PRESCRIPTION – A STEP ON THE ROAD TO DEPENDENCE, OR A CURE FOR PROCESS SAFETY ILLS?

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In planning how to organise themselves for managing process safety, companies have decisions to make. In cases where companies are faced with mergers, acquisitions and major restructuring, there is no status quo; decisions have to be made. Centrally prescribing rules and standards gives clarity and is easily auditable, but can lead to a loss of mindfulness. Decentralised reliance on risk management defers to the expertise of those who are best placed to control the risk, but can lead to a loss of control if local risk management processes fail. Prescriptive systems are more expensive to set up and run than risk management ones. Prescription is conceptually easy, risk management is conceptually difficult. Prescription works best when applied to a specific technology, risk management is more widely applicable. This paper was stimulated by the book "Failure to Learn, the BP Texas City Refinery disaster" by Andrew Hopkins (2008). The book makes extensive use of material, unusually made public, by lawyers preparing civil actions for damages against BP. The book makes the case for a more centralised organisation, and one based more on rule compliance and less on risk management. Analysis is made in this paper of the published information to understand how the risk management processes failed at Texas City. An examination will be made as to how the balance between prescription and risk management might have influenced decision making practices in the refinery. Lessons are also drawn from health and safety regulatory frameworks. The paper concludes with some thoughts about where the balance should be, especially in cases where companies face major reorganisation and cautions against reliance on prescription.

INTRODUCTION

On 23rd March 2005, operators starting up the Isomerisation Unit (ISOM) at BP's Texas City Refinery overfilled the raffinate splitter. Pressure relief valves lifted and liquid hydrocarbon was discharged to a blowdown drum (F-20), whose vent was to atmosphere. The drum subsequently overfilled, flammable liquid was emitted from the vent and fell to the ground, creating a gas cloud which ignited. The resultant vapour cloud explosion killed 15 people and injured many others. All of the fatalities were in nearby wood framed portable buildings (trailers) (CSB 2007 and Mogford 2005).

Process safety management decisions had been made at the refinery which allowed this accident to happen. This paper will examine some of the related decision making practices. The purpose is not to blame or criticise either BP or the people at Texas City. But the information which has been made available at www.texascityexplosion.com provides a fascinating mirror we can hold up to ourselves to help understand how we should manage major accident hazards.

Imperial units have been used throughout the paper to make it easier for readers who wish to refer to the source reference material. 1 foot = 0.305 m. 1 psi = 0.07 bar.

DESCRIBING CULTURES AS "RULE COMPLIANCE" OR "RISK MANAGEMENT"

Characterising cultures according to where they lie on a two dimensional scale between "rule compliance" (prescriptive) and "risk management" might seem simplistic. But it seems to be useful nevertheless. The Robens Committee (Robens 1972) for example, used it when discussing what was wrong with health and safety regulation in the UK at the time. They said that the then present system "encourages rather too much reliance on state regulation, and rather too little on personal responsibility and voluntary self generating effort". It is useful to try to define the two extremes of the scale. Organisational culture can be viewed as the collective and individual decision making processes in an organisation (Reason 1997, Hopkins 2005; 7). A wholly "rule compliance" culture is taken to be one which makes decisions by applying externally created rules, without regard to what were the underlying assumptions, and what might be the limitations of the rules; there is no need for goals. A wholly "risk management" culture is one where decisions are made on a case by case basis, weighing up and analysing a range of influencing factors; measures are implemented only if they are directly linked to meeting organisational goals. Reason (2008; 67) talks about rule compliance as *controlling the process* and risk management as *controlling the output*. We are interested in the decisions which the Texas City organisation made relating to managing major accident hazards, or process safety.

Hopkins (2008) argues that Texas City's inability to learn led to the overfilling of the raffinate splitter distillation column, the release to atmosphere from the blowdown drum stack, the ignition of the gas cloud and the trailers in which the 15 fatalities occurred being too close to the ISOM. He attributes the failure to learn, amongst other things, to BP Texas City treating process safety management not enough as a matter of rule compliance, and too much as a matter of risk management. There is no question that the process safety management processes failed. But the question which this paper will address is, could the failures have been prevented if the culture had been more one of rule compliance. The discussion will focus on the decision making processes related to the trailer siting. I have chosen to focus on this one not because of its significance in the development of the incident, but because of the amount and quality of relevant information which is available. The paper will discuss the decision to allow the blowdown drum vent to remain routed to atmosphere, but in much less detail due to space constraints.

SITING THE J.E. MERIT TRAILER TOO CLOSE TO THE ISOM

BACKGROUND OF THE TRAILER PHA

The ISOM lies immediately to the south of the Ultracracker Unit (ULC) (Fig. 1). In September 2004, the project manager of the ULC Motorization Project, needed a trailer to accommodate contractors working for J.E.Merit. Other trailers had taken all available space in the ULC, and he decided to site the Merit trailer over the road between the Naphtha Desulfurization Unit (NDU) and the ISOM. Trailers had been placed at this location since 1981, and utility hook-ups had previously been installed to facilitate their periodic reinstallation. The process of approving a trailer siting was controlled within the refinery's Management of Change (MOC) process. Carrying out a risk assessment or Process Hazard Analysis (PHA) was one of the requirements for MOCs. He had the project engineer raise an MOC, and asked a colleague from the TAR (maintenance turnaround) organisation to be the PHA leader.

The PHA leader had graduated from Texas A&M in 1999 with a bachelor's degree in mechanical engineering. He had worked for BP and legacy companies since that time initially as an asset reliability engineer, providing mechanical engineering support to operating units, and subsequently planning and scheduling turnarounds (planned maintenance shut downs). Most of his work had been in the crude division in the East Plant, and he had only on a few occasions visited the West Plant where the ISOM was situated. None of his engineering experience had been on the ISOM.

It was an expectation at Texas City that new engineers become MOC and PHA leaders. He had attended a two day PHA course run by the site PSM (Process Safety Management) Department, and had received on the job mentoring on MOC, PHA and HAZOP. When he first lead them on his own, he had sent them to the PSM Manager for checking. As was the practice, when the PSM Manager was satisfied that he was competent, he was signed off as approved and added to the approved MOC leader list. As a unit engineer he had conducted several MOCs, including the associated PHAs. Specifically he had previously led approximately five trailer siting PHAs. He had not received any specific training in trailer siting PHA, but this was not a requirement, and he considered that he was fully authorised as a PHA leader. His knowledge about trailer siting PHA had been gained from the mentoring and the documents he had downloaded from the Texas City PSM website.

The ULC Motorization Project Manager contacted the PHA leader one afternoon in September 2004, and the next morning they performed the PHA. The ULC Motorization Project project engineer convened the meeting. It was attended by the Project Manager and the PHA leader, three operations people from the ULC, a safety specialist from J.E.Merit and two union health and safety representatives. Crucially there was nobody at the meeting from the ISOM.

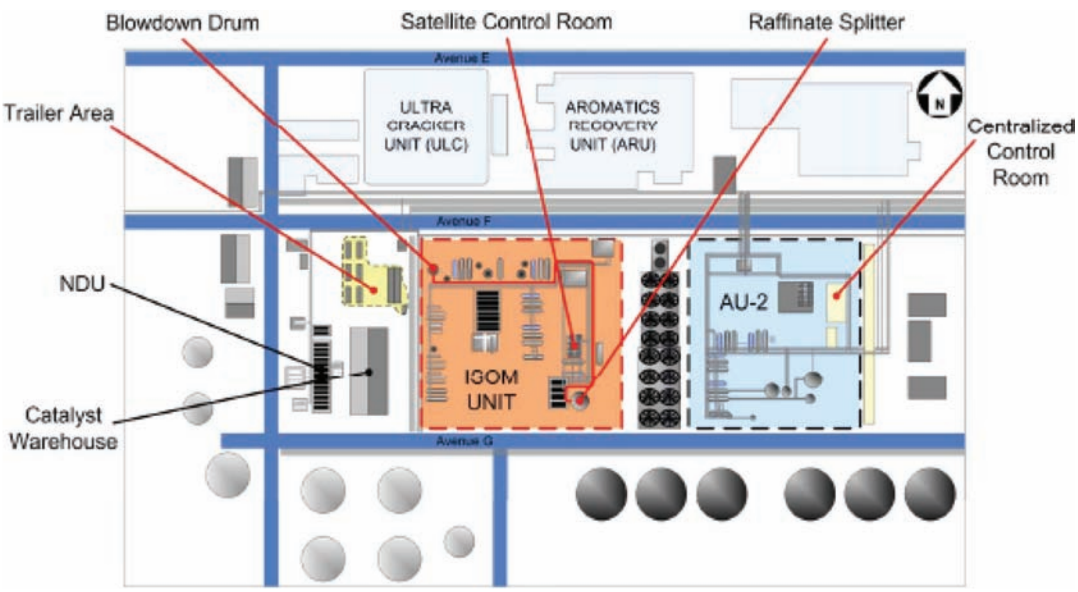

Figure 1. Plot plan of the ISOM and adjacent areas (US Chemical Safety & Hazard Investigation Board)

THE TRAILER SITING PHA MEETING

The PHA Leader brought with him the documentation he had downloaded, and the relevant facility plot plans. Texas City's framework for assessing the risks to people in occupied buildings was based on a pre-merger Amoco document dating from 1995, the "Facility Siting Screening Workbook" (Sorrels and Lash 1995). The complete PHA framework, or to put it another way, what the agenda for the meeting should have comprised was (Seele 2006;204):

- A "What-If" hazard review, brainstorming hazards, guided by a checklist.
- All MOCs, including those not related to trailers, required a Supplemental MOC Requirements Checklist to be completed.
- A Process Hazards Analysis (PHA) Trailer Siting Checklist – a four page tick box check list. The checklist specified that if the trailer were to be less than 350 ft from any process unit, a facility siting analysis (risk assessment) would be required. The methodology for the siting analysis was in the "Facility Siting Screening Workbook".
- A Building Occupants Summary was required to be filled out, listing the job type, number of occupants and hours per week occupancy. This was intended as input data for the siting analysis, if required.
- All buildings, regardless of distance from units, required a Facility Siting Building Analysis Checklist to be completed. This was, according to the procedure, intended to deal with personal safety concerns.

With the exception of the facility siting analysis, the procedure required that all of these elements were to be addressed at the PHA meeting. If required, the facility siting analysis would be referred to the PSM Department, since application of the methodology required specialist knowledge.

This is a rather confusing series of documents, whose roles are not immediately obvious. They made errors at the PHA meeting. They failed to identify the risks from the nearby ISOM, and did not follow the PHA procedure.

FAILURES AT THE PHA MEETING

The What-If analysis should have been the time when the team would identify the hazards due to fires or explosions from nearby process units. It did not. But it did identify other hazards, including the hazard of the use of forklift trucks in the nearby Catalyst Warehouse (Seele 2006;207). They were concerned that a pedestrian from the trailer could be struck and injured or killed. At deposition the PHA leader recounted how the team had discussed a fatality which had occurred at BP's Cooper River site. A pedestrian had been crushed by a forklift truck. They had been made aware of this incident through an internal company bulletin. They recommended to consider closing the road which ran from Avenue "F" to Avenue "G" between the ISOM and the trailer (Fig. 1). This recommendation was recorded but not implemented. Implementation of risk reduction measures was not the responsibility of the PHA team.

Although the team did not discuss explosion hazard incidents, the CSB found that there had in fact been eight serious ISOM blowdown drum incidents at Texas City from 1994 to 2004. In two the blowdown system had caught fire and in six the blowdown system had released flammable hydrocarbon vapours that had resulted in a vapour cloud at ground level. In 2004 there had been a liquid hydrocarbon release out of the ULC blowdown stack. A supervisor observed that "liquid began to spew out of the top of the [blowdown system]", which then fell to ground level. At deposition the PHA leader was asked:

> *Q. Do you recall any concerns being raised by anyone in the meeting about locating that trailer in that close proximity to an operating unit? PHA Leader. . . . no.*

Despite the incidents in the ISOM and the ULC, there was no discussion about previous incidents at the meeting.

There was a question in the Process Hazards Analysis (PHA) Trailer Siting Checklist which asked:

> *"Is the trailer located at least 350 feet from any process unit? If "No", perform a facility siting analysis."*

The PHA team answered "No", and wrote "Closest unit is NDU". Indeed the NDU was nearby, but the ISOM was even closer. In fact the trailer was to be sited less than150 ft from the ISOM unit. But the PHA leader did not refer the MOC for a Facility Siting Screening Analysis. Examination of the PHA leader's deposition (Seele 2006;238) explains why:

> *Q: What is the purpose of the building analysis checklist for facility siting? . . . Do you fill this out in every instance when you are locating a trailer or only when the trailer is within 350 feet of a unit?*
>
> *PHA Leader. My understanding was that this was only filled out when a trailer was within 350 feet of a unit . . . As a result of the question that asks if it was within 350 feet, this checklist was required.*

So the PHA leader was under the mistaken belief that the Building Analysis Checklist was the facility siting analysis for buildings closer than 350 ft to a unit. In fact it was only intended to deal with personal safety and was required to be filled out for all building PHAs. The facility siting analysis (the occupied buildings risk assessment using the workbook) was consequently not done.

RISK ASSESSMENT METHODOLOGY NOT SUFFICIENTLY PROTECTIVE

Even if the PHA leader had initiated a Facility Siting Analysis, as prompted by the checklist, the analysis methodology was not sufficiently protective. The Facility Siting Screening Workbook (Sorrels and Lash 1995) would anyway have underestimated the risk. The Workbook had been published by the Amoco corporate process safety department in Chicago in 1995, and Texas City had at that time used a summer student to apply the analysis to buildings throughout the refinery.

CONSEQUENCE ASSESSMENT

The workbook provides a methodology which predicts the overpressure at a particular distance from a vapour cloud explosion in a congested volume of plant equipment. Charts are provided which relate overpressure as a function of the volume of the congested volume and the distance from it. The methodology proceeds to provide an estimate of the vulnerability (probability of being killed) for building occupants as a function of the overpressure and type of building construction.

SCREENING CRITERIA FOR SAFE DISTANCES

The workbook lists safe distances to screen out buildings which do not need to be further analysed. Mogford (2005) noted that these screening distances were too low for a number of reasons, including that the vulnerability prediction charts were not sufficiently protective. For wood frame and siding buildings such as trailers, the screening distance was 350 ft.

An MOC was required in all cases, but if the building fell outside the screening distances, no facility siting analysis (risk assessment) was required. Trailers were allowed to be closer than other buildings such as steel framed ones because, according to the Amoco Workbook:

> "*Data from actual events indicate that trailers tend to roll in response to a VCE, and walls and roofs do not collapse on occupants, resulting in fewer serious injuries/fatalities*."

This statement is problematic for two reasons. Firstly, at Texas City trailers were tied down to resist hurricanes and therefore will not roll. This was pointed out by the summer student in 1995, but it appears that his comment was not acted upon. Secondly, this is a strange mitigation to claim; I have been unable to find any other literature either which gives similar advise regarding rolling, or that under any circumstances trailers represent a lower risk to occupants than steel framed buildings.

Scaling from the drawings in the reports is not straightforward because they are not given scales. Nevertheless, scaling from CSB (2007) Fig H-2 p263 would seem to indicate that, had the trailer been situated at 350 ft from the blow down drum, it would have seen an overpressure of approximately 1.5 psi peak side on. According to CCPS (1996;65) this would have resulted in a vulnerability of 25%, or approximately 5 fatalities.

An analysis by BP of the ISOM scenarios in 2002 using the Facility Siting Screening Workbook, for a trailer at approximately the same position as the Merit trailer predicted an overpressure of only 1.5 psi peak side on. According to the workbook, at this overpressure there would not have been any fatalities. This is not consistent with the then standard reference CCPS (1996) which would have predicted 25% vulnerability. API 752 (2003) would have provided a similar conclusion to CCPS (1996). Of the 22 people in the J.E. Merit trailer, 11 were killed, which represents an actual vulnerability of 50%. Mogford (2005;100) reported that the actual overpressure at the trailer was estimated to be 2.5 psi peak side on; the CSB (2007;261) estimated 2.8 psi. CCPS (1996) predicts a vulnerability of 50% for 2.5 psi.

The CSB posted information about actual trailer damage at Texas City on their web site (CSB 2006). The data included details of the injuries and structural damage that occurred among some 44 different trailers that were located in the vicinity of the ISOM. They reported that the roof of a wooden trailer 249 ft from the ISOM was no longer present after the explosion and the walls had been destroyed. Occupants were injured in trailers as far away as 479 feet from the drum. Damage was noted in trailers almost 1000 feet away. At a distance of 597 feet from the source of the flammable vapour, the roof of one trailer collapsed and its walls were heavily damaged.

Vulnerability prediction is not an exact science. Examination of aerial photographs of the ISOM after the explosion show evidence that the event was more complex than a single explosion radiating a hemispherical blast wave. Nevertheless it appears reasonable to conclude that although application of the 350 ft rule would have reduced (possibly halved) the number of fatalities, it would not have achieved its objective of keeping the trailers at a safe distance.

RISK ASSESSMENT

For the building under study, the workbook specifies that all congested volumes which could generate damaging overpressures be taken into account. For each congested volume, the workbook uses a frequency of VCE of 4.3×10^{-4} per year. This figure is the average of all refinery plants as reported in CCPS (1996) and is an annualised frequency. It is therefore an underestimate of the frequency of incidents during startup which are known to be more hazardous. As it happened, the frequency was irrelevant, because the workbook predicted no fatalities. But if the CCPS (1996) vulnerability curves had been used, this too optimistic frequency would have resulted in predictions of individual and population risk which were low enough that no action would have been required.

SUMMARY OF THE PROBLEMS WITH THE TRAILER SITING PHA

The following deficiencies were found in the Merit trailer PHA or risk assessment:

- The PHA failed to recognise the existence of explosion hazards in the "What-if" exercise.
- The PHA failed to consider relevant past incidents.

- The PHA failed to recognise that a risk assessment using the Facility Siting Screening Workbook was required.
- If the risk assessment had it taken place, it would have predicted that there was no risk to the people in the Merit trailer, and that the location was acceptable.
- If the trailer had been sited 350 ft from the ISOM, as required by the refinery procedure, 5 or 6 people of the 22 occupants would probably anyway have been killed.

COULD THE ERRORS IN THE TRAILER SITING RISK ASSESSMENT HAVE BEEN PREVENTED BY RULE COMPLIANCE?

Examination of the completed trailer siting PHA forms and the follow up interviews, (Seele 2006 and Bonse-Geuking 2006a), indicate that the PHA leader took his responsibilities seriously and performed them with diligence. He had responded promptly to the request to lead the PHA; he had downloaded the forms and check lists from the PSM website and had filled them out; the results were communicated to the ISOM Superintendent and the PSM Department. He was not asked at deposition whether any of his previous trailer PHAs had related to siting positions less than 350 ft from a unit. If he had and those had been similarly incorrect, it would have been instructive regarding root causes of his misunderstanding.

Nevertheless he made some serious mistakes and omissions. His failure to initiate the facility siting analysis appears to have been a "routine violation" of the PHA procedure (Reason 1990). But application of a just culture model (Reason 1997), in particular the substitution test, would indicate that he was not culpable. At interview the PSM Manager said that the PHA leader had misunderstood the 350 ft. question in the PHA check list, which is correct. But he went on to say that the facility siting "check list" had not been done. The facility siting analysis in the workbook is definitely not a check list, so one wonders whether the PSM Manager might have been confused about the procedure (Bonse-Geuking 2006b).

The following exchange took place with the PSM Manager's boss, the HSSE Manager during deposition (Barnes 2006;163):

Q. Did you ever go look around the facility at all?

HSSE Manager. Absolutely. I am commonly out in the plant . . . .

Q. Do you ever look for safety violations ensuing?

HSSE Manager . Absolutely.

Q. Do you think putting a trailer next to an ISOM unit like this might be a safety violation?

HSSE Manager. I could say that it's – based on the knowledge that we have now with the events that occurred, it was – it was one of the causal factors that created the results of March 23rd. It by itself did not create the incident.

So it would appear that prior to March 2005, despite the 350 ft rule, the HSSE Manager would not have regarded the position of the Merit trailer as a safety violation.

On the basis of these interview responses, it seems quite possible that the PSM and HSSE Managers would have made the same mistake as the PHA leader.

On the face of it, the failure of the PHA team leader to initiate the facility siting analysis could be attributed to a failure of rule compliance; its initiation should have been triggered by the trailer being between two operating units and less than 350 ft from both. It might be possible to attribute his failure to consider explosion hazards in the "what-if" to the lack of or failure to apply a suitable rule about considering explosions hazards. But a more complete explanation would appear to be that the PHA and the team were placing too much reliance on the PHA process. Their goal was to comply with the MOC procedure rather than manage the risks. Rather than viewing their goal as complying with the MOC procedure, if they had regarded it as managing the risks, they could apparently have thrown away the MOC procedure and done a better job.

INFORMAL TRAILER SITING RISK ASSESSMENT BY A CONTRACT I&E TECHNICIAN

Evidence that the accident was a consequence of failed rule compliance and could have been prevented by risk management is illustrated by the following story. An instrument and electrical (I&E) technician who had had no training in trailer siting had expressed worries about the trailers between the ISOM and the NDU (Runfola 2006). He was of the opinion that the ISOM was in poor repair, a "pretty raggedy unit". He had raised his concerns about the position of the trailers with the ISOM Superintendent and the West Site Manufacturing Delivery Leader (MDL). To his credit the West Site MDL took the technician's concerns seriously enough to follow them up. But his follow up was only to check that an MOC and PHA had been done. The West Site MDL responded to the technician that the matter was "out of his hands" because an MOC had been done, and the trailers complied with the site policy. This kind of *learned helplessness* is evidence of a rule compliance culture. In fact the West Site MDL did have the authority to relocate the trailers if he had wished. The I&E technician had done an informal risk assessment and concluded the trailers were unsafe; the people responsible had complied with the procedure (as far as they understood it) and had concluded it was safe. Rule compliance had come up with the wrong answer. The technician said that he went into one of the trailers a week or so before the incident and told them, "It would be a good idea if y'all contacted operations to find out when they are going to start [the ISOM] up because you don't want to be here during the startup."

TRAILER SITING RISK ASSESSMENT SHOULD NOT BE LIKE TORTURING A SPY

Hopkins (2008) argues that the decision on the trailer siting could better have been controlled by compliance with a centrally determined rule. Such a rule, although based on risk assessment, would he says be less subject to the desire to justify an outcome, and be less subject to bias. He says that a risk assessment carried out in a plant puts pressure on risk assessors. He goes on to say "It is almost inevitable that local risk assessments of this nature [facility siting] will be carried out by people who are not competent".

But the centrally determined rule was in this case not sufficiently protective. None of the material published gives an indication why that might have been the case. The information on building structural assessments was provided by EQE International who were at the time a leading authority on seismic risk assessment. Maybe wood framed buildings respond better to seismic loads than blast waves. Or it might have been because the authors were concerned about the perception of "head office" imposing draconian measures on the refineries. We do not know. The Amoco Process Safety Director who was in post in Chicago in 1995 when the workbook was published said at deposition (Sorrels 2006;93 et seq.) that it was developed over approximately two years and took full account of available information including API 752. He also commented that it was at the time of the accident about five years overdue for revision.

Decisions on trailer siting in many cases involve a fairly simple risk assessment, since often the cost of positioning them outside of damaging blast contours is low. So risks as low as reasonably practicable (ALARP) in those cases is zero risk. In that case, the risk assessment only needs to consider the relevant major accident scenarios.

It has been said that risk assessment is like torturing a spy. If you do it for long enough you will get the answer you want! Risk assessment must always be done carefully and honestly by competent people.

FINAL THOUGHTS ON THE TRAILER SITING

It would appear then that there was too much reliance on rule compliance in relation to trailer siting. The PHA leader diligently followed the wrong rules. The HSSE Manager was not enforcing the rules. The PSM Manager appeared somewhat confused about the rules. The West Site Manager placed too much reliance on the MOC rule. Only the I&E technician did an adequate risk assessment, and he did that without reference to any rules. Finally, I disagree with the conclusion in Hopkins (2008;50) that if the refinery had applied the 350 ft rule it would probably have prevented all the fatalities; I think 5 or 6 people would probably anyway have been killed.

BLOWDOWN DRUM VENT

Prior to the BP merger in 1998, Amoco had had a large process safety group in Chicago (Bonse-Geuking 2006c), which was responsible for 35 to 40 process safety standards (Sorrels 2006;118). One of these was Process Safety Standard No. 6, "Flare, Blowdown, Pressure Relief, Vent and Drain Systems for Process Units". It was originally issued September 20, 1977 and updated in 1986, 1990, and 1994 (Mogford 2005;109). The version in force at the time of the incident said:

> *... 1) New blowdown stacks which discharge directly to the atmosphere are not permitted.*
>
> *2) When the size of the existing facility is outgrown or when major modifications are made to the existing facility, existing blowdown systems which are still necessary should be replaced with connections to depressure via another processing unit, hydrocarbon-recovery system, or flare.*

The CSB (2007;108) were of the opinion that three modifications had taken place between 1985 and 2003 which according to this rule should have triggered connection of the vent to flare. In particular, in 1997 the blowdown drum and vent were completely replaced due to corrosion. BP managers stated in interviews after the incident that the 1997 work was a "replacement in kind" and therefore should not trigger the conversion to a flare system. The lawyers found this curious (Sorrels 2006;145).

> *Q Have you ever bought a new refrigerator or dishwasher for your house?*
>
> *A. Yes I have.*
>
> *Q. Did you tell people you were buying a new dishwasher or refrigerator or did you tell them you bought a replacement one?*
>
> *A. I probably told them I bought a new one.*

Texas City had on a number of occasions considered connecting the vent to the flare, but had decided not to. They were aware of the safety problems associated with atmospheric vents. In 1992, OSHA had cited a similar blowdown drum and stack on a different unit as unsafe (CSB 2007;111). The refinery had argued that it complied with the widely accepted industry standard API RP 521, and OSHA subsequently agreed. In 1994 OSHA withdrew the citation.

Hopkins (2008;27) says that following the Texas City incident, the CSB made an urgent recommendation to the API that it revise its standard to prohibit the release of flammable material to the atmosphere. But its urgent recommendation related only to trailer siting, not to the vent design. Following the incident, the CSB's recommendation (2007;241) to the API regarding vent design was rather more circumspect and did not recommend prohibition. They recommended that API revise the standard "to ensure that the guidance .... warns against the use of atmospheric blowdown drums and stacks attached to collection piping systems that receive flammable discharges from multiple relief valves and urges the use of appropriate inherently safer alternatives such as a flare system."

I disagree with the conclusion in Hopkins (2008) that "had there been a rule based approach rather than a risk management approach to the question of replacing the vent with a flare, the tragedy at Texas City would most likely have been averted." They had a rule but did not follow it. With the history of incidents it might have been clear, even without a formal risk assessment, that this was a problem in need of a solution. Anyway a rule which says "all vents must go to flare" is hard to conceive, and will be subject to "situational violations" (Reason 1990), with attendant risks. The CSB's circumspection is not surprising. There are many cases where an atmospheric vent is quite acceptable. There are even cases where an atmospheric vent is safer. The guidance in API RP 521 (2007) recognises that this is a matter for risk management.

OTHER EVIDENCE OF UNHELPFUL RULE COMPLIANCE AT TEXAS CITY

THE 25% FIXED COST CHALLENGE

In 1999, after the merger, BP issued a company wide challenge to each of the refineries to further cut their fixed costs by 25% without jeopardising asset integrity (Baker 2007;82). The Coryton UK manager refused to commit to this target, citing earlier cost cutting and lack of scope for further reductions. He described the challenge as "non-sensical" (Maslin 2006). The manager of the Kwinana Australia refinery "took it with a grain of salt" (Lucas 2006). In the six years prior to the merger, Amoco had also cut maintenance and capital spending at Texas City significantly. Nevertheless refinery management took the challenge "very seriously" (Carter 2006), and offered a 28% reduction. Progress towards this milestone was a target in each refinery manager's performance contract, and the Coryton manager suffered career consequences as a result of his refusal. Nevertheless, the Coryton and Kwinana managers had decided that the risk of implementing the reduction was too great. Texas City complied with the rule. Subsequently a 2002 internal study indentified integrity problems and recommended an increase in maintenance spending of $235 M a year. The same study criticised the refinery for a "can do but can't finish" culture.

INEFFECTIVE COMPLIANCE

CSB (2007;181) found that rather than actual control of major accident hazards, BP Texas City managers relied on an ineffective compliance based system that emphasised completing paperwork. The trailer siting PHA had been performed in a tick the box manner with insufficient risk assessment; overfilling the raffinate splitter had been checked off as not credible; critical steps in the start-up procedure were checked off, but were not complete; an out of date version of the start-up procedure was checked off as being up to date.

ORGANISATIONAL GOALS FOCUSED ON RULE (REGULATORY) COMPLIANCE

At deposition the PSM Manager was questioned extensively about what his job entailed, and his views about how process safety should be managed. His responses consistently referred to compliance with the 14 elements of OSHA PSM (e.g. Ralph 2006 Vol 2;337) "So if you don't remain vigilant across all of the 14 of those elements, then it's possible that one of those potential hazards could manifest itself in a catastrophic event." A PSM Manager in a risk management culture would be more likely to respond that his job was to manage the risks of major accident hazards.

WIDER SYSTEM CONDITIONS WHICH IMPEDED PROCESS SAFETY MANAGEMENT

MONETARY VALUE OF PREVENTING A FATALITY

Demonstration that risks are as low as reasonably practicable (ALARP) can be achieved either by applying an accepted standard (a rule), or if no suitable standard is available, by analysing the cost of the risk reduction in relation to its benefit (HSE 2002). Such a cost benefit analysis may involve assigning a monetary value to preventing a fatality (VPL). This is an inherent part of risk assessment, and is applied in the US in decision making related to aviation and road transport (see e.g. Federal Aviation Administration 2008). Nevertheless it was not widely in use in BP in the US (e.g. see Sorrels 2006;311), and would appear to have been culturally difficult in the US. This might be a legacy of the commonly held opinion in the US, that the Ford Motor Company acted irresponsibly in using the VPL concept to decide whether to implement risk reduction measures on the fuel tanks of Pinto cars (Grimshaw v Ford Motor Co. 1981). With its US heritage, Amoco's process safety decision making practices were base on standards, which as we have seen, resulted in some problems.

LEGACY COMPANY CULTURAL MISALIGNMENT

A rule compliance culture can work (see below), but there is evidence that this was impeded at Texas City by cultural misalignments, which existed between the legacy BP and Amoco organisations. These had not been resolved, even six years after the merger. According to an internal email discussing risk assessment using the value of preventing a fatality, "BP embraced ... cost benefit analysis. Amoco was generally unwilling to take this step" (Mancini 1999). Training was given at Texas City on this aspect of the BP approach to major accident risk assessment (BP 2002). But Texas City were in 2005 still attempting to apply the legacy Amoco philosophy of adherence to standards, even though those standards were no longer being maintained and were in the case of facility siting ten years old. Schein's (1992) model of organisational culture comprises three layers: *artefacts*, the visible organisational structures and processes; *espoused values*, the strategies goals and philosophies; and *underlying assumptions*, the unconscious, taken for granted beliefs. After the merger BP appears to have imposed organisational artefacts on the legacy Amoco sites which were designed around a risk management culture. But this was incongruent and dissonant with the espoused values and underlying assumptions in the US, which remained strongly rule compliant.

HEALTH & SAFETY REGULATORY FRAMEWORK

The health and safety regulatory systems in the US and the UK comprise three tiers. The top tier in both countries is an act which sets out broad duties. The second tier in the US comprises regulations or standards which are prescriptive in nature, and do not address risk management. Regulation 1910.119, also known as OSHA PSM (Process Safety Management) prescribes the use of process hazard analysis, but it is not until the non-mandatory third tier ("interpretations") that the issue of risk is dealt with directly. In the UK, the second tier also comprises regulations, but these impose a duty to carry out suitable and sufficient risk assessment (e.g. HSE 1999). The third tier provides (mostly) non-mandatory guidance. Similar comments apply to Regulation 40 CFR 68 EPA Chemical Accident Prevention, and although sites have to develop a "Risk Management Plan", it is more concerned with consequence than risk.

INTERPERSONAL INTERACTIONS BETWEEN SENIOR MANAGERS

Engagement of senior managers is important in successful process safety management (Webb 2008). This is especially the case in a risk management culture. This engagement process was hampered by "accountability delegations [which] were muddled and confusing throughout the organization from the ISOM unit all the way to the R&M [Refining & Marketing] leadership" (Bonse-Geuking 2007). There were also relationship difficulties between managers. There was a "stand-off" between the Chief Executive of the R&M Segment and the GVP Refining & Marketing, who was accused of having created "fortress refining". The Regional VP North America was responsible for appointing the Texas City Refinery Business Unit Leader but acknowledged that this person did not appreciate him as a supervisor and did not communicate with him; he considered him to be weak, and brought in an additional manager to strengthen the operational management at the refinery, but did not give her support.

HAVING A "PASSION FOR SAFETY" IS NOT THE SAME AS BEING COMPETENT TO MANAGE IT

People in key management positions did not have the right HSE competences. The Refinery HSSE Manager (responsible for process safety) who had failed to recognise breaching of the 350 ft trailer rule as a safety violation, claimed to have a "passion for HSSE" (Barnes 2006). But he had no previous management or professional experience in HSSE in general, or process safety in particular. He had insufficient knowledge of the requirements of OSHA PSM. This is a significant problem in a culture which relies on rule compliance. His aspirations were to be in the HSSE post for three years and move on to be a business unit leader. People with HSE functional responsibilities must have competence in the relevant aspects of HSE management. The West Plant Manufacturing Delivery Leader who failed to act on the I&E technician's concerns, had begun his career as an operator and had had no technical education; he was renowned for having his own way of doing things. Line managers must have held jobs where they have been responsible for analysing and assessing process safety risks, for example as process engineers preparing safety cases.

HOW DO HIGH RELIABILITY ORGANISATIONS DEAL WITH RULES?

Organisations such as the better run nuclear powered aircraft carriers, air traffic control systems and nuclear power plants rarely fail. This is even though they encounter unexpected events. Weick and Sutcliffe (2007) attribute the success of these high reliability organisations (HROs) in managing the unexpected, to their determined efforts to act mindfully. Mindfulness preserves the capability to see the significance of weak signals and respond vigorously. Reliability is a dynamic non-event. It is a non-event because safe outcomes go unnoticed. Processes remain within acceptable limits due to moment-to-moment adjustments and compensations by human operators.

Several practices at Texas City showed evidence of not being aligned with the principles of HROs. If they had been *preoccupied with failure*, the previous releases from blowdown drums would have been considered during the trailer siting PHA. If they had been *reluctant to simplify*, the trailer siting PHA procedure would have been less "tick box" and more analysis. The decision on a number of occasions not to reroute the blowdown drum vent to flare was an attempt to oversimplify a decision by the application of a rule. If they had been more *sensitive to operations* they would not have allowed the "25% fixed cost challenge" to affect integrity in the way it did.

If they had been *committed to resilience*, the trailer siting PHA would have included somebody who understood facility siting risk assessment. If they had shown *deference to expertise* they would have acted on the summer student's comment that credit should not be taken at Texas City for trailers rolling in response to blast waves; the E&I technician's comments about the unsafe location of the J.E. Merit trailer would have been heeded. HROs push decision making down and around.

According to Weick and Sutcliffe (2007), unvarying performance cannot cope with the unexpected. Rule compliance cultures have unvarying performance as one of their main objectives.

CAN A RULE COMPLIANCE CULTURE WORK?

Bourrier (1998) spent three to five months at each of four nuclear power plants in France and the US, analysing their maintenance activities. She examined the daily activities during annual and decennial shutdowns, which in the nuclear industry are highly proceduralised. Adjustments and micro-deviations are nevertheless required to get the job done. She observed that whether these adjustments were done openly and legally, or secretly and illegally was dependent on whether the organisation had *built in processes* that enabled workers to modify rules. At Diablo Canyon, California, US for example, they applied "verbatim compliance", and workers complied strictly with the procedures. Hale et al. (2003) suggest a seven step model for a rule management process, the last two of which are "Monitor, enforce and evaluate" and "Modify rules". At Diablo Canyon, if a procedure was found to be inadequate, it was immediately referred to a "section engineer" for modification. There were as many section engineers as maintenance foremen. The disadvantage of this organisation is that it is expensive, and Bourrier noted that costs at Diablo Canyon were such a problem that a major reorganisation had been initiated. Bugey, France did not have such an organisation, and procedures were violated by informal processes. There was a greater reliance on the competence of the workers to know where the boundaries of safety were, and they learned this through a long apprenticeship. She did not find statistically significant differences in performance between the sites she studied.

It is important to note that the procedures which the nuclear power stations were successfully using were locally set and the process of procedure monitoring and modification was locally managed.

It is easier to write good rules when the range of technologies across which they have to work is narrow. Regarding the mining industry in Queensland Australia, the government has not left the risk assessment hazard identification step to the operating companies (Hopkins 2002). They have prescribed that companies develop management plans for six "principal hazards" specific to the industry: ventilation management, gas management, emergency evacuation, methane drainage, spontaneous combustion and strata management (roof control).

So a rule compliance culture can work, especially in a narrow field, if the organisation is in place to deal with rules which are wrong or inadequate. But there is another problem. Hopkins (2005;16) writes how workers in New South Wales underground coal mining were subject to a government inspectorate rule not to stand under unsupported roofs. Studies showed that the rule was being routinely violated, because it was causing the miners to expose themselves to other risks which they judged as more severe – for example falls of coal from the side wall, being hit by machinery and other vehicles. In the major hazards industries, the risks of complying with a bad rule (such as the facility siting analysis), or deviating from a good one (for example that the blowdown drum should have been connected to flare) are not as obvious as falling lumps of coal.

CONCLUSIONS

This paper has argued that the individual and collective decision making practices at Texas City would have been more successful if they had been more concerned about the output than the process. I have argued that process safety management should be more about risk management and less about rule compliance. The work of Bourrier (1998) showed that properly functioning rule compliant cultures are heavy on resources, but that is not to say that risk management is "easy". The following lessons can be learned from the Texas City experience, about what is required for risk management to work.

Safety must rank high in the corporate goals.

Senior managers must be engaged in process safety. Webb (2008) argued that process safety performance indicators is one tool which they can use to get engaged.

Organisational structures, accountabilities and lines of communication relating to process safety must be clear all the way to the top. Interpersonal "stand offs" and organisational "fortresses" will impede this process. 360° appraisals are a tool which can help to manage this (O'Dea & Flin 2003;65).

People at all levels must understand the hazards, their potential consequences and the risks at their own organisational level. They must be "sitewise". They must be kept "situationally aware" by training, exercising and through performing risk assessments.

During organisational change, cultural differences must be recognised, acknowledged and a strategy developed for dealing with them. Trying to force two cultures together can introduce risks. Also, the approach taken to health and safety management has to be consistent with the broader style of general management (Wright 1996). Care must also be taken during organisational change if structures which previously supported management processes will be affected, such as the dismantling of the Amoco process safety department in Chicago which had previously supported the process safety standards.

Risk management involves several layers of decision makers: government, authorities (regulators), company, management, staff. Influencing of performance from one layer to the next is best achieved by transmitting expectations in guidelines and goals.

There has to be trust between the different layers of decision makers. This is also true between authorities and companies (Williams 2002).

Rules work best when they are created and managed within a layer, by people seeking to meet expectations. Nevertheless, there will be rules which will need to be transmitted between the layers – rules requiring management processes to be in place, for example compliance with a management standard such as ISO14001; incident reporting arrangements so that senior managers get a reliable indication of performance across the company; technology specific design rules. Especially when rules are required to work between layers, care must be taken to ensure that there are strong lines of communication. This is so that rule users can get clarification, interpretation and if necessary exemption, and so that rule writers can find out about the need for revisions.

Organisations must establish process safety management competence criteria for all roles with process safety responsibilities. This includes roles from engineers, PHA leaders, maintenance technicians and operators up to site managers and vice presidents. The criteria must reflect the specific nature of process safety risks in the role's field of responsibility. Rules should not be seen as an alternative to competence, especially since maintaining risk awareness is more difficult when people have rules available to them; risk awareness and competence are closely linked.

The evidence is that implementation of risk management processes which meet these criteria will not only achieve better process safety performance, but will do it more efficiently with resources focused more on delivering performance and less on managing the system.

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