RISK ASSESSMENT

Tom Smith – Davas Ltd

Use of shells – Risk assessment

- Shell failures
- The difference between RISK and HAZARD
- Individual and societal risk
- Operators and Audience
- Risk assessments
- Cost/benefit analysis of controls

Health warnings!

- This approach is illustrative only
- It is not the only way of doing things
- It does not replace your doing adequate assessments of risk for your operations, methods, materials etc
- Assessments of risk are NOT THE SAME as "doing a risk assessment"!

Failure Modes

- Where the shell performs "properly"
  - Shell drift
  - Low bursts
- Where the shell fails
  - Muzzle breaks
  - Flowerpots
  - Duds
- Where the mortars fail
  - Mortar failure
  - Rack failure

RISK and HAZARD

- HAZARD is the intrinsic harm the action might do
- FREQUENCY is a measure of the likelihood of that situation occurring
- RISK is a measure of both the hazard AND the frequency

RISK calculations

- RISK = HAZARD x FREQUENCY

Individual vs Societal risk

- INDIVIDUAL RISK
  - The risk to a specified individual
- SOCIETAL RISK
  - The risks to the population as a whole
- Here we will effectively look at both as we are considering risks PER SHELL FIRED

Individual risk

- 10^{-6} – broadly acceptable
- 10^{-5} – 10^{-4} ALARP (10^{-3} for workers)
- $>10^{-4}$ - unacceptable

Societal risk

- Number of people affected vs frequency
- Public perception
- Society has a greater aversion to an accident killing 10 people than to 10 accidents killing one person each
  - Nuclear disasters
  - Road traffic accidents
  - Firework accidents

Risk Assessments

- Qualitative
  - Too simple
- Semi quantitative
  - BPA recommended approach
  - Frequency = 1->10, hazards = 1->10, Risks = 1->100
- Quantitative
  - Merited in this case

Aims of Risk Assessment

- Identify risks
- Rank them to see which are broadly acceptable, unacceptable etc
- Address those in between – determine if the risks are ALARP
- Put in effective, but cost justified, control measures
- Monitor effectiveness
- Review etc etc

ALARP

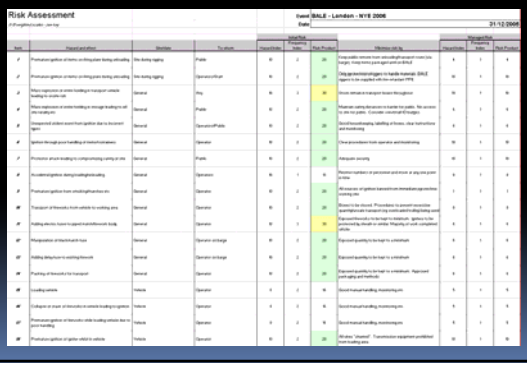
- As Low As Reasonably Practical
- By definition - has Cost/Benefit implications
- Control measures may vary depending on the circumstances of the risk
- http://www.hse.gov.uk/risk/theory/alarp1.htm

Determining that risk has been reduced ALARP

- Thus, determining that risks have been reduced ALARP involves an assessment of the **risk** to be avoided, of the **sacrifice** (in money, time and trouble) involved in taking measures to avoid that risk, and a **comparison** of the two.
- This process can involve varying degrees of rigour which will depend on the nature of the hazard, the extent of the risk and the control measures to be adopted. The more systematic the approach, the more rigorous and more transparent it is to the regulator and other interested parties. However, duty-holders (and the regulator) should not be overburdened if such rigour is not warranted. The greater the initial level of risk under consideration, the greater the degree of rigour HSE requires of the arguments purporting to show that those risks have been reduced ALARP.

(HSE website)

Semi-quantitative RA


Risk Assessment

Operators and Audience

- Normally - Have to consider both
- Some things that reduce risk for operators MAY increase risk to audience (and *vice versa*)
- HOWEVER – for the following we will look at risks to audience only

The "gotcha"

- If something goes wrong no Risk Assessment will protect you against action (but it should)
- An enforcer will always try and find something wrong
- The Courts tend to address Hazards NOT RISK
- Insurance issues

Risk Assessments

- What are the critical events to consider
- Rate of shell failure
- Rate of mortar failure
- Disruption of adjacent mortars
- Shells reaching the crowd
- Injuries/fatalities

Critical events (for crowd)

- "Normal" Fallout
- Stars landing in crowd
- "Blind" shells falling into crowd
- Shell bursts over crowd
- Mortar debris towards crowd
- Single shell fired towards crowd
- Rack disruption towards crowd

Failure Modes

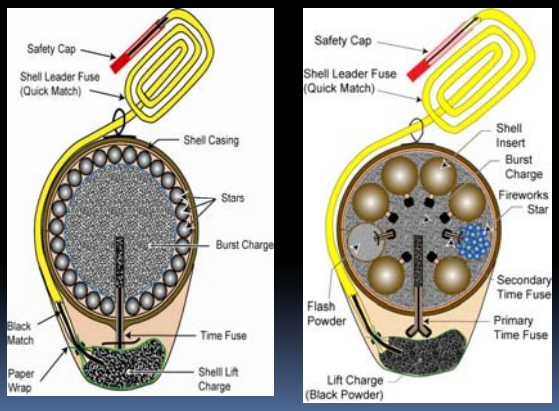
Failure	Injuries	Fatalities
Normal fallout	Yes – minor	
Stars in crowd	Yes - burns	Unlikely
Blind falling in crowd	Yes – impact or ground burst	Yes – impact or ground burst
Shell bursts over crowd	Yes - burns	Unlikely
Mortar debris	Yes	Yes - if distance short
Single shell falling towards crowd	Yes	Yes
Rack disruption and subsequent shell firing	Yes	Yes

Failure Modes

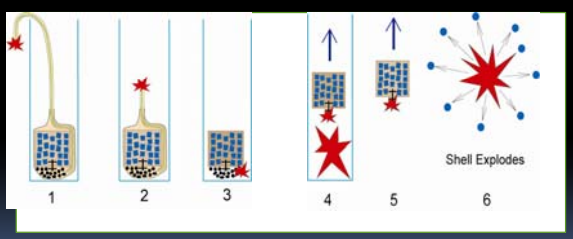
Failure	Frequency	Notes
Normal fallout	Medium	Depends on site layout/wind
Stars in crowd	Low	Depends on site and rigging techniques
Blind falling in crowd	Very low	
Shell bursts over crowd	Very low	
Mortar debris	Very low	Dependent on construction & distance
Single shell falling towards crowd	Very low	Shell unlikely to reach crowd – treat as low burst
Rack disruption and subsequent shell firing	Very low	**This is what we shall consider further – but don't ignore the others!**

Historical data

- Medium/Large UK display company
  - Fires approx 50000 shells per year in 100 shows
  - About 5 shows have evidence of lit debris on crowd
  - About 3 insurance claims per annum (trivial to serious)
  - Operators reports from 20 shows say some shells performed badly (trivial to serious)
  - About 5 mortars per year show signs of some distortion/explosion



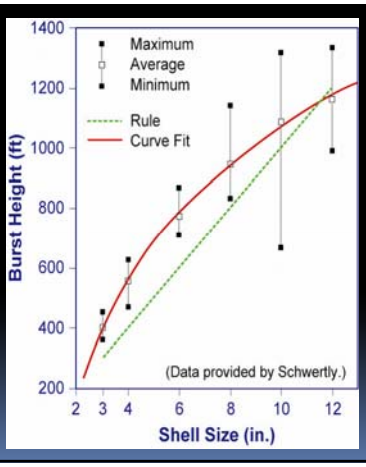
How do shells perform



Shell heights

- "Rule" is 100 feet per shell inch

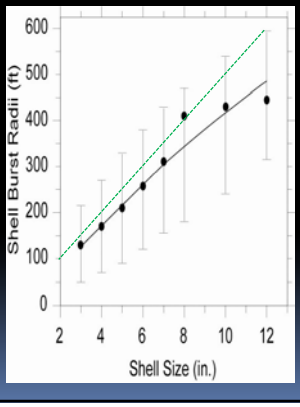
(ie somewhat underestimates)



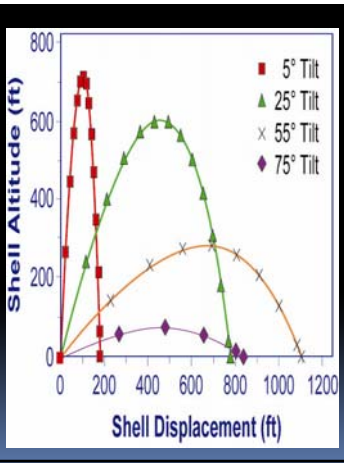
Shell Bursts

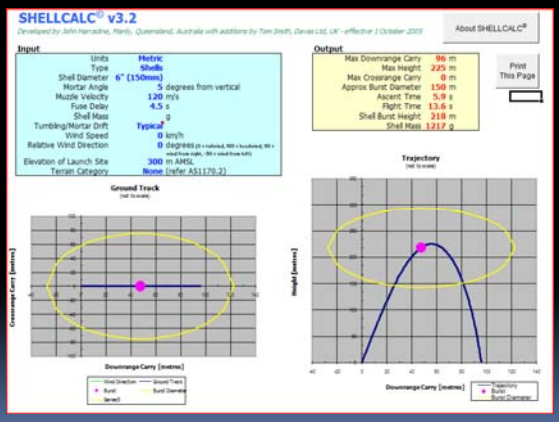
- "Rule" is 50 feet per shell inch

(ie somewhat overestimates)



Shell drift



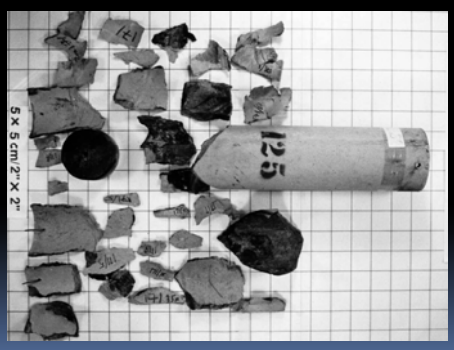


Malta

Rate of shell failure

- 50000 shells / 100 shows = average 500 shells per show (take this as medium show)
- 50000 shells /5 accidents = 1 accident per 10000 shells fired
- 50000 shells / 20 reports of malfunction = 1 shell in 2500 reported as malfunctioning
- 50000 shells / 5 mortar failures = 1 in 10000 shells fired

Paper – Star shell



Duds

Pessimistic views

- about 1 in 100 shells fired fails to perform EXACTLY as desired
- About 1 in 100 of those cause mortar damage
  - (ie 1 in 10000 – as observed)
- How many effect racked mortar tubes leading to disruption?

Shells failing in tube

- Simple failure
  - Tube distortion
  - Low burst
  - Flower pots
  - Muzzle breaks
- Complex failure
  - Ejects shell at low trajectory
  - **Leads to rack disruption**

Rack disruption

- Are there shells in affected tubes?
- Are there control measures to halt firing?
- How many shells will actually fire?
- How many will fire towards audience?
- How many shells will reach audience?
- How many shells will burst to affect audience?
- Effects on audience?

Rack failure

Rack disruption

- If racks contain on average 5 tubes, then
  - Some failures can affect more than one adjacent tube
  - 1 out of 5 does not affect adjacent tube (ie it is the last to fire)
- If racks are stacked together then this effect is diminished
- ASSUME any disruption of a mortar rack affects at least 2 adjacent shells

How likely is a shell to fire from a disrupted rack?

- Method of firing – electrical vs manual?
- Spark-proofing of fuses?
- Mortar integrity
- ASSUME 1 in 10 shells in disrupted mortars will fire
- ASSUME 1 in 2 of those will fire with mortar essentially intact

How likely is a shell fired from a disrupted rack to reach the audience?

- Rack design, positioning, orientation and rigging
- Position of audience
  - Audience subtend small angles
  - 360° sites
- Elevation (angle) or mortar at time of firing
  - High angle firings
  - Ground skipping
  - Unconstrained/unsupported mortar effects

How many shells reach audience?

- Normal sites audience subtend approx 1/10 circle (ie 36° - to make maths easy)
- ASSUME 1 in 10 angled towards audience
- ASSUME 1 in 10 have some elevation which could reach audience (ie not too low or too high)
- NUMBER that reach audience depends on distance
- For "average" sites/shells ASSUME 1 in 10 will reach audience and cause direct hit or burst within audience (ie not just a low burst)

Impact/Burst effects

- If a shell reaches the audience without bursting:-
- ASSUME single fatality
- If shell bursts in audience
- ASSUME single fatality
- If shell bursts before audience (on ground or in air)
- ASSUME 1 in 10 fatality (ignore this for next slides as swamped by above)

Maths for medium show per shell fired

Failure	Frequency	
Any shell failure	0.01	
Shell failure leading to mortar failure	0.01	
No of shells at risk in racks	2	
Shell ignited	0.1	
Fired "normally"	0.5	
Angled towards audience	0.1	
Elevation	0.1	
Reach audience	0.1	
Fatality frequency	1	
Overall RISK per shell fired	2×10^{-8}	

Notes

- As shows get larger the proportion of shells that can reach the audience decreases as crowd is beyond shell design range
- Small Shows – 0.2
- Medium Shows – 0.1
- Large shows – 0.05

Risks per show

Show type	No of shells	Crowd angle subtended	Crowd distance factor	Overall risk of fatality with NO controls
Small	100	0.1	0.2	2×10^{-6}
Small	100	1	0.2	2×10^{-5}
Medium	500	0.1	0.1	5×10^{-6}
Medium	500	0.5	0.1	2.5×10^{-5}
Medium	500	1	0.1	5×10^{-5}
Large	2000	0.1	0.05	1×10^{-5}
Large	2000	0.5	0.05	5×10^{-5}
Large	2000	1	0.05	1×10^{-4}

Pessimistic assumptions made

- Rate of shell failure (quality is improving)
- Rate of mortar failure (quality is improving)
- Rate of affecting adjacent shells
- Fatalities (assuming 100% is very pessimistic)

Cost/benefit considerations

- How many mortars are used?
- How many times are they reused?
- How many shows?
- How much would they reduce the risk?
- What cost a life?
  - And also consider injuries

Use model from HSE's COMAH seminar – Manchester 2005

- Assumptions
  - Fatality cost = £1 million
  - Proportionality factor = 1 for risks c. 10^{-6}
  - Proportionality factor = 4 for risks c. 10^{-5}
- Take 4 costs scenarios per mortar or display
- Amortise costs over lifetime of mortar

Typical display company – "medium" show

- 100 shows per year
- 2000 mortars in stock
- Total shells fired = 50000
- Mortars resused on average 25 times per year
- Mortar lifetime = 5 years
- Shells fired in a lifetime per mortar = 125
- Total population per show = 1000 – of which assume 100 at risk

Possible risk reduction measures (medium show, people occupy 1/10 circle)

Method	Cost per mortar	Risk reduction	CBA suggests justified
Tinfoil to protect from sparks	£0.10	5×10^{-6} -> 1×10^{-6}	Yes
Waterproof fibreboard mortars	£1.00	5×10^{-6} -> 5×10^{-7}	Yes
All new mortars each year	£10.00	5×10^{-6} -> 2.5×10^{-7}	No
Redesigned racks & new mortars each year	£100.00	5×10^{-6} -> 1×10^{-7}	No

Typical "large" display

- 100000 audience
- 1000 at risk
- Work out costs per mortar for single display
- 2000 mortars

Possible risk reduction measures (large show, people occupy 180º)

Method	Total cost	Risk reduction	CBA suggests justified
Tinfoil to protect from sparks	£200	5×10^{-5} -> 1×10^{-5}	Yes
Waterproof fibreboard mortars	£2000	5×10^{-5} -> 5×10^{-6}	Yes
Additional sand barriers, new racks etc	£20000	5×10^{-5} -> 2×10^{-6}	Marginal – may be justified for large budget productions
"Catchers"	£200000	5×10^{-5} -> 1×10^{-6}	Generally No

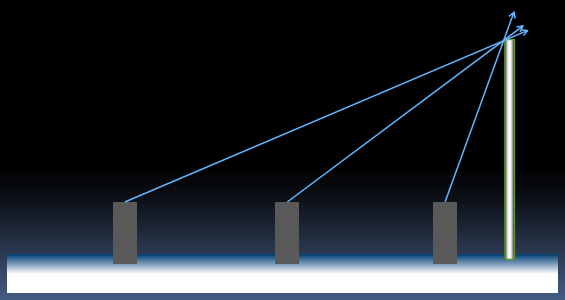
Health warning ...

- These examples are hypothetical
- YOU should adapt to suit
  - The shells you use
  - The mortars/racks you use
  - The types of displays you fire
  - The rigging methods you use
  - The failure rates you experience

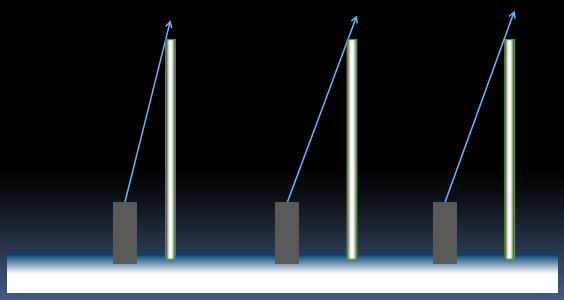
In practice ...

- Disney use "catchers" – but they fire a display every night
- Some (cheap) measures are justified for all shows
- Simple "housekeeping" (ie checking mortar/rack integrity) is essential
- Modern rack designs may reduce risks significantly – but cannot be adopted by all "overnight"

"Catchers"



"Catchers"



Conclusions

- The risks from firing shells range from "broadly acceptable" upwards – they DO NOT pose unacceptable risks
- Larger displays merit greater "in depth" analysis than smaller shows and can justify additional expenditure on risk reduction matters
- Many potential controls are not justified on Cost/Benefit analysis – BUT SOME ARE
- Beware the "gotcha"

The "gotcha"

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- An enforcer will always try to find something wrong
- The Courts tend to address Hazards NOT RISK
- Insurance issues