

A METHODOLOGY FOR THE ASSESSMENT OF DUST EXPLOSION RISKS: INTEGRATION INTO A GENERIC ASSESSMENT SYSTEM.

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Risk management covers the whole business process and has been the subject of numerous publications. This paper covers one critical part of the risk management process, namely the control of hazards specific to the manufacture and handling of chemicals. In particular it discusses the *integration of a* method for assessing the risks from dust explosions with an existing system that examines chemical reaction hazards. This revision to the original system also allows the assessment of vapour phase explosions, powder handling hazards & occupational hygiene hazards to be performed.
COMPASS (Computerised Process Assessment Safety System)[1] was originally conceived to assess only the thermal hazards and risks from chemical reactions. However, the use of a common system based on the properties of materials *in combination* with defined operations & plant, allows assessment of a wider range of hazards. Methods were available in house for the assessment of risk with the exception of those from dust explosions. A new method was developed for the safe, rapid and cost effective assessment of potential dust explosions for integration into COMPASS. The approach which has been adopted is similar to that used in the Laporte "Vapour Phase Explosion" guide[2].
The integration of this methodology into the company systems has resulted in common high standards, guides and codes of practice at all manufacturing sites. The approach enhances awareness of the hazards and the tolerable residual risk results in cost-effective controls.
The methodology outlined in this paper was developed for Laporte, and specifically for the fine chemicals group. During the first half of 2001, Laporte was purchased by Degussa.

Keywords: Dust explosions, risk assessment, generic systems

INTRODUCTION

The Speciality Chemical industry is under increasing pressure to provide a manufacturing service that is not only safe but also cost effective & rapid.

Laporte Fine Chemicals is well established in the toll-manufacturing sector. Here, the ability to respond rapidly is of paramount importance. Many modern chemical processes use new reagents and introduce complex reaction hazards. It is therefore important to have assessment systems that are based on modern concepts, employ best practice, and which allow rapid, uniform but effective assessment of these hazards.

Laporte manufactures chemicals at twenty-two sites worldwide. The Catalyst & Initiator Group, the Fine Chemicals Group & the Performance Chemicals Group have businesses & manufacturing operations in Australia, Austria, Brazil, Canada, Germany, Korea, Spain, South Africa, Thailand, The Netherlands, France, U.K. and U.S.A.

These businesses operate with different national cultures and regulatory bodies. They use muti purpose plant, face differing hazards and levels of operational complexity, as well as rapid change. It is essential that the company has an approach to managing the hazards and risks associated with chemical processes that recognises these differences but also provides a rigorous, rapid yet flexible approach. Methodologies that require an analysis on a case by case basis have short term advantages but could not be sustained nor supported in the medium to long term. Generic systems are required, preferably that use simple and similar strategies.

COMPASS

COMPASS[1] was originally conceived in order to assess only the thermal hazards and risks from chemical reactions. However, we soon realised that since the risk and consequence were dependent on the properties of the substance(s) and how they were to be processed on a particular scale, COMPASS could have a wider use. It became very clear that the full power of developing an integrated chemical properties database could best be exploited by developing a series of models to cover the range of assessments required to handle chemicals safely. We therefore developed a range of standards based on the principle that the basis of safety and its control system need to address the properties of materials *in combination* with defined operations and plant. These standards included generic approaches for the assessment of organic peroxide manufacture, vapour phase explosions and occupational hygiene, in addition to chemical reaction hazards. One area where no consistent approach was used was for dust explosions. A new methodology has been written and is being integrated into COMPASS. It should be noted that generic systems, of necessity, need to be conservative but practicable.

COMPASS is a system that guides the user through a series of assessments. It can be used at a number of levels. At its most basic, it will guide the user through the assessments required for control of vapour phase explosions, dust explosions, reaction hazards and toxic hazards, prompting for relevant information. There is an expert system built in that will guide the user through the assessment, interpret the answers and flag up warnings where appropriate.

At a higher level, there are calculation routines that will allow knowledgeable staff to determine properties such as boiling rates and cooling efficiency.

Help screens are also aimed at providing enough background to enable the user to understand what the programme is doing at each stage of the assessment.

Data is stored in a central database that contains detailed information on the physical and toxicological hazards of a wide variety of chemicals.

DUST EXPLOSION MODULE

There have been numerous excellent publications[3,4,5] providing information or methods for the prevention or minimisation of dust explosion risks. However we were unable to locate a strategy that suited the needs of the businesses in the company. The main reasons were:

- Many small sites with little or no local in-house specialist knowledge on dust explosions
- Fast turn round in projects with many process / plant changes
- Businesses with pilot plants operating at small to medium scale with limited campaigns
- Extremely high cost pharmaceutical products & intermediates
- Limited availability of materials for test purposes
- Businesses operating at high levels of GMP / FDA quality compliance standards
- Businesses operating with high potency materials
- A need to support growth by decentralising the hazards assessments

A standard was required which allowed minimum or no testing in some circumstances yet provided a basis of safety that was sufficiently robust and within our tolerable limit criteria (internal equivalent of as low as reasonably practicable, ALARP). It should be noted that the module was designed for Laporte and was based on an intimate knowledge of the businesses, their technical ability, plant, operations, chemistry etc. The suitability for other businesses has not been assessed. Therefore the list of operations may not be exhaustive or even appropriate for all other businesses.

BASIC PRINCIPLES

Many processes involving powders and dusts, suspended or accumulated, have the potential to lead to fire, explosion or decomposition in the presence of oxygen. The risk of dust explosions increases as more and more products take the form of powders or require the use of powders during manufacture. Indeed, modern complex molecules have shown a tendency to be easier to ignite and to produce stronger explosions than the simpler molecules produced a quarter of a century ago. Currently, there are approximately 50 dust explosions per year in the U.K. In Europe, it is close to one a day on average. Many are secondary explosions initiated by ignition of a flammable vapour cloud in the vicinity. The initial explosion may ignite further dusts and powders that have accumulated on level surfaces. The damage caused by dust explosions is generally worse than that caused from vapour phase explosions. This emphasises the need for proper housekeeping to ensure that these incidents are not escalated.
A dust explosion can only occur if there is a flammable atmosphere (an explosive dust mixed with air/oxidant) and an ignition source. The conditions required to ignite dust clouds are dependent on several factors;

- The dust must be explosible. Solids are grouped in three classifications.
  - Explosible (UK Group A)
  - Non-explosible (UK Group B)
  - Complex (Hybrids of vapour & dust)
- The dust must have a particle size distribution that will allow the propagation of flame
- The dispersed cloud or suspension must have sufficient oxidant to support combustion.
- The dust cloud must be within the explosible range
- Sufficient ignition energy must be in contact with the dust cloud in order to ignite it

DEFINING THE BASIS OF SAFETY FOR THE PREVENTION & PROTECTION AGAINST DUST EXPLOSIONS.

The requirement to ensure safe handling and processing of powders and dusts relies on the operational effectiveness of employees and equipment to ensure that at least two of the above conditions are removed during operation. The basis of safety must be maintained through the lifetime of the process.

The probability of a dust explosion during processing is related to the properties of materials, such as the minimum ignition energy, K_{st} value etc. together with the nature of the operation being performed and the equipment used. One can therefore specify the level of safety required for any powder – operation combination.

A set of simple flowcharts and matrices has been developed which allow the combination of intrinsic and extrinsic factors to be easily assessed. The output for a given combination dictates controls and conditions for operations to be performed at tolerable levels of risk.

The specification of the level of safety required is a <u>six-stage process</u> and is described below.

STAGE 1: DETERMINE THE CORRECT GUIDANCE TO FOLLOW.

The purpose of Flow Chart 1 (see figure 1 at end of paper) is to ensure that the correct guidance is being followed. If the powder has no explosive properties then dust explosivity is not a problem. If the powder is wet then there is little or no dust explosivity hazard if the solvent is not flammable and is present at levels above ca 25%[4]. If the powder is wet to between 10% and 25% then dust explosions are possible but depend to a great extent on the ability to raise a dust cloud. If the solvent is flammable and present at levels greater than 1% then a vapour phase explosion (VPE) model[2] should be used as the vapour phase explosion presents a greater risk.

If the particle size is above 400µ[8], then a dust explosion is unlikely to propagate and so there is little dust explosion problem.(Other sources, for example the I Chem E guides [4], give a value of 500µ, however for internal use, and given the recent data[8] we are confident with the lower value). It should be emphasised that if fines can be formed, by attrition or otherwise, then the material should be treated as having the properties of a fine powder .Flow Chart 1 accepts the concept that testing (either for dust explosivity properties or particle size) is not always possible, practical or desirable. In such circumstances, the user of this guide has two options. A DEFAULT level of safety (LEVEL 3d) may be used, or the powder can be assigned a classification of **High** risk (see stage 2). In order to avoid misuse, these options can only be applied with approval of a knowledgeable person .

If Flow Chart 1 takes the exit "NO DUST EXPLOSIVITY PROBLEM" or "USE VPE", then the required action is self-explanatory.

If Flow Chart 1 takes the exit "USE DUST GUIDE DEFAULT LEVEL 3d", then the user can go straight to table 2 showing the requirements for ensuring this basis of safety.

If Flow Chart 1 takes the exit " ASSUME HIGH RISK POWDER", or "USE DUST GUIDE", then stage 2 is required.

STAGE 2 : CLASSIFYING DUSTS AND POWDERS

The matrix below (table 1) classifies powders according to three criteria.

The K_{st} value,
The minimum ignition energy (MIE) and
The bulk resistivity (R_b).

The numbers in the classification tables are listed in this order.

Table 1 Dust classification

CLASSIFICATION	**1**	**2**	**3**
K_{st} value	**K_{st} 1**	**K_{st} 2**	**K_{st} 3**
M.I.E.	**> 50 mJ**	**10 – 50 mJ**	**< 10 mJ**
Bulk Resistivity	**< 10^6 Ωm**	**10^6 – 10^9 Ωm**	**> 10^9 Ωm**
<u>HIGH RISK</u>	3,3,3	3,2,3	2,3,2
	3,3,2	2,2,3	2,3,3
	3,3,1	3,2,2	3,1,3
<u>MEDIUM RISK</u>	2,2,1	1,2,2	1,3,3
	2,2,2	3,2,1	3,1,2
	2,3,1	1,2,3	1,3,2
<u>LOW RISK</u>	1,1,3	1,2,1	2,1,3
	1,1,2	2,1,1	3,1,1
	1,1,1	2,1,2	1,3,1

All powders can be assigned a K_{st}, MIE and R_b classification. The combination of these classifications (in that order) categorises powders into three bands of low, medium and high risk.

For example a powder that is K_{st} 2, with an MIE of 8mJ and bulk resistivity of 10^{10} Ωm would be classified as a 2,3,3 material & a powder that is K_{st} 1, with an MIE of 30mJ and bulk resistivity of 10^{6} Ωm would be classified as a 1,2,2 material.

Once the classification is known, it is possible to move to stage 3.

STAGE 3 : OPERATIONAL RISKS (TABLE 2)

All common operations have been classified as low, medium, high or very high risk.

Note: many plant operations require a combination of powder movement, charging, discharge etc. As different hazards and risks can be present at each step, each must be reviewed separately.

The criteria below were based on the propensity of a given operation to generate:

Combustible dust cloud
Heat source or ignition source
Charge on a solid

If all three were likely then the operation was classed as very high, if two were likely the operation was classed as high, etc. This table contains approximately 15% of the available operational risk charts, which could not be published in full in this paper.

Table 2 Operational Risks

OPERATION	0 LOW	1 MEDIUM	2 HIGH	3 VERY HIGH
Solids Movement				
Vibrating table			H*	
Conveyor belt (continuous)		M*		
Bucket elevator Open				VH
Pneumatic (only an issue if >1m)				VH
Vacuum			H*	
Disc			H*	
Screw feeder (closed flights)			H*	
Chutes >2m				
Non conductive/not inerted				VH
Conductive/not inerted			H	
Non conductive/inerted			H	
Conductive/inerted		M		
Chutes <2m				
Non conductive/not inerted			H	
Conductive/not inerted		M		
Non conductive/inerted	L			
Conductive/inerted	L			

* Discharges move up 1 level   + Seek advice on these operations.

† This may be a significant flammable hazard that could initiate a secondary dust cloud explosion. This classification, whilst strictly correct for dust clouds alone, is misleading where there is a flammable vapour present. Under these circumstances, it is recommended that this be treated using a Vapour Phase Explosion model in addition to a Dust Explosion model. (Footnotes are for the full table.)

Table 3 Operation/Material Matrix

MATERIAL CLASSIFICATION	OPERATIONAL CLASSIFICATION			
	Low Risk	**Medium Risk**	**High Risk**	**Very High Risk**
Low Risk	Level 1	Level 1	Level 1	Level 1
Medium Risk	Level 1	Level 2	Level 2/3	Level 2/3
High Risk	Level 2	Level 2/3	Level 3	Level 3

Note: For high resistivity solids (*,*,3), earthing cannot be used as the sole basis of safety (LEVEL 2 minimum).

STAGE 4 : USE OF OPERATIONS/MATERIALS MATRIX

During stage 2 and stage 3 the operation and powder will have been classified. The operations/material matrix (table 3) above specifies a level of safety for any combination of operation and material. The majority of combinations are specific, however some combinations need a further review.

If a specific level of safety of 1 or 2 is defined, then it is possible to move directly to stage 6. If the level is 2/3 or 3, then stage 5 must be used.

STAGE 5 : SELECTING THE APPROPRIATE BASIS OF SAFETY.

Where stage 4 requires a level 2/3, Flow Chart 2 (see figure 2 at end of paper) differentiates between the use of level 2 and level 3 depending on risk and consequence. This is achieved by reviewing the quantities used in total and/or at any one time.

Where stage 4 requires a level 3, Flow Chart 2 differentiates between the different protective systems that may be used (LEVEL 3c containment, LEVEL 3v venting or LEVEL 3s suppression).

The flow chart also covers all operations/powders combinations and is therefore a double check of stage 4.

STAGE 6 : DEFINING REQUIREMENTS OF THE BASIS OF SAFETY

By following the preceding stages, a level of safety will have been specified for the material/operation combination. These levels obviously increase the rigour, reliability and security of the control systems moving from BASIC to Level 4. The requirements are listed in table 4 below.

It cannot be stressed enough that good housekeeping, including the avoidance of dust layers and major ignition sources, is a BASIC level of safety. Almost all significant damage and/or injuries from dust explosions result from the SECONDARY event rather than the primary. Typically the primary event will shake a structure, room or equipment and dislodge powders sufficient to result in a secondary explosion. This event is usually involving larger quantities in a larger volume with no protective systems.

Note: Where other modules of COMPASS, such as those to control hazards from flammable gases and vapours, are used in combination with the dust module, the basis of safety must reflect the whole process, not only the control measures from one module.

Level 1 and Level 2 are preventative levels of safety.

Level 3 incorporates the preventative measures of LEVEL 2 PLUS one of the following:

(c) Containment of the overpressure by the equipment/structure
(v) Venting the overpressure through a properly designed bursting panel and discharge system
(s) Suppression of the explosion by extremely rapid addition of an inert diluent/phlegmatiser to stop the explosive reaction
(d) The default system requires a high reliability of preventative measures

Approval should be sought for the use of level 3(c) or level 3(d) and expert advice must be taken and implemented before 3(v) or 3(s) can be operated.

Level 4 has no common solution. Expert advice must be sought.

For the purposes of the guide, specified Laporte persons were designated as either "Knowledgeable Persons", "experts" or both.

Table 4 Requirements for the Basis of Safety for dust explosions.

LEVEL	REQUIREMENT
BASIC LEVEL:	Good housekeeping, avoidance of dust layers, no electrical ignition sources. Proper use of electrical zones
LEVEL 1: **Preventative**	BASIC LEVEL PLUS Earthing and bonding of equipment, minimising electrostatic ignition sources, earthing people (not a requirement if MIE > 50 mJ). Use earthed scoops / solids movement systems (not a requirement if MIE > 50 mJ). An electrostatics guide should be consulted.
LEVEL 2: **Preventative**	LEVEL 1 PLUS Either: Inerting with N_2, CO_2, steam to <6% oxygen (or ½ MOC (Minimum or limiting oxygen concentration) if known, whichever is lower) OR: Dilution with air or other suitable material to reduce the dust concentration below 5 $g.m^{-3}$
LEVEL 3: **Preventative +** **Protective**	LEVEL 2 PLUS Protective system (c) Containment (v) Venting (s) Suppression
DEFAULT LEVEL: **LEVEL 3d**, agreed with a knowledgeable person	LEVEL 2 PLUS all of the following: Reliability of inerting, or dilution (see Vapour Phase Explosion and Inerting Guides) Avoidance of ignition sources Closed system Isolated area (typically this would be a full enclosure often with blow-out panels, but it could be interpreted in other ways. In all cases, the agreement of a knowledgeable person must be obtained.) High integrity earth continuity testing
LEVEL 4:	Seek expert advice

THE ASSESSMENT REPORT

Once the chemical properties database has been updated with the relevant test results, COMPASS will automatically display these when the Dust Explosion Assessment module is opened (see figure 3), as well as the calculated Dust Hazard Rating. The user is then guided through a set of questions driven by the expert system and based on the decision trees shown above. The system then displays the appropriate basis of safety and the systems required to support it. The full assessment, including the questions asked and the responses given, can be printed out together with the system requirements. Part of the assessment from which the report is generated is shown in figure 4.

EXAMPLES.

1. A new pharmaceutical intermediate needed to be produced for ongoing trials. The quantity required was ca 200 kg, but this could only be manufactured in lots of 65kg or so. The intermediate was the final stage in a multi-step synthesis and was itself the final step before the bulk active ingredient. As such, the product was very valuable both financially and in the ability to produce more material. As an intermediate, there was only limited toxicity data available but the end pharmaceutical product was known to have potent pharmacological properties. There were no data on dust explosivity and little physical property data.

The manufacturing plant operates to current good manufacturing practice (cGMP) and has obligations to comply with standards required by the Food and Drug Administration (FDA). In addition, the safety management system (SMS) and hazards management system (HMS) are regularly audited by independent people using recognised methodologies. The isolation, drying and packing was planned to be via centrifuge, small double cone dryer operating at 6-7 rpm and direct discharge via a closed system into lined 50kg fibreboard kegs. Using the dust assessment module of COMPASS the business decided that they did not wish to generate dust explosivity data because:

- No material was available
- Hazards involved to persons performing the tests
- The small quantity being produced
- High cost of material for testing
- The business would not operate the process any differently because of FDA, GMP, SMS requirements, even if the material had been shown to be low hazard or even non explosible.

Using flow chart 1 (see figure 1) the exit "use default level 3d" was chosen. This was approved by competent persons internally. The plant was reviewed as part of the hazard study and the requirements of level 3d verified to be in place, maintained and calibrated.

2. A product expansion involved the inclusion of a new formulating facility. Powder from an existing plant was taken in flexible intermediate bulk containers (FIBCs) to the feed hopper of the formulating unit. The design specification for the throughput was greater than 1500 tonne per annum. Measurements on the powder had previously shown the following properties

K_{st} 331 bar m/s
MIE 10mJ
Bulk resistivity 2.5 x 10^{15} Ωm

The new formulating unit consisted of a number of unit operations such as screw feeds, hoppers & dust collection. These units were treated separately using the dust module of COMPASS. For this paper, only the feed and intermediate discharge hoppers will be considered. Using flow chart 1, the exit was "use dust guide, flow chart 2". It should be noted that the default level 3d could not be used as data was available on the material and this takes precedence. In addition approval would not have been obtained from the in house specialists given the properties of the material and the scale of operation.

From table 1 it is obvious that the material is classified as a high risk. The unit operations were each classified as medium risk. From table 3 this combination requires a level 2/3 basis of safety and therefore requires clarification using flow chart 2. This brought the assessor to "protective system must be used". There was no information to show that the hoppers had been designed to withstand any specific overpressure so level 3c was not evaluated further. Level 3v was considered as both hoppers had an area available that could be fitted with a venting panel. Using the VDI 3673 method[4], with;

K_{st} of 350 bar m/s,
Volume of the two units as $0.96 m^3$ and $0.24 m^3$,
Reduced explosion pressure (P_{red}) as 0.4 bar
Vent bursting pressure (P_{stat}) as 0.1 bar and
Vent duct of less than 3m,

the vent areas were calculated as $0.37 m^2$ and $0.13 m^2$ respectively. Note that level 3v requires a vent *in addition* to the preventative measures from levels 1 & 2.

CONCLUSION

Similar principles to those described above are used for the vapour phase explosion assessment. The Reaction Hazards module has been described elsewhere[1]. The Occupational Hygiene module works on a similar principle using our banding system (which is broadly similar to the CIA banding system[6]) and COSHH Essentials[7]. This link will form the subject of another paper. This method of assessing risk using a combination of material banding with an operational risk rating has been shown to have wide application.

This approach provides the ability for rapid assessment for safe scale up and manufacture. It also provides a mechanism for consistent standards, smoother process and technology transfer. The methodology enhances line management involvement, allows integration of hazards and risk assessments and incorporates safety, health & environment in the early stages of process development.

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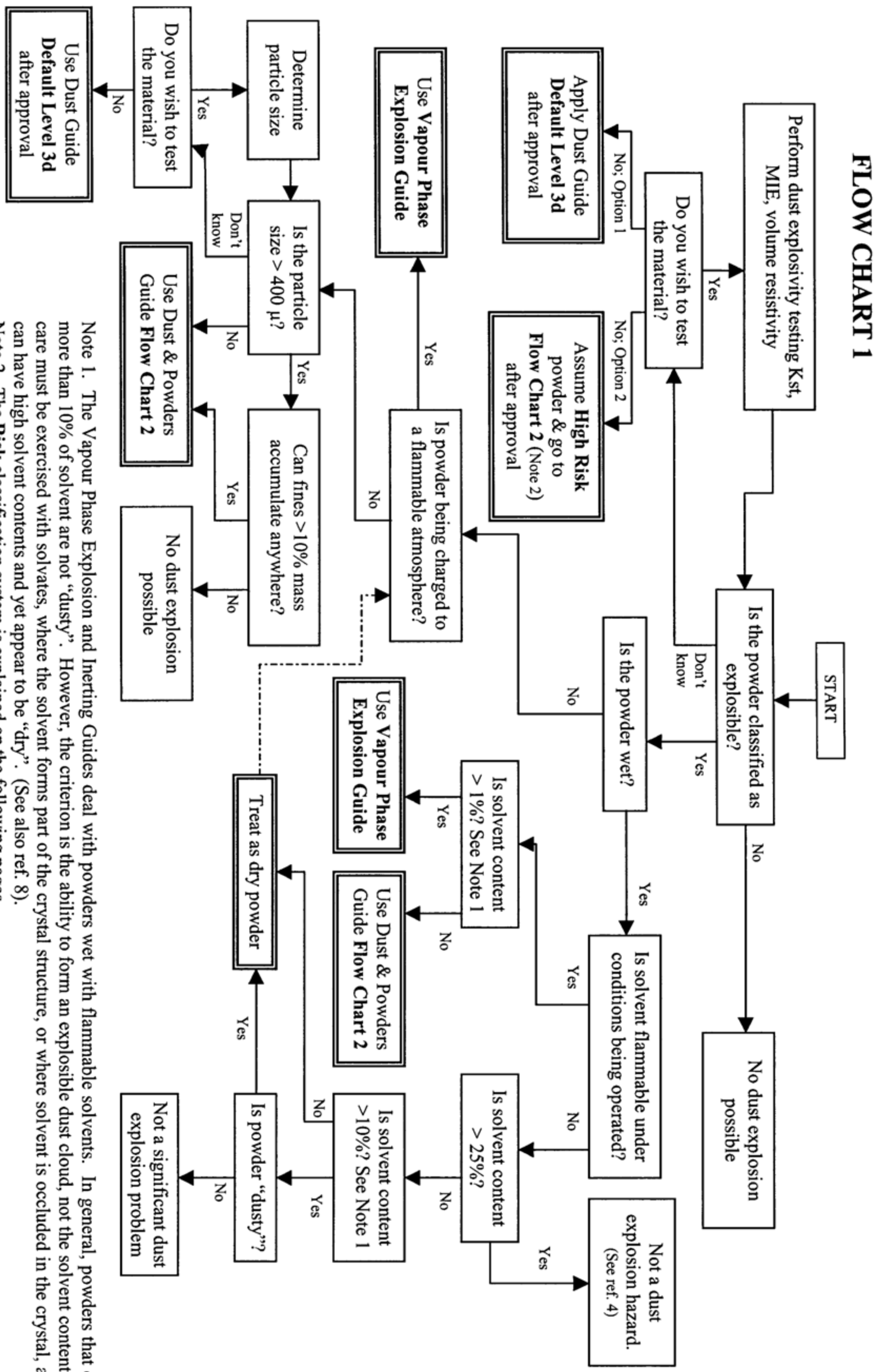

Note 1. The Vapour Phase Explosion and Inerting Guides deal with powders wet with flammable solvents. In general, powders that contain more than 10% of solvent are not "dusty". However, the criterion is the ability to form an explosible dust cloud, not the solvent content. Also, care must be exercised with solvates, where the solvent forms part of the crystal structure, or where solvent is occluded in the crystal, as these can have high solvent contents and yet appear to be "dry". (See also ref. 8).

Note 2. The **Risk** classification system is explained on the following pages.

Figure 1. Flow Chart 1.

FLOW CHART 2

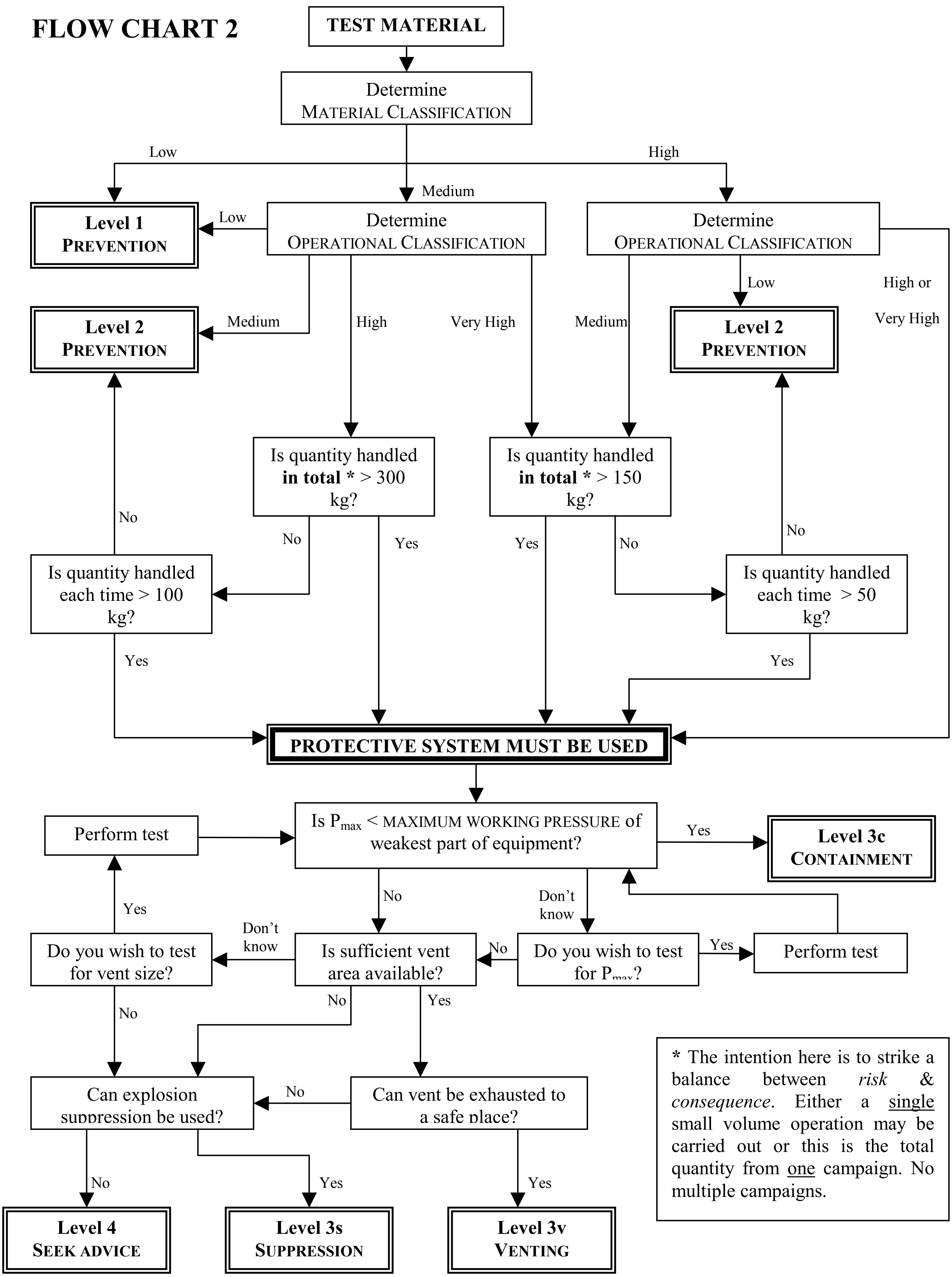

Figure 2. Flow Chart 2.

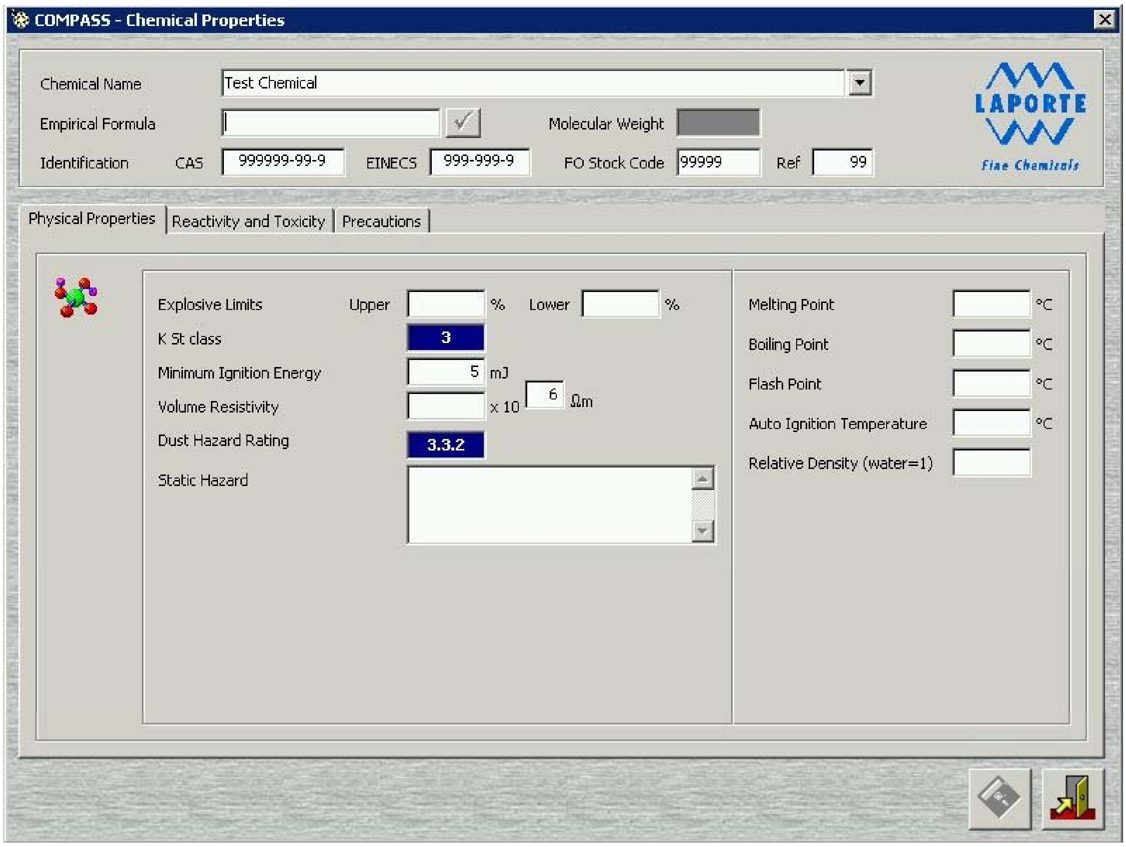

Figure 3. The physical properties screen showing the dust hazard rating.

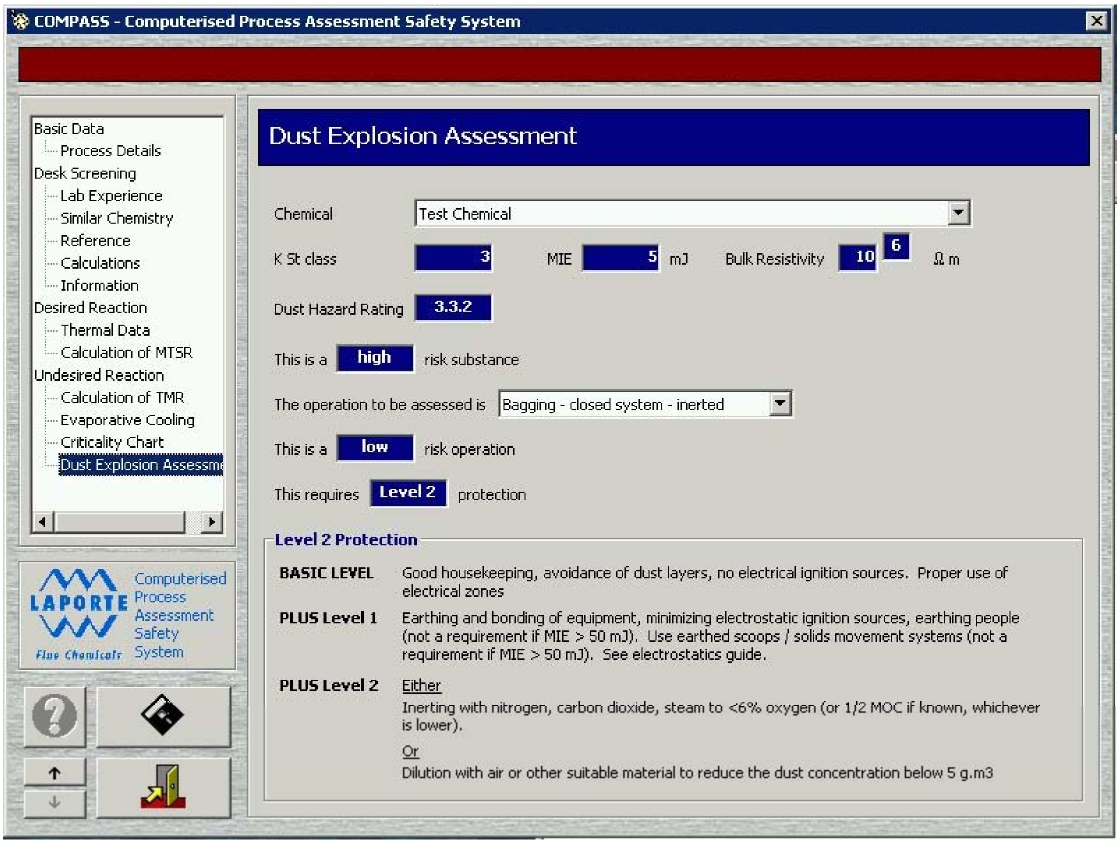

Figure 4. The basic assessment report.