Assessing the Risks — Suggestions for a Consistent Semi-Quantified Approach

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ABSTRACT

Assessing the risks of an operation, the operation of a whole factory, or the consequences of firing a firework display has become a way of life. Much modern legislation, certainly in the UK, is based less on "prescription" and more on "goal setting", which requires the risk creator to determine the nature of the risk and to allow him to control it adequately. Everyone involved in almost any activity, be it sport, driving, or managing a pyrotechnic production facility, has always assessed the risks—normally in their head and on the job. Modern legislation demands that these informal processes, accurate as they may have been, be documented, monitored and revised as appropriate, partly at least to "prove" in any post-accident enquiry that adequate steps had been taken to identify the particular circumstances that caused the accident. Failing to identify a particular risk is as negligent as failing to control a risk that had been identified.

Keywords: risk assessment, consequence, hazard management

What Does Assessing the Risks Mean?

Assessing the risk is not the same as "doing a risk assessment". The latter term has become devalued. In many cases it simply involves photocopying the last risk assessment! Assessing the risks is a serious task, and although in any operation, for instance a firework display, many factors remain constant, there are always site specific factors that must be addressed.

For instance constant factors may include:

- the range of fireworks used,
- the methods of erecting mortars, and
- the firing system.

Factors that change from site to site, and crucially from event to event include:

- local weather conditions,
- the physical site, for instance, can mortars be dug in, can angle irons be used, or does everything have to be supported by sandbags,
- constraints of the site, for example, where there is plenty of room for varying the firing position, the choice of fireworks may be made knowing that the site can be adapted with knowledge of likely wind conditions during the display—for instance, barges held by tugs may be moved to maximize the fallout area. On the other hand, where the site is fixed, the choice of fireworks may be conservative and dictated by the "worst case" scenario, and
- local hazards (e.g., gas cylinders in the fallout zone).

That is not to say that previous risk assessments are not valuable. Over time, previous risk assessments form a valuable resource, especially where they have been shown—as a result of a "near miss" or real incident—to be lacking. Revision and modification of existing risk assessments in the light of extended experience are probably the most valuable revisions possible.

Assessing the risks does not stop when a risk assessment is written. The process is iterative and risks are not adequately controlled if the process is stopped at any point. Old, out of date risk assessments are almost as useless as no risk

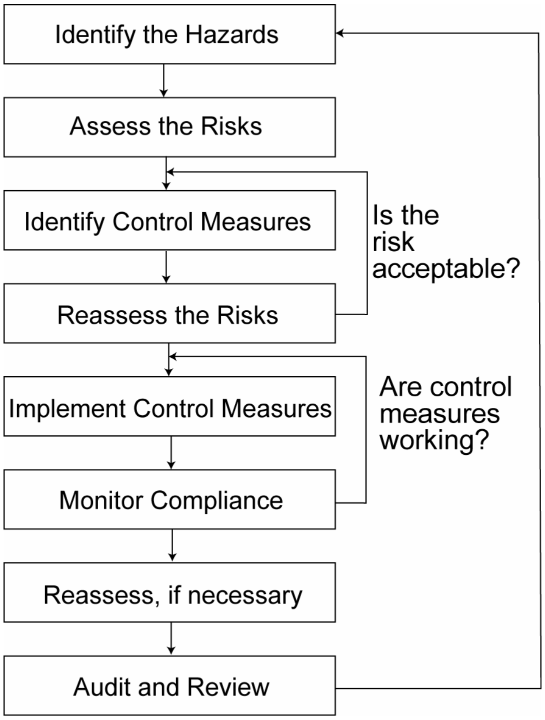


Figure 1. Flow chart for risk assessment.

assessment. Figure 1 presents a generalized flowchart for risk assessment.

Principles of Risk Assessment

Risk assessment is determining the risk posed by an operation. In its most general form the risk of an operation can be described as the product of the consequences of a particular identified incident and the frequency of the particular incident happening. Commonly this is described as

$$\text{Risk} = \text{Hazard } (H) \times \text{Frequency } (F)$$

To determine the overall risk of an operation each identified risk is summed, for a variety of potential occurrences and thus consequences from a particular operation

$$\text{Total Risk} = H_1F_1 + H_2F_2 + H_3F_3 + \ldots + H_nF_n$$

For example, as a result of a fire (from whatever source) in a magazine containing solely 1.4G fireworks, which are packaged and stacked properly, the overall risk is comprised of the factors listed in Table 1.

Risk and Hazard

So what is meant by “Risk” and “Hazard” and why are the two so often confused?

The hazard of an event is the potential consequences of the event—however infrequently that event may occur. It is the intrinsic potential for harm, the consequence of an event. Synonyms for hazard include

- consequence and
- danger (a poor term and one with negative connotations)

The risk arising from that event considers both the intrinsic hazard of the identified event and the frequency of that event occurring.

Synonyms for frequency include

- likelihood,
- probability,
- incidence, and
- rate.

Table 1. Overall Risk from a Fire in a Magazine Containing Only 1.4G Fireworks.

Event	Hazard	Frequency
Rapid escalation leading to mass explosion	Building destruction, fragmentation, blast wave, “domino effects” to adjacent magazines	Very low
Projection of firework stars through open door	Burns, thermal effects, ignition of adjacent magazines, etc.	Probable
Smoke plume, deposition of heavy metal salts, etc.	Toxic hazard to fire fighters, environmental aspects, etc.	Probable
Effects confined entirely within magazine	No hazard to outside, however hazard during clean up, etc.	Low

Quantitative vs. Qualitative Risk Assessment

Quantitative Risk Assessment (sometimes referred to as “Quantified Risk Assessment”—but both Quantitative and Qualitative Risk Assessment are also referred to, ambiguously, as QRA) is the process of trying to determine the consequences of an event and the frequency of that event happening using “real” numbers. In this way an estimate of the overall risk may be obtained that is comparable with other risks that workers and the public face during normal activities. For example, in the UK a risk to a specified individual is considered broadly acceptable if it leads to a fatality at a frequency of 1 in 10^{-6} (i.e., about one in a million years). Fatalities more frequent than this may be acceptable provided they are “As low as is reasonably practical”, so called ALARP, or they may be unacceptable. The upper end of the ALARP region in the UK is taken to be about 1×10^{-4} (or about one every ten thousand years) for members of the public. For workers, who may accept a greater level of risk as a consequence of working, the figure is taken to be 1×10^{-3} (or about one every thousand years).

ALARP implies that necessary steps should be taken to reduce the risk, provided that they are “reasonable”. Ultimately therefore the measure of ALARP is often based on cost. Sometimes changes could be made that reduce risk slightly, but are cost prohibitive and therefore not practical. On the other hand, some risk control measures may be simple to achieve and also are cost effective.

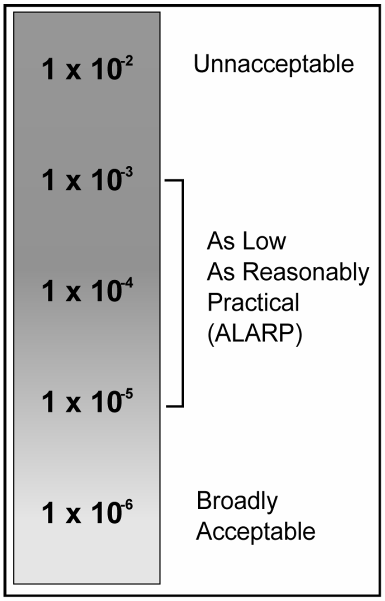


Figure 2. Individual risk.

Quantitative Risk Assessment is a very complicated and rather imprecise science. For instance, to assess the overall risk resulting from an explosion in a brick built magazine, the following facts (and many others) all need to be quantified:

1) Frequency of the event
    a) How often does an ignition occur?
    b) How often does this lead to a mass explosion?
2) The effect on workers and the public
    a) How far away are potential victims (e.g., do they lie in a debris zone, a blast zone or a fire zone)?
    b) How much time does each potential victim spend at that location?
    c) What is the effect of the incident on people in the open, or within buildings?
3) For people in the open
    a) How much time are they in the open?
    b) What fragments from the explosion are fatal to them?
4) For people in buildings
    a) What is the building construction?
    b) What is the effect of building collapse?
    c) What is the effect of window shatter?
5) What control measures are there
    a) Earth mounding?
    b) Directional effects?

It is obvious that this process is not simple!

Attempts have been made to quantify some of these variables. Merrifield and Moreton[1] conclude that accidents at licensed explosives sites occur at about 1×10^{-4} per building year—in other words, if there are 5000 licensed buildings in the UK, they would expect an unintended ignition about once every other year. Their analysis concentrated on events that led to investigation and thus may actually under-report the frequency of unintentional ignitions. On the other hand, their own figures suggest that post 1974 (the introduction of new general Health and Safety regulations in the UK), the frequency dropped markedly.

Calculating a pure frequency for unintentional ignitions on a firework display site is much more difficult. In many cases a premature ignition may go unrecognized during a display; however, the consequences of such an ignition are usually negligible—providing that the firework continues to function normally. On the other hand, ignitions during rigging and testing have potentially severe consequences, and although the frequency remains low, good risk assessment and consequence control measures are needed to prevent accidents. For instance, responsible firework companies do not test electrical circuits with personnel in the firing area.

The consequences of an incident are also complex to determine. For instance the effect of debris on a person depends on:

- the trajectory of the debris,
- the area they present to debris (for low trajectory debris this is their frontal area, but for high trajectory debris this is their plan area),
- their distance from the explosion, and
- the amount and type of debris produced.

An extensive analysis of models used to predict consequences of an explosion was carried out in the recent review of UK explosives legislation.[2] A comprehensive paper detailing various consequence models available has also been produced by the UK's Advisory Committee on Dangerous Substances.[3] Both papers mainly consider the consequences of high explosive events, whether they are from blast wave or debris. Similar analysis of lower order events, especially those involving fireworks and pyrotechnics, is very rare.

Individual and Societal Risk

Not only does the risk need to be quantified as above, but the risk to two quite separate types of person must be considered. The two types are:

Individual, identified persons—for instance the operator of a particular process or the occupier of a particular dwelling that lies within an area likely to be affected by an incident.

Society as a whole—people passing by a factory on a busy road and the whole population surrounding a particular facility.

The assessment of the risks to these two separate types of person is termed "Individual Risk" and "Societal Risk".

Previously it was stated that the standard for acceptability of individual risk is taken to be 1×10^{-6}. The acceptability of a societal risk is much more complicated. In the most general terms, society's acceptance of a risk is inversely proportional to the number of people who may be affected by the risk. For instance, we all accept, although perhaps we shouldn't, that individuals are killed in road accidents every day of the year. These fatalities rarely make even local news reports; this risk has become a fact of life. However, if, a pile-up kills 10 people, we can be sure that the event will be reported widely in the locality and may even make national news. If hundreds of people are killed, the event will be reported internationally. If children are involved the event will get wider attention for smaller numbers of fatalities.

A plot of cumulative frequency of incidents (F) and number of fatalities (N), the F/N curve (Figure 3), is very reminiscent of the simple plot for individual risk and highlights the same three areas:

- where the risk is unacceptable,
- where risk reduction is required, and
- where the risk is considered negligible.

In practice the calculated societal risks resulting from an incident are normally laid over the acceptability chart above, and the overall acceptability of the risk (or otherwise) determined from where the points lie in relation to the areas above. Calculations may be made on

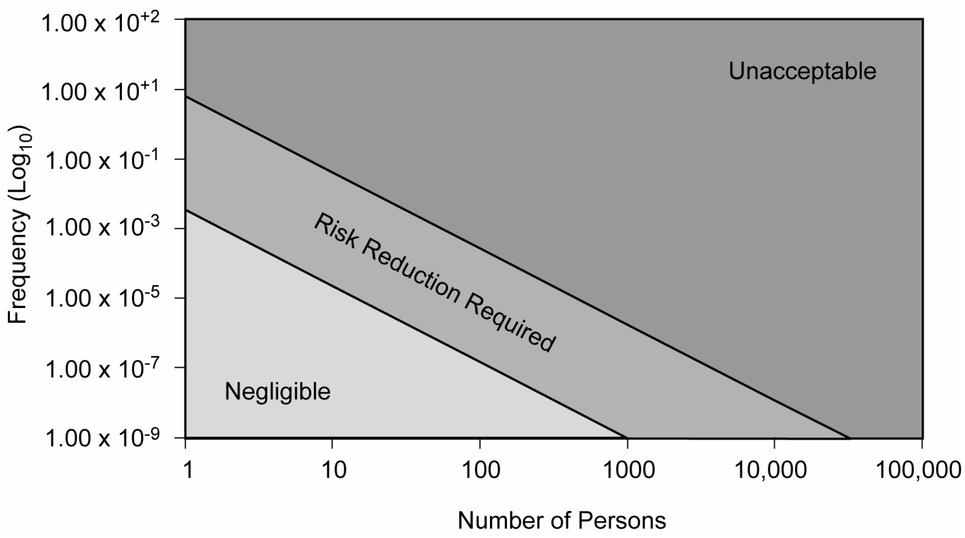


Figure 3. Generalised f/N curve.

the basis of hazard identification and mathematical modelling of consequence analysis.

This is not to say that we should necessarily equate acceptable societal risk with media perception, but the two run closely hand in hand!

Societal risk should be, but not always is, summed over an entire population—that is, in any one year, any event leading to multiple fatalities should be considered, and therefore the total risk should be calculated across all establishments that may pose that risk. It is unlikely that society would accept multiple incidents over a range of establishments during a relatively short time scale without rightly asking questions as to whether the risks were properly controlled across the entire industry.

Sadly, the public who thus determine the acceptable levels of societal risk are also the people who least understand the nature and mathematics of risk calculations. Indeed the public have little concept of frequency—otherwise why would so may indulge in the lottery!

As a result, most risk assessment is carried out on a qualitative or semi-quantitative basis. The remainder of this paper will concentrate on this approach.

Qualitative Risk Assessment Schemes

There are almost as many qualitative risk assessment schemes as there are people carrying out risk assessments—each may have had its merits, but we are now firmly convinced that a biased 0–10 rating system is the best. See Table 2.

Table 2. Comparison between Some Qualitative Risk Assessment Schemes.

Scheme	Ratings	Comments
Descriptive	Low, Medium, High	Too crude and too few divisions.
Simple 3 tier numeric	1,2,3	As above
Simple 6 tier numeric	1,2,3,4,5,6	Better - but need a “zero” entry
Simple 7 tier numeric with zero	0,1,2,3,4,5,6	Good
Biased 0–10 numeric	0,1,2,3,4,6,8,10	Good, puts greater weight on risks of high consequence or high frequency events

Potential Frequency Rating (PFR)

PFR	Description of Frequency	Approximate Frequency (per year)	Example
0	NEVER happens	$F = 0$	Firework debris falling 2 miles upwind
1	Very unlikely to happen	$F < 10^{-7}$	
2	Happens only rarely	$10^{-5} > F > 10^{-7}$	
3	Occasionally happens	$10^{-3} > F > 10^{-5}$	
4	Happens	$10^{-1} > F > 10^{-3}$	Firework fuse fails
6	Frequently happens	$1 > F > 10^{-1}$	
8	Almost always happens	$F > 1$	Lit firework debris landing in firing area
10	ALWAYS happens	$F > 10$	Firework debris landing on ground

Potential Severity Rating (PSR)

PSR	Description of Severity	Example
0	NOTHING of consequence	Ash on hand
1	Single trivial injury	Lit ash on hand causing very minor burn (e.g., from a sparkler)
2	Multiple trivial injuries	
3	Single minor injuries	Ash in eye
4	Multiple minor injuries	
5	Single major injury	Loss of limb
6	Multiple major injuries	
8	Single fatality	Death - immediate or as a result of injury
10	Multiple fatalities	

The advantages of a biased 0–10 scheme as indicated in the above chart are as follows:

- It includes a zero rating for both frequency and severity. This relates to risks that have no identified consequence or those that simply cannot happen. For example an explosives incident at an explosives factory cannot, by itself, affect a nuclear power station 10 miles away. An explosive incident at the same plant that resulted in release of a toxic gas could, on the other hand, affect the same power station as a result of wind drift and dispersion. Although many regulations (in the UK at least) require only the assessment of "significant risks", it is often better to document and dismiss a risk than not to document it at all!
- Although what follows rating of frequency and severity is just mathematics, the multiplication of the Hazard and Frequency components to evaluate Risk, biasing both ratings at the top end, the highest frequencies and highest consequences, allows risks where more than one group of people are affected to be rated higher than where only one group is affected, and frequently occurring risks to be rated higher than rare occurrences.
- The scheme has enough divisions to allow risks to be rated in a meaningful way and to allow risk control measures to have a real effect on the mathematics of the risk. For instance, a risk that potentially injured many people may be reduced to one that only caused minor injuries to many people once control measures are in place. Both these might be considered "medium" severities in a simple 3 tier scheme, so no risk reduction would be apparent.

Each potential identified risk should be assessed for both hazard and frequency and then rated for risk. In this way, each risk is related on a scale of 0–100 (Figure 4), and for multiple effects from the same event (e.g., both on-site

PFR/ PSR	0	1	2	3	4	5	6	8	10
0	0	0	0	0	0	0	0	0	0
1	0	1	2	3	4	5	6	8	10
2	0	2	4	6	8	10	12	16	20
3	0	3	6	9	12	15	18	24	30
4	0	4	8	12	16	20	24	32	40
5	0	5	10	15	20	25	30	40	50
6	0	6	12	18	24	30	36	48	60
8	0	8	16	24	32	40	48	64	80
10	0	10	20	30	40	50	60	80	100

░	Broadly acceptable
▒	ALARP region
▓	Unacceptable region

Figure 4. Simple semi-quantified risk assessment.

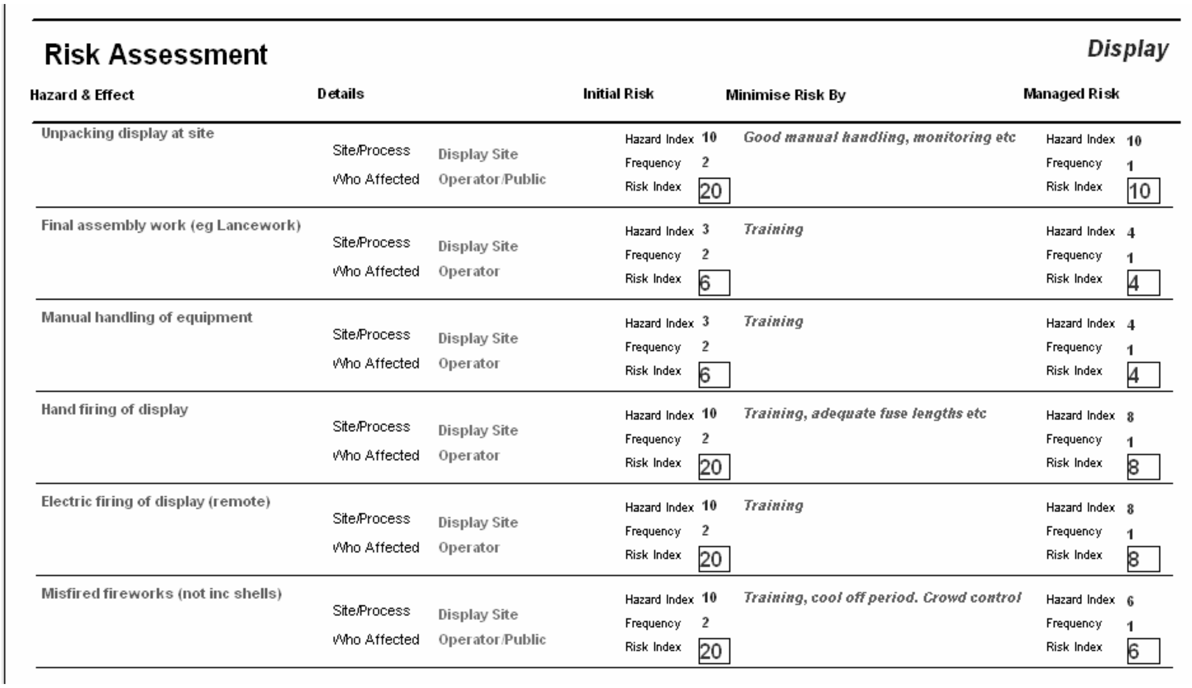
and off-site fatalities), those events that pose the greatest risk are identified by simple addition. Figure 4 also identifies those areas where the resulting risk may be considered acceptable, often described by regulators as "broadly acceptable". This term acknowledges that the risk is not completely controlled and—once higher risks have been reduced—this area may merit revisiting to control the risk further. No enforcing authority will ever commit themselves to agreeing that a risk is fully and acceptably controlled and that it always will be. The remaining regions are those where the risk is unacceptable, and the vast majority where the risk is "ALARP". Again the plot resembles that for individual and societal risks.

In the ALARP band, steps should be taken to reduce the risks, but any such risk reduction measures must be proportionate with the effort required to achieve them, both practically and financially. Ultimately, therefore, risk reduction cannot be separated from cost expenditure. Every firework fired could be entirely safe to the operator if the operator is situated behind a 30 cm thick steel plate 2000 m from the firing area, but this is neither practical nor cost effective.

The challenge to industry is to be consistent in assessing both the hazard and frequency of any event in this simple, semi-quantitative, approach where definitions have been made in terms of, for instance, "happens" and "frequently happens". The virtue of using an extended 0–10 scale is that, in the light of experience, the frequency or hazard of an event may be reassessed when control measures are in place and the risk reassessed. For instance, shells discharging prematurely from stray sparks where the shell leaders are completely unprotected "happens". It is not a frequent event, nor is it an infrequent event. Covering each leader with tinfoil and protecting the mouth of each mortar with more tinfoil may reduce this to "happens only rarely"—a reduction in potential frequency rating (PFR) from 4 to 2. Assuming the consequences stay the same, this reduction in PFR reduces the overall risk from *this event* by half.

It is important to realize, however, that measures taken to reduce a particular risk to one set of individuals may actually increase the risk to others. The classic case here is electrical firing of racks of shells. Removing the operator from the firing point reduces the risk to him, but he may be so removed that he is unable to determine that the rack has been disrupted in some way and is now pointing horizontally towards the audience, thus greatly increasing the risk to them! All risk reduction measures must be such that the consequential risks to all parties are examined. The analysis may ultimately conclude that the measure is not effective. In the case of electrical firing of shells in mortar racks the

Example 1. Extracts from generalised risk assessment for a UK Firework Competition. Note that each competitor in the competition also has to provide a site specific risk assessment pertinent to the materials they are firing and their methods of rigging.



Risk Assessment *Display*

Hazard & Effect	Details	Initial Risk	Minimise Risk By	Managed Risk
Unpacking display at site	Site/Process: Display Site Who Affected: Operator/Public	Hazard Index 10 Frequency 2 Risk Index 20	*Good manual handling, monitoring etc*	Hazard Index 10 Frequency 1 Risk Index 10
Final assembly work (eg Lancework)	Site/Process: Display Site Who Affected: Operator	Hazard Index 3 Frequency 2 Risk Index 6	*Training*	Hazard Index 4 Frequency 1 Risk Index 4
Manual handling of equipment	Site/Process: Display Site Who Affected: Operator	Hazard Index 3 Frequency 2 Risk Index 6	*Training*	Hazard Index 4 Frequency 1 Risk Index 4
Hand firing of display	Site/Process: Display Site Who Affected: Operator	Hazard Index 10 Frequency 2 Risk Index 20	*Training, adequate fuse lengths etc*	Hazard Index 8 Frequency 1 Risk Index 8
Electric firing of display (remote)	Site/Process: Display Site Who Affected: Operator	Hazard Index 10 Frequency 2 Risk Index 20	*Training*	Hazard Index 8 Frequency 1 Risk Index 8
Misfired fireworks (not inc shells)	Site/Process: Display Site Who Affected: Operator/Public	Hazard Index 10 Frequency 2 Risk Index 20	*Training, cool off period. Crowd control*	Hazard Index 6 Frequency 1 Risk Index 6

process will present a lower risk overall, only if adequate precautions have been taken to secure the mortar racks from disruption (e.g., adequate sandbagging, stakes, separation of tubes within the rack, etc.).

The Role of Risk Assessment in UK Pyrotechnic Operations

As noted above, UK law has gradually changed from one of “prescription” to one of “goal-setting”. This change, brought about in essence by the publication of the Robens Report[4]—a fundamental review of UK Health and Safety legislation—has not been universally welcomed. Small businesses, which are predominant in the pyrotechnics sector—at least in the UK, would generally rather be told what they can and cannot do. Small businesses do not have the resources, time or staff to base their entire operations on even semi-quantified risk assessment. The Manufacture and Storage of Explosives Regulations (due for adoption in early 2004) recognize this and do lay out prescribed “Quantity/Distance” tables relating the permitted quantity allowed to be stored in a building to the “Hazard Type” of the material being stored, the construction of the building, and the proximity of inhabited buildings, major roads, etc.

Which Risks Are the Most Important To Address First?

Which risks are the most important to control effectively? It is tempting to conclude that high frequency risks are the most important, because they are the most easily dealt with. However, these risks should be of low consequence. (If they are high consequence *and* high frequency, then you are in the wrong business.) The most important risks to control are those of high consequence that occur infrequently. The plain truth is, we control these risks poorly. We assume they will not occur, and we don’t quite know how to control them anyway.

Examples of both types of event can again be found in the firing of shells.

A high frequency, low hazard incident is the premature ignition of a shell from stray sparks, leading to the shell being ejected from the mortar in its normal manner, exploding normally in the air, and presenting the same risks from functioning as a shell fired deliberately.

A mortar tube that has been disrupted (i.e., displaced or tipped over by the malfunction of an adjacent tube) provides an example of a low frequency, high hazard incident. As described in Example 1, this example also illustrates the need to calculate the risk to both operator and audience. In this case remote electrical firing of the shell would almost certainly lead to lower risk to the operator, but if he is unable to witness the disruption of the mortar, and additional measures have not been put in place to prevent a shell discharging at a low trajectory towards the audience, and he then "presses the button", oblivious to the disruption of the mortar, a significant increase in risk to the audience may result.

Keeping Risks in Perspective

As previously noted, the public has little concept of risk. There is a danger with public information that "a little knowledge is a dangerous thing". The need for scientific education of the public is far beyond the scope of this paper, pressing though it may be, but the following points are important:

- The public (or legislators or event organisers) should not be misled into thinking risks are infinitesimally small when in reality accidents and incidents do occur.
- The public should be not bombarded with overly scientific information that they are unable to understand or to draw conclusions from.
- Information should be presented dispassionately, but concisely.

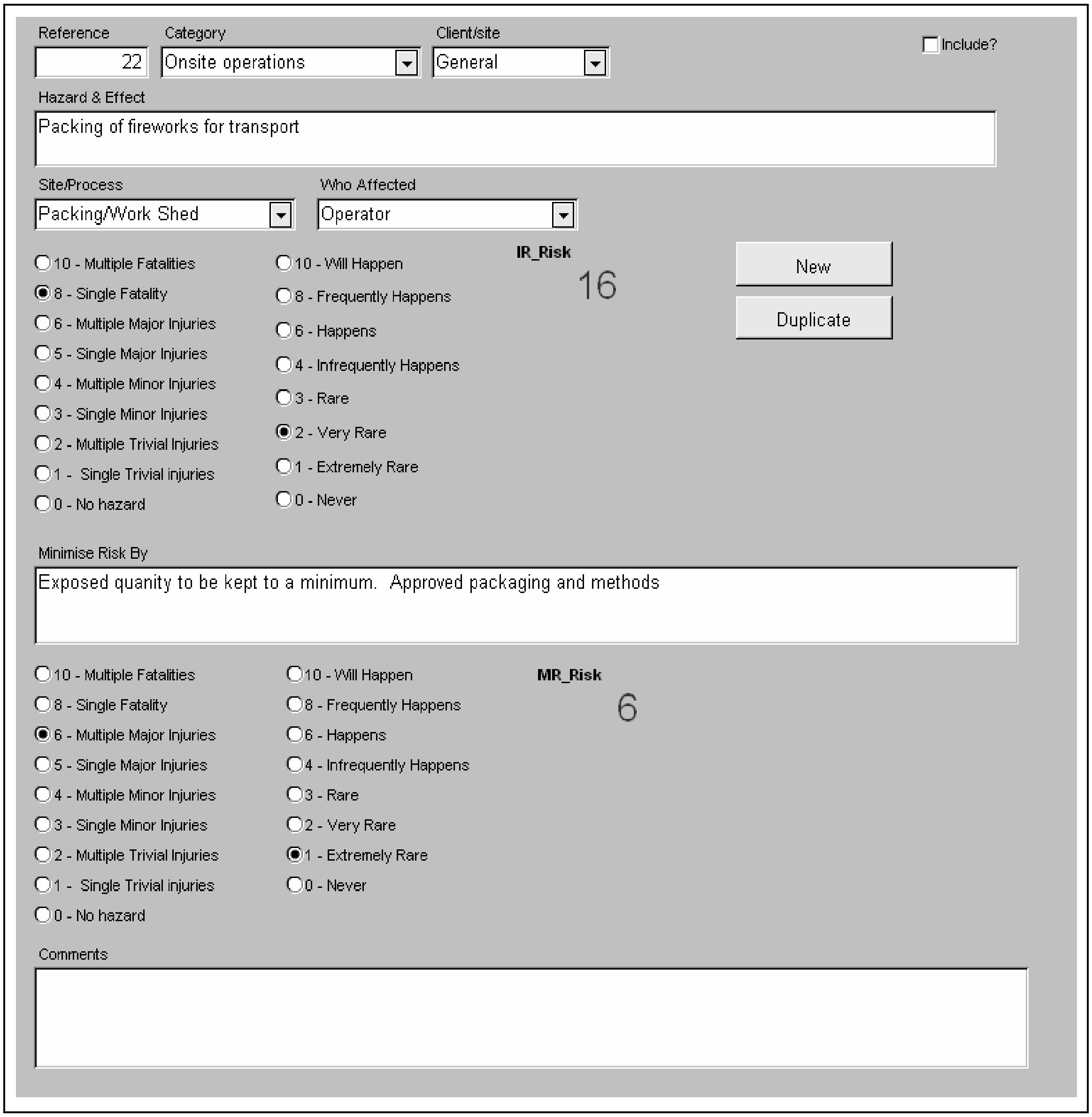
If risks in the ALARP region are controlled, they are infrequent, but the consequences may be relatively severe. This is why these risks are the most difficult to present to the public, and ironically they are the most difficult to control. How many times has the press been full of "We never knew the ... factory was there" or "I didn't know we were living next to a bomb ..."?

It is important to present the information at the appropriate level to the intended audience. Poorly documented risk assessment may be rejected by enforcers, and it is hoped that the methods presented here at least provide a degree of consistency of approach that makes the enforcers' task easier.

Presenting pages of detailed analysis to the public may convince them the operation is so "risky" that it is unacceptable. On the other hand, glib, "dumbed down" statements to the public may actually increase their suspicions and lead to the conclusion that proper risk assessment has not been carried out.

Documenting Risk Assessments

Like Risk Assessment methodology, there are as many ways of documenting the assessment of risks as there are people doing it. Risk assessments range from simple, single page, documents that generally lack detail and do not address all the risks, to multipage documents full of science that fail to highlight the most important risks, and the methods in place to control those risks. Example 1 presents a sample of the documentation we now adopt. Each row (each risk) is rated on the 0–10 system outlined above and details the identified hazards, the recipients of the hazard and the consequences and frequency of the risk occurring. It also details methods to control each identified risk. In essence therefore the column of control measures becomes an operating manual. If each of these measures is in place and is working effectively, then the risks are controlled to an acceptable level. Monitoring of the controls is paramount. The failure to implement a control measure may render a risk unacceptable. Data entry to this database is via a simple screen (Figure 5). Using a database is not, however, merely a means of regurgitating old documents, this would be hardly better than merely photocopying old risk assessment forms. Instead it encourages the user to re-examine old entries on the database pertinent to the tasks being examined, and to enter and quantify newly identified hazards, particularly site-specific hazards for pyrotechnic and firework displays. It does, however, provide examples on which to base the current risk assessment and outputs data in a concise manner.



Reference: 22
Category: Onsite operations
Client/site: General
☐ Include?

Hazard & Effect: Packing of fireworks for transport

Site/Process: Packing/Work Shed
Who Affected: Operator

○ 10 - Multiple Fatalities
● 8 - Single Fatality
○ 6 - Multiple Major Injuries
○ 5 - Single Major Injuries
○ 4 - Multiple Minor Injuries
○ 3 - Single Minor Injuries
○ 2 - Multiple Trivial Injuries
○ 1 - Single Trivial injuries
○ 0 - No hazard

○ 10 - Will Happen
○ 8 - Frequently Happens
○ 6 - Happens
○ 4 - Infrequently Happens
○ 3 - Rare
● 2 - Very Rare
○ 1 - Extremely Rare
○ 0 - Never

IR_Risk: 16

Minimise Risk By: Exposed quanity to be kept to a minimum. Approved packaging and methods

○ 10 - Multiple Fatalities
○ 8 - Single Fatality
● 6 - Multiple Major Injuries
○ 5 - Single Major Injuries
○ 4 - Multiple Minor Injuries
○ 3 - Single Minor Injuries
○ 2 - Multiple Trivial Injuries
○ 1 - Single Trivial injuries
○ 0 - No hazard

○ 10 - Will Happen
○ 8 - Frequently Happens
○ 6 - Happens
○ 4 - Infrequently Happens
○ 3 - Rare
○ 2 - Very Rare
● 1 - Extremely Rare
○ 0 - Never

MR_Risk: 6

Comments:

Figure 5. Data entry screen.

Conclusions

The process of assessing the risks from any operation, facility or event is a complex process, but one that ultimately not only helps quantify the risks involved but highlights, sometimes surprisingly, the highest risk operations.

Good analysis of risk also leads to identification of control measures, and thus the basis of operating procedures. However, the risk reductions achieved on paper only are meaningful if these operating procedures are adopted and monitored.

This paper presents a semi-quantified risk assessment protocol based on biased 0–10 scales for both hazard and frequency that we hope will find widespread use within the vast variety of operations throughout the pyrotechnic industry.

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