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PROMIS branch solution and services
Chemical Process Safety

Author: Richard Gowland

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PROMIS@Service S.a.r.l.,21, Rue de Nassau, L- 2213 Luxembourg
Tel: 00352 273510 1
Fax: 00352 273510 28,
Email: crehm@promisatservice.eu

Chemical Process Safety:

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The PROMIS Chemical Process Safety Pyramid contains the elements for Process Safety Management and Risk Assessment which are valuable in meeting operator and regulator needs for hazardous facilities. The hazards considered are: Fire, Explosion and Release of Toxic Substances to the air. The aim is to have a progressive system which ensures that the larger risks (based on potential consequences) receive the most study and as a result, control. Methods of determining Tolerable Risk targets are included in the tools. The aim is to provide simple systems which allow the depth of study to be determined at plant level, thus involving the plant operation staff in understanding the risks and their role in managing them to a tolerable or broadly acceptable level. The advantages of using the PROMIS resources which can be downloaded, populated and edited by the subscriber include the fact that the methods are used by many companies, are proven in use, and where relevant, seen as good practice by regulators. They are simple enough for use by non specialists and the understanding of plant operators. The three sides of the pyramid contain the methods (Content), training materials (Training), services available (Services). Further help is available from the authors registered in the PROMIS organisation. (Rtgowland@aol.com)

PROMIS Pyramid access to Process Safety Management Systems for SMEs

Figure 1: The PROMIS PYRAMID

Initial Review

Legislation in E.U.

Process Safety Management

Audit and follow up

User Area

Safer Processes

Process Risk Management

Reactive Chemicals

Chemical Process Safety Pyramid Content:

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Progressive Process Safety Management Systems. A structure using screening tools for prioritizing topics for deeper study. (see Figure 2) A typical Example from a SME.

Summary diagram of a progressive system adjusted with experience

LEVEL 1: PROCESS HAZARDS ANALYSIS

– Triggers : All plants, significant projects and changes

- Fire & Explosion Index (FEI)
- Chemical Exposure Index (CEI)
- Credible case scenarios and lines of defence (with frequency or LOPA target factors).
- Worst case scenarios and relationship to Emergency Plan
- Explosion Impact (Building Overpressure) evaluation*
- PHA Questionnaire

LEVEL 2: RISK REVIEW

– Triggers: F&EI >=110 or CEI = ERPG2 at fence line , LOPA Target Factor to be defined (check output from Level 1) e.g. fatality at freq > KNR governance criteria

- Cause-Consequence pair Identification* e.g. 'bow tie'
- HAZOP.
- LOPA and Triggers: LOPA Target >= 6 or LOPA inappropriate.
  - Structured Hazard Analysis (Fault Tree analysis*, FMEA, Checklist, etc.)

LEVEL 3: ENHANCED RISK REVIEW

– Triggers: LOPA Protection Gap > 0 i.e. we are not meeting governance criteria

- More accurate Dose considerations e.g. AEGLs or AETLs
- Screen for QRA*

LEVEL 4: QUANTITATIVE RISK ASSESSMENT

– Triggers: Individual Risk contours in off-site population exceeds Business Governance Elevation Criteria

- Combination of Consequence Analysis, Frequency of Impact
- Focuses on highest risk activities

Figure 2: Diagram of a progressive Process Safety Management System.

Process Hazard Analysis (PHA) workbook covering:

- Fire
- Explosion
- Toxic Vapour Release
- Reactive Chemicals
- This workbook is designed to lead a team responsible for operating a hazardous process through a series of questions going all the way to the detail of unit operations such as pumps, reactors, heat exchangers. The outcome should be a valuable record of the methods used to manage the hazards and a tool for training operators.

B.6.01	The objective of these questions is to determine if the appropriate test data have been obtained. It is preferred that the test data be consolidated into a folder for easy review. (If in a folder please provide a copy or a path.)				This has primary relevance for thermally unstable or autcatalytic materials, materials which react violently with water or other materials in the plant. What is the protocol by which thermal testing is determined? Who is involved in the decision of what to test? Who does the testing?
B.6.02	Has a compatibility chart been developed for chemicals used in the unit that may be mixed unintentionally?				Can provide an example of what is expected. Useful exercise to create and a good training tool.
B.6.03	Has the technology center provided a template and testing information for you to use for your compatibility charts?				The technology centre may be taken as technical support on site as well as from central providers
B.6.04	Are self-reactive materials, materials of construction and maintenance materials included on the chart?				
B.6.05	Are wastes and absorbents included?				
B.6.06	Is the compatibility chart posted where all unit employees can use it?				
B.6.07	Is it used in training?				
B.6.08	Are there predefined responses to the inadvertent mixing of the high hazard potential chemicals indicated on the chart?				
B.6.09	Is the compatibility chart up-to-date? (That is does it contain current data on all the chemicals in the facility?) When was the last update?				
	Does it include:				
B.6.10	All raw materials, lubricants and heat exchange fluids				
B.6.11	Mixtures that may result from abnormal conditions? (This would include upsets like feeding too fast or too slow or adding the components in the wrong order.)				
B.6.12	Materials of construction throughout the process?				

Figure 3: Extract of PHA workbook

Basic workbooks for estimating consequence:

- Fire based on the Dow Chemical Company's Fire and Explosion Index (see Figure 4)
- Explosion based on TNO Multi Energy methodology (see Figure 5)
- Toxic vapour release based on the Dow Chemical Company's Chemical Exposure Index. (see Figure 6)

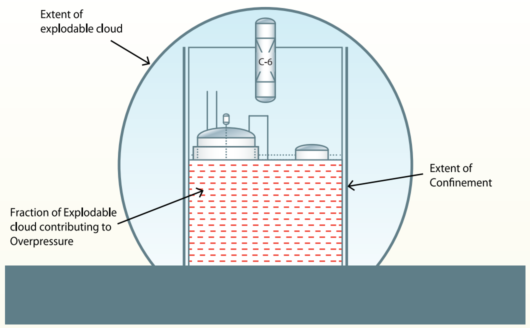
Fire and Explosion Index

Butadiene Unloading	
Fire and Explosion Index	*103.34*
Material Factor (see Material Data tab)	*24.00*
NFPA Health rating (Nh)	*2*
NFPA Flammability rating (Nf)	*4*
NFPA Instability rating (Ni)	*2*
General Process Hazards	
Base	*1*
Exothermic Reaction (range of input 0.3 - 1.25)	*0.00*
Endothermic Reaction (input range 0.2 - 0.4)	*0.00*
Material Handling and Transfer (input range 0.25 - 0.8)	*0.50*
Enclosed or Indoor Process or storage Units handling Flammable materials	*0.00*
Ease of Access for Emergency Responders	*0.20*
Drainage and Spill Control	*0.10*
General Process Hazards Factor	*1.80*
Base	*1*
Toxicity of the material handled.	*0.40*
Process or Storage operates at vacuum (<500mmHg) - penalty 0.5	*0.00*
Operation in or near the flammable range (input range 0.0 - 0.8)	*0.30*
Dust Explosion (input range 0.0 - 2.0)	*0.00*
Pressure Penalty	*0.12*
Low Temperature Operation	*0.00*
Combustible and Flammable materials in Process	*0.00*
Liquids or gases in Storage	*0.48*
Solids in Storage or Process	*0.00*
Corrosion and Erosion (input range 0.0 -0.75)	*0.00*
Leakage, Joints, packing, flexible joints	*0.10*
Use of Fired Equipment (fig 6)	*0.00*
Hot Oil Heat Exchange Equipment (table 5)	*0.00*
Rotating Equipment	*0.00*
Special Process Hazards Factor	*2.39*
Fire and Explosion Index	*103.34*

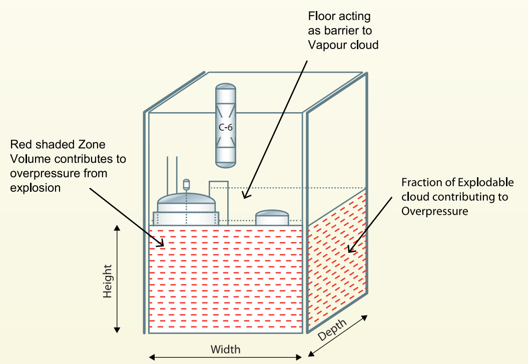
Figure 4: Fire and Explosion Index example

Explosion Overpressure using TNO Multi Energy method

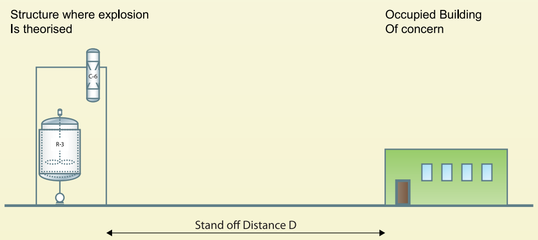
Overpressure from a Vapour Cloud Explosion



Example where leak occurs below first floor level



In cases where flammable materials are handled above flash point AND above boiling point.
Can my occupied Building survive an explosion overpressure?



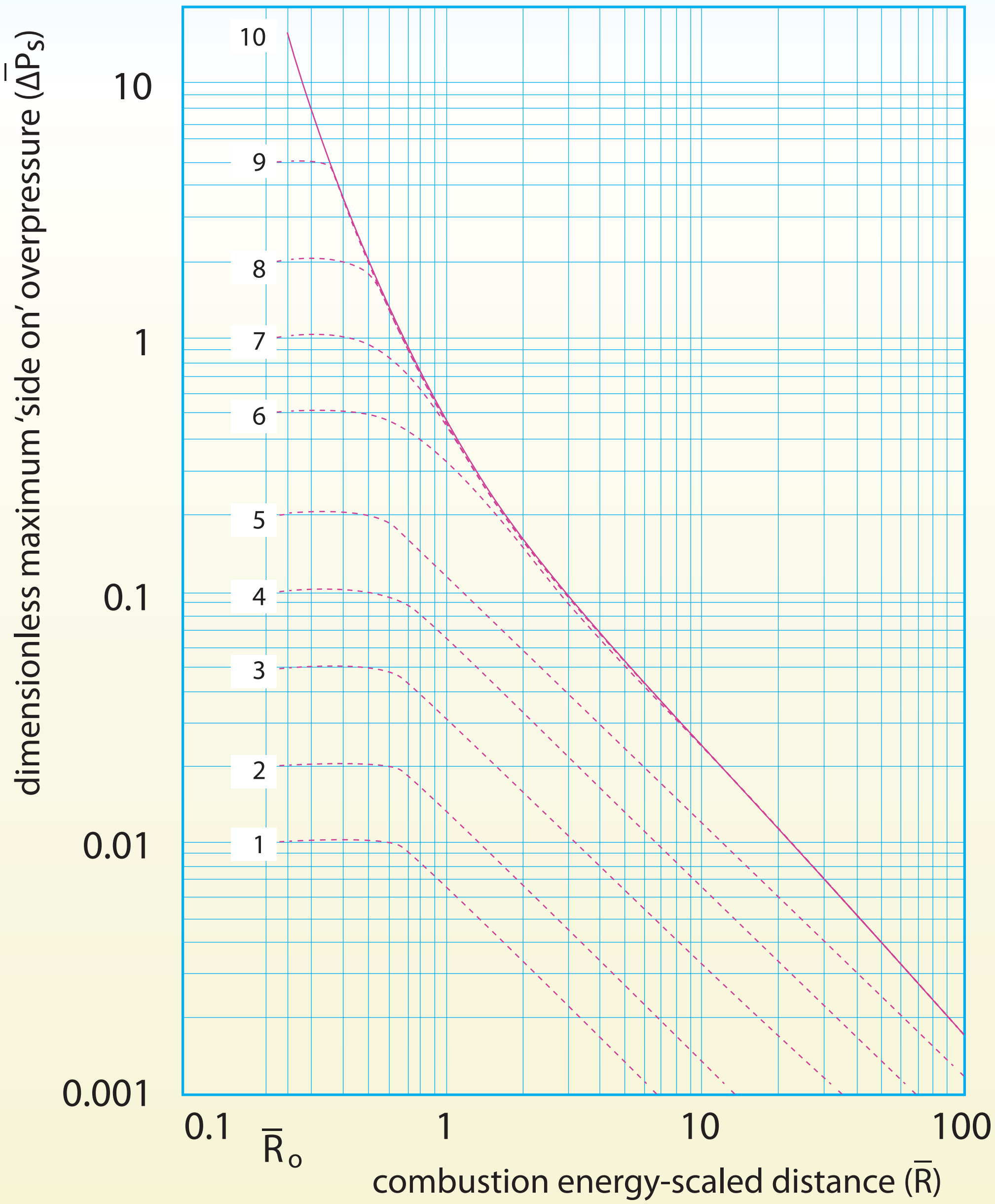


Figure 4.58A Scaled overpressure for partially-confined vapor cloud explosion given by the multi-energy method (reproduced by permission of Elsevier Science Publishers, Inc.)

Figure 5: Overpressure; Simple calculation workbook using user inputs and embedded TNO method.

Chemical Exposure method

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Piping release or vessel nozzle release	
Quantity of liquid available for release kg	100000
Quantity of gas available for release kg	
Temperature of released material deg C	5
Molecular Weight	70.91
Boiling Point C	-34
Vapour Pressure t 25 C kPa	778
Vapour Pressure at Pool Temperature kPa	101
Liquid Density kg/M3 at storage temp C	1458
Liquid Density kg/M3 at BP	1562
Gas Density kg/M3 at 25C	25.07
Heat Capacity Cp Joules/kg-deg C	
Latent Heat of Vaporisation Hv Joules/Kg	
Ratio of Cp/Hv	0.0033
Absolute Pressure (Pa) kPa	432
Gauge Pressure in Process (Pg) kPa	332
Temperature C	5
Diameter of hole mm	100
Height of leak above grade (Metres)	6
ERPG2 Mg/M3	9
ERPG3 Mg/M3	58
Dike area M2	100000
Distance to Property or fence line M	300

Gas Releases	
Airborne Gas Release (continuous assuming large inventory)	2.675023161
Airborne Gas Release (inventory exhausted within 5 minutes)	2.675023161
CEI	**357**
Distance travel by ERPG2 concentration	**3571**
Distance travel by ERPG3 concentration	**1407**
Maximum Release Duration	623

Figure 6: Chemical Exposure calculation example.

Hazard and Operability Study (HAZOP)

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- Loss of Primary Containment
- Layer of Protection Analysis
- Method description
- Calculation workbooks addressing needs for Safety Instrumented Systems see figure 7

Scenario N o.	P&ID/ Equipment No.	Scenario Description:	Reasoning/Justification	Study team	
1					
Consequence Description/Category:					
Risk Tolerance Criteria					
Control system Initiators					
Human Factor Initiators		Description of possible error	Enter Number of opportunities per year in column below	Probability of error per opportunity	
Other initiators					
ENABLING EVENT OR CONDITION					Probability
Enabling Events/Conditional Modifiers		Probability of Ignition (POI) (Fire or Explosion events only			
		Probability that ignition leads to explosion. (Entry in cell E9 required only if explosion is the hazardous phenomenon, otherwise leave default value of 1)			
		Probability that personnel will be EXPOSED in affected area			
		Others (e.g. time when risk is present)			
FREQUENCY OF UNMITIGATED CONSEQUENCES					
INDEPENDENT PROTECTION LAYERS				PFD	
BPCS actions with trip					
BPCS alarm and operator response Independent of BPCS trip)*					
Pressure Relief Device - overpressure events					
Other Safety Related Protection Systems					
Safety Instrumented Function A			Add position in range		
Safety Instrumented Function B			Add position in range		
TOTAL PROBABILITY OF FAILURE ON DEMAND FOR ALL IPLS					
FINAL FREQUENCY OF CONSEQUENCES WHEN ALL FACTORS TAKEN INTO ACCOUNT					
Risk Tolerance Criteria Met?					

Figure 7: LOPA workbook containing all data needed for a Layer of Protection Analysis study.

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- Typical Risk Assessments for ATEX compliance
- Reactive Chemical Review methods
- Self Assessment and Audit for:
    - Process Safety
    - Management of Change
- Inherently Safer Process Design

Training materials (Presentations and manuals) for:

- Process hazard Analysis:
    - Who needs to be in the analysis
    - What resources are needed
- Fire consequence
    - How the Dow Fire and Explosion Index works
    - Limitations
- Explosion effects estimation
    - How to calculate approximate overpressures from small and medium scale vapour cloud explosions
- Toxic vapour release
    - How to calculate the distance a toxic cloud release will travel in average weather conditions
- Hazard and Operability Study
    - The Basics of the method
    - Facilitating a HAZOP study
- Layer of Protection Analysis
    - The Basics of the method
    - Facilitating a LOPA study
    - ‚ALARP' evaluations
- Reactive Chemicals Review
    - Setting up and running a review
    - Basic Reactive Chemicals Hazards (instability, Interreactivity., Dust explosions etc.)
- Explosive Atmospheres (ATEX)
    - The regulations
    - The risk assessment
    - The Explosion Protection Document

Author

Richard Gowland
Holy Lodge
2, Lynn Road,
HEACHAM
Norfolk PE317HY
England.

Email: Rtgowland@aol.com

Curriculum Vitae

Richard Gowland graduated 1965 in Mechanical Engineering at the University of Durham, England. He is Technical Director of the European Process Safety Centre, which is an industry funded association dedicated to improving best practice in Process Safety in the Chemical, Oil and Gas industries. He also acts as an independent specialist in Chemical process and Occupational Safety. In this role he sets up Safety Management Systems, carries out risk reviews using techniques such as Process Hazard Analysis, Hazard and Operability Study and Layer of Protection Analysis. He also provides public training courses on these topics. His main career history covers the Steel Industry, Microporous Polymers and a long career in Engineering, Project Management, Production Management, new technology introduction and Process Safety leadership in the Dow Chemical Company. Since retiring from Dow he has carried out major risk reviews and Safety Management projects in the gas and mining chemicals industries in addition to regular specialist work on risk for Small and Medium Enterprises.

Recent key landmarks:

- Awarded the Institution of Chemical Engineers Franklin medal for Inherently Safer Process Design.
- Award for collaboration to produce Dow company policy on Safety Instrumented Systems.
- Chairman (now retired) of the European Technology Platform for Industrial Safety (Supporting Framework 7 research)
- Chairman of the UK Health and Safety Executive Subgroup for proper application of Layer of Protection Analysis to fuel storage facilities (following the Buncefield major fire and explosion)

Birth date: 3/12/1943

Education: Bachelor of Science, Durham University U.K. 1965

Work experience:

Mechanical Engineering in Steel Industry 1961-8
Project Engineering in Polyurethanes Industry 1968-71
Mechanical Engineering and Projects Dow Chemical Co. 1971-5
Project Management Dow Chemical Co. 1975-7
Major Plant Construction project (Pesticides production and formulation)
Production Management of Pesticides synthesis and formulations (Dow) 1977-1984
Production Management of all Agricultural products in U.K. for Dow Chemical Co. 1984-7.
- Chlorpyrifos
- Chlorpyifos-Methyl
- Fluroxypyr
- Formulation and packing of all above

Technology Centre Project Manager Dow USA 1987-9
- Scale up production for new molecules. (Developing from lab scale to market launch quantities)
- Technology improvement for Formulating and Packing Agricultural products.
- Successful project to upgrade the U.S. Agricultural Chemical Industry's management of public warehousing and distribution.

Process Safety Manager Dow Europe 1989-95
- Built and managed the EHS audit process for Dow Europe
- Set up HAZOP training for Dow Europe. Acted as training resource.
- Revised and operated Project Hazard Analysis for Dow Europe

Process Safety Associate, Dow Global Process Safety Management Core. 1995- 2004.
- Author and owner of Responsible Care® Process Safety element, Process Safety Technical Standards, Risk Analysis Software tools (Fire and Explosion Index, Chemical Exposure Index), HAZOP standard, compliance checking software and Process Safety audit protocols, Process Safety Auditing Training course.
- Member of team designing and launching Layer of Protection Analysis (LOPA) for Safety Instrumented Systems. (Received company award).
- Set up basic analysis for Overpressure effects from Vapour Cloud explosions in confined and semi confined structures.
- Process Safety Technology Leader for Dow Agrosciences. PHA and Risk Management for all European, Indian and South African operations. Author of protocol for contract manufacturing of Dow Agricultural products at third party supplier facilities. Evaluation of Process Safety at contractors making unstable molecules.(Nitration processes).
- Trainer for Layer of Protection Analysis, HAZOP study, Basic Risk Analysis, Process Safety Auditing, Inherently Safer Process Design.
- Member/delegate on European Commission Technical Work Groups for guidance on implementation of the Seveso Directive. (Risk Assessment and Land Use Planning) and meetings of the Committee of Competent Authorities.
- Process Safety Lead Auditor
- Due Diligence leader for Process Safety on acquisitions

Current Activity:

Technical Director of European Process Safety Centre (EPSC) 2004 (50 days per year commitment)….
Founder member of Technology Platform for Industrial Safety (European Commission support) – now chairman of Management Board
Institution of Chemical Engineers Director of training course on Layer of Protection Analysis (LOPA)
Major Layer of Protection Analysis Studies for STATOIL Norway (2006-ongoing)
Layer of Protection Analysis Studies for Eli Lilly Ireland (2007)
Consultant for Process Safety Management System creation at BHP Billiton (Chemicals div.) Australia 2005/2006
Consultant for Process Safety Management System creation at SASOL (South Africa)
Member/delegate on European Commission Technical Work Groups for guidance on implementation of the Seveso Directive. (Risk Assessment and Land Use Planning) and meetings of the Committee of Competent Authorities.
Chairman of team sponsored by the U.K. Health and Safety Executive to produce good practice guidance on LOPA (Working Group 3) http://www.hse.gov.uk/comah/buncefield/fuel-storage-sites.pdf

Other:

EPSC Founding member
EPSC Board member 1996 – 2003

CEFIC (Federation of European Chemical Industry) Major Hazards Group Chairman. Interface with European Commission on pending legislation (retired 2004)

Winner of Institution of Chemical Engineers Franklin Medal for work and publication in the field of Inherently Safer Process Design.

Accredited member of National Fire Protection Association committee (U.S.) 704 (classification of Hazardous Materials – health, flammability, instability)

Member of advisory groups for the European Commission on the Seveso 2 Directive (Major Chemical Hazards)

Leader of U.K. Health and Safety Executive study group on overfill protection for large gasoline storage tanks. (Buncefield follow up)

Member of EPSC study group on Leading and Lagging Performance indicators

Papers Published:

Reviews of Implementation of Seveso Directive in different E.U. Member States In:

The Chemical Engineer (Institution of Chemical Engineers)
Journal of Hazardous Materials
European Commission Committee of Competent Authorities

Experience in the use of Layer of Protection Analysis in meeting the requirements of IEC 61511. (ICHEAP – Italian Federation of Chemical Engineers, Palermo 2004)
A large Layer of Protection Analysis study for a gas terminal (2000+ cases)

Experience in applying the EPSC report on Design of Buildings in hazardous areas: (Loss Prevention Symposium of the European Federation of Chemical Engineers – Prague 2004)

Inherently Safer Process Design:
(Plant Operations Progress (American Institute of Chemical Engineers))

Design of Buildings in hazardous areas:
Guidance on applying the ATEX Directives:
(EPSC member only technical reports.)