Developments in thinking about emergency liquid containment systems in the process and allied industries

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The areas covered by this paper include

i) The benefits that are realisable from the UK's basic 110/25% rule for sizing bunds protecting multiple tanks,
ii) The capacity requirements for containment systems protecting storage of flammable materials contained in IBC's or drums
iii) Bund emptying and acceptable disposal of bund contents, including appropriate practice for bunds and sites that are not normally manned.
iv) The capacity requirements and response times for transfer systems that are suitable for use for moving liquids round a large site in an emergency.
v) Total and Tertiary Containment requirements, including firewater containment requirements.
vi) Tertiary Containment Plans

The paper considers the demands placed on these systems in an emergency and give an indication of solutions which in the Authors opinion are appropriate.

Keywords: bund, secondary containment, tertiary containment, total emergency containment, legislation and guidance, multi-tank bund, firewater, flammables storage, IBC and drum storage, firefighting foam, emergency transfer, monitoring discharges, tertiary containment plan

Summary

When considering emergency containment provisions, engineers and managers need to look behind the legislation and guidance and think for themselves what is best for their business rather than be totally reliant on guidance and regulatory controls. A number of areas are identified in this paper which are outside existing regulations and guidance but would appear to be worthy of consideration by both operators and their agents when designing and assessing the fitness for purpose of liquid containment systems. The more significant ones are

- Consideration should be given to allowing at least 200 mm freeboard for firefighting foam retention if foam is likely to be applied for fire suppression.
- Flammable drum and IBC stores should be protected by bunds that can contain 110% of the total inventory of liquids that can be stored in them with an appropriate allowance for rainfall as necessary.
- The likely demand on tertiary containment facilities from a premises which protects a number of tanks with a single bund should be carefully reviewed as there are a number of foreseeable potential demands that will not be adequately met by the 25% rule.

A new estimation method for the quantities of firewater that are likely to be required when fighting a major petrochemical storage fire and some new thinking about tertiary containment plans are presented here

Introduction and Background

While preparing training for Environmental Regulatory Officers on secondary and tertiary containment systems, the author identified a number of areas where existing guidance could be enhanced. One of those areas, the management of inspection of secondary and tertiary containment systems, was addressed in his paper to Hazards 27 – Dickinson (2017). This paper addresses more technical matters.

There are typically two types of Regulations – precise, prescriptive ones that engineers like because they establish a clear design basis upon which to engineer solutions and more "goal setting" ones which establish targets. An English example of a prescriptive element regulation is Regulation 3 (2) a) of the Oil Storage Regulations (2001) which requires oils covered by the regulations to be situated within a secondary containment system which must have a capacity of not less than 110% of the containers capacity or, if there is more than one container within the system, of not less than 110% of the largest container's storage capacity or 25% of their aggregate storage capacity, whichever the greater. A UK example of a well known "goal setting" regulation is Regulation 5 of COMAH (2015) which requires every operator to take all measures necessary to prevent major accidents and to limit their consequences for human health and the environment.

There are similar differences in the types of guidance issued – the precise prescriptive, numerical parts that reflect hard won experience and can be applied directly by engineers and the bits that say "this factor may be worth considering". This second type of guidance is far easier to identify but far harder to respect in the real world, but probably if applied correctly more valuable in avoiding future problems than the more prescriptive statements. As will be discussed by example in this paper, the problem with the prescriptive guidance is that it is a means of providing solutions to problems at the time the regulation was developed. Changing patterns of design, management and custom and practice can change the nature of the problem thus negate the real value of the regulation. Prescriptive regulations suffer a second disadvantage in that they usually only represent a minimum level of protection. It is very attractive, especially to justify not making further expenditure, to say that the company meets the legal requirement so does not need to do anything more, rather than to think about what is actually best overall value for the business.

Equally, guidance can take both forms – precise and quantitive which allows teams looking at hazards to apply it directly and imprecise and qualitative which is less easy to follow. As with regulations, precise and quantitive guidance is relatively easy to follow because it does not encourage looking outside the box and people feel that, as long as they have followed the guidance, they have met all reasonable requirements. All reasonable requirements include taking into account all reasonably foreseeable events: published guidance does not necessarily do that. If for no other reason, than the guidance was produced at a point in time but understanding of technical matters evolves. Precise qualitative guidance has its place because it sets a minimum standard for compliance but it should always be remembered that it is a minimum. Quantitive guidance is popular with some organisations because they can demonstrate that they have covered their responsibilities – after a fashion. Qualitative guidance is a lot more difficult to fully comprehend, organisations feel that they are out on their own re-inventing the wheel so the conclusions of any studies are more difficult to justify and are therefore less likely to be implemented. A recent example of this identified by a chemical plant operator who was considering the recently published Industrial Emissions Directive Best Available Techniques (IED BAT) Conclusions Document for the Chemical Sector (2017). Compliance to the published BAT associated emission levels (BAT-EAL's) can be assessed and if necessary engineering steps taken to comply with them. Financing is relatively easy as it is a clear legal non-compliance if they company does not spend the money. The requirement is to comply within 4 years of the BAT Conclusions Document being published and if a derogation is needed to extend the time frame, again it is possible to write a Cost Benefit Analysis (CBA) case to support this. The qualitative BAT conclusions are the opposite. Without anything other than vague targets, it is not possible to develop anything other than a range of engineering solutions with no confidence that any of them would meet the requirements. It would be very difficult to obtain funds for any of the possible engineering solutions as the company would have no confidence that on the next review of IED BAT Conclusions Document it will not be changed.

The details that follow, which tend to focus on quantification, should be considered in the above context.

The benefits that are realisable from the UK's basic 110/25% rule for sizing bunds protecting multiple tanks

Before considering the benefits that are realisable from the UK's basic 110/25% rule for sizing bunds protecting multiple tanks, the caveats that should accompany it are reviewed. These caveats, which are included in CIRIA C736 (2014), are possibly not adequately taken into account when applying the 110/25% rule.

The Caveats to the 110/25% Rule

<u>Multi-tank bunds should be avoided if possible:</u> The main reason for this is that an event effecting one tank is more likely to affect other tanks in a muti-tank bund than tanks in separate bunds. The first example of this guidance was given in Watts (1951) who recommends in the investigation report of an incident in an oil terminal at Avonmouth "I consider from a safety point of view that wherever practicable each tank of any size should be situated in its own Imperforate bund so that the event of a fire occurring the fire can be localised" More recent guidance includes paragraph 159 of HSG 176 (2015), which says "Individual bunding is preferred to common bunding"

<u>The 110/25% capacity rule is the minimum recommended:</u> This is clearly stated in a number of places, including HSG 176 (2015), PPG 2 (2011) and the Oil Storage Regulations (2001). CIRIA R164 (1997) does not say this explicitly, but says this is the criterion commonly adopted by industry in 1997. Its replacement, CIRIA C736 (2014), recommends that bunds are sized using the more complex bund sizing criteria given in Chapter 4.3 which inevitably will end up with a larger bund size for storage of flammable materials.

<u>If multi-tank bunds cannot be avoided, the number of tanks that should be protected by a single bund should be restricted.</u> General advice on this is included in Box 4.1 of the EI Model Code of Practice 19 (2015). The box in Section 2.4. the BP/IChemE (2005) guidance goes further than this and says "The number of tanks in a bunded/diked compound should not exceed six or the total capacity exceed 60,000 m3." Para 159 of HSG 176 (2015) also recommends that "the total capacity of tanks in a bund should not exceed 60 000 m3 (120 000 m3 for floating-roof tanks)".

<u>Intermediate divisional walls should be provided to restrict the impact of minor leaks:</u> This advice is included in section 4.8.3 of the EI Model Code of Practice 19 (2015) and Para 159 of HSG176 (2015) which say "intermediate lower bund walls are recommended to divide tanks into groups to contain small spillages and to minimise the surface area of any spillage."

<u>Multi-tank bunds are more likely to fail in an emergency:</u> Davies et al (1995) suggests that multi tank bunds are three times more likely to fail than bunds protecting a single tank in a fire. Regrettably, this is not mentioned in the standard reference document for COMAH operators All Measures Necessary (2016) but a request has been made for it to be included there in the next revision as it is potentially a very important factor to consider by COMAH operators when completing appropriate Environmental Risk Assessments, for example consistent with CDOIF ERA (2015)

The 110/25% Rule for Stock Tanks

The rule as it now stands appears to have been developed in the late 1990's during the development of CIRIA R164 (1997). It is simple, namely where two or more tanks are installed within the same bund, the recommended capacity of the bund is the greater of:

a) 110% of the capacity of the largest tank within the bund, or

b) 25% of the total capacity of all of the tanks within the bund, except where tanks are hydraulically linked in which case they should be treated as if they were a single tank.

As set out in the PSLG Final Report (2009), the 110% of tank capacity is based on its brim full capacity or the maximum credible capacity if high integrity trip systems are used to prevent it from overfilling. The tank capacity for the 25% calculation is taken as the tanks normal maximum controlled fill capacity, which one would expect to be marginally lower than any alarm capacity. The benefits of the 110% capacity of the largest stock tanks, and the shortfalls of the 25% capacity rule will now be reviewed

CIRIA C736 (2014) is the standard guidance in this area and lists five principle benefits from the 10% design margin in the 110% element of the rule as follows:

- Reduction of overtopping in the event of a surge of liquid following the sudden failure of a primary tank
- An allowance for firefighting agents, including a foam blanket on the surface for firefighting water
- Some protection against overfilling
- An allowance for rain that might collect in the bund and reduce its net capacity, or for rain that might fall coincident with, or immediately following the failure of the primary containment.
- Prevention of overtopping which may be caused by wind-induced wave action during the time that the bund is full following failure of a primary tank

Looking at the benefits, the way that the design margin is expressed is not particularly useful – three of the benefits are obtained from having extra bund wall height and it is only protection against overfill that is volume related.

Clark et al (2001), Thyer et al (2002) and Atherton (2005) undertook work on bund overtopping following catastrophic failure of stock tanks which had been commissioned by HSE in the early 2000's and a reasonably clear picture emerged. The fraction that escapes the confines of the bund is mainly a function of bund wall height (**h**)/Liquid height in the Tank (**H**) and generally increases if **h/H** is reduced and the bund moved further away from the tank to maintain the same bund volume. In most storage applications **h** is potentially very much smaller than **H** and the marginal increase of **h** will make very little difference to the fraction of the tank contents that would overtop the bund in the albeit unlikely event of a catastrophic failure of a stock tank. Figure 1, taken from Atherton (2005), shows the main effects quite well. The left hand Axis, Q_c & Q_h, is the ratio of the volume contents that overtop to the total contents of the tank.

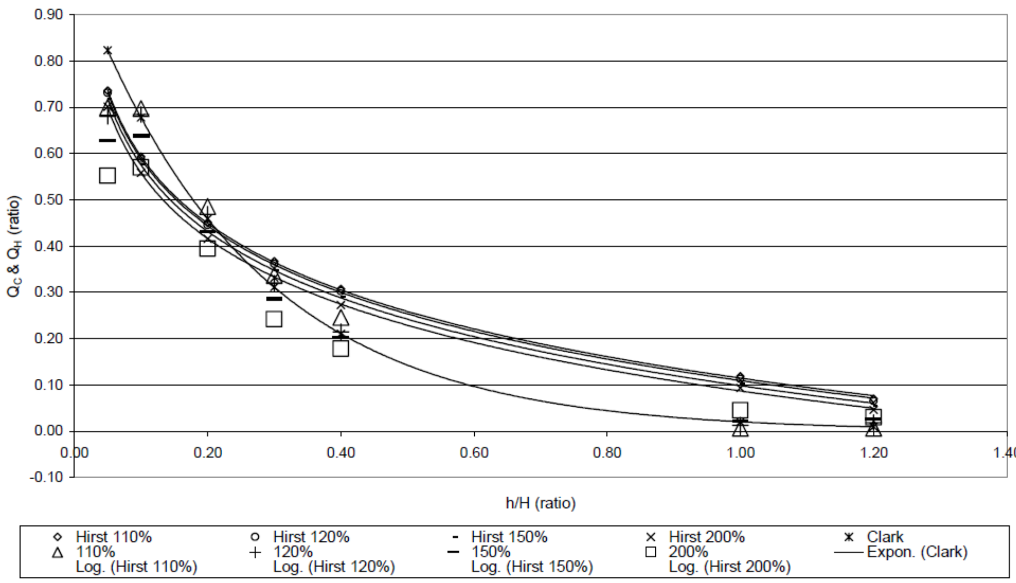


Figure 1 – the effects of the tank height/band wall height ratio on bund overtopping for catastrophic tanks failure

Although CIRIA C736 (2014) recommends that additional freeboard will reduce the quantities that overtop, or and contoured bund walls as advocated by Petitt (2003) may aslo do this, the only way is can be fully catered for is by attenuation over distance and tertiary containment..

Conventional guidance generally suggests that an allowance for retention of firefighting foam of 100 mm should be adequate. The author has reviewed this based on the firefighting foam application volumes for liquid bund fires in the Engineering EI Model Code of Practice 19 (2015),, confirmed by the more practical Angus Foam Application Estimator (2017)used by most Fire and Rescue Services in the UK, and, even with due allowance made for foam die-back from Dlugororsli et al (2002) and others, 100 mm freeboard looks to be inadequate. Even with the conservative assumptions the author has taken, the allowance should be at least 200 mm to hope to retain the target foam volumes that these references suggest should be applied. Experience suggests that 100 mm freeboard is inadequate to enable a foam layer to be fully established when a bund is on fire and there is a consequential high risk of re-ignition after foam has been applied. For different reasons, CIRIA C736 (2014) Table 4.7 recommends minimum freeboards of 250 mm for vertically walled bunds and 750 mm freeboard for bunds with sloping walls.

If a tank overfills, 100% of the liquid capacity is retained in the tank and all the bund capacity is available to contain the overflow. The 10% design margin does not really offer much extra protection.

The degree of protection offered by the design margin against rainfall will depend on both regularly emptying the bunds and whereabouts in the country the establishment is located. Nothing will protect an operation from leaving the bunds full of water for extended periods – bund should be checked and if necessary emptied daily. In the drier areas, the extra height will probably be significant but less so in the wetter areas in particular on the western coasts.

Reflected waves following a catastrophic bund failure are considered in the bund overtopping work cited previously. These effects are generally relatively small compared to the initial catastrophic failure event. It would appear unlikely that wind-induced wave action would be a significant factor in bund overtopping, especially if other measures have been put in place to minimise it.

Nicholas, M.J (2017) has recently reviewed the origins of the 25% element of the 110/25% rule. One of the assumptions made, mentioned in CIRIA C736 (2014), is that a loss of containment will occur in only a single tank. Following Buncefield, it is recognised that a single initiating event can result in a loss of containment in a number of stock tanks and HSE Guidance on HFL risks (2017) now specifically guides operators to consider Vapour Cloud explosions as a possible consequence of cold failure of stock tanks. The 25% rule is also justified by a typical tank utilisation of 50% in groups of tanks and typically 50% of the tank contents remaining in the tanks after a major fire. Normal tank utilisation has risen quite a bit since the rule was first developed. There is a national shortage of tank capacity and this is why former oil refinery storage facilities are being bought back into use. To maintain business reserves operators are not running groups of tanks down to effectively empty and technical improvements allow tanks to be safely operated nearer their absolute maximum levels. Some tanks are normally essentially full because they are used as price sensitive hedging stores. It is believed that the typical total tank fill in most storage establishments nowadays is nearer 70% of the installed tank capacity than 50%. The original work does include the statement "Increased bund volume should be considered on a case specific basis if tanks a routinely stocked fuller than this" but this caveat seems to have been lost in the mists of time.

The capacity requirements for containment systems protecting storage of flammable materials contained in IBC's or drums.

Generally, current guidance is that the 110% capacity is based on the absolutely full capacity of the largest container held in the store and the 25% capacity is based on the absolutely full capacity of all the containers that could be kept in the store when full to its permitted maximum capacity. The shortfalls in 110/25% capacity for IBC and drum storage, especially for storage of flammables, will now be reviewed

Existing guidance on this is confusing. HSG 51 (2015) only calls for containment of 110% of the largest container capacity. HSG 71 (2009) calls for 110% of the capacity of the single largest container in the bund except in the case of oil storage where 25% of the total volume should be used. PPG 26 (2011) refers back to the statutory guidance published with the Oil Storage Regulations (2001) which allows storage of one or more oil barrels if they are protected by a drop tray with a capacity exceeding 25% of the total stored capacity, but if they are not stored with drop tray protection, they must be stored in bunds with a capacity of at least 110% of the largest container in the system or 25% of the aggregate total capacity of the containers. When talking about storage inside warehouses, HSG 71(2009) says "IBC's containing flammable substances should be stored in bunded areas specifically to reduce the risk of running pool fires. The bund should consider the volume that could be released from an individual IBC failure and consideration should be given to containing the whole IBC inventory.

Atkinson (2007) reports on experimental work undertaken by HSL for HSE and published in 2007(42) which looks at escalation from a minor source of ignition of plastic IBC' containing flammable and materials that support combustion and metal clad IBC's containing flammables or other materials that support combustion – including lubricating oil. The results are essentially the same – they lose containment rapidly causing a pool fire that would envelop large sections of a bund. It just takes slightly longer if the plastic IBC contains materials that support combustion, or is metal clad containing flammables or other materials that support combustion. The FRS (Fire and Rescue Service) is unlikely to be able to respond in the sorts of times indicated for escalation and the potential local heat fluxes are such that sprinkler systems are unlikely to be able to prevent escalation.

Good Practice for secondary containment bunds protecting IBC/drum stores containing flammable materials or materials that could support combustion is to size them to contain 110% of the total liquid inventory and rainfall, if located outside. Further containment provisions may be required to contain any material displaced by the use of firefighting water or its runoff. It would be adequate for IBC's and barrels containing non-flammable materials (aqueous solutions) to be stored in bunds with a capacity of at least 110% of the largest container in the system or 25% of the aggregate total capacity of the containers. This agrees with the recommendations given in the EI Model Code of Practice 19 (2015) for storage of IBC's

Bund emptying and acceptable disposal of bund contents, including appropriate practice for bunds and sites that are not normally manned.

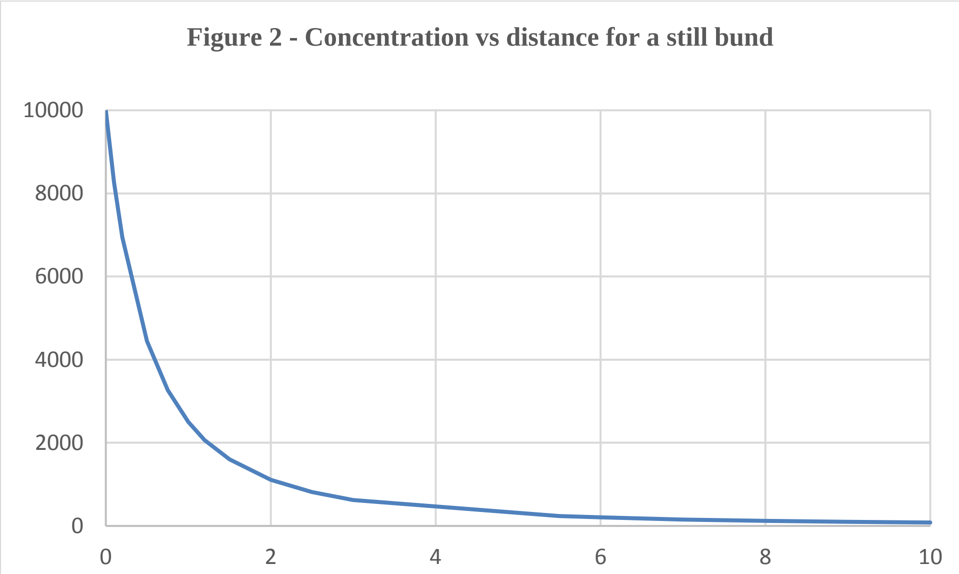
There is limited standard guidance covering these aspects of containment system management. Dickinson (2017) mentioned that smaller low risk sites can be operated remotely but even they should be visited periodically (weekly) or as required. This is acceptable where the inventories of hazardous substances is zero or extremely low. Remote operation and monitoring can have a very important part in running a higher hazard installation, but it is extremely unwise not to inspect the hardware (tanks and bunds) on at least a daily basis and to have people available to rapidly respond to problems indicated by instrumentation.

As a general rule, all bunds should be visited daily and any liquid in them should be attended to on each visit. Every time this is undertaken, two basic principles should be respected:

1) The contents of a bund should be checked before and possibly during emptying
2) Unless the bund contents are reprocessed on site, they are classified as wastes. Wastes must be disposed of using normal waste "Duty of Care" arrangements to an appropriate destination.

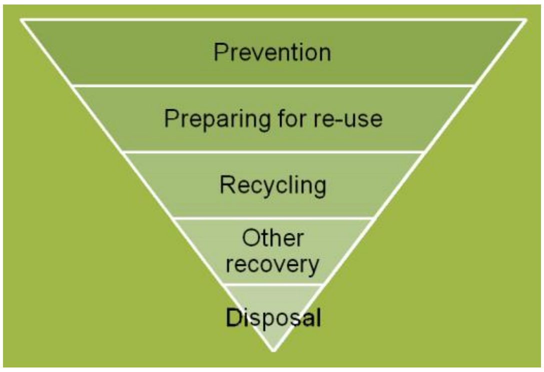
The way the contents of the bunds can be checked depends on the nature of the materials in the tanks protected by the system. Potentially, one of the best ways of detecting any level of insoluble oil contamination is by looking for the oil sheen. One of the Environment Agency's traditional requirements in an EPR permit was to visually observe an effluent stream and report whether there is any visible oil and grease in it. If the flow is not too disturbed, the light is right and the background suitable, visual observation is quite sensitive. In poor light in a dirty bund with a bit of disturbance – not uncommon industrial conditions – the "test" is not that accurate. It can be made more sensitive by designing the area where the observations are being made by ensuring that any water flow is gentle and constant, the background is clean and lighting adequate. Alternatively, there are now analytical systems that will pick up oil almost if not as well as the human eye

It is unlikely that water soluble contamination will be picked up by visual observation. Apart from potential ammonia contamination, it is usual to use a surrogate test for potential contamination – one or more of pH, conductivity, turbidity or TOC may be used. It should be noted that unlike oils which spread across the surface of a body of still water, contamination leaking into a body of clean water will not necessarily mix and a concentration profile could develop within the water body. Figure 2 shows a typical example of a concentration profile that could develop across a still bund. It is essential that the contents of a bund potentially containing soluble contamination is tested throughout the emptying activity as it could well change during the emptying cycle.



The waste hierarchy (see Figure3) needs to be applied to determine the most appropriate disposal destination for materials removed from a bund.

Figure 3 The waste Hierarchy



Prevention strategies could include providing a cover for the bund and ensuring that rain from any tanks is diverted away from it. This creates confined space restrictions and is not generally suitable for storage of flammable materials because of the risk of flammable atmospheres being generated. Rainfall from clean roofs may be sent directly to soakaways bypassing any potential demand on the emergency containment systems.

Some petroleum products are imported contaminated with water and some tanks with floating roof tanks route the rainwater falling on the top of the tank into the tank itself. Both impose a dewatering duty on the tank. The water removed should monitored for oil content and routed directly to an effluent management system rather than drained into the bund. This oil monitoring needs to be high integrity, essentially to BS EN 51611 standards, as there is a known risk of pipework in tanks failing and oil discharging from the tank this way. In any oil storage application, effluent can be routed through an Oil-Water separator. The oil can then be recovered and reused on a refinery or a waste oil processing plant, otherwise tankered off to a waste oil recycler and the oils recycled in some way.

One of the most difficult effluents to dispose of is where the contamination concentration is too low for economic recovery but too high to dispose of using the operator's normal liquid effluent disposal routes. Disposal of it will be expensive. It will probably need to be shipped off site, normally by road tanker, and sent to an appropriate waste management facility. Separation of contamination from aqueous effluents is undertaken by some waste operators, but all too often, the only safe way of disposing of this sort of effluent is to incinerate it. Some water companies will accept more contaminated effluents by road tanker than they will by sewer because they can control its disposal better that way.

The best way of disposing of an aqueous effluent, if available, is to use the operations normal effluent disposal routes, as long as this meets any limits imposed on them. The Environment Agency should be consulted in any case if is intended to dispose of an unusual effluent down a consented effluent disposal route. If no limits are imposed, minimum good practice must be applied which would mean that no environmental harm arises from the disposal operation. The Environment Agency may allow discharge to regulated waters in an emergency via an unconsented discharge point but it will probably take some time (days) to allow it and there will possibly be conditions imposed on the discharge which may only be imposed at the last minute following assessment.

The capacity requirements and response times for transfer systems suitable for moving liquids around a large site in an emergency.

CIRIA C736 (2014) Chapter 10 is dedicated to Transfer systems. It does, however, use quite a wide definition of transfer systems – the following is more focussed to systems that immediately are available for contaminated liquid transfers during emergencies. There are two basic requirements of Emergency Transfer systems

1) The emergency transfer system must have adequate capacity to meet the anticipated demand in an emergency
2) The emergency transfer system must be suitable for transferring effluent without loss

Emergency transfer systems may be needed to transfer effluent from the main tranche of secondary containment to remote secondary containment, from secondary containment to tertiary containment or between elements of tertiary containment. Regardless of how they are used, they must have adequate capacity to perform their function and not discharge contaminated material where it is not wanted.

Unlike most emergency transfer systems, effluent transfer from the main tranche of secondary containment to remote secondary containment must always be available and be fail safe. In the author's opinion, the only credible way that this can be assured is using a gravity flow system of adequate design. Transfers from secondary to tertiary containment can be assisted by pumps but in general pumps should be close to the source of the liquid, which means that the pump may be at some risk if there are flammables present. The safest option is remotely actuated gravity flow systems. It is accepted that gravity flow systems for emergency duties like this are likely to involve some underground pipework but the integrity of that pipework must be assured. Transfers between elements of tertiary containment systems will normally be pumped using fixed or temporary pipe runs, which may include flexible and fire hoses.

CIRIA C736 (2014) Chapter 10.6.1 suggests that the operator agrees with the regulator the transfer system capacity appropriate to allow for the catastrophic failure of a stock tank. A transfer system from secondary containment with adequate capacity to cope for an instantaneous burst would be extremely large. Inevitably there will be significant overtopping of the bund if a reasonably sized stock tank bursts instantaneously – it is the design of areas round the bund that will determine how much of the escaped liquid will eventually be trapped and determine the attenuation of the burst flow. It is unlikely that any regulator will be in a position to agree a figure.

The other potential demands on emergency transfer systems mentioned in CIRIA C736 (2014) Chapter 10.6.1 are more restricted loss of primary containment events, firefighting water flow, rainwater and problems within the tertiary transfer system itself. A possible requirement to transfer material from primary or secondary containment if it appears it is likely to fail but has not actually done so is not mentioned. Firefighting water flow is likely to be the largest of these demands.

The author has considered the firefighting water flow likely from a series of bunds containing a number of stock tanks. The bund arrangement given in HSG 176 (2015) to illustrate the tank spacing rules was used with three sizes of tank and bund estimated. The bund sizes considered were 35 x 20 m, 55 x 30 m and 115 x 70 m. It was assumed that there had been a major loss of containment of a flammable petrochemical from one of the larger stock tanks which has covered the floor of the bund and is alight by the time the FRS arrive on the scene. Having dealt with any missing persons, the preference of the FRS will always be to put a fire out, if possible. The FRS commander will estimate how much foam concentrate would be needed to attempt to fight the fire using foam during his initial planning stage. In these examples, calculations indicate that they would need about 3,000 litres of foam concentrate for the smaller bund, about 7,000 litres for the intermediate one and 40,000 litres for largest one. In foam terms, these are not trivial quantities and they will be stored in a central FRS base. Most FRS's will not have 40,000 litres themselves and will obtain it using mutual aid arrangements. It may take considerable time – hours – to get enough foam on site so the FRS will try to hold the position by applying cooling water to the tanks to minimise the probability of the fire getting any worse. This initial phase is likely to have the highest demand on transferring water out of a bund. The EI Code of Practice 19 (2015) suggests that cooling water flow should be applied to any tanks involved in a pool fire above their fill line at a rate of at between 2 and 10 l/min/m2 of surface area. Even in the largest bund, the tanks are relatively small and it would be difficult to control the water to being only above the fill level. If the pool fire is fully established in the bund, all the tanks in the bund, including the one that has leaked, would require the application of cooling water. The cooling water demand rates assuming that the whole tank is cooled but the water rate is actually limited to 2 l/min.m2 have been calculated as 237 m3/h for the smaller bund, 416 m3/h for the intermediate bund and in excess of 1000 m3/h for the largest one.

Table 1 Capacity of underground pipes, m3/h		
Pipe Diam	Slope	
mm	1%	2%
100	22	30
150	65	104
200	140	200
250	250	360
300	400	600
230	600	900
400	900	1250

It is likely, certainly in the case of the larger fires, that used firefighting water will need to be removed from the base of the bund before the foam can be used when it arrives. It may be possible to route it down the site drainage system, assumed to be an underground gravity flow system. Table 1, derived by the author using standard calculation techniques, illustrates the indicative maximum carrying capacity of straight unobstructed runs of underground drainage systems of various sizes and slopes. If the underground route has sharp bends in it its carrying capacity will be significantly lower. Alternatively, it may be necessary to pump the liquid effluent. A pumped system comprises three elements – the inlet pipework, the pump and the delivery pipework. The pipe diameter of the inlet pipe is usually one pipe size bigger than the outlet pipework. If a fixed pump is not available or not big enough, typical pump capacities of temporary pumps are worth considering. A standard utility water pump used to clear excavation water or over-pump sewers has a typical volumetric capacity of order 200 m3/h delivering against relatively low head. A standard FRS pump has a volumetric capacity of 100 m3/hr delivering against a higher head. Illustrative pressure drops over delivery pipework for various pipe diameters and flowrates per 100 m pipe run are given in Table 2. Certainly for the larger flowrates, the FRS would expect the operator to provide the means to extract the firefighting water from the bund and may not be able to commit their pumps for that duty. The operator would need to have 1 or preferably 2 utility pumps for the smallest bund, 2 or 3 for the intermediate bund and 5 or more for the largest one. If there is a fire going on, the utility pumps do not have to be intrinsically safe but it is worthwhile noting that they could be an unintended source of ignition. If the only pipework available is firefighting hoses, they can be set up in parallel and intermediate pumps can be installed to maintain an adequate water flow.

Table 2 Pressure Drop down pumped systems, Bar					
Flow, m3/h	Pipe Diameter, mm				
	100	150	200	250	300
100 m3/h	1.4	0.17			
250 m3/h		1.04	0.23	0.07	
400 m3/h		2.63	0.59	0.19	0.07
700 m3/h			1.79	0.56	0.21
1000 m3/h				1.14	0.44

These numbers are indicative. The operator needs to consider the numbers himself and is it is strongly recommended that he discusses the firefighting plan and numbers with the FRS that would support the premises in an emergency.

Another potential demand on emptying bunds that is worth considering is the possible requirement to transfer material from primary or secondary containment if it appears it is likely to fail but has not actually done so. CIRIA C736 (2014) Chapter 6.3.5 suggests that bunds should be designed to be able to retain any liquids that could be released into them for potentially a number of weeks but the only flexibility available to an operator is to be able to transfer liquid out of them should they show signs of distress. It is suggested that the transfer system be designed to empty an individual element of the containment system in a reasonable timescale in this situation – say 8 hours.

Total and Tertiary Containment requirements

Sometimes, total containment capacity and tertiary containment capacity are considered as interchangeable terms. Strictly speaking, they are not, as under certain circumstances total containment capacity can include the containment capacity provided by secondary containment as well as that provided by additional tertiary containment capacity but in other circumstances it cannot. This paper looks at the total containment capacity requirements then briefly considers weather secondary containment provisions may be included in that total.

All the guidance on emergency liquid containment systems in the UK points to either CIRIA R164 (1997) or its replacement CIRIA C736 (2014) as the best guidance. All references to CIRIA R164 (1997) should now be read as references to CIRIA C736 (2014). CIRIA C736 (2014) Chapter 4.3 is the definitive guidance on total containment system capacity and this section should be read in conjunction with it.

The term "reasonably foreseeable" appears quite a few times in guidance on this subject. This needs careful consideration for the process and allied industries. In this professionally operated context, "reasonably forseeable" should be seen as considering the consequences of an action or inaction could be reasonably predicted by an appropriately qualified engineer, considering all relevant circumstances.

<u>Volume of Inventory:</u> A premises does not necessarily have to have flammable liquids stored on site to require containment provisions. Wood and waste are not generally considered to be flammable, yet all too often fires break out in stores of them so are reasonably foreseeable. It is unusual to store wood in bunds and although it is good practice to store waste in bunded areas, often the bunding is incomplete to enable, for example, fork lift truck access. There may also be liquids stored on site close to the material that catches fire that would be effected by it, and this site close to a sensitive environmental receptor. Tertiary containment would be required in such examples to enable contaminated firewater runoff to be retained. Solids that remain solid at combustion temperatures are not included in the quantity of material at risk, but if they can melt they are. For liquid storage, the tertiary containment capacity does not need to consider the total liquid inventory on the site if loss of that total inventory is not reasonably foreseeable. It is worthwhile pointing out that it is considered reasonably foreseeable that a

bund protecting stocks of flammable materials will fail because the contents of the bund is on fire, so its capacity should not be included in the total capacity available.

Rainfall: CIRIA C736 (2014) recommends that the rainfall for the duration of the event and rainfall for a further 8 days be allowed for in the total containment volume requirements. The expectation that materials will only stay in on site containment for a maximum of 8 days should not be inferred from this – only that arrangements should be able to be made on that timescale to start shipping enough effluent off site to maintain the levels against further rainfall. It should also be borne in mind that the rainfall diagram in CIRIA C736 (2014) Figure 4.2 only represents actual data up until 1986. Intense periods of rainfall have become more frequent and more intense since then and it is important that more up to date local information is obtained when undertaking detailed designs. As a rule of thumb, the author would multiply the figures in the table beneath Figure 4.2 by a factor of 1.3 even for preliminary estimation work.

Firefighting water and firefighting agents: It is likely that the requirement to contain all the potential firefighting water generated during an emergency involving a fire will dominate the total containment requirement. CIRIA C736 (2014) Section 4.3.4.2 starts by looking at potential ways of reducing the potential maximum firefighting water demand. Whatever the total containment capacity provided, it is always beneficial both environmentally and economically to minimise the firewater arisings so these arrangements are worthwhile regardless of whether they can be taken into account for total containment capacity sizing purposes. The problem with all firewater minimisation systems is that they can be bypassed or fail. The decision about whether they can be taken into account for total containment system sizing should be based on a full Environmental Risk Assessment using for example the CDOIF ERA (2015) methodology. For this purpose, the potential failure of the firewater minimisation hardware and procedures should be taken into account in calculating the mitigated risk of the establishment. If this remains in the intolerable region then adequate containment capacity needs to be provided for a more conventional firefighting approach or if it ends up in the TifALARP regime, a Cost Benefit Analysis should be undertaken to demonstrate that the provision of further containment provisions would be excessively expensive.

CIRIA C736 (2014) reflects on how difficult it is to estimate the quantities of firewater that could be generated in an emergency. Box 4.1 in CIRIA C736 (2014) possibly represents the best published summary of the methods that are available. In preparation for this paper, the UNECE Press release (2017) was found which said that UNECE has started to look into this area. Since then, the Author has seen the first draft of the UNECE and had the opportunity to comment on it. The Author was able to obtain some real data on the firefighting effort at Buncefield and has worked this up into "The Buncefield Method" not published elsewhere and summarised in Box 1

Looking into the methods themselves, it is clear that they all are a function of the firefighting approach used. The methods that are applicable to unrestricted firefighting include the "Sandoz" and "CIBA" magic numbers (3 – 6 m^3/t product), which relate to relatively small stored volumes, the Buncefield magic number (1 – 3m^3/t) which relates to a larger stored volume and the ICI method. All the other methods seen by the author relate to the arisings where either the fire or the quantity of firewater used are restricted and an operator needs to be sure that these are realistic and robust enough to be used.

The EI Model Code of Practice 19 (2015) gives additional guidance to that given in CIRIA C736 (2014) for conventional firefighting and the use of foam. The author is also aware that there is increasing interest in the UK in the possible use of wetting agents for fighting in particular waste fires.

Box 1 – the Buncefield Method

Buncefield statistics from Nicholas, M.J. (2015)
HOSL – consent to store 34000 tonnes motor spirit and 15000 tonnes kerosene
BPA – consent to store 70000 tonnes of motor spirit and other fuels
786 000 litres of foam concentrate and 68 million litres of water (53 million 'clean' and 15 million recycled) were used overall to contain the incident during the period of firefighting operations.
22 tanks and 7 bunds involved in fire
Approximately 35 million litres fuel saved
53 million litres of "clean water" used
15 million litres of water recycled and reapplied to fire
10 million litres of water moved on site to protect the environment.

These numbers have to be to be considered along with the way the fire was fought. Atkinson (2017) gives a comprehensive description.

After the event, the site held over 35 million litres of petrol, diesel and aviation fuel. The quantity of fuel that was held at Buncefield before the incident is unknown. The total quantity of fuels that were consented to be stored at Buncefield was 34,000 + 15,000 + 70,000 = 119,000 t. Based on reasonable assumptions, it is estimated that the average tank fill was about 65% giving 75 80,000 t total present. The density of gasoline ranges from 0.71–0.77 kg/l and Kerosene 0.81 kg/l so the 35 million litres quoted as being left after the fire would only weigh 26 – 27,000 t. On this basis it is estimated that they lost something between 48 to 54,000 t of material.

There were 53 million litres of "clean water" used and 15 million litres of water recycled and reapplied to fire. It is assumed that the 786,000/0.03 = 26 million litres needed to make up the foam that was actually used is included in the total 53 million litres of clean water. The raw data suggests that they only used 67/(between 46 and 54) = 1.25 and 1.45 m3/t product lost. If the assumption that the water used to make up the foam is incorrect, this goes up to 93/(between 46 and 54) = 1.72 and 2.02 m3/t product lost.

It is clear from Atkinson's description of the firefighting activity that they were very short of water for the first 24 hours of the incident. Atkinson describes the main activity where they would have used copious quantities of water as lasting about 24 hours, most of which would have been because they were waiting for foam supplies to arrive. If you say they applied the 67,000 m3 over the 24 hours, this works out at an average rate of about 2,800 m3/h. It is concluded that a more normal firefighting response would have resulted in nearer 3 m3/t than the values actually used at Buncefield so a range of 1 – 3 m3 for the "Buncefield" method should be quoted.

Dynamic effects and allowance for firefighting foam: Both of these were discussed earlier. There should be little need to allow for dynamic effects in anything other than the secondary containment element of the total containment system. The Author suggests that 200 mm wall height is a more appropriate allowance for firefighting foam detention than the 100 mm allowance suggested in all the current guidance.

Tertiary Containment Plan

Tertiary containment can be provided as one of more dedicated emergency facilities not used for any other purpose. It is probably most appropriate for premises which handle toxic and flammable materials. In some premises it is not possible to provide such good facilities and alternative existing emergency containment facilities, possibly usually allocated for other duties, may be utilised. It is very rare that such alternative facilities can be utilised without restrictions, or are big enough individually to totally meet the premises' total containment requirements and this is where the tertiary containment plan becomes relevant and vital.

Tertiary containment plans have a lot in common with other emergency plans. It is not reasonable to expect site personnel to remember all they need to in the heat of the moment, and individuals will tend to have their favourite document they want to have by their side when they find themselves in an emergency situation. Industrial operating personnel should be trained in emergency response but, possibly unlike the emergency services, they will not have been drilled in it and need a "go to" plan on demand. This should be something that is useful to the individual, given that they know what their day job but is comprehensive in filling the gaps that are relevant in an emergency. When reviewing them, it is important to gather the views of all relevant parties in an actual operation - it is their (joint) view of them that maters, not the reviewers.

The tertiary containment plan could be a stand-alone document or it could be part of the sites On-site Emergency Plan.

It is suggested that the contents of a tertiary containment plan should include

1) Potential demands
2) Any key enabling actions
3) Potential receivers
4) Receiver incompatibility
5) Potential transfer routes
6) Equipment required
7) Equipment sources
8) Other contacts
9) Effluent disposal plan
10) Facility cleaning plan

Potential Demands: this is the most "theoretical" part of the plan. The potential demands should have been identified qualitatively by Hazard Identification techniques (HAZOP, PHR, Operations meetings etc) and some thought put in to what and how much material (both product and contaminated firefighting water) may be released. The tertiary containment plan should include a simple list – a list of potential events, what releases could be, what volumes of them are expected and what possible worst case volumes need to be catered for.

Key enabling actions: This should list things that need to be done on the site for the tertiary containment plan to have a chance of success, for example shut the site drain valve, shut off the effluent feed to the sewerage undertaker, start the drain pump etc. The more of these that are activated automatically by the site alarm system the better. High integrity instrumentation and control systems to at least SIL 1 standards are recommended. The plan should also list key off-site actions, assuming that the emergency services have been called. It, may include obtaining further supplies of firefighting foam, bringing in extra operating personnel, bringing in extra transfer pumps and hoses etc on site as soon as reasonably practicable.

Potential receivers: This should comprise a list of cells that could be deployed as tertiary containment containers, along with their capacity and any known restrictions to their use. It would probably include:

- any dedicated tertiary containment or emergency bunded areas,
- all the standard bunds,
- any normally empty or partially full stock tanks
- any third party facilities that may be available, especially if their use has been previously agreed

and any identified sacrificial areas for use in the last resort. Multi-purpose liquid storage sites could supplement these with a complete list of their tanks and the status of each tank saying whether the tanks is:

- full and in service with Product X,
- empty but allocated to Product Y,
- dirty awaiting cleaning,
- empty awaiting allocation,
- being cleaned or
- under maintenance.

For the tertiary containment plan, it is vital that this list indicates whether a tank is open or boxed up if it is to be used for emergency response allocation.

Receiver incompatibility: The restrictions to use should include what a potential receiver cannot receive. Examples include:

- The receiving bund lining system is not acid/alkali/polar solvent/hydrocarbon resistant
- The vessel itself cannot receive an acid or alkaline effluent (aluminium or copper)
- The vessel or lining system is unprotected plastic or plastic lined and cannot receive hot effluent

- If the premises stores flammable materials, the fire resistance and potential ignition sources
-

Potential transfer routes: However recorded, all potential transfer routes should be easy to identify. The record could take the form of a table of transfer routes from one location on site to another point on site, or a (colour coded) site map showing the locations of the potential receivers and the transfer routes. Potential transfer routes include (intact) drains, pipelines, gullies, pipe trenches, kerbed hard standing etc. An indication of the water carrying capacity of any gravity flow transfer system would also be very useful. This would be easier to include on a table than on a map, but it could be included as a clear number on a map.

Equipment required: If any additional equipment is needed to enable material to be put into a transfer route or extracted from it, this should be identified along with the basic specification (nature, capacity and head duty) of the equipment required. This includes electrical generators if they may be required.

Equipment sources: If additional equipment is needed, the tertiary containment plan should include a list of any daytime and 24/7 phone numbers of potential suppliers. If there is call off contract in place or a preferred supplier identified, these can be marked as priority for calling but all other potential suppliers should be listed – in preference order if wanted or appropriate. Contracts, even emergency call off contracts cannot be relied on absolutely and it is unlikely that the manager or his assistant on the ground would have the time or opportunity to wait for ring-backs or marginal improvement on prices.

Other contacts: If there is a plan to get effluent of the site quickly in an emergency, the phone numbers of the resources (transport, receiver etc) should also be included in the tertiary containment plan.

Disposal Plan*:* Once full, tertiary containment facilities are no longer available so they should be emptied as soon as reasonably practicable. The contents at this stage have become waste so should be disposed of using the normal waste hierarchy. Planning possible disposal routes will make it a lot easier to send them for beneficial use if this is possible or at minimum cost if they need to be disposed of

Facility cleaning plan: Facilities used for temporary tertiary containment will probably need to be decontaminated to enable them to return to their original duty. The quicker this is completed the least disturbance will have been caused by their use and, with an appropriate plan, probably the less expensive the cleaning will be.

Conclusions

A number of areas are identified in this paper which are outside existing guidance but would appear to be worthy of consideration by both operators and their agents when designing and assessing the fitness for purpose of existing liquid containment systems. In particular

- Standard bund walls are likely to be overtopped if a stock tank fails catastrophically. The collection capability for liquids immediately outside the bund should be considered in any assessment of the potential impact of a catastrophic failure of a stock tank and if necessary enhanced.
- Consideration should be given to allowing at least 200 mm freeboard for firefighting foam retention if foam is likely to be applied for fire suppression.
- The demands placed on a containment system by rainfall during and after an incident will be very dependent on the geographical location of the premises.
- The likely demand on tertiary containment facilities on a premises which protects a number of tanks with a single bund should be carefully reviewed as there are a number of foreseeable potential demands that will not be adequately met by the 25% rule.
- Flammable drum and IBC stores should be protected by bunds that can contain 110% of the total inventory of liquids that can be stored in it with an appropriate allowance for rainfall as necessary.
- If the contents of the tanks protected by a bund are soluble in water, the quality of any effluent discharged from the bund should be monitored throughout the discharge period, not just at the start of it.
- If some elements of a secondary containment provision is remote, ensure that the availability and capacity of the transfer system between the various parts of the secondary containment system are at least as high as the containment elements of it.
- If pool fires develop in bunds, check what tank cooling water flowrates are likely to be used and the resources needed to remove them as these flowrates may need to be removed from the bund before firefighting foam can be deployed to put then fire out.
- Consider what an acceptable time would be to empty a bund should it show signs of distress and that the resources needed to do this are adequately available.
- A premises does not necessarily have to have flammable liquids stored on site to require containment provisions. They may be required for premises that store toxic, Dangerous to the Environment and materials that support combustion as well.

A guideline for estimating the total firewater use based on experience at Buncefield, 1 – 3 m^3 of water/t material involved in the fire, is presented.

It is suggested that the contents of a tertiary containment plan should include:

- o Potential demands
- o Any key enabling actions
- o Potential receivers

- Receiver incompatibility
- Potential transfer routes
- Equipment required
- Equipment sources
- Other contacts
- Effluent disposal plan
- Facility cleaning plan

References

(All internet links checked 30-Dec-17)

All Measures Necessary (2016), All Measures Necessary", The COMAH Competent Authority, v2, 2016, **https://www.sepa.org.uk/media/219152/d130416_all-measures-necessary-guidance.pdf**

Angus Foam Application Estimator (2017), carried by most FRS crew commanders and available from Angus fire. **www.angusfire.co.uk**

Atherton (2005), An experimental investigation of bund wall overtopping and dynamic pressures on the bund wall following catastrophic failure of a storage vessel, Atherton, W, Liverpool John Moores University HSE RR 333, 2005, **http://www.hse.gov.uk/research/rrpdf/rr333.pdf**

Atkinson (2007) HSE RR564, Fire performance of composite IBCs, HSE Books, 2007, **http://www.hse.gov.uk/research/rrpdf/rr564.pdf**

Atkinson (2017) Buncefield: Lessons learned on emergency preparedness. Graham Atkinson, Health and Safety Executive, UK, IChemE Loss Prevention Bulletin 254 April 2017 **http://www.icheme.org/~/media/Documents/LPB/LPB254pg23.pdf**

BP/IChemE (2005), BP Process Safety Series, Safe Tank Farms and (Un)loading Operations, 2nd Edition, IChemE 2005, **http://www.icheme.org/bp-safety**

CDOIF ERA (2015), Guideline, Environmental Risk Tolerability for COMAH Establishments, Chemical and Downstream Oil Industries Forum, v2, 2015, **https://www.sepa.org.uk/media/219154/cdoif_guideline__environmental_risk_assessment_v2.pdf**

Clark et al (2001), Effects of secondary containment on source term modelling, Clark, SO and Deaves, DM, HSE Contract Research Report 324/2001, **http://www.hse.gov.uk/research/crr_pdf/2001/crr01324.pdf**

CIRIA R164 (1997), Design of containment systems for the prevention of water pollution from industrial incidents, Construction Industry Research and Information Association, Mason et al, CIRIA Report R164, 1997 (withdrawn)

CIRIA C736 (2014), Containment Systems for the Prevention of Pollution, Secondary, tertiary and other measures for industrial and commercial premises, I L Walton, CIRIA Report C736, 2014, **http://www.ciria.org/Resources/Free_publications/c736.aspx**

Davies et al (1995) Bund effectiveness in preventing escalation of tank farm fires, Davies, Harding, McKay, Robinson and Wilkinson, IChemE symposium series No 139, 1995, **http://www.icheme.org/communities/subject_groups/safety%20and%20loss%20prevention/resources/hazards%20archive//~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/S139%20-%20Major%20Hazards%20II/S139-17.pdf**

Dickinson (2017), Inspection of Secondary and Tertiary Containment Systems, IChemE Symposium Series No 162 Chris Dickinson, HAZARDS 27 Paper 18, **https://www.icheme.org/~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/XXVII/XXVII-Paper-18.pdf**

Dlugororsli et al (2002), What Properties Matter in Firefighting Foam, Dlugororsli BZ, Kennedy EM, Schasfer TH and Vitali JA, national Research Institute of Fire and Desaster, 2nd NRIFD Symposium – Conference Proceedings, Tokyo. 2002, **https://www.solbergfoam.com/getattachment/3fe1d44d-3b44-4714-89f4-4af37e381b5b/WP-WHAT-PROPERTIES-MATTER-IN-FIRE-FIGHTING-FOAMS.aspx**

EI Model Code of Practice 19 (2015), The Energy Institute's Model code of safe practice Part 19 – Fire precautions at petroleum refineries and bulk storage installations. The Energy Institute, 2015 **http://publishing.energyinst.org/topics/petroleum-product-storage-and-distribution/distribution-installations/model-code-of-safe-practice-part-19-fire-precautions-at-petroleum-refineries-and-bulk-storage-installations2**

HSE Guidance on HFL risks (2017) HFL SRAG, PM/Technical/07 HID - Safety Report Assessment Guide: Highly Flammable Liquids (HFL) **http://www.hse.gov.uk/comah/sraghfl/highly-flammable-liquids.pdf**

HSG 51 (2015), HSG51 Storage of flammable liquids in containers, HSE Books, 3rd edition 2015, **http://www.hse.gov.uk/pUbns/priced/hsg51.pdf**

HSG 71 (2009) HSG71 Storage of Packed Dangerous Substances in Warehouses, HSE Books, 4th edition, 2009, **http://www.hse.gov.uk/pUbns/priced/hsg71.pdf**

HSG 176 (2015), HSG 176 Storage of flammable liquids in tanks, HSG Books. 2nd Edition 2015, **http://www.hse.gov.uk/pUbns/priced/hsg176.pdf**

IED BAT Conclusions Document for the Chemical Sector (2017), **http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D2117&from=EN**

Nicholas. M.J. (2015) Internal Environment Agency Presentation "Tertiary Containment"

Nicholas, M.J. (2017), "When bunding costs too much: A COMAH inspired case study", presented at TSA conference 2017, **https://www.tankstorage.org.uk/assets/TSA-_Conference-_Presentation-_2-_Mike-_Nicholas-_September-_2017-_v1.pdf**

Oil Storage Regulations (2001), The Control of Pollution (Oil Storage) (England) Regulations 2001, SI 2001 No 2954, **http://www.legislation.gov.uk/uksi/2001/2954/pdfs/uksi_20012954_en.pdf**

Petitt (2003), Bund design to prevent overtopping, Pettitt G, IChemE Symposium Series No 149 pp 329 – 339, 2003 **https://www.icheme.org/communities/subject_groups/safety%20and%20loss%20prevention/resources/hazards%20archive/~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/XVII/XVII-Paper-26.pdf**

PPG 2 (2011), PPG 2, Pollution Prevention Guidelines, Above Ground Oil Storage Tanks, Environment Agency, SEPA and NIEA but no longer supported by the Environment Agency, Apr-11, **https://www.sepa.org.uk/media/60073/ppg-2-above-ground-oil-storage.pdf**

PPG 26 (2011) PPG26, Pollution Prevention Guidelines, Drums and intermediate bulk containers, Environment Agency, SEPA and NIEA but no longer supported by the Environment Agency, Apr-11: **https://www.sepa.org.uk/media/60190/ppg-26-safe-storage-drums-and-intermediate-bulk-containers.pdf**

PSLG Final Report (2009). Safety and environmental standards for fuel storage sites, Process Safety Leadership Group, Final report, HSE Books, 2009 **http://www.hse.gov.uk/comah/buncefield/fuel-storage-sites.pdf**

Thyer et al (2002), Bund overtopping — the consequence of catastrophic tank failure, Thyer,, AM, Hirst, LM and Jaggera, SF, Journal of Loss Prevention in the Process Industries 15 (2002) 357–363, **http://www.sciencedirect.com/science/article/pii/S0950423002000232**

UNECE Press Release (2017) **https://www.unece.org/info/media/presscurrent-press-h/environment/2017/unece-prepares-guidance-on-fire-water-retention-to-avoid-another-sandoz-accident/doc.html**

Watts (1951), Report on Explosion and fire at Regent Oil Co. Ltd. Premises, Royal Edward Dock, Avonmouth, Bristol, on 7th September 1951, H R Watts, CBE, PhD, BSc, F.R.I.C, H M. Chief Inspector of Explosives, Home Office, HMSO, 1952