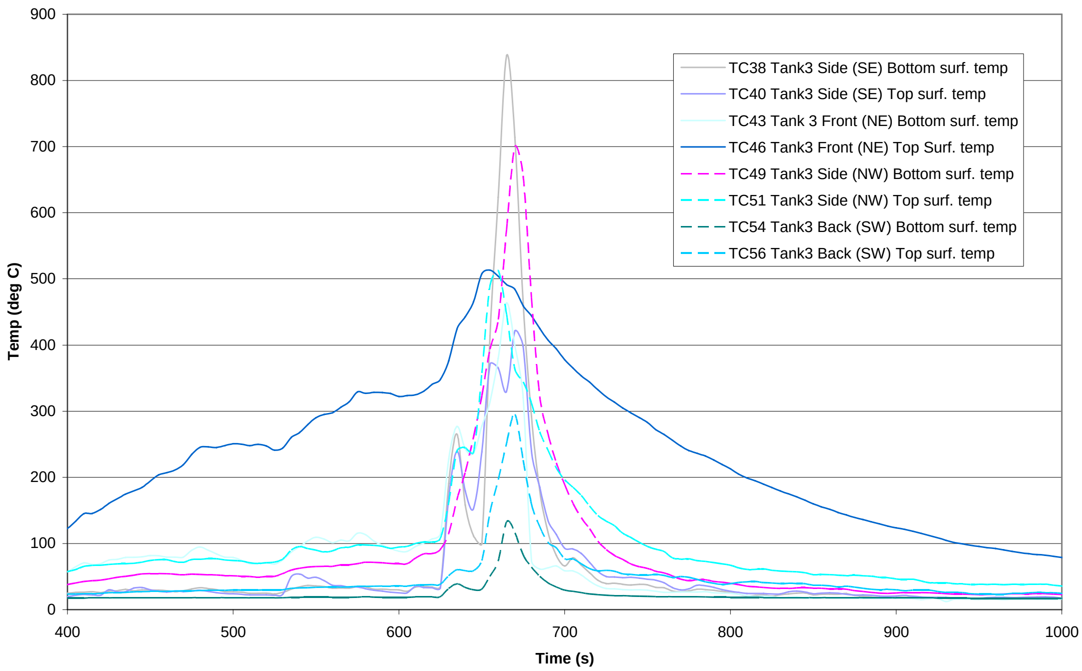

Figure A 36 Experiment 10 – Surface temperature – Tank 3 Colorbond Metal (mist green)

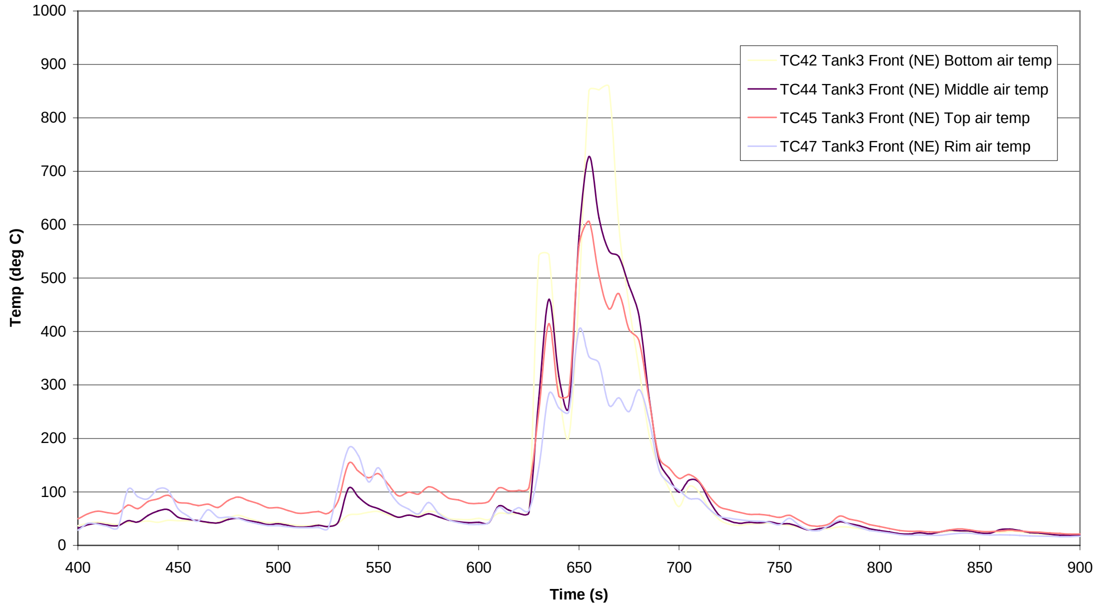

Figure A 37 Experiment 10 – Front temperature - Tank 3 Colorbond Metal (mist green)

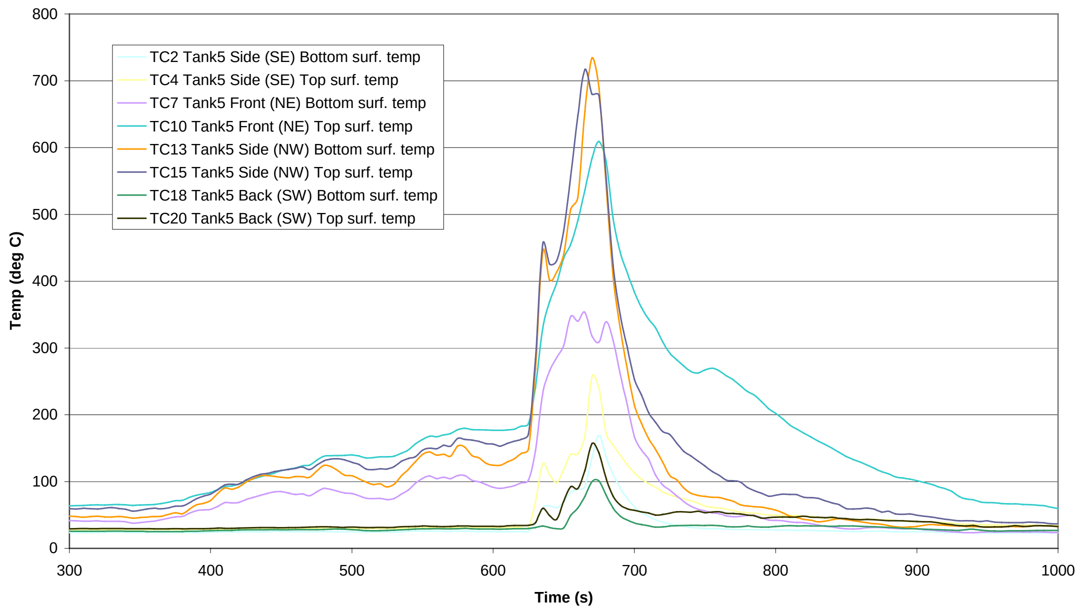

Figure A 38 Experiment 10 – Surface temperature – Tank 5 Spiral wound metal galvanised

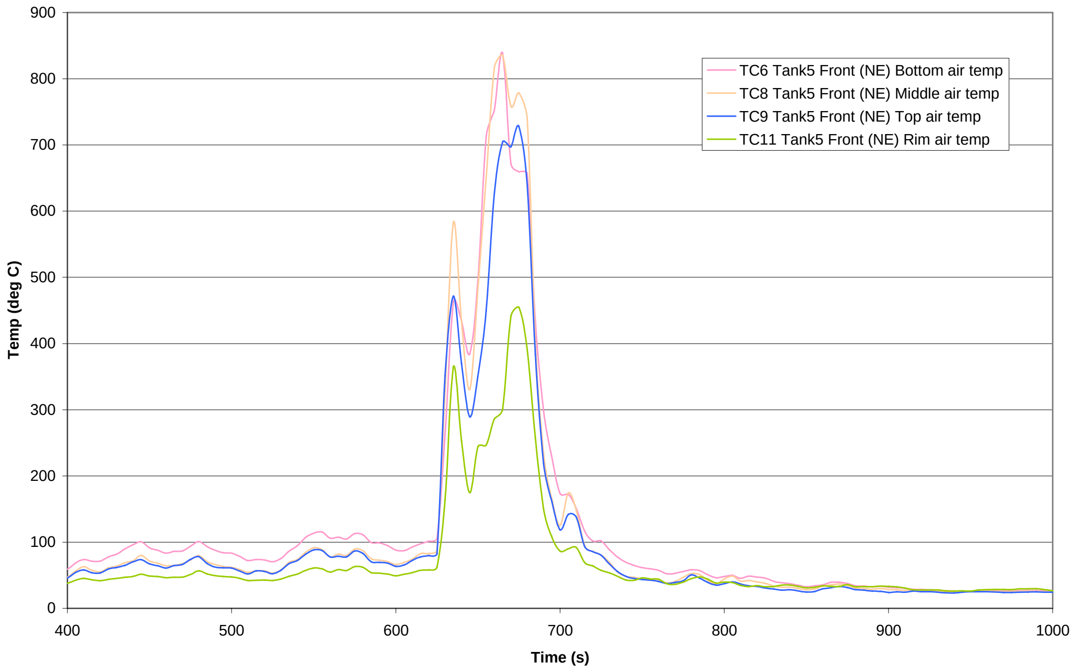

Figure A 39 Experiment 10 – Front temperature - Tank 5 Spiral wound metal galvanised

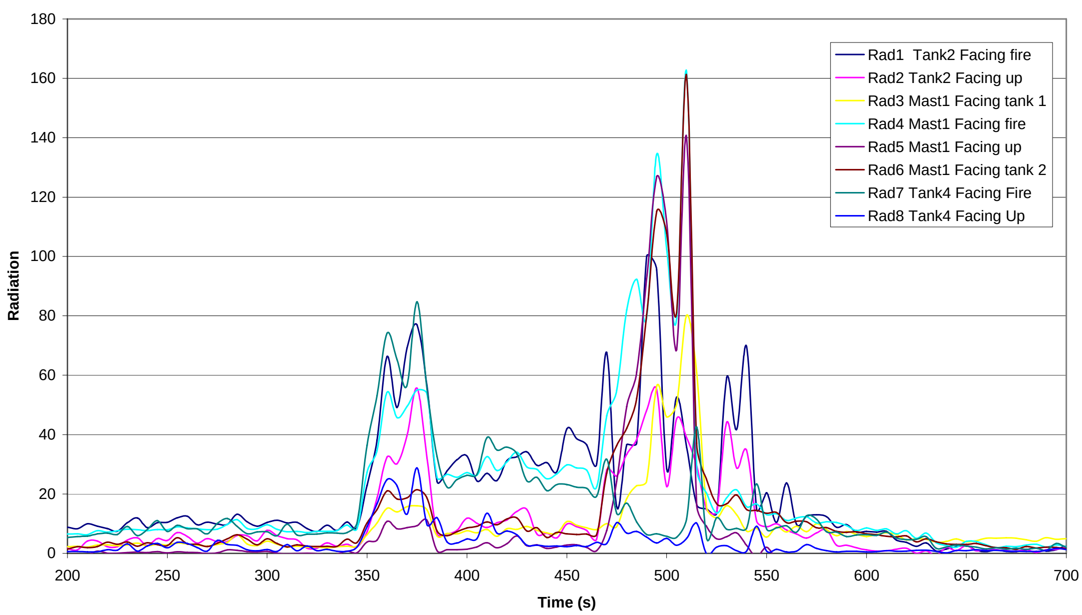

Figure A 40 Experiment 13 – Radiant heat flux – Tank 2 Colorbond Metal, oval shape and Polyethylene dark green

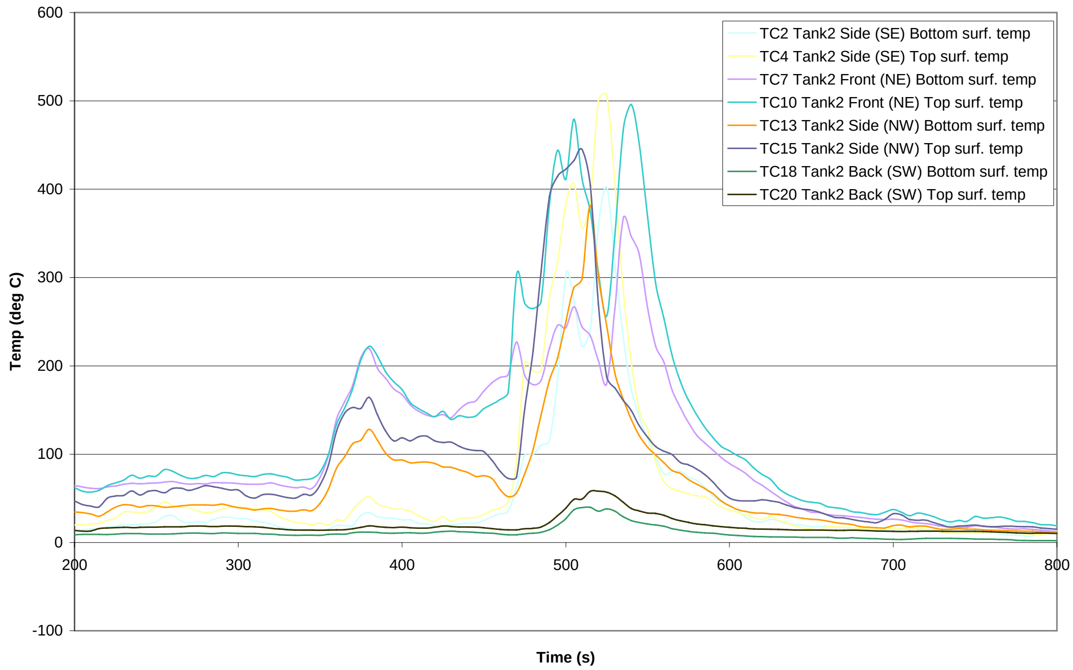

Figure A 41 Experiment 13 – Surface temperature – Tank 2 Colorbond Metal, oval shape

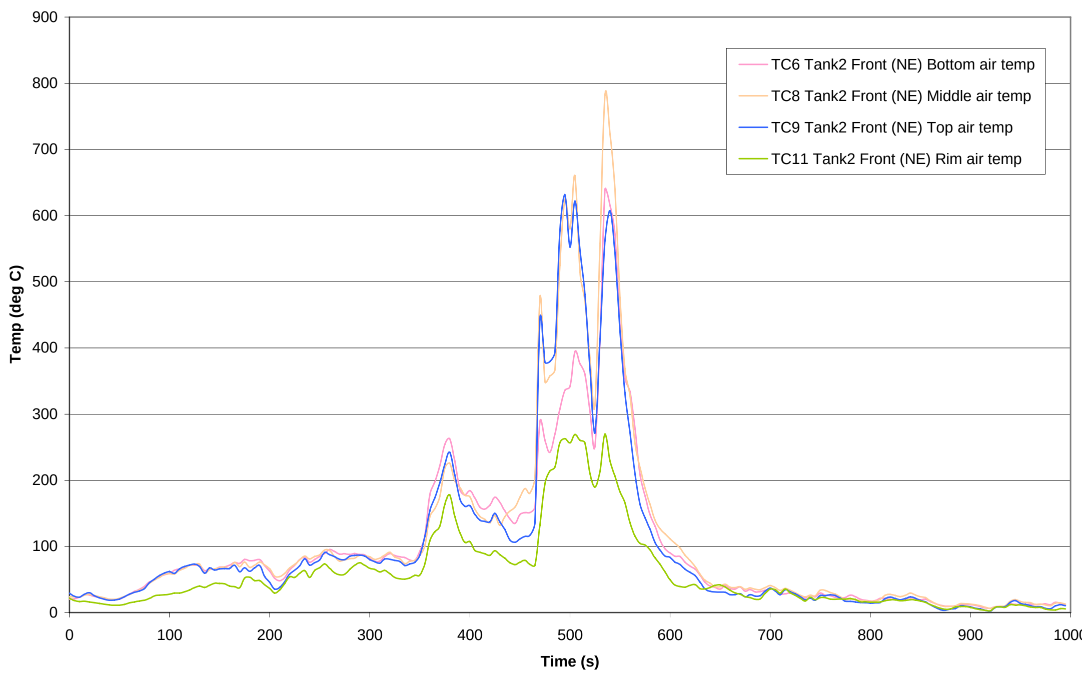

Figure A 42 Experiment 13 – Front temperature - Tank 2 Colorbond Metal, oval shape

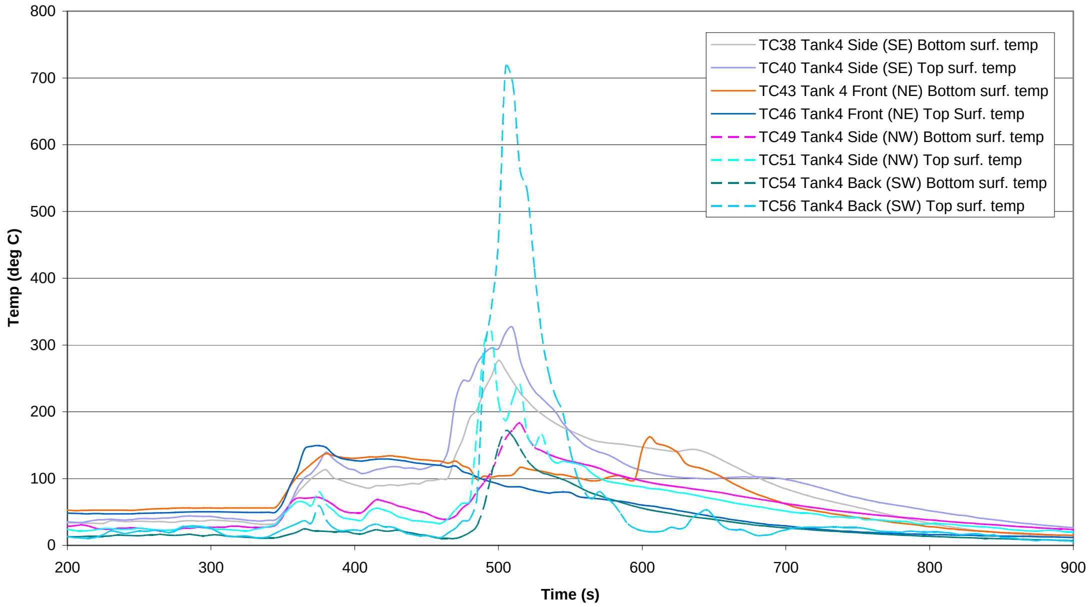

Figure A 43 Experiment 13 – Surface temperature – Tank 4 Polyethylene dark green

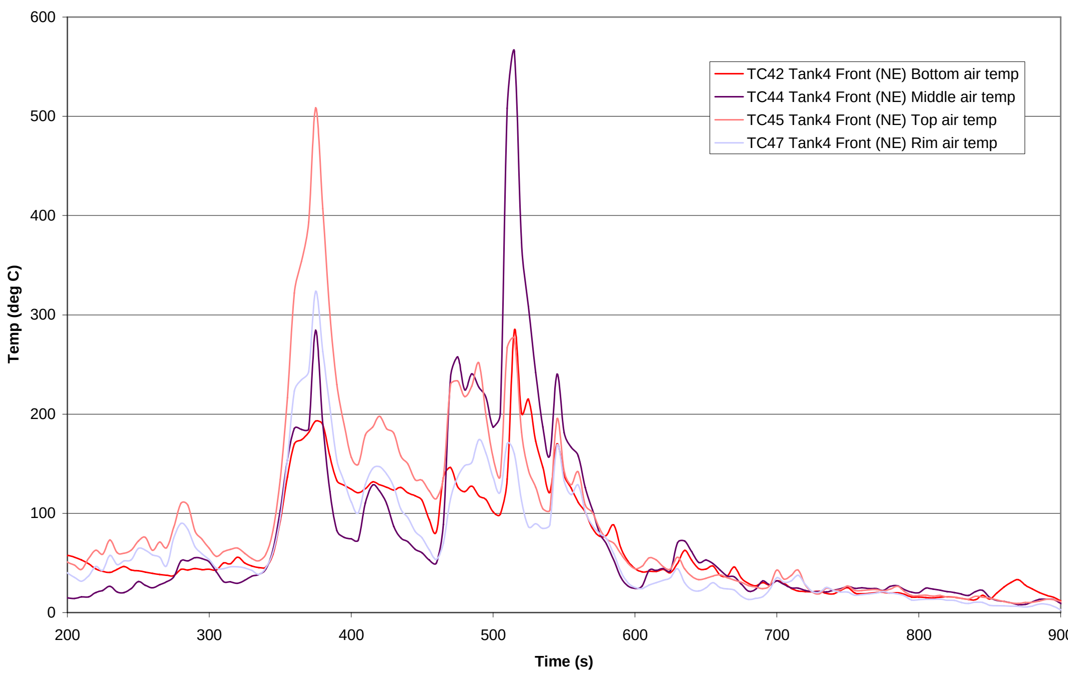

Figure A 44 Experiment 13 – Front temperature - Tank 4 Polyethylene dark green

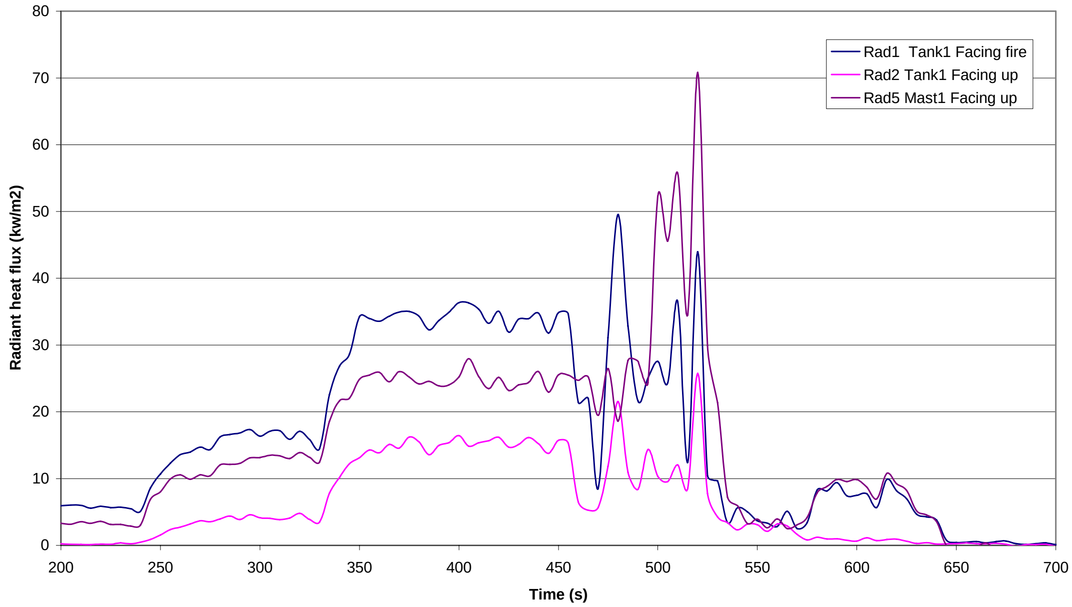

Figure A 45 Experiment 16 – Radiant heat flux – Tank 7 Spiral wound metal galvanised

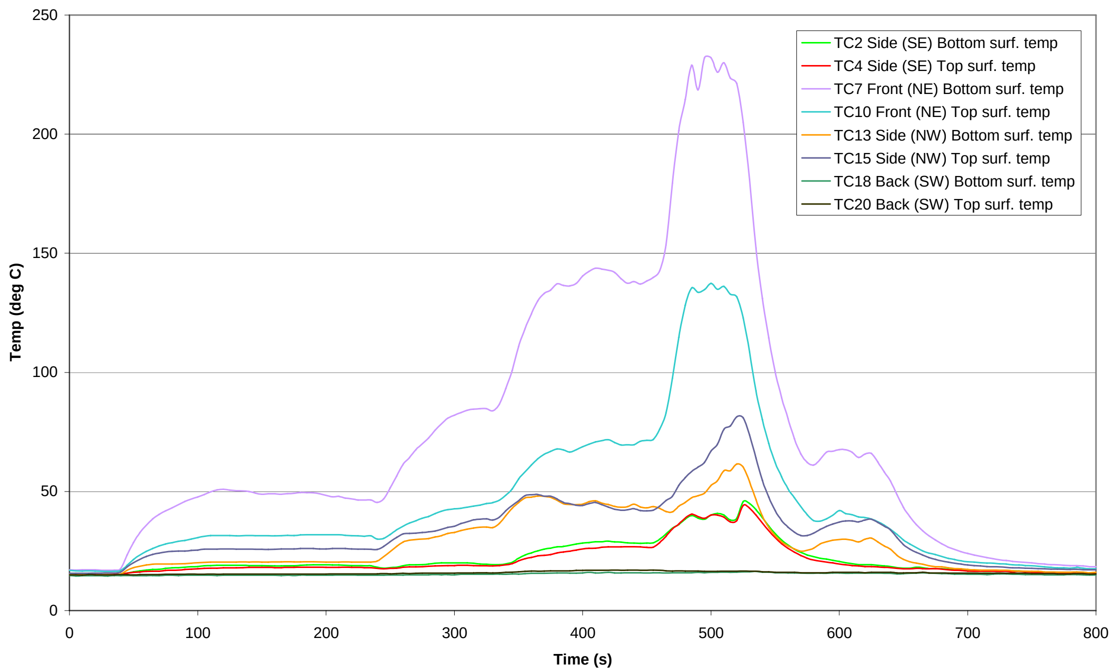

Figure A 46 Experiment 16 – Surface temperature – Tank 7 Spiral wound metal galvanised

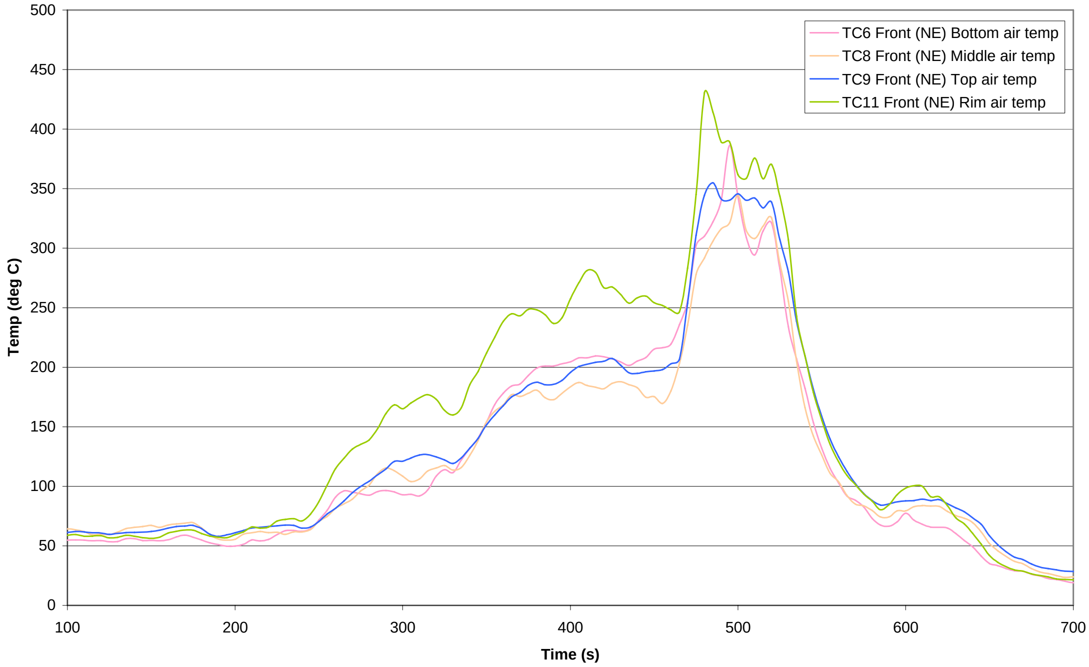

Figure A 47 Experiment 16 – Front temperature - Tank 7 Spiral wound metal galvanised

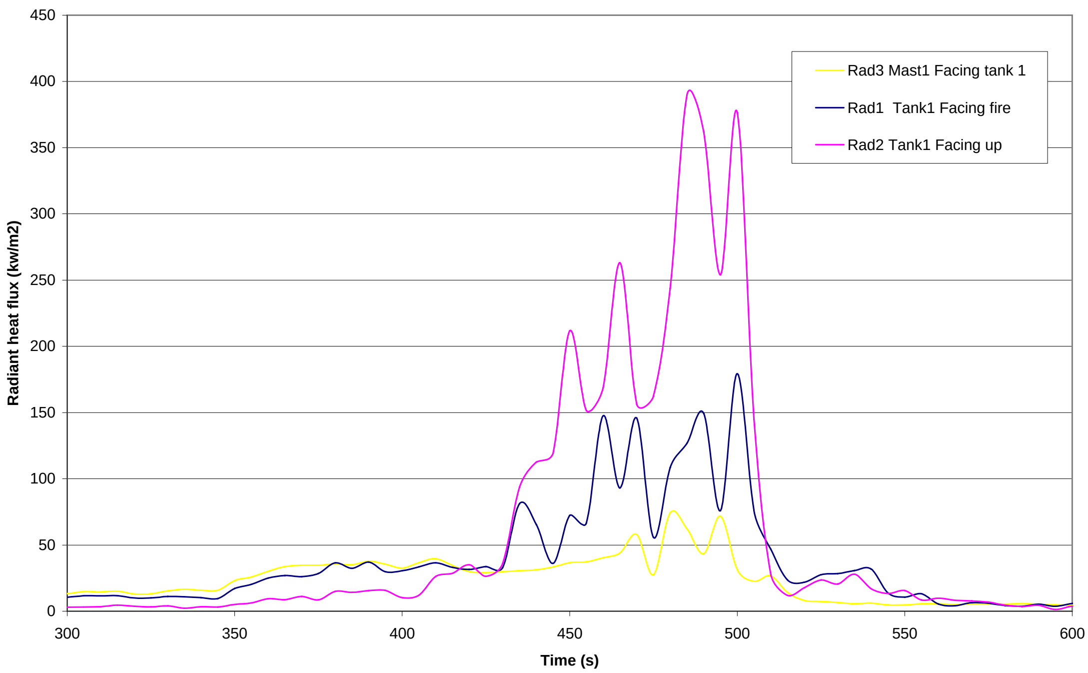

Figure A 48 Experiment 20 – Radiant heat flux – Tank 8 Polyethylene black

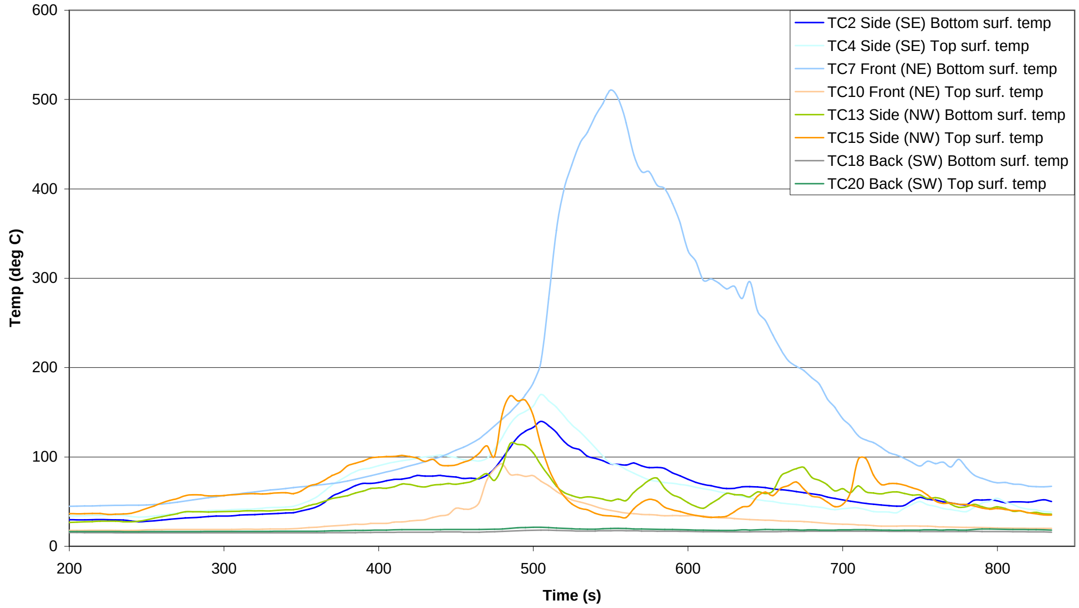

Figure A 49 Experiment 20 – Surface temperature – Tank 8 Polyethylene black

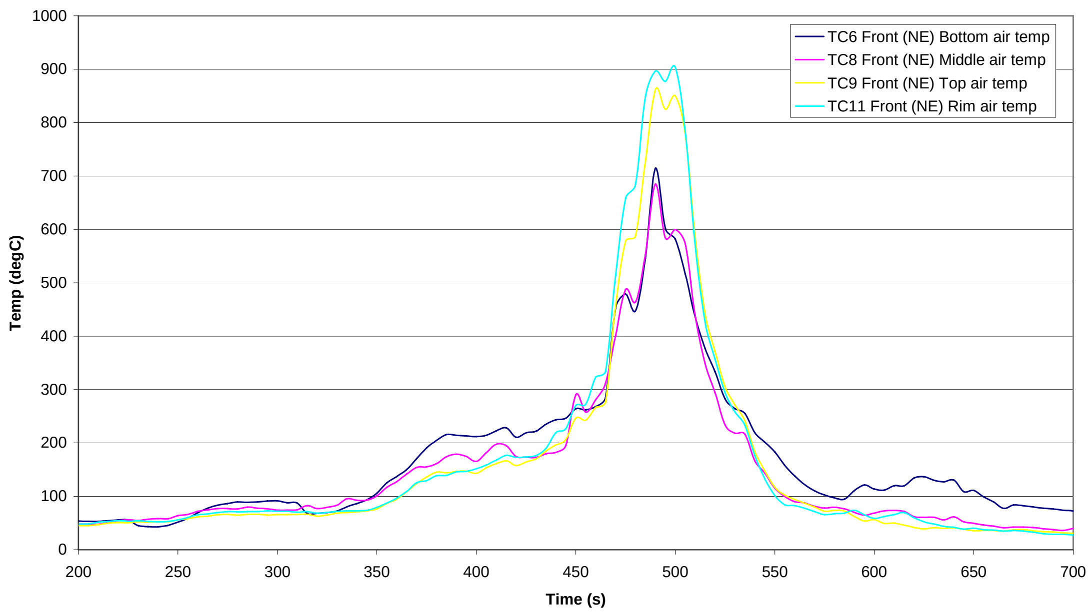

Figure A 50 Experiment 20 – Front temperature - Tank 8 Polyethylene black

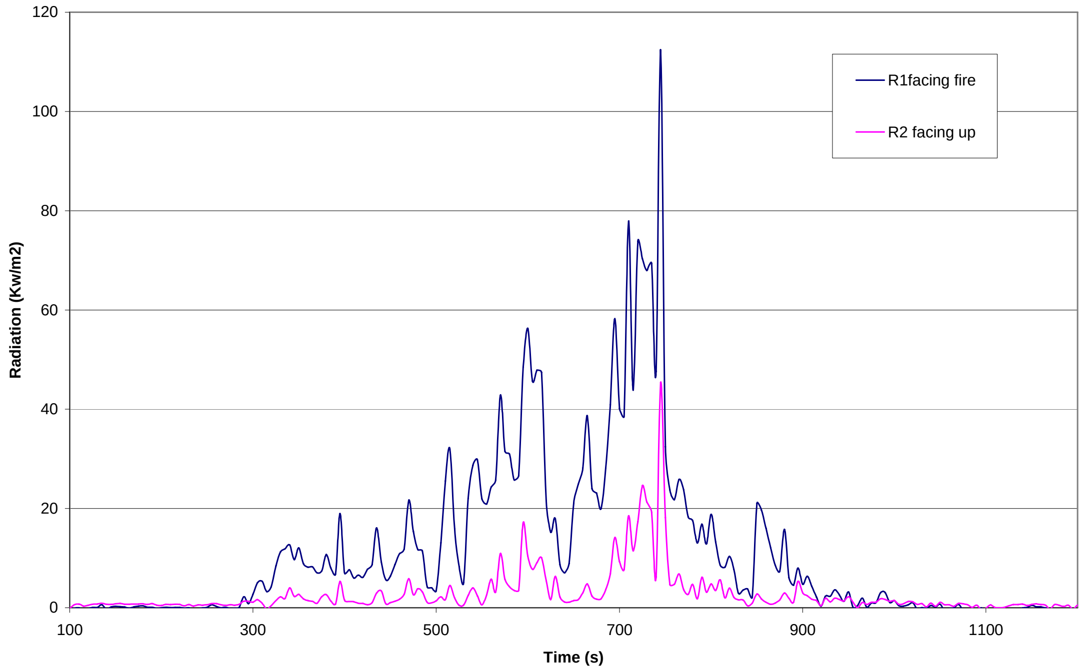

Figure A 51 Experiment 23 – Radiant heat flux – Tank 9 Bladder tank

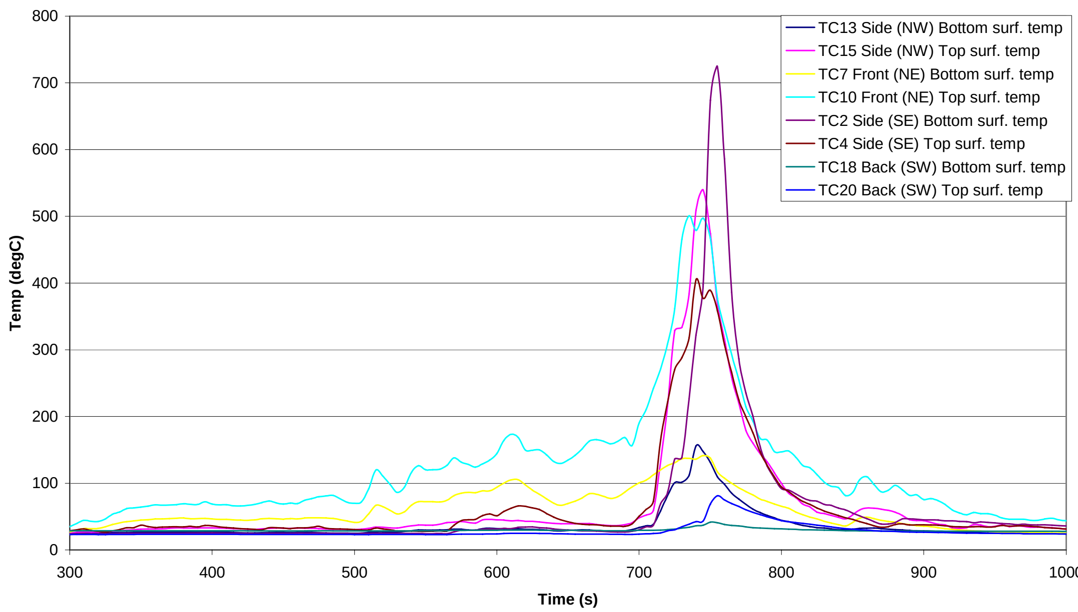

Figure A 52 Experiment 23 – Surface temperature – Tank 9 Bladder tank

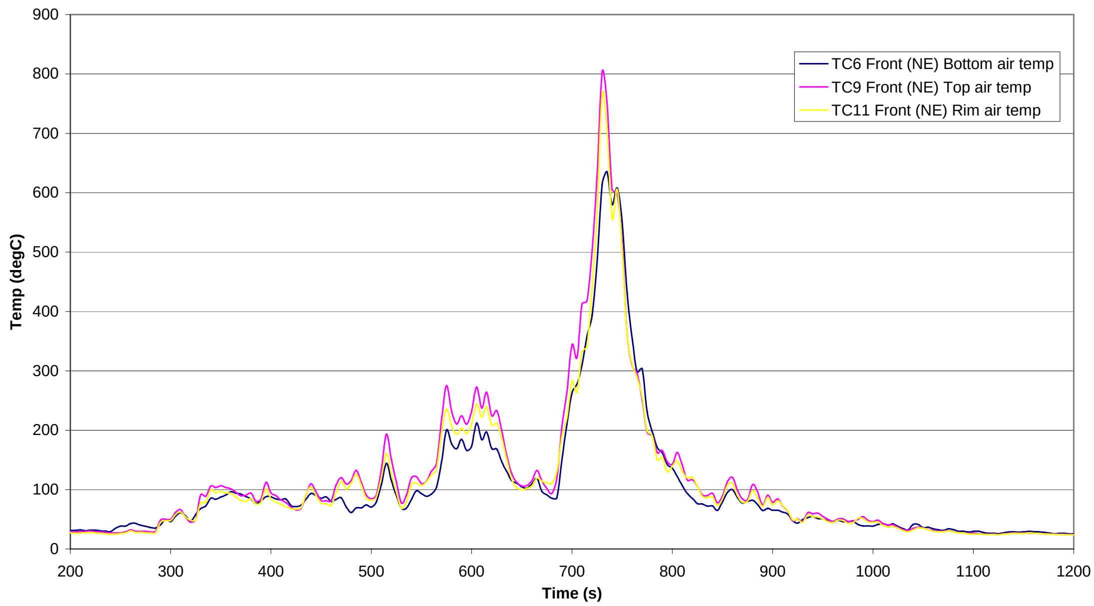

Figure A 53 Experiment 23 – Front temperature - Tank 9 Bladder tank

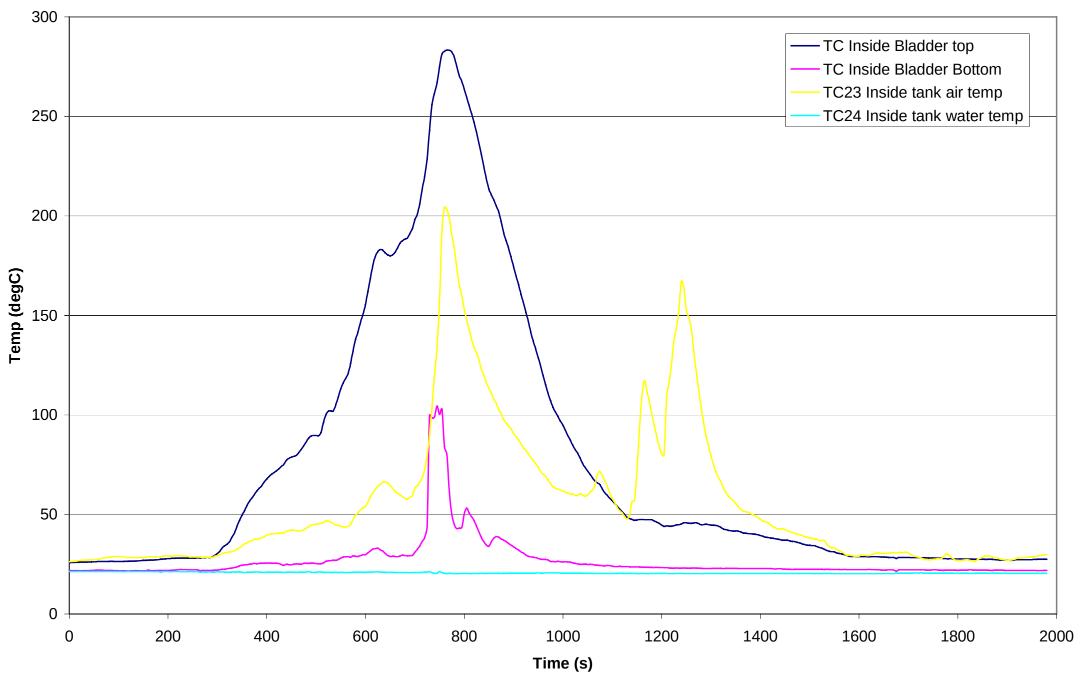

Figure A 54 Experiment 23 – Inside temperature - Tank 9 Bladder tank

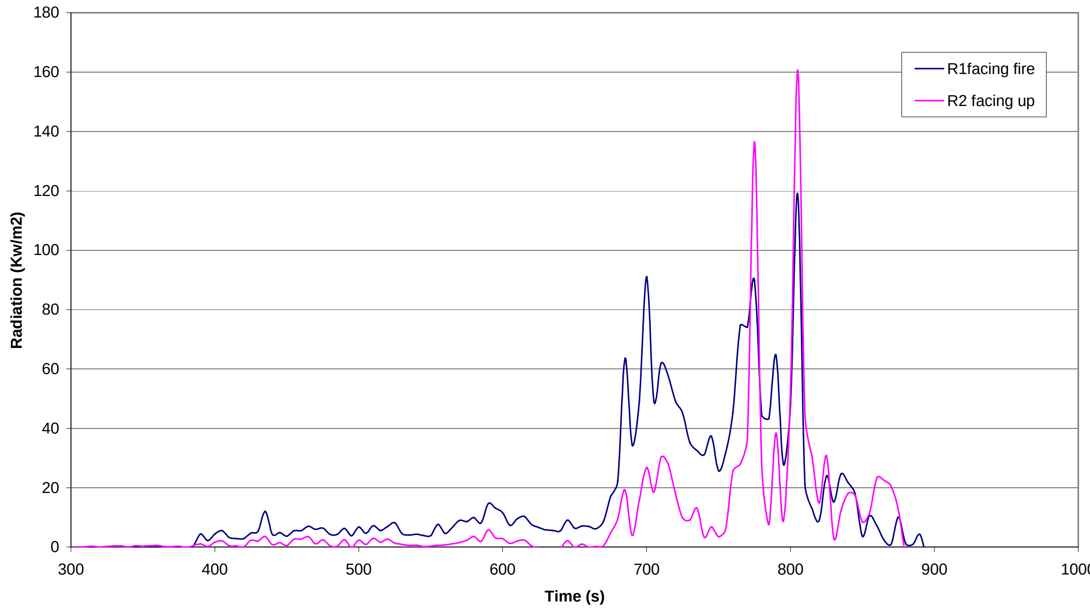

Figure A 55 Experiment 26 – Radiant heat flux – Tank 10 Used polyethylene tank (black)

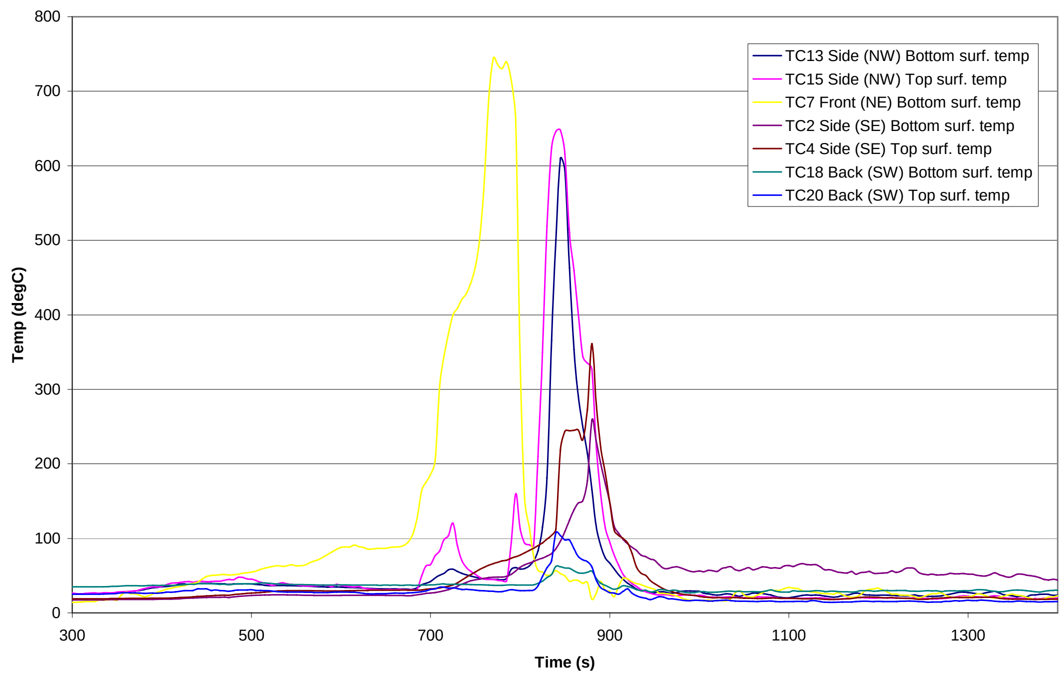

Figure A 56 Experiment 26 – Surface temperature – Tank 10 Used polyethylene tank (black)

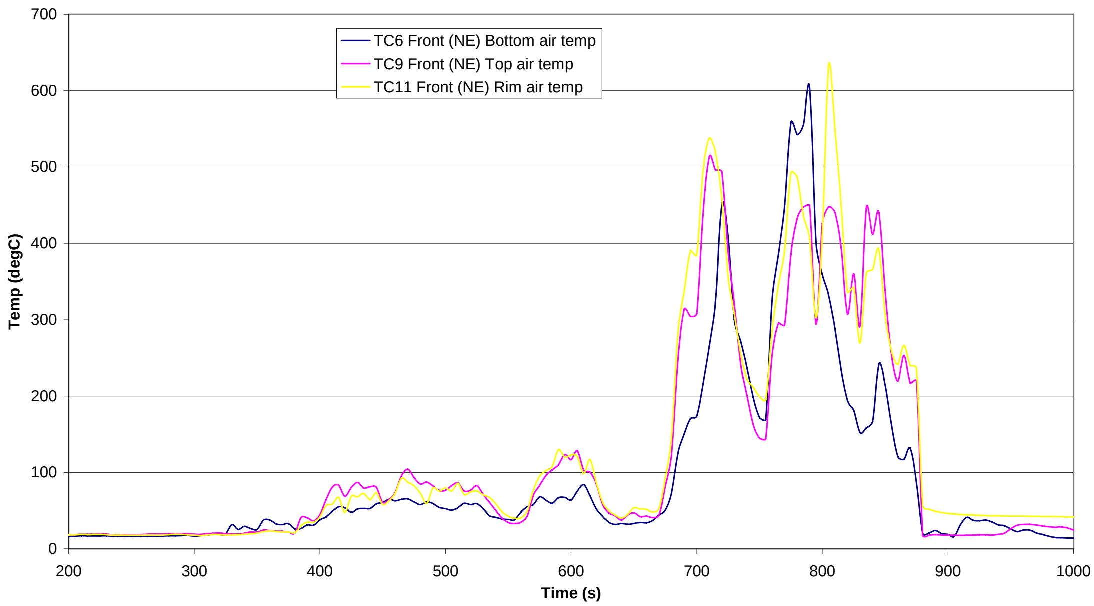

Figure A 57 Experiment 26 – Front temperature - Tank 10 Used polyethylene tank (black)

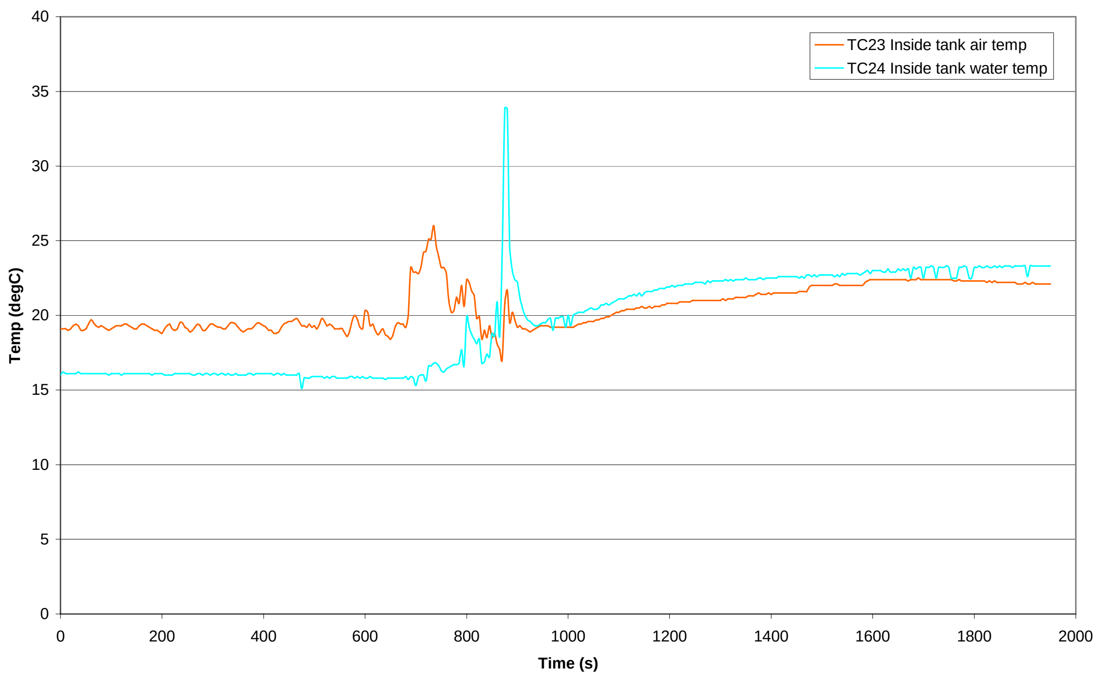

Figure A 58 Experiment 26 – Temperature inside tank - Tank 10 Used polyethylene tank (black)

9.2. *Structure exposure*

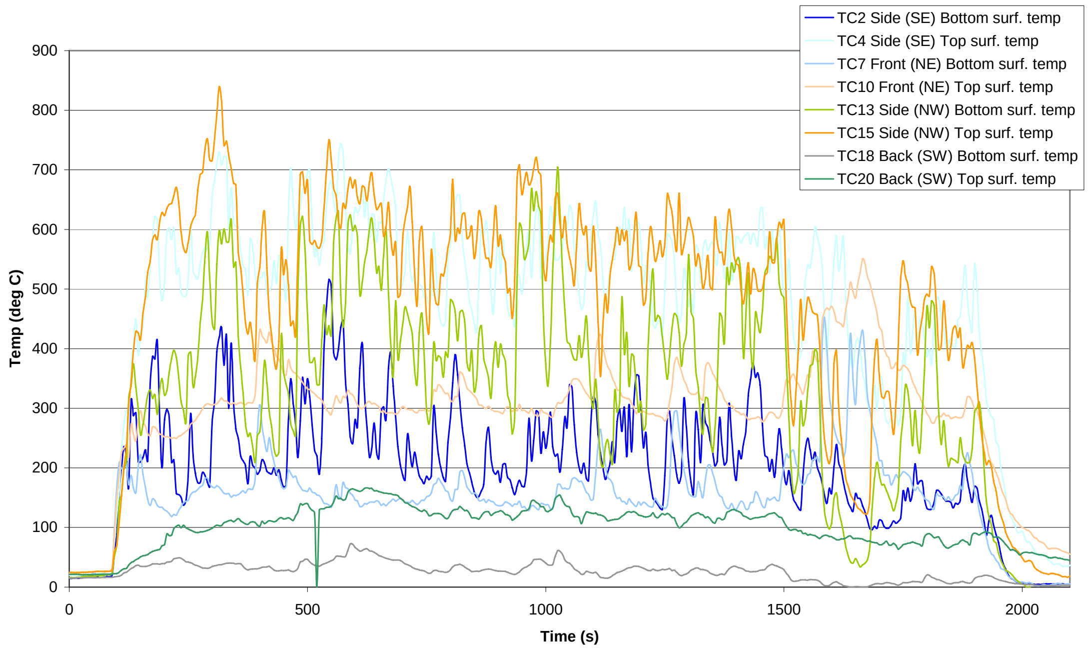

Figure A 59 Experiment 3 – Surface temperature – Tank1 Colorbond Metal (mist green)

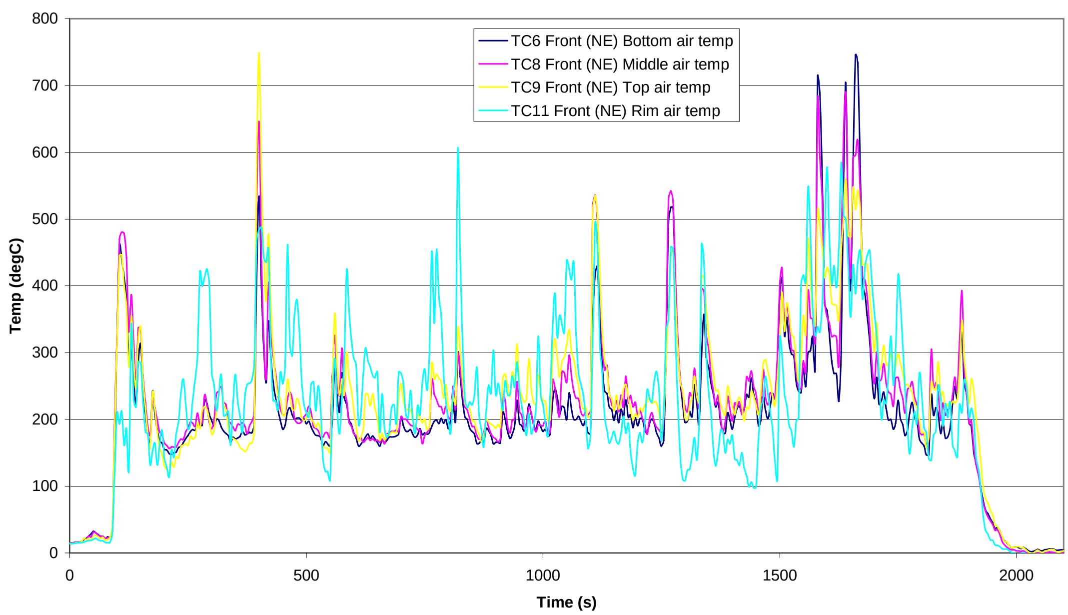

Figure A 60 Experiment 3 – Front temperature - Tank1 Colorbond Metal (mist green)

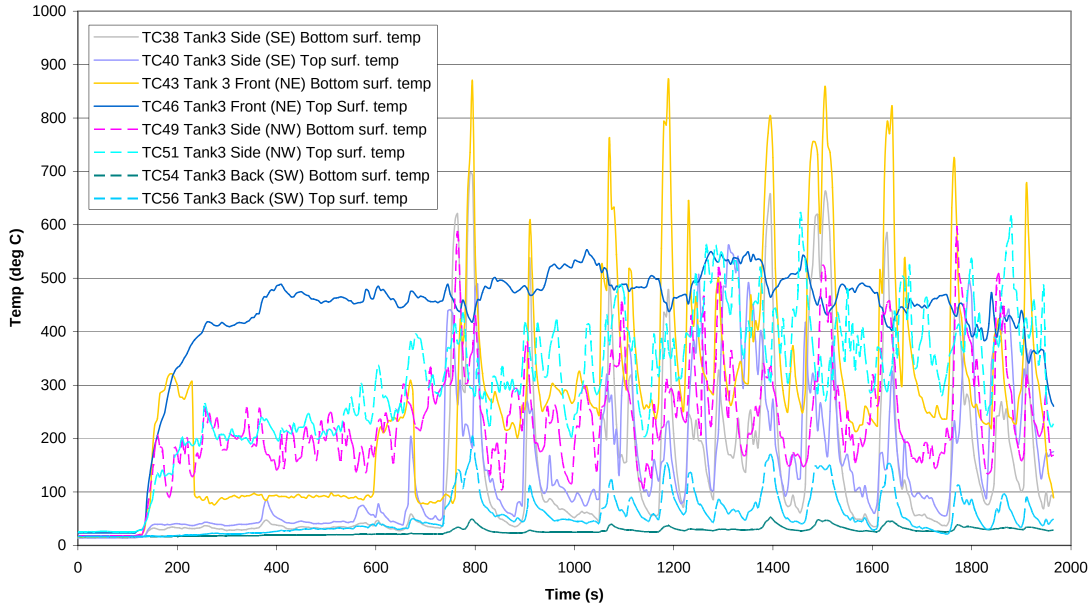

Figure A 61 Experiment 11 – Surface temperature – Tank 3 Colorbond Metal (mist green)

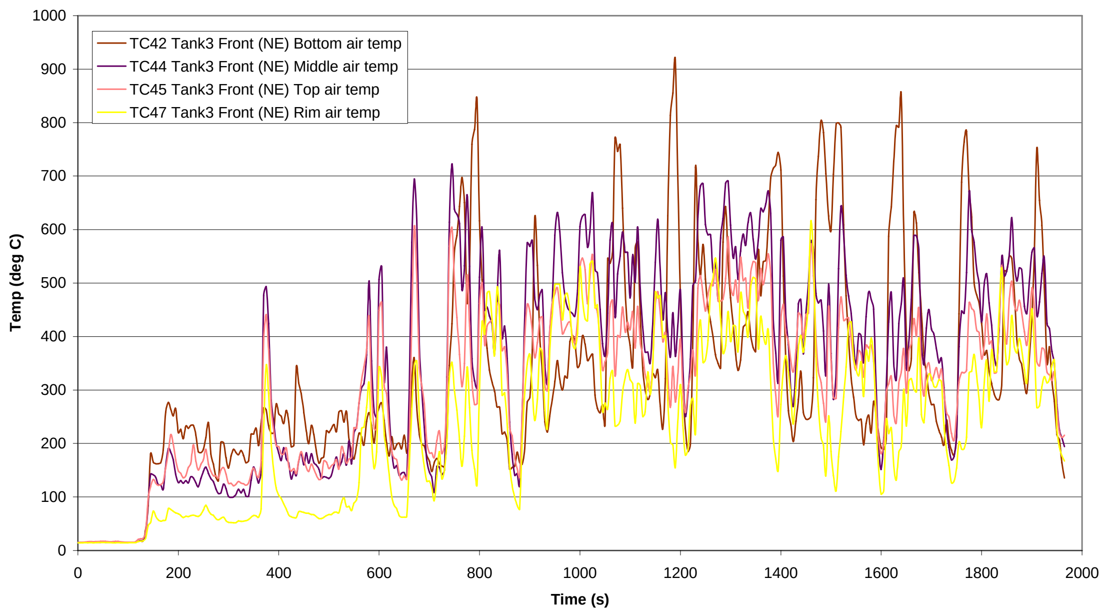

Figure A 62 Experiment 11 – Front temperature - Tank 3 Colorbond Metal (mist green)

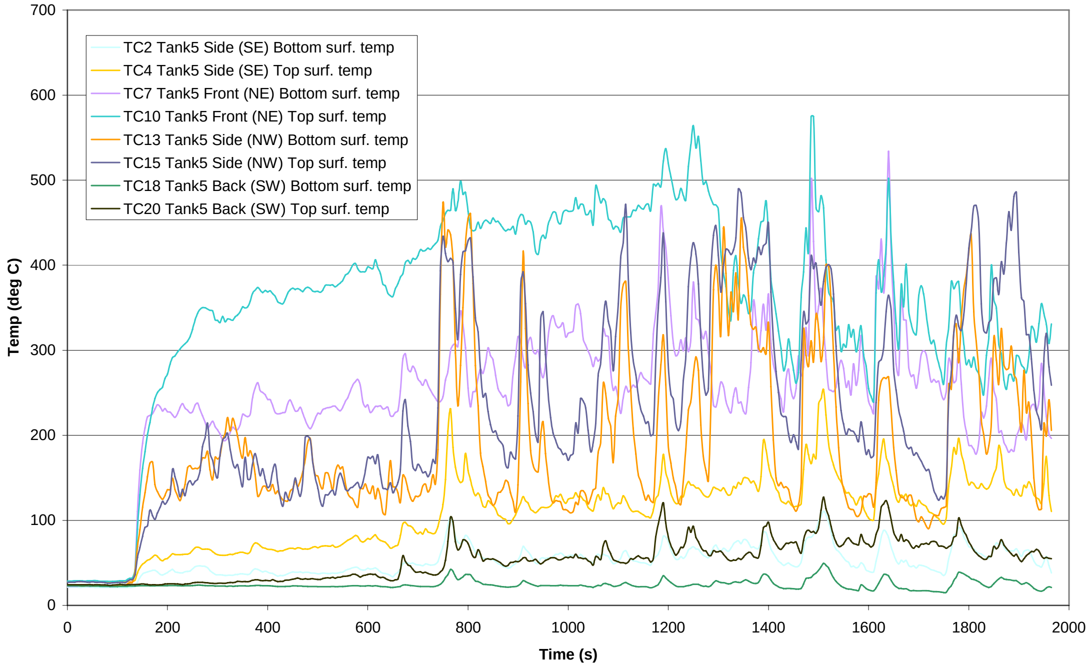

Figure A 63 Experiment 11 – Surface temperature – Tank 5 Spiral wound metal galvanised

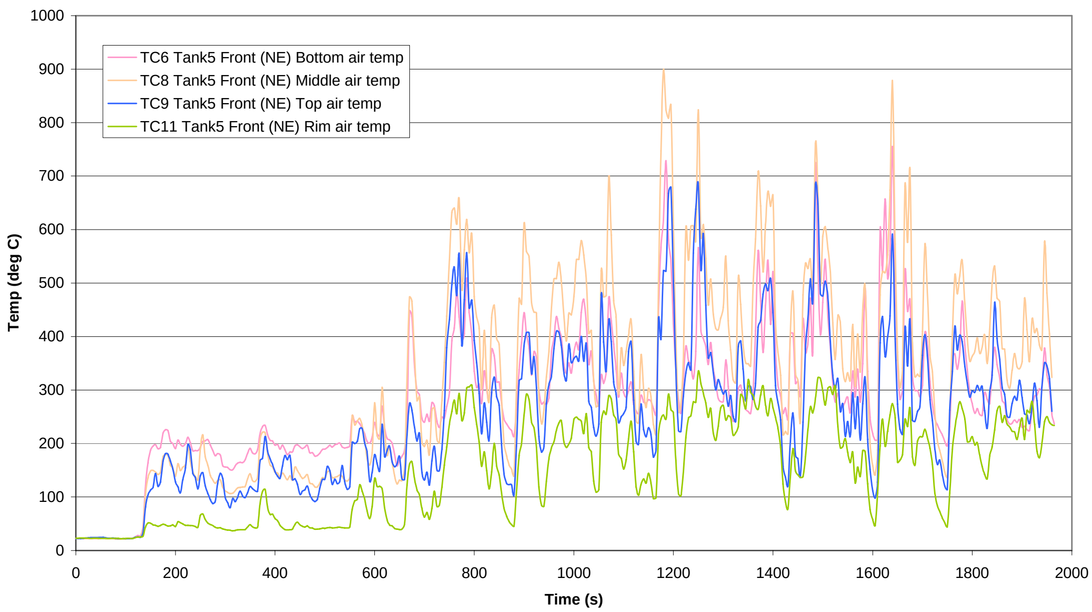

Figure A 64 Experiment 11 – Front temperature - Tank 5 Spiral wound metal galvanised

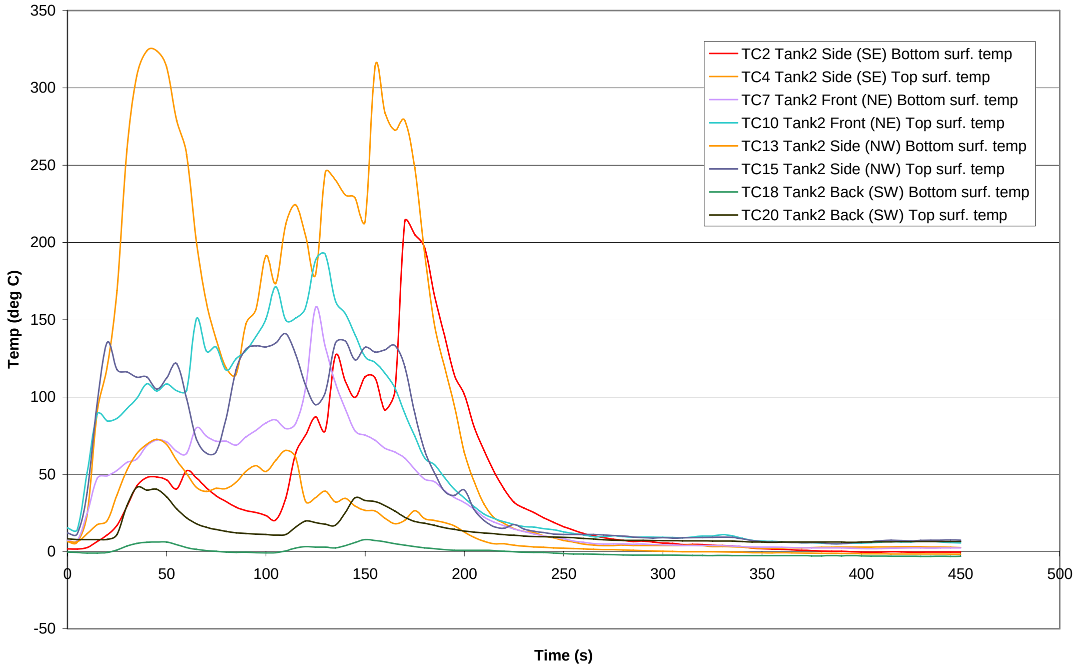

Figure A 65 Experiment 14 – Surface temperature – Tank 2 Colorbond Metal, oval shape

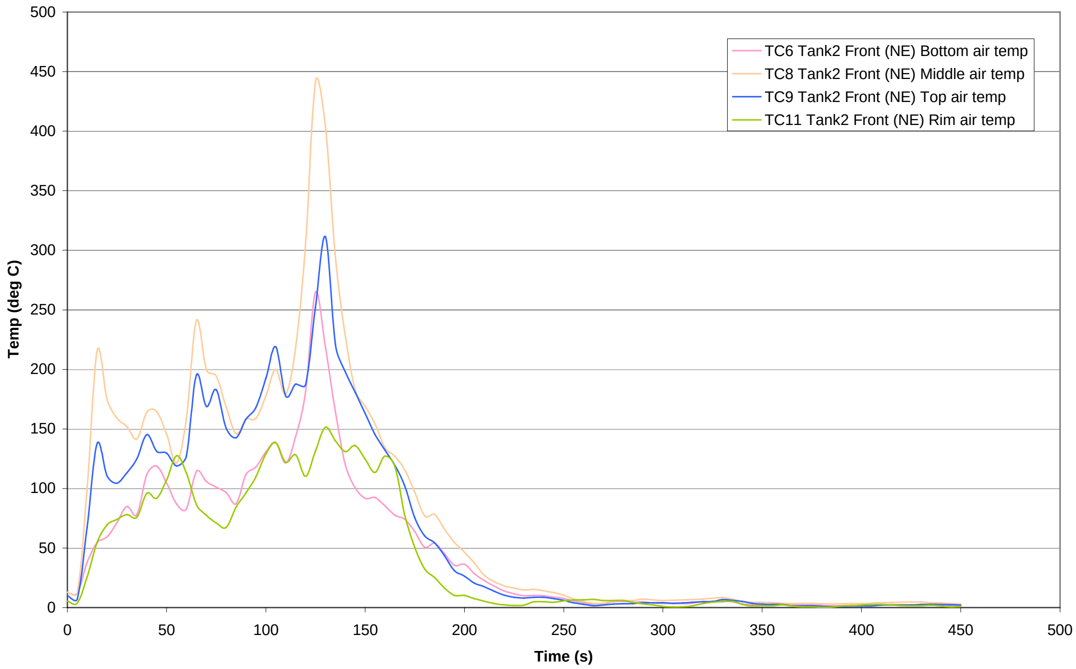

Figure A 66 Experiment 14 – Front temperature - Tank 2 Colorbond Metal, oval shape

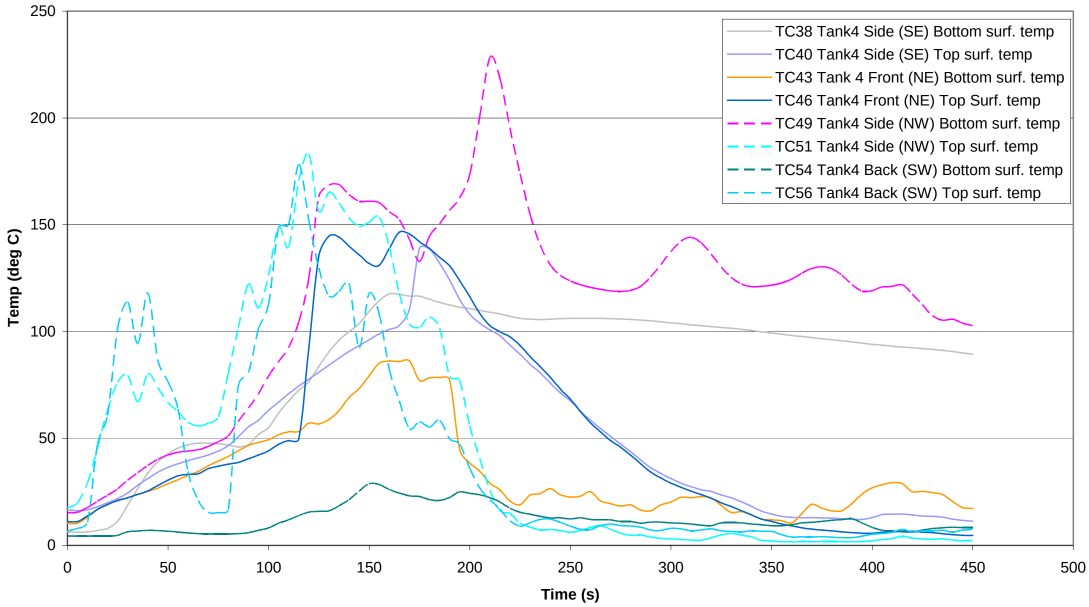

Figure A 67 Experiment 14 – Surface temperature – Tank 4 Polyethylene dark green

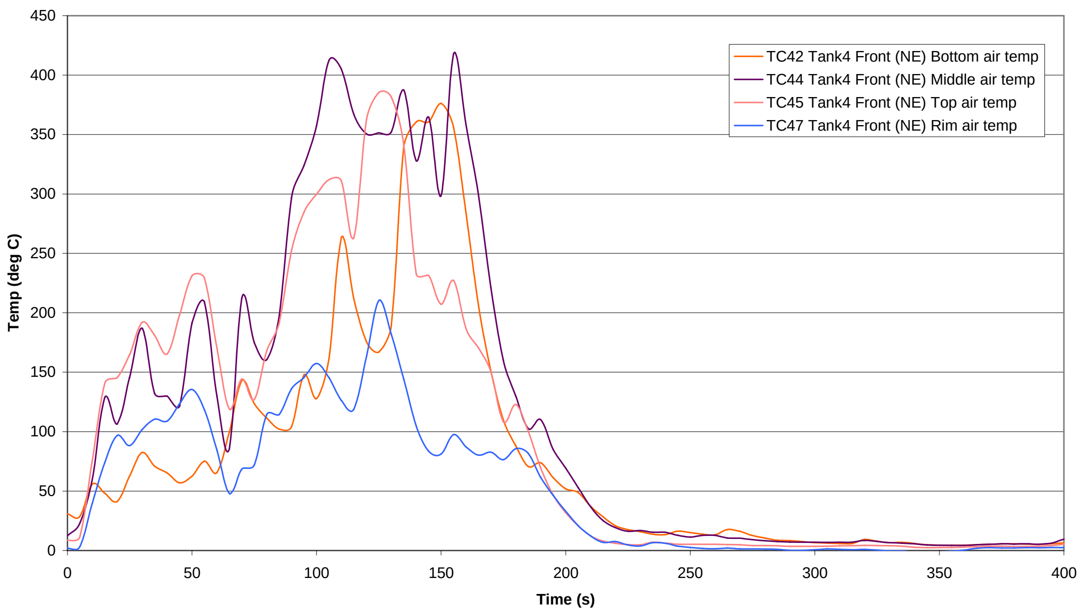

Figure A 68 Experiment 14 – Front temperature - Tank 4 Polyethylene dark green

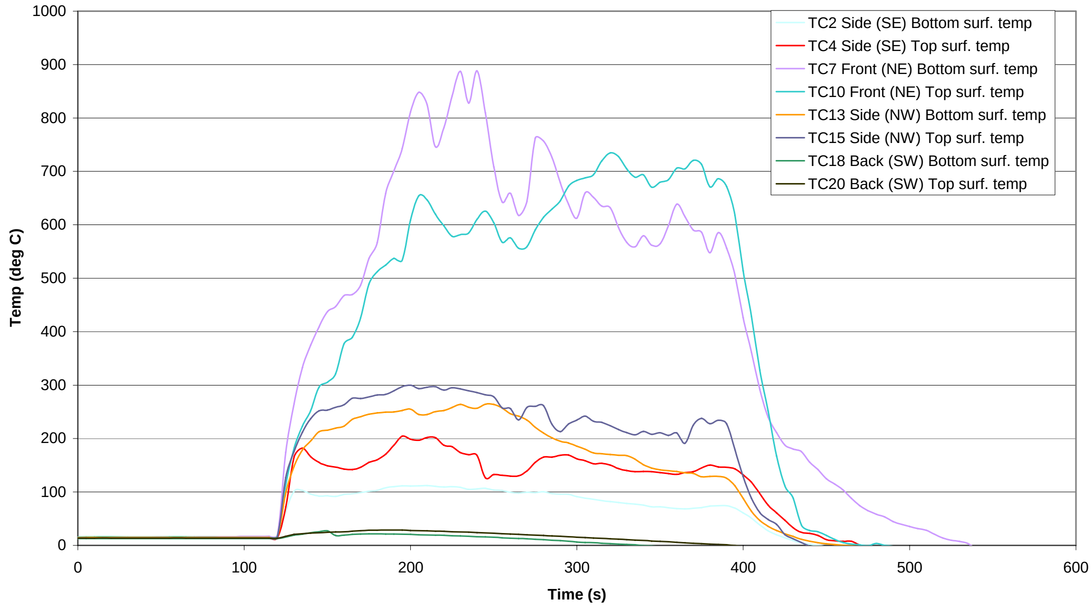

Figure A 69 Experiment 17 – Surface temperature – Tank 7 Spiral wound metal galvanised

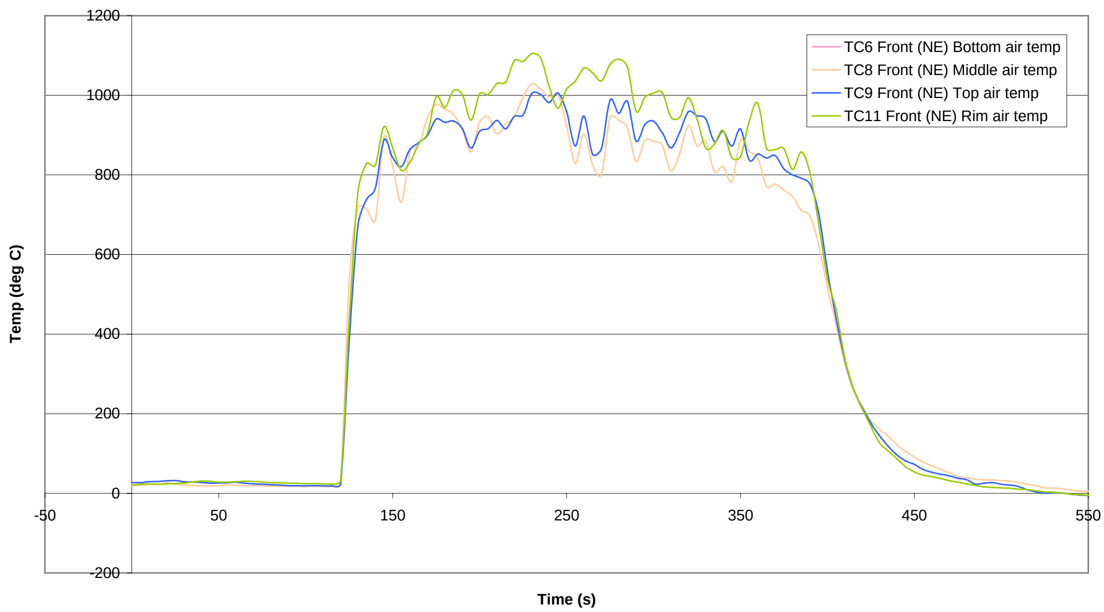

Figure A 70 Experiment 17 – Front temperature - Tank 7 Spiral wound metal galvanised

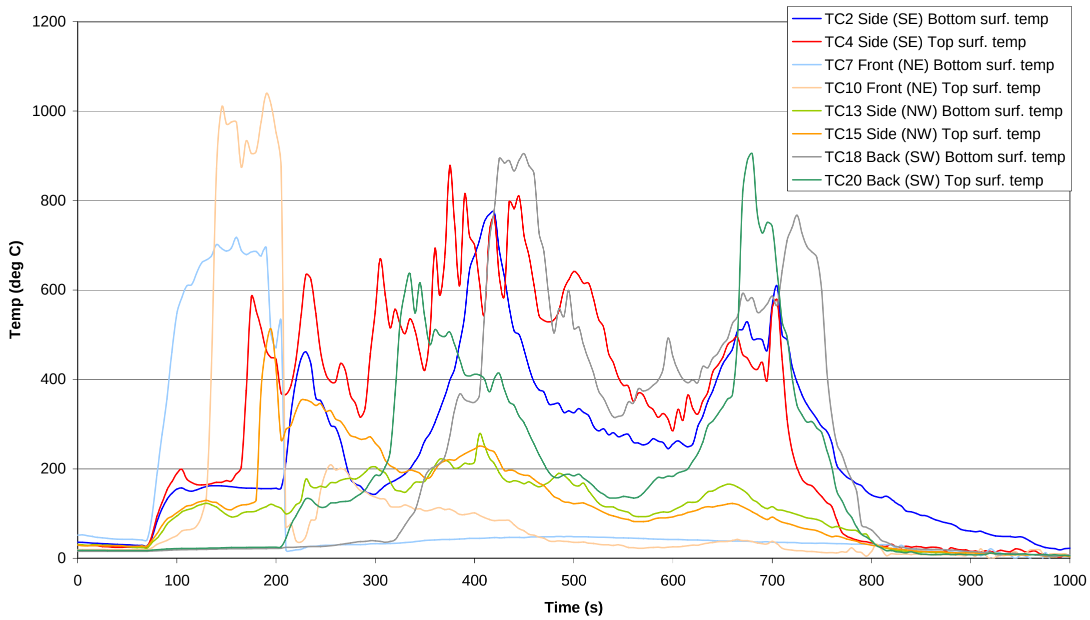

Figure A 71 Experiment 21 – Surface temperature – Tank 8 Polyethylene black

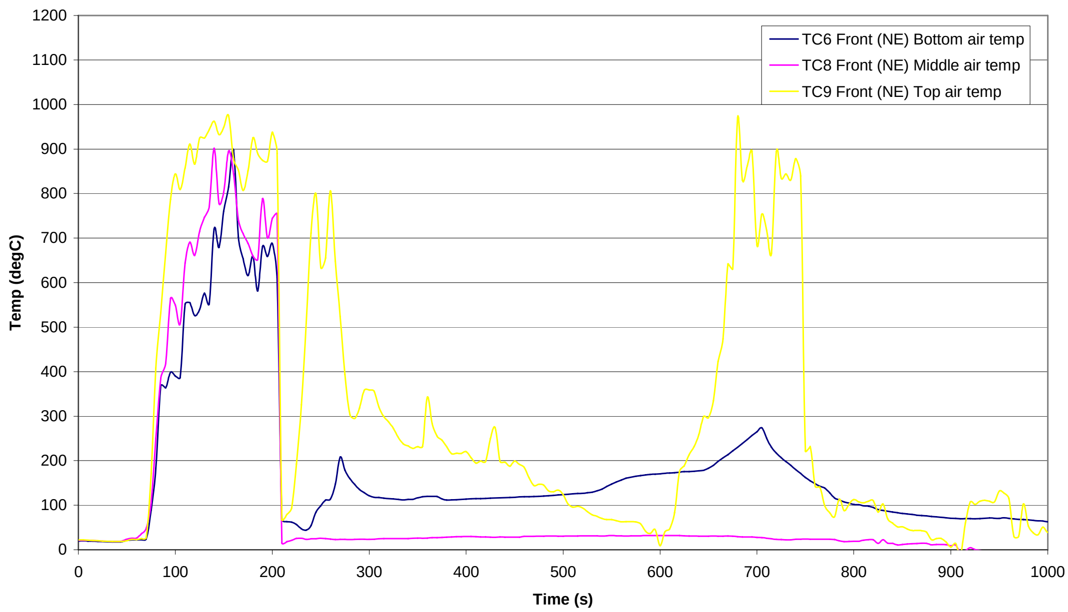

Figure A 72 Experiment 21 – Front temperature - Tank 8 Polyethylene black

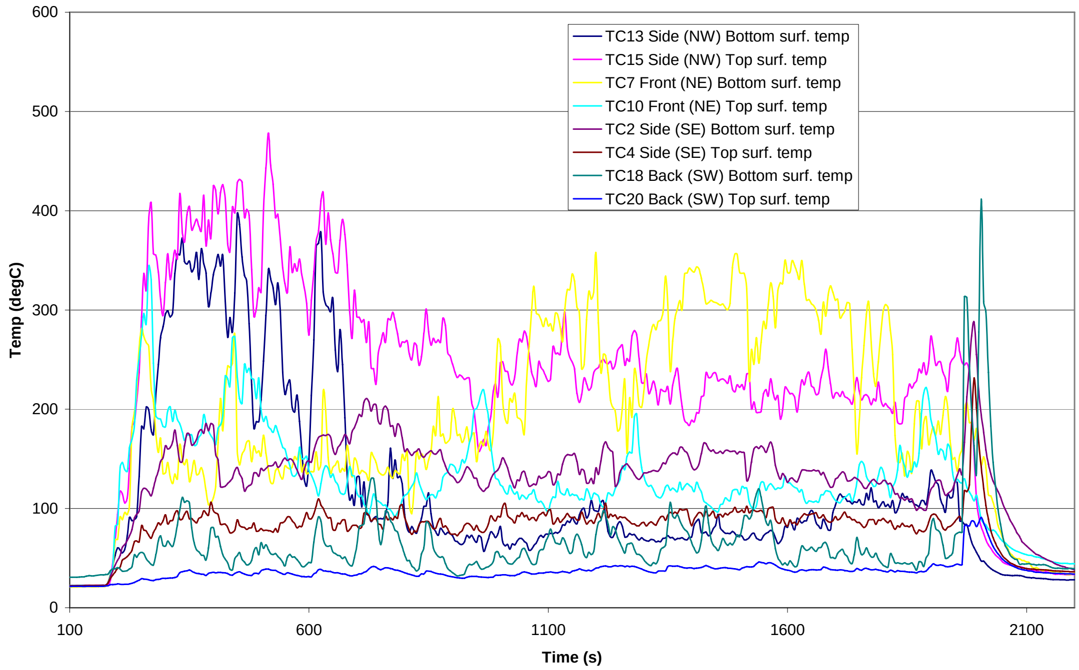

Figure A 73 Experiment 24 – Surface temperature – Tank 9 Bladder tank

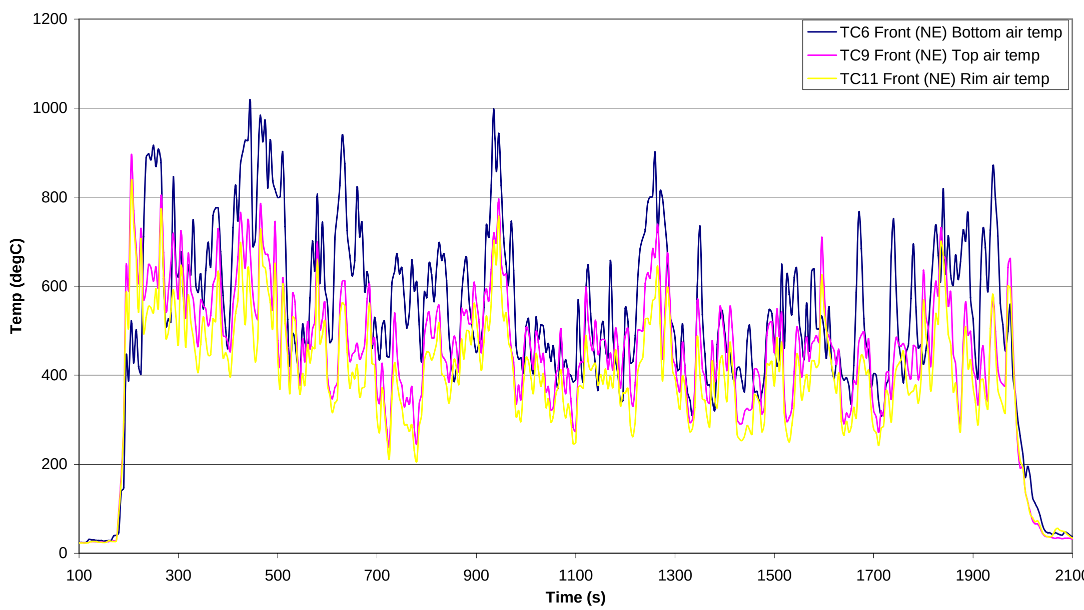

Figure A 74 Experiment 24 – Front temperature - Tank 9 Bladder tank

10. Annexe B Experimental set up

Schematic of the test experiments

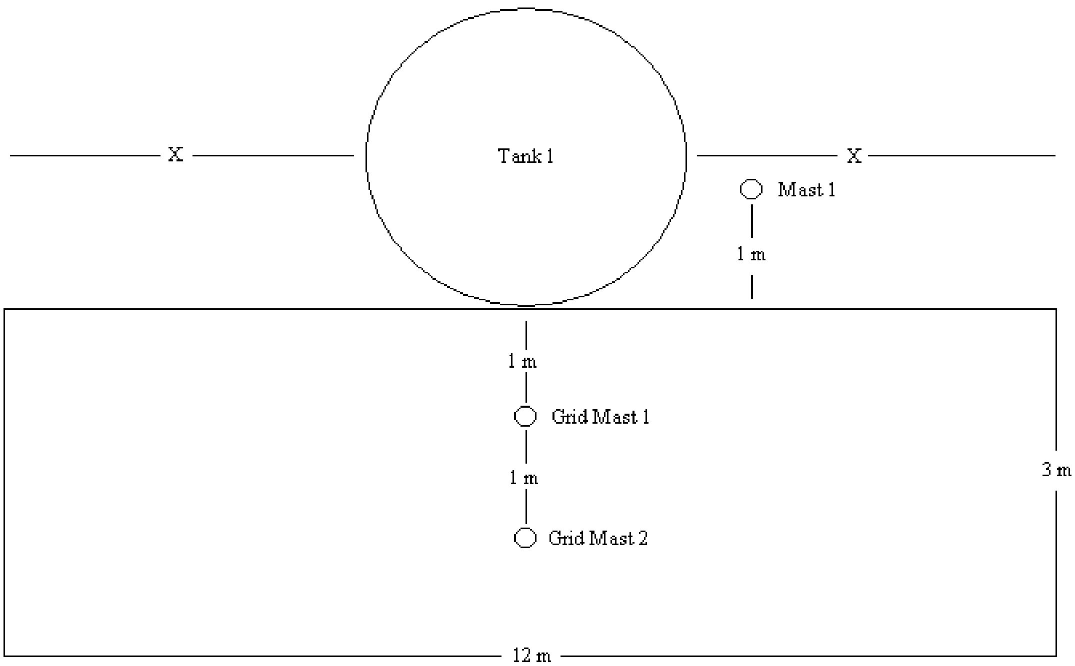

Figure B 1 Experimental set-up with one tank (top view)

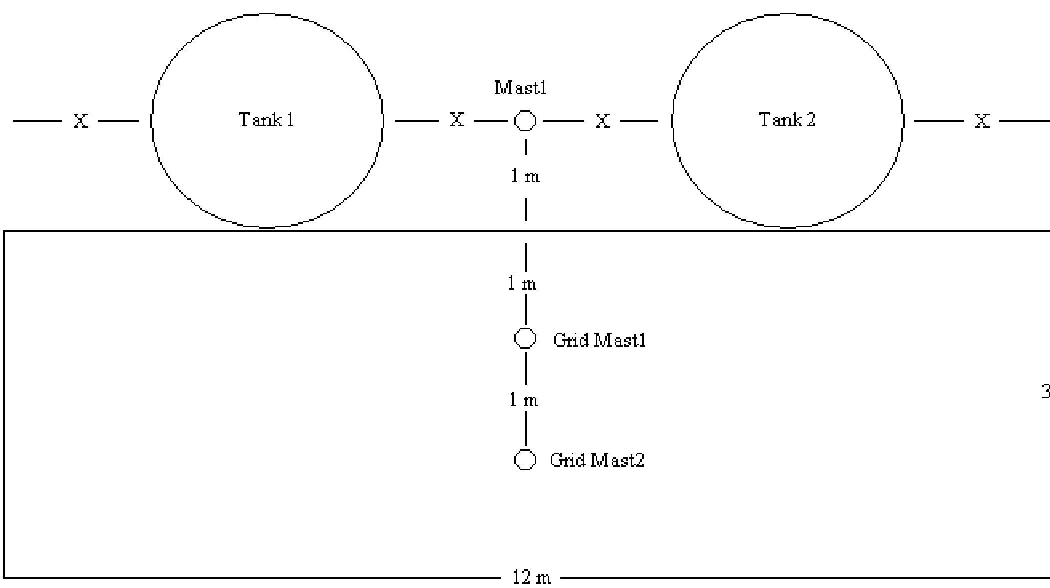

Figure B 2 Experimental set-up with two tanks (top view)

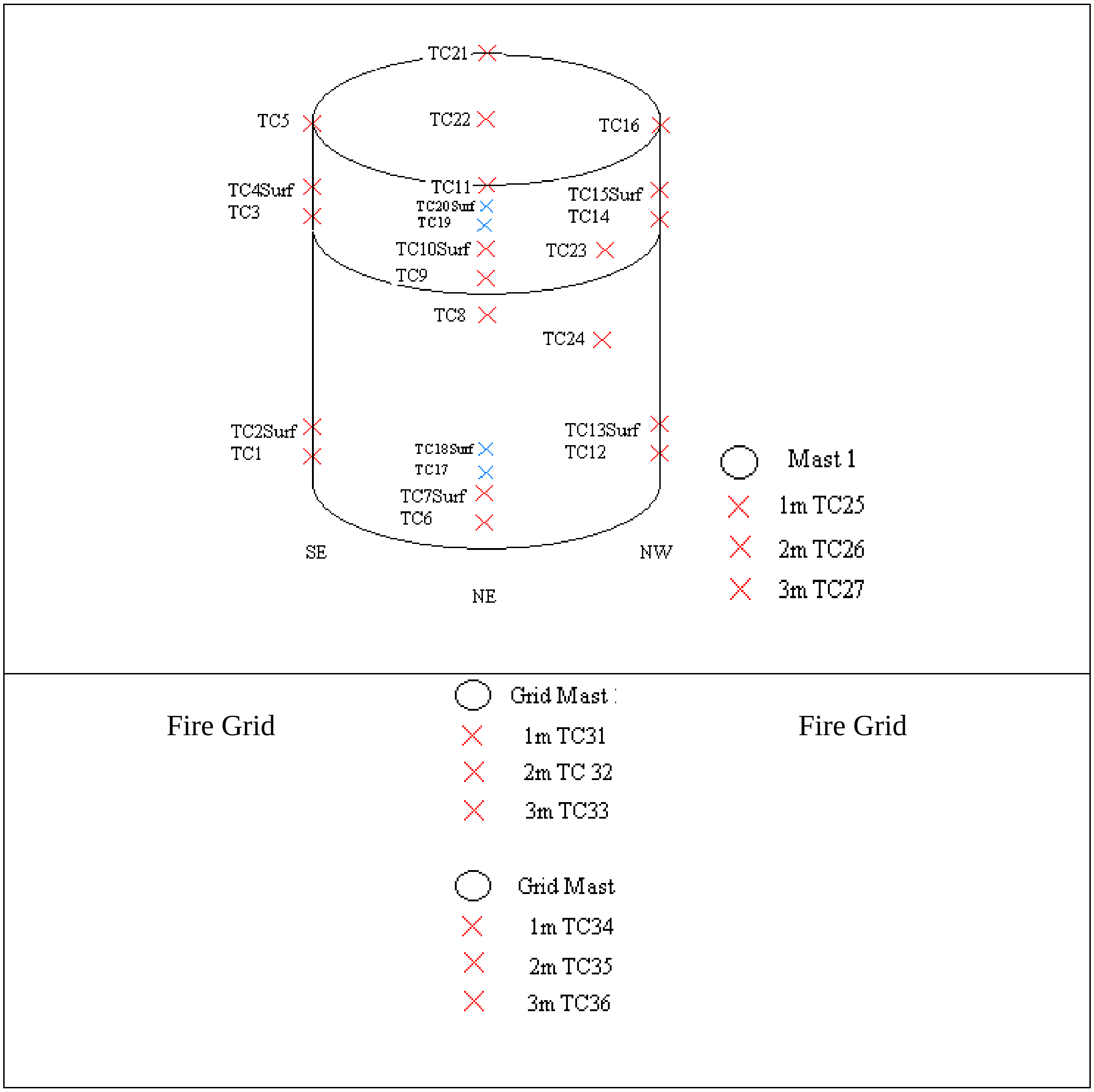

Figure B 3 Experimental set-up with one tanks (front view)

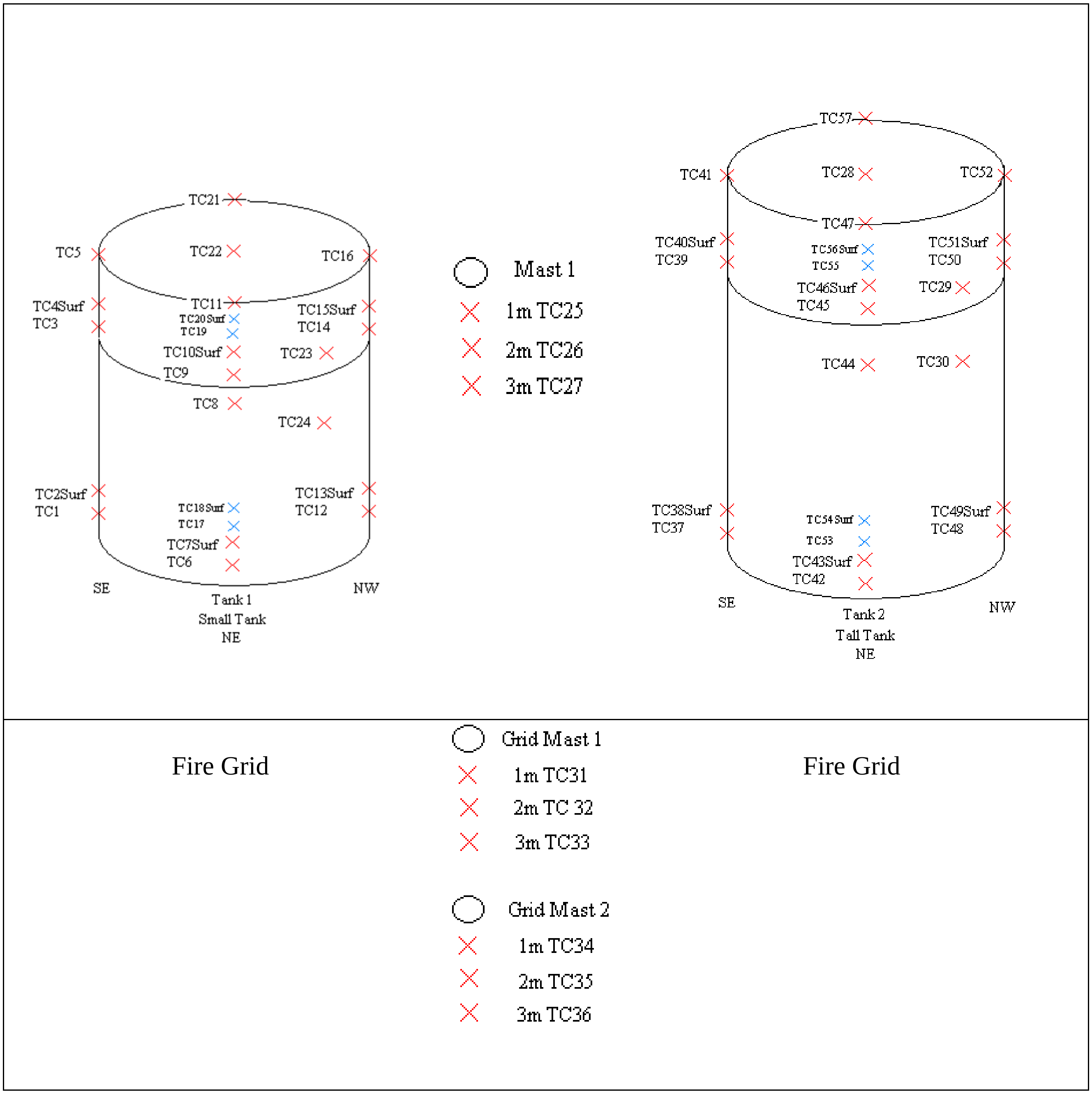

Figure B 4 Experimental set-up with two tanks (front view)

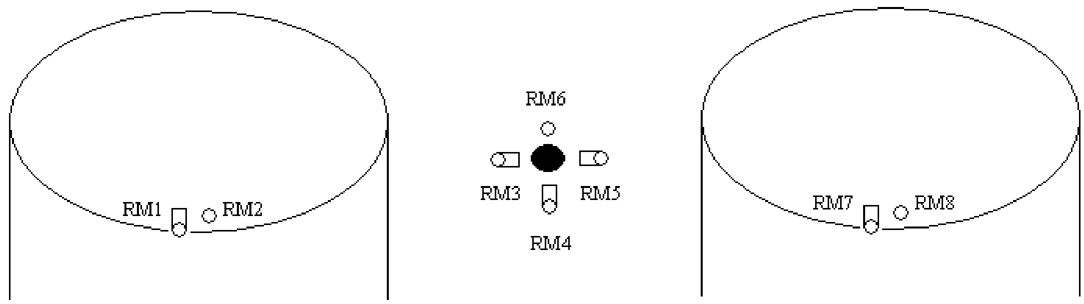

Figure B 5 Experimental set-up – radiometer position

Table B 1 Description and placements of the thermocouples

Name	Position	Name	Position
TC1	Tank1 SE Bottom Air Temp	TC31	Mast Grid1 1 Meter
TC2	Tank1 SE Bottom Surface Temp	TC32	Mast Grid1 2 Meter
TC3	Tank1 SE Top Air Temp	TC33	Mast Grid1 3 Meter
TC4	Tank1 SE Top Surface Temp	TC34	Mast Grid2 1 Meter
TC5	Tank1 SE Rim Air Temp	TC35	Mast Grid2 2 Meter
TC6	Tank1 NE Bottom Air Temp	TC36	Mast Grid2 3 Meter
TC7	Tank1 NE Surface Temp	TC37	Tank2 SE Bottom Air Temp
TC8	Tank1 NE Middle Air Temp	TC38	Tank2 SE Bottom Surface Temp
TC9	Tank1 NE Top Air Temp	TC39	Tank2 SE Top Air Temp
TC10	Tank1 NE Top Surface Temp	TC40	Tank2 SE Top Surface Temp
TC11	Tank1 NE Rim Air Temp	TC41	Tank2 SE Rim Air Temp
TC12	Tank1 NW Bottom Air Temp	TC42	Tank2 NE Bottom Air Temp
TC13	Tank1 NW Bottom Surface Temp	TC43	Tank2 NE Bottom Surface Temp
TC14	Tank1 NW Top Air Temp	TC44	Tank2 NE Middle Air Temp
TC15	Tank1 NW Top Surface Temp	TC45	Tank2 NE Top Air Temp
TC16	Tank1 NW Rim Air Temp	TC46	Tank2 NE Top Surface Temp
TC17	Tank1 SW Bottom Air Temp	TC47	Tank2 NE Rim Air Temp

TC18	Tank1 SW Bottom Surface Temp	TC48	Tank2 NW Bottom Air Temp
TC19	Tank1 SW Top Air Temp	TC49	Tank2 NW Bottom Surface Temp
TC20	Tank1 SW Top Surface Temp	TC50	Tank2 NW Top Air Temp
TC21	Tank1 SW Rim Air Temp	TC51	Tank2 NW Top Surface Temp
TC22	Tank1 Top Center Air Temp	TC52	Tank2 NW Rim Air Temp
TC23	Tank1 Inside Tank Air Temp	TC53	Tank2 SW Bottom Air Temp
TC24	Tank1 Inside Tank Water Temp	TC54	Tank2 SW Bottom Surface Temp
TC25	Mast1 1 Meter	TC55	Tank2 SW Top Air Temp
TC26	Mast1 2 Meter	TC56	Tank2 SW Top Surface Temp
TC27	Mast1 3 Meter	TC57	Tank2 SW Rim Air Temp
TC28	Tank2 Top Center Air Temp		
TC29	Tank2 Inside Tank Air Temp		
TC30	Tank2 Inside Tank Water Temp		

Description and placement of the radiometers.

Name	Position
R1	Tank1 Facing Fire
R2	Tank1 Facing Up
R3	Mast1 Facing Tank1
R4	Mast1 Facing Fire
R5	Mast1 Facing Up
R6	Mast1 Facing Tank2
R7	Tank2 Facing Fire
R8	Tank2 Facing Up

11. Annexe C Pictures

Test One

Figure C1 Tank one, metal tank with plastic coating, Pre Radiation exposure.


Figure C2 Tank one slight surface damage due to pre radiation.


Figure C3 Tank one with damaged over flow outlet.

Test Two

Figure C4 Tank one slight structural damage due to flame exposure

Figure C4 Tank slight damage to joins

Test Three

Figure C5 Tank one severe damaging resulting from structural exposure

Figure C6 Tank one leaks resulting from severe damage during structural exposure.

Test Four

Figure C7 Tank six Litter ignition.

Figure C8 Tank six smouldering litter contacting exterior of tank.

Test Five

Figure C9 Tank six pre radiation exposure. Approx 25Kw/m^2

Figure C10 Tank six ignition and flaming due to pre radiation exposure.

Figure C11 Tank six server structural damage down to water level as a result of per radiation exposure.

Test Seven

Figure C12 Tank three burnt leaf litter, no damaged to tank.

Figure C13 Tank three and five pre-radiation exposure.

Test Eight

Figure C14 Tank three and five Pre Radiation exposure.

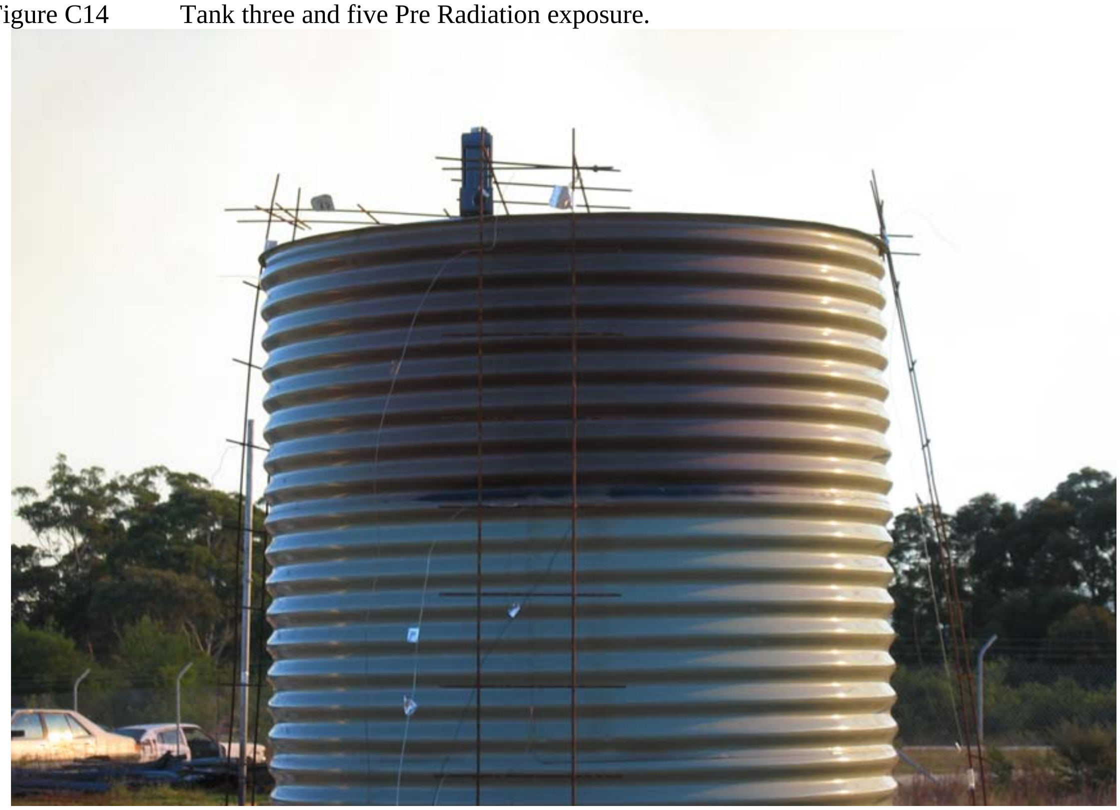

Figure C15 Tank three scorch mark above the water line.

Test Nine

Figure C16 Tank three and five pre radiation flame contact.

Figure C17 Tank five minor scorching from litter ignition.


Figure C18	Tank three overflow outlet damage.


Figure C19	Tank five surface scorching above water line.

Test Ten

Figure C20 Tank three and five pre radiation exposure.

Figure C21 Tank three and five flame exposure.

Figure C22 Tank three water leaking from damage seams.

Test Eleven

Figure C23 Tank three and five flame exposure.

Figure C24 Tank three and five flame exposure.

Figure C25 Tank three severe damage resulting from structural exposure.

Figure C25 Tank three severe damage resulting from structural exposure.

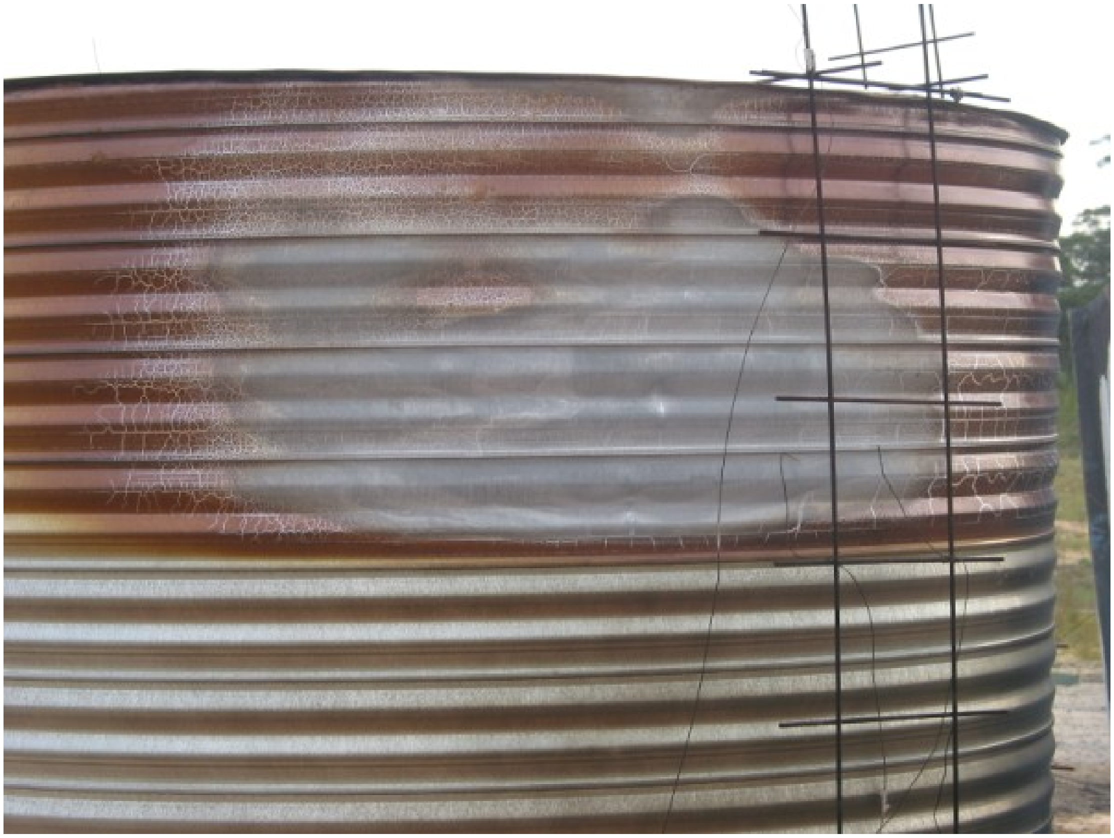
Figure C26 Tank five server damage resulting from structural exposure.

Test Twelve

Figure C27 Tank two and four pre-radiation exposure.

Figure C28 Tank two and four slight external damage resulting from pre-radiation exposure.


Figure C27 Tank four pre-radiation exposure.

Test Thirteen

Figure C28 Tank four flame exposure.

Figure C28 Tank four severely leaking due to flame exposure.

Figure C29 Tank two external damage due to flame exposure.

Test Fourteen

Figure C30 Tank four structural exposure.

Figure C31 Tank four complete failure due to structural exposure. Escaping water extinguished gas burners.

Figure C32 Tank four complete wall failure due to structural exposure.

Test Fifteen

Figure C33 Tank 7 prior to pre-radiation exposure.

Test Sixteen

Figure C34 Tank 7 pre-radiation exposure.

Figure C35 Tank 7 pre-radiation exposure.

Test Seventeen

Figure C36 Tank 7 structural exposure.

Figure C37 Tank 7 structural exposure.

Figure C38 Tank 7 severe external damage resulting from structural exposure.

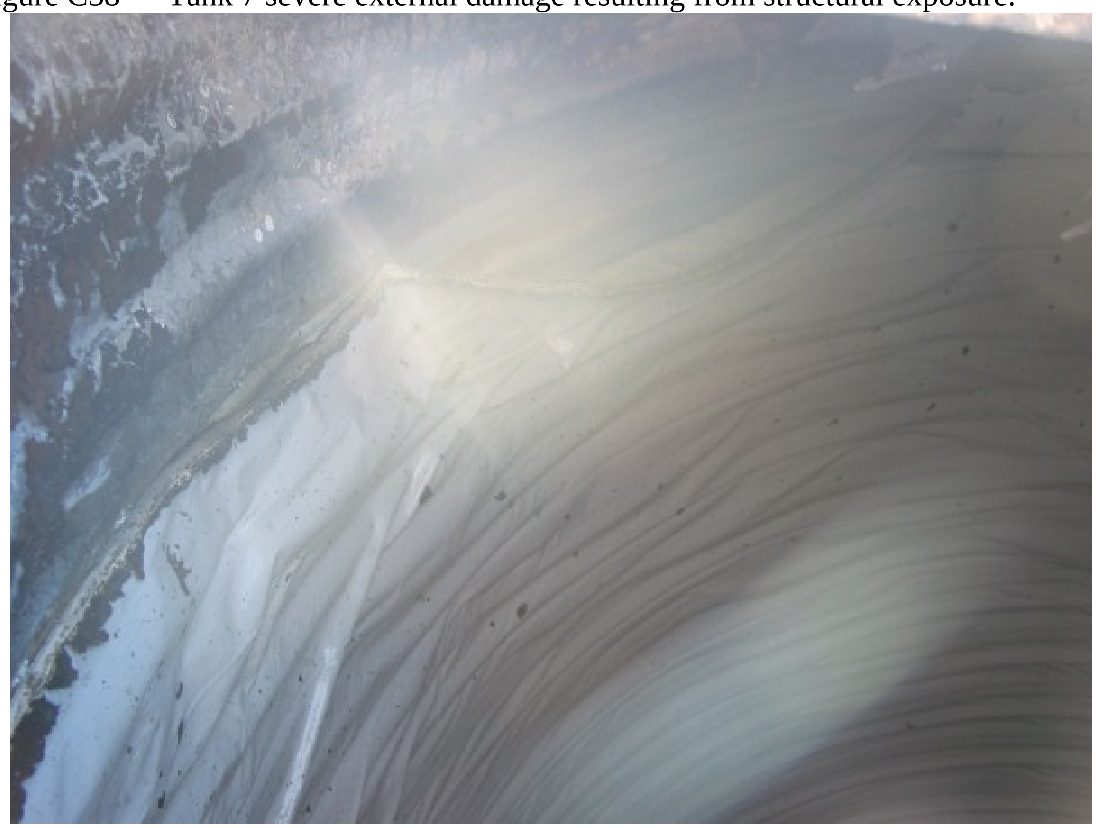

Figure C39 Tank 7 severe internal damage resulting from structural exposure.

Figure C40 Tank 7 damage resulting from structural exposure.

Test Eighteen

Figure C41 Tank 8 litter ignition .

Figure C42 Tank 8 litter ignition .

Figure C41 Tank 8 litter ignition .

Test Nineteen

Figure C42 Tank 8 litter ignition and pre-radiation exposure.

Figure C43 Tank 8 litter ignition and pre-radiation exposure.

Figure C44 Tank 8 ignition as a result of litter ignition and pre-radiation exposure.

Figure C45 Tank 8 ignition as a result of litter ignition and pre-radiation exposure. Flowing water from the collapsing upper portion of the tank assisting extinguishing flames.

Test Twenty

Figure C46 Tank 8 ignition as a result of litter ignition and pre-radiation and flame exposure.

Figure C47 Tank 8 ignition as a result of litter ignition and pre-radiation and flame exposure.

Figure C48 Tank 8 ignition as a result of litter ignition and pre-radiation and flame exposure.

Figure C49 Tank 8 ignition as a result of litter ignition and pre-radiation and flame exposure.

Figure C50 Tank 8 ignition and failure above waterline as a result of litter ignition and pre-radiation and flame exposure.

Test Twenty One

Figure C52 Tank 8 ignition due to structural fire exposure.

Figure C53 Tank 8 ignition and initial stages of failure due to structural fire exposure.

Figure C53 Tank 8 ignition and initial stages of failure due to structural fire exposure.

Figure C54 Tank 8 failure due to structural fire exposure.

Figure C55 The remains of what was tank eight.

Test Twenty Two

Figure C55 Tank 9, bladder tank.

Figure C56 Bladder tank pre-radiation exposure.

Figure C57 Bladder tank pre-radiation exposure.

Figure C58	Bladder tank overflow charring during pre-radiation exposure.

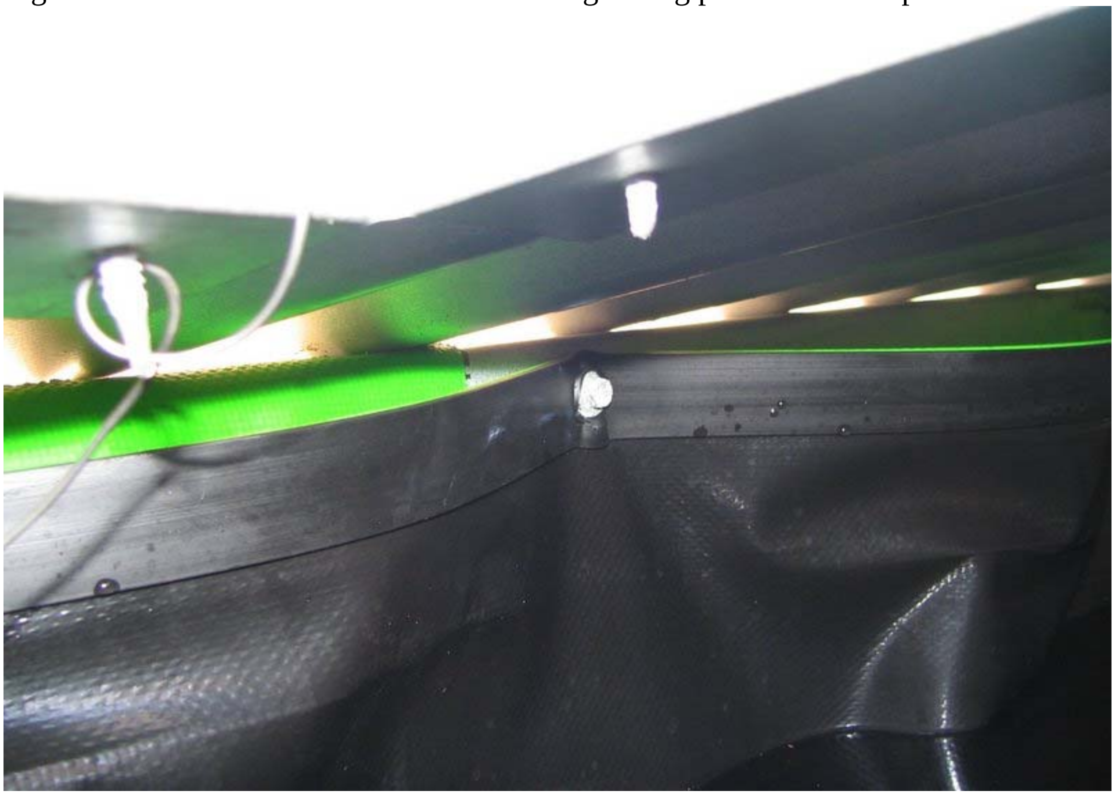

Figure C59	Bladder tank liner slightly damaged due to pre-radiation exposure.

Test Twenty Three

Figure C60 Bladder tank pre-radiation and flame exposure.

Figure C61 Damage to bladder tank overflow during pre-radiation and flame exposure.

Figure C62 Damage to bladder tank overflow resulting from pre-radiation and flame exposure.

Figure C63 Damage to bladder tank liner resulting from pre-radiation and flame exposure.

Test Twenty Four

Figure C64 Tank 9, bladder tank structural exposure.

Figure C65 Tank 9, the bladder tank structural exposure.

Figure C66 Bladder tank leaking and join damage as a result of structural exposure.

Figure C67 Damage to tank 9 liner resulting from structural fire exposure.

Test Twenty Five

Figure C68	Tank 10 litter ignition and pre-radiation exposure.

Figure C69	Ignition of tank 10 during the litter ignition and pre-radiation exposure.

Figure C70 Tank 10 continuing to burn post the litter ignition and pre-radiation exposure.

Figure C71 Tank 10 leaking as a result of litter ignition and pre-radiation exposure.

Test Twenty Six

Figure C72 Tank 10 litter ignition, pre-radiation and flame exposure.

Figure C73 Tank 10 completely alight and about to fail as a result of litter ignition, pre-radiation and flame exposure.

Figure C73 Tank 10 completely failing with contents flowing out due to flame exposure.

Figure C74 What remains of the completely destroyed tank 10.