This paper presents an attempt at modifying the Dow Fire & Explosion Index for use in assessing hazard and risk of experimental setups in research laboratories. The proposed modifications are based on several years of systematic risk assessment of experimental setups at the Department of Chemical Engineering at the Technical University of Denmark. The setups range in size from small fume hood setups to large pilot plants, that may in fact be assessed by the Dow Fire & Explosion Index.

The proposed changes to criteria for selection of penalties are described for both the special process hazards factor and the special process hazards factor. The penalties are unchanged in order to arrive at hazards levels similar to those in the original index.

Proposed modifications for the loss control credit factor are also described. Again the original credit factors are maintained, by the activity or system needed to achieve a particular credit has been modified. The modified hazard assessment procedure can then be used in conjunction with the recently proposed Likely Loss Fire & Explosion Index (Jensen and Jørgensen, 2006) to assess the risk of a particular experimental setup.

Examples of the application of the modified procedure to several experimental setups in the Department of Chemical Engineering are presented.

INTRODUCTION
The Dow Fire & Explosion Index is widely used for the assessment of relative hazards of different process units in the chemical industry. The index provides a standard approach for assessment of hazards due to facility design and due facility operation. The general procedure for use of the index is shown in figure 1. The application of the F&EI involves a number of steps:

1. Selection of the process unit that would have the greatest impact on the magnitude of a potential fire or explosion.
2. Select the most hazardous material present during realistic operating scenario, and determine its material factor. The material factor is a measure of potential energy release from fire or explosion produced by combustion or chemical reaction (Dow Guide, 1994).
3. Calculation of Fire & Explosion Index, which is a measure of the degree of hazard associated with a particular process unit.
4. Calculation of the Loss Control Credit Factor (LCCF) to obtain a more probable and realistic risk assessment in terms of dollars at risk.
5. Analysis of the risk of equipment damage and other financial loss from a fire or explosion in a particular process unit.

The third step involve the choice of penalty factors for a number of facility design features, such on the how exothermic or endothermic a reaction is, how material is handled or transferred, weather the unit is indoor or otherwise enclosed, how accessible the unit is, and how easily liquid may be drained from the area. These are combined into the general process hazards factor, as shown in table 1. For each hazard considered a range for the penalty factor is given.

In addition to the facility design features some operational features are assessed and combined to the special process hazards factor. The operational features assessed are: toxicity of materials involved, operation at sub-atmospheric pressure, operation in or near flammable range, dust explosion hazard, operating pressure, quantity of flammable or unstable material in process unit, corrosion possibilities, leakage possibilities, use of direct fire, hot oil usage, and rotating equipment. For each of these operational features the penalty ranges shown in table 2 are used.

The loss control credit factors used to account for features of the experimental setup or pilot plant aimed at reducing or controlling hazards fall in three categories: process control credit factors, material isolation credit factors and fire protection credit factors. An overview of the possible loss control credit factors and their possible values are shown in table 3.

When modifying the procedure for use in connection with experimental research and teaching setup it is desirable to retain the penalty factor ranges, and only modify the criteria for choosing a given size of penalty factor. Similarly with respect to the loss control credit factors it is desirable to retain the actual credit factor values, and only modify the criteria for choosing them.

GUIDING PRINCIPLES FOR MODIFICATION OF CRITERIA FOR PENALTY FACTORS SELECTION
The general principle used in modifying the criteria for determination of penalty factors has been, that penalty factors related to phenomena, such as exothermic or endothermic reactions have been left unchanged from the
criteria stated in the Dow Guide (1994), while criteria clearly dependent on quantities or areas, such as quantity of flammable/unstable material, have been adapted for use in laboratory and pilot plant setups. Also the word ‘process unit’ has been changed to ‘experimental setup’ or just ‘setup’, which is meant to cover both setups in laboratories and pilot plants.

MODIFICATION OF CRITERIA FOR GENERAL PROCESS HAZARDS PENALTY FACTORS
Thus with respect to the general process hazards the criteria for the exothermic chemical reaction and the endothermic chemical reaction penalty factors are unchanged, while the criteria for choosing the other penalty factors related to general process hazards have been modified. The criteria for the transfer and handling of material penalty factor have been change to focus on the hazards associated with the connection and disconnection of pressurized gas cylinder often associated with experimental setups in laboratories as well as the plastic containers frequently used to store materials. The criteria for the access penalty factor has been modified to reflect the smaller size of laboratories and associated storage facilities, compared to production unit, and the drainage and spill control penalty factor has been adapted to reflect normal design of
floors in laboratories and pilot plants, where features such as diking and impounding basin are generally not relevant.

As an example the wording of the criteria for selection of the drainage and spill control penalty factor has been changed to the following:

This penalty is only applied if the material in the experimental setup has a flash point below 60°C or if the material is being used above its flash point.

Table 1. Penalties for calculation of the general process hazards factor. This factor is the sum of the base penalty factor and the other relevant penalty factors. If a penalty factor is not relevant a value of zero is assumed, e.g. for outdoor units the penalty ‘Indoor or otherwise enclosed facility’ is zero. Source of ranges is the Dow Guide (1994). Penalty factors for which the selection criteria have been adapted to the laboratory and pilot plant environment are indicated by ‘*’ after the description.

<table>
<thead>
<tr>
<th>Penalty factor description</th>
<th>Value/range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base penalty factor</td>
<td>1</td>
</tr>
<tr>
<td>Exothermic chemical reactions</td>
<td>0.30 to 1.25</td>
</tr>
<tr>
<td>Endothermic chemical reactions</td>
<td>0.20 to 0.40</td>
</tr>
<tr>
<td>Handling and transfer of materials*</td>
<td>0.25 to 1.05</td>
</tr>
<tr>
<td>Indoor or otherwise enclosed facility*</td>
<td>0.25 to 0.90</td>
</tr>
<tr>
<td>Access to facility*</td>
<td>0.20 to 0.35</td>
</tr>
<tr>
<td>Liquid drainage from area*</td>
<td>0.25 to 0.50</td>
</tr>
</tbody>
</table>

Table 2. Penalties for calculation of the special process hazards factor. This factor is the sum of the base penalty factor and the other relevant penalty factors. If a penalty factor is not relevant a value of zero is assumed, e.g. if direct fired equipment is not used, then the penalty ‘Use of direct fired equipment’ is zero. Source of ranges is the Dow Guide (1994). Penalty factors for which the selection criteria have been adapted to the laboratory and pilot plant environment are indicated by ‘*’ after the description.

<table>
<thead>
<tr>
<th>Penalty factor description</th>
<th>Value/range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base penalty factor</td>
<td>1</td>
</tr>
<tr>
<td>Toxicity of material used</td>
<td>0.20 to 0.80</td>
</tr>
<tr>
<td>Operation at sub-atmospheric pressure</td>
<td>0.50</td>
</tr>
<tr>
<td>Operation in or near flammable range</td>
<td>0.30 to 0.80</td>
</tr>
<tr>
<td>Dust explosion hazard</td>
<td>0.25 to 2.00</td>
</tr>
<tr>
<td>Operating pressure*</td>
<td>0.16 to 1.50</td>
</tr>
<tr>
<td>Low temperature operation</td>
<td>0.20 to 0.30</td>
</tr>
<tr>
<td>Quantity of flammable or unstable material*</td>
<td>0.12 to 4.00</td>
</tr>
<tr>
<td>Corrosion*</td>
<td>0.10 to 0.75</td>
</tr>
<tr>
<td>Leakage*</td>
<td>0.10 to 1.50</td>
</tr>
<tr>
<td>Use of direct fired equipment</td>
<td>0.00 to 1.00</td>
</tr>
<tr>
<td>Hot oil exchange system*</td>
<td>0.15 to 1.15</td>
</tr>
<tr>
<td>Rotating equipment*</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Table 3. Loss control credit factors. The overall credit factor is the product of these. If a credit factor is not relevant a value of 1.00 is assumed. Sources of information is the Dow Guide (1994). Credit factors for which the selection criteria have been adapted to the laboratory and pilot plant environment are indicated by ‘*’ after the description.

<table>
<thead>
<tr>
<th>Credit factor description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency power</td>
<td>1.00, 0.98</td>
</tr>
<tr>
<td>Cooling</td>
<td>1.00, 0.99, 0.97</td>
</tr>
<tr>
<td>Explosion control</td>
<td>1.00, 0.98, 0.84</td>
</tr>
<tr>
<td>Emergency shutdown</td>
<td>1.00, 0.99, 0.98, 0.96</td>
</tr>
<tr>
<td>Computer control</td>
<td>1.00, 0.99, 0.97, 0.93</td>
</tr>
<tr>
<td>Inert gas</td>
<td>1.00, 0.96, 0.94</td>
</tr>
<tr>
<td>Operating procedures*</td>
<td>1.00 – 0.91</td>
</tr>
<tr>
<td>Reactive chemical review*</td>
<td>1.00, 0.98, 0.91</td>
</tr>
<tr>
<td>Other process hazard analysis</td>
<td>1.00, 0.98, 0.96, 0.94, 0.93, 0.91</td>
</tr>
<tr>
<td>Remote control valves*</td>
<td>1.00, 0.98, 0.96</td>
</tr>
<tr>
<td>Dump / Blow down</td>
<td>1.00, 0.98, 0.96</td>
</tr>
<tr>
<td>Drainage</td>
<td>1.00, 0.95, 0.91</td>
</tr>
<tr>
<td>Interlock</td>
<td>1.00, 0.98</td>
</tr>
<tr>
<td>Leak detection</td>
<td>1.00, 0.98, 0.94</td>
</tr>
<tr>
<td>Structural steel</td>
<td>1.00, 0.98</td>
</tr>
<tr>
<td>Fire water supply</td>
<td>1.00, 0.97, 0.94</td>
</tr>
<tr>
<td>Special systems</td>
<td>1.00, 0.91</td>
</tr>
<tr>
<td>Sprinkler systems*</td>
<td>1.00, 0.97, 0.87, 0.84, 0.81, 0.74</td>
</tr>
<tr>
<td>Water curtains</td>
<td>1.00, 0.98, 0.97</td>
</tr>
<tr>
<td>Foam</td>
<td>1.00, 0.97, 0.95, 0.94, 0.92</td>
</tr>
<tr>
<td>Hand extinguishers*</td>
<td>1.00, 0.98, 0.97, 0.95, 0.93</td>
</tr>
<tr>
<td>Cable protection</td>
<td>1.00, 0.98, 0.94</td>
</tr>
</tbody>
</table>

Penalties are selected as follows:

1. A floor, which is designed to prevent a spill from spreading to other experimental setup areas, receives a penalty of 0.50.
2. A general floor, which allows a spill to spread to other experimental setup areas, receive a penalty of 0.50.

The wording of all criteria for selection of general process hazards penalty factors is available as supplementary material from the author.

MODIFICATION OF CRITERIA FOR SPECIAL PROCESS HAZARDS FACTORS PENALTY FACTORS

As far as the special process hazards are concerned the criteria for the following penalty factors have been left unchanged: toxic material penalty factor, sub-atmospheric pressure penalty factor, operations in or near flammable range penalty factor, dust explosion penalty factor, low temperature penalty factor and the direct fired equipment penalty factor. The remainder, i.e. the operating pressure penalty factor, the quantity of flammable or unstable material penalty factor, the corrosion penalty factor, the
leakage penalty factor, the hot oil exchange system penalty factor and the rotating equipment penalty factor, have been adapted for use in laboratories and pilot plants. Most adaptation relates to amounts of material and areas.

As an example the wording of the criteria for choosing the rotating equipment penalty factor have been changed to the following:

This penalty factor recognizes the hazard exposure of experimental setups incorporating large pieces of rotating equipment. Although formulas have not been developed for evaluating all types and sizes of rotating equipment, there is statistical evidence indicating that pumps and compressors beyond a certain size are likely to contribute to a loss incident. For use on experimental setups in laboratories and pilot plants the equipment sizes, which trigger this penalty has been arbitrarily reduced.

A penalty of 0.50 is applied to experimental setups that utilize or are:

1. A compressor with an effect of 100 hp or more.
2. A pump with an effect of 10 hp or more.
3. Agitators (mixers) and circulating pumps in which failure could create an exotherm due to lack of cooling from interrupted mixing or circulation of coolant or due to interrupted and resumed mixing.
4. Other large high speed rotating equipment with a significant loss history, e.g. centrifuges.

The wording of all criteria for selection of special process hazards penalty factors is available as supplementary material from the author.

MODIFICATION OF CRITERIA FOR LOSS CONTROL CREDIT FACTORS

Loss control credit factors are intended to account for features in the experimental setup or pilot plant, which based on experience have proven beneficial both in preventing serious incidents and in reducing the probability and magnitude of a particular incident. The intent of the loss control credits is to reduce the dollars at risk to a more probable and realistic value. Thus only features that will actually contribute to reducing or controlling the setup hazards being analyzed should be considered.

The overall loss control credit is the product of all the relevant loss control credit factors. Thus credit factors are multiplied, whereas penalty factors are added.

APPLICATION EXAMPLES

Two different application examples for the laboratories of the Department of Chemical Engineering at the Technical University of Denmark will be presented: A pectine extraction exercise and an ammonia absorption exercise.

PECTINE EXTRACTION EXERCISE

Pectine is an important material in the food industry. It is found in the peel of different fruits and can be extracted into a hot slightly acid solution, from which the pectine is precipitated after filtration by adding an alcohol. The flow diagram for the exercise is shown in figure 2.

The alcohol used in the exercise is isopropanol, which according to the Dow Guide (1994) has the material factor and properties listed in table 4.

AMMONIA ABSORPTION EXERCISE

Ammonia is an important industrial chemical, which over the years have caused significant losses both in terms of

Figure 2. Flow diagram of pectine extraction exercise in the unit operations laboratories of the Department of Chemical Engineering at the Technical University of Denmark. The ellipses show the different batch vessels involved, and the square boxes the steps performed in each vessel
Table 4. Material factor and other information about isopropanol needed for application of Dow Fire & Explosion Index

<table>
<thead>
<tr>
<th>Material factor</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat of combustion, Btu/lb/kJ/kg</td>
<td>13100/30470</td>
</tr>
<tr>
<td>NFPA Health Classification</td>
<td>1</td>
</tr>
<tr>
<td>NFPA Flammability Classification</td>
<td>3</td>
</tr>
<tr>
<td>NFPA Reactivity Classification</td>
<td>0</td>
</tr>
<tr>
<td>Flash Point, deg F/deg C</td>
<td>53/12</td>
</tr>
<tr>
<td>Boiling Point, deg F/deg C</td>
<td>181/83</td>
</tr>
</tbody>
</table>

Table 5. Summary of results of modified F&EI calculations for the pectine extraction setup. The M-F&EI corresponds to an intermediate degree of hazard, and the LL-F&EI corresponds to a moderate degree of risk

| General Process Hazards Factor, $F_1$ | 2.30 |
| Special Process Hazards Factor, $F_2$ | 3.29 |
| Process Unit Hazards Factor, $F_3$  | 7.57 |
| Modified Fire and Explosion Index, M-F&EI | 121 |
| Process Control Credit Factor, $C_1$ | 0.95 |
| Material Isolation Credit Factor, $C_2$ | 1.00 |
| Fire Protection Credit Factor, $C_3$ | 0.95 |
| Loss Control Credit Factor, LCCF   | 0.91 |
| Damage Factor, DF                  | 0.66 |
| Likely Loss-Fire & Explosion Index, LL-F&EI | 43 |

Q1 Table 7. Summary of modified F&EI calculations for the ammonia absorption exercise including the LL-F&EI information

| General Process Hazards Factor, $F_1$ | 1.80 |
| Special Process Hazards Factor, $F_2$ | 1.80 |
| Unit Process Hazards Factor, $F_3$  | 3.24 |
| Modified Fire & Explosion Index      | 13  |
| Process Control Credit Factor, $C_1$ | 0.95 |
| Material Isolation Credit Factor, $C_2$ | 1.00 |
| Fire Protection Credit Factor, $C_3$ | 1.00 |
| Loss Control Credit Factor, LCCF   | 0.95 |
| Damage Factor, DF                  | 0.08 |
| Likely Loss-Fire & Explosion Index, LL-F&EI | 2 |

CONCLUSIONS
The criteria for assessment of special process hazard penalties and special process hazard penalties of in the Dow Guide (1994) has been modified to be more suitable for experimental setups, such as those found in unit operations laboratories, research laboratories and pilot plants. The resulting procedure is called the modified fire and explosion index or M-F&EI.

The modified fire and explosion index has been applied to two experimental setups in a university unit operations laboratory: a pectine extraction batch process and an ammonia absorption process. The application of the procedure shows that these setups represent an intermediate and a light hazard respectively. Further calculation of the LL-F&EI (Jensen and Jørgensen, 2006) indicate the two setups represents a moderate and a light risk. These results are what one would expect based on sound engineering judgement, and indicates the modification of the penalty assessment criteria are reasonable.

The M-F&EI presented here together with the LL-F&EI presented by Jensen and Jørgensen (2006) allows chemical engineers to receive practical training in the application of the procedures of an index such as the Dow Fire and Explosion Index by applying it to familiar unit operations setups in university laboratories and hence be better prepared to participate in risk assessment work in their future places of employment.

REFERENCES
APPENDIX A PENALTY FACTOR DETERMINATION FOR EXPERIMENTAL SETUPS

EXOTHERMIC CHEMICAL REACTION PENALTY FACTOR

The criteria for choosing the exothermic chemical reaction penalty factor are unchanged from those stated in the Dow Guide (1994). This penalty factor only applies if a chemical reaction takes place in the experimental setup, i.e. a reactor is present.

1. Mild exotherms require a penalty of 0.30. Examples of mild exotherms are hydrogenations, isomerizations, sulfonations, neutralizations and hydrolysis. For further details and examples of these types of reactions see page 16 in the Dow Guide (1994).
2. Moderate exotherms require a penalty of 0.50. Examples of moderate exotherms are alkylations, esterifications, oxidations, polymerizations, condensations and additions. For further details and examples of these types of reactions see page 16 in the Dow Guide (1994).
3. Critical-to-control exotherms require a penalty of 1.00. An example of this type of reaction is halogenations. For further details see page 16 in the Dow Guide (1994).
4. Particularly sensitive exotherms require a penalty of 1.25. An example of this type of reaction is nitrations. For further details see page 16 in the Dow Guide (1994).

ENDOTHERMIC CHEMICAL REACTION PENALTY FACTOR

The criteria for choosing the endothermic chemical reaction penalty factor are unchanged from those stated in the Dow Guide (1994). This penalty factor only applies if a chemical reaction takes place in the experimental setup, i.e. a reactor is present.

1. A penalty of 0.40 is required for calcinations. For further details see page 17 in the Dow Guide (1994).
2. A penalty of 0.20 is required for electrolysis. For further details see page 17 in the Dow Guide (1994).
3. A penalty of 0.20 or 0.40 is required for pyrolysis or cracking reactions. The higher penalty apply to direct fired systems.

TRANSFER AND HANDLING OF MATERIAL PENALTY FACTOR

The criteria for choosing the transfer and handling of material penalty factor have been changed from those stated in the Dow Guide (1994). This penalty factor only applies to setups involving transfer of material to/from storage or the actual warehousing of a material.

1. A penalty of 0.50 is applied to any setup involving the connection and disconnection of transfer lines for class I flammable or LPG-type materials. This applies e.g. to disconnection and connection of pressurized gas cylinders containing the indicated type of gases to the setup.

2. A penalty of 0.50 is applied to any setup, where the introduction of air during manual addition of some ingredients into batch reactors, batch mixers or centrifuges may create a flammability or reactivity hazard.
3. A penalty is applied to any storage of various items based on the materials fire hazard:
   a. A penalty of 0.85 is applied to flammable gases and liquids with NFPA flammability ratings of 3 or 4 for materials stored in drums, cylinders, aerosol cans or portable flexible container, i.e. plastic bottles of any size. Examples are pressurized gas cylinders and liter sized glass or plastic containers near experimental setups.
   b. A penalty of 0.65 is applied to flammable solid with NFPA flammability rating of 3, e.g. foam, fiber, powder including rubber goods such as tires, boots, styrofoam plastics, methocel cellulose ethers in dust/leak-free packages.
   c. A penalty of 0.40 is applied to flammable solid with NFPA flammability rating of 2, e.g. course granular material such as plastic pellets, rack storage, wood pallets and non-dusting ground material such as polystyrene.
   d. A penalty of 0.25 is applied to flammable liquids with a closed cup flash point above 37.8 C and below 60 C.
   e. A penalty of 0.20 is added to any a situation, where any of the above mentioned materials are stored on racks without in-rack sprinklers. Examples are storage in a ventilated chemical storage cabinet or other storage facility with racks.

INDOOR OR OTHERWISE ENCLOSED AREA PENALTY FACTOR

The criteria for choosing the Indoor or otherwise Enclosed Area Penalty Factor are changed from the Dow Guide (1994). This penalty factor applies to any indoor experimental setup.

1. A penalty of 0.50 is applied to dust filters and collectors located inside an enclosed area.
2. A penalty of 0.30 is applied to any process in which flammable liquids are handled at temperatures above their flash point in an enclosed area.
3. A penalty of 0.60 is applied to any process in which liquefied petroleum gas (LPG) or any flammable liquids are handled at temperatures above their boiling point in an enclosed area.

Where a properly designed mechanical ventilation has been installed the penalties listed under 1 and 3 above may be reduced by 50%.

ACCESS PENALTY FACTOR

The criteria for choosing the Access Penalty Factor are changed from the Dow Guide (1994). This penalty factor should be considered for all indoor experimental facilities. Usually emergency access from at least two sides is considered a minimum requirement.
All laboratory areas over 50 m² not having adequate access receive a penalty of 0.35. All warehouses over 50 m² not having adequate access receive a penalty of 0.35.

Areas smaller than the above mentioned may receive a penalty of 0.20 if sound engineering judgment indicates the potential for fire control problems due to inadequate access.

**DRAINAGE AND SPILL CONTROL PENALTY FACTOR**

The criteria for choosing the Drainage and Spill Control Penalty Factor are changed from the Dow Guide (1994). This penalty factor applies if the material in the experimental setup has a flash point below 60 °C or if the material is being used above its flash point.

Penalties are selected as follows:

1. A floor, which is designed to prevent a spill from spreading to other experimental setup areas, receives a penalty of 0.50.
2. A general floor, which allows a spill to spread to other experimental setup areas, receives a penalty of 0.50.

**TOXIC MATERIAL PENALTY FACTOR**

The criteria for choosing the toxic material penalty factor are unchanged from those stated in the Dow Guide (1994). Toxic materials can complicate the emergency response, by reducing the ability of emergency response personnel to investigate or mitigate damage during an incident. Use a penalty of 0.20 times the NFPA health factor. For mixtures, use the component with the highest NFPA health factor.

The NFPA health factor, NH, of a material is defined in NFPA 704 or given in NFPA 325M or NFPA 49. The health factor of many materials may be found in Appendix A of the Dow Guide (1994). For new materials an industrial hygiene specialist should be consulted.

The following are the definitions of the health factor, as given in NFPA 704:

\[
\begin{align*}
N_H &= 0 \text{ Materials that on short exposure under fire conditions would offer no hazard beyond that of ordinary combustible materials.} \\
N_H &= 1 \text{ Materials that on short exposure could cause irritation but only minor residual injury, including those requiring the use of an approved air-purifying respirator.} \\
N_H &= 2 \text{ Materials that on intense or short exposure could cause temporary incapacitation or possible residual injury, including those requiring the use of respiratory protective equipment that has an independent air supply.} \\
N_H &= 3 \text{ Materials that on short exposure could cause serious temporary or residual injury, including those requiring protection from bodily contact.} \\
N_H &= 4 \text{ Materials that on very short exposure could cause death or major residual injury.}
\end{align*}
\]

**Note:** These factors are for emergency response situations. They are not intended to be used in industrial hygiene or environmental situations.

**SUB-ATMOSPHERIC PRESSURE PENALTY FACTOR**

The criteria for choosing the sub-atmospheric pressure penalty factor are unchanged from those stated in the Dow Guide (1994). This penalty applies to experimental conditions where leakage of air into a system could create a hazardous situation. A hazardous situation could occur if air comes in contact with moisture-sensitive or oxygen sensitive materials or if air is mixed with flammable vapors in a closed system. In either of these situations and if the pressure is less than 500 mm Hg, then a penalty of 0.50 is applied.

Typical units where this penalty is applied are: stripping operations, compressors (some times) and distillations (a few times).

If this penalty is applied, then one should be careful not to duplicate or repeat by applying either the Operations In or Near Flammable Range Penalty Factor or the Relief Pressure Penalty Factor.

**OPERATIONS IN OR NEAR FLAMMABLE RANGE PENALTY FACTOR**

The criteria for choosing the operations in or near flammable range penalty factor are unchanged from those stated in the Dow Guide (1994). This penalty factor is applied to certain operating conditions which can cause air to enter and be entrained into the system, and thereby lead to the formation of flammable mixtures, which creates a hazard. The following conditions are covered:

1. A storage tank for liquids with an NFPA flammability rating, NF, of 3 or 4, where air can be breathed into the tank during pump-out or sudden cooling of the tank.

   Open vent or non-inert gas padded operating pressure-vacuum relief system, i.e. a system to protect a vessel from destruction by vacuum.

   Storage of combustible liquids at temperatures above their closed cup flash points without inerting.

   Either of these 3 situations require a penalty of 0.50.

   If an inerted, closed vapor recovery system is used and its air-tightness can be assured, no penalty is applied.

2. Experimental equipment or storage tanks that could be in or near the flammable range only in the event of instrument or equipment failure require a penalty of 0.30.

   Any experimental equipment that relies on inert purge to keep it out of the flammable range requires a penalty of 0.30. This also applies to padded parges and tank cars.

   No penalty is applied if a Sub-Atmospheric Pressure Penalty Factor already has been taken.

3. Equipment or operations that are by nature always in or near the flammable range, either because purging is not practical or because it was elected not to purge, receive a penalty of 0.80.
DUST EXPLOSION PENALTY FACTOR
The criteria for choosing the dust explosion penalty factor are unchanged from those stated in the Dow Guide (1994). The maximum rate of pressure rise and maximum pressure generated by a dust are largely influenced by the particle size. In general, the finer the dust, the greater the hazard because of the rapid rate of pressure rise and maximum pressures attained.

The penalties listed in this section are intended to apply to any experimental setup involving dust handling operations: transferring, blending, grinding, bagging, etc.

All dusts have a particle size range. For determination of the penalty use the 10% size, i.e. the particle size at which 90% of the dust is coarser and 10% is finer.

Unless dust explosion testing has shown that no dust explosion hazard exist, dust penalties should be applied, as listed in the following table:

<table>
<thead>
<tr>
<th>Particle size, microns</th>
<th>Tyler mesh size</th>
<th>Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;75</td>
<td>&gt;200</td>
<td>2.00</td>
</tr>
<tr>
<td>75 to 100</td>
<td>150 to 200</td>
<td>1.25</td>
</tr>
<tr>
<td>100 to 150</td>
<td>100 to 150</td>
<td>0.75</td>
</tr>
<tr>
<td>150 to 175</td>
<td>80 to 100</td>
<td>0.50</td>
</tr>
<tr>
<td>&gt;175</td>
<td>60 to 80</td>
<td>0.25</td>
</tr>
</tbody>
</table>

If the equipment is inerted, then the penalty is reduced by 50%.

OPERATING PRESSURE PENALTY FACTOR
The criteria for choosing the operating pressure penalty factor have been adjusted for errors in the Dow Guide (1994). Where operating pressure is above atmospheric, a penalty is applied due to the higher release rates caused by higher pressure in the event of a leak. The concern is the possibility of failure of some component in the experimental setup causing the release of flammable materials. The operating pressure penalty evaluates the specific spill hazard potential at different pressure levels. Relief pressure also affects dispersion characteristics. Since the spill potential greatly increases at higher pressures, equipment design and maintenance become more critical as the operating pressure increases.

Systems operating at pressures above 20685 kPag (3000 psig) are outside the range of standard pressure vessel codes, such as ASME Code for Unified Pressure Vessels, Section VIII, Division I. For such systems, lens ring joints, cone seats or equivalent closures must be used in the flange design.

To determine the operating pressure penalty factor the following equation applies in the range from 0 to 6895 kPag:

\[
Y = 0.16109 + 1.61503 \times (X/6895) \\
- 1.42879 \times (X/6895)^2 + 0.5171 \times (X/6895)^3
\]

where X is the operating pressure in kPag and Y is the penalty factor. For pressures above 6895 kPag use the following table:

<table>
<thead>
<tr>
<th>Pressure, kPag</th>
<th>Pressure, psig</th>
<th>Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,895</td>
<td>1,000</td>
<td>0.86</td>
</tr>
<tr>
<td>10,343</td>
<td>1,500</td>
<td>0.92</td>
</tr>
<tr>
<td>13,790</td>
<td>2,000</td>
<td>0.96</td>
</tr>
<tr>
<td>17,238</td>
<td>2,500</td>
<td>0.98</td>
</tr>
<tr>
<td>20,685 to 68,950</td>
<td>3,000 to 10,000</td>
<td>1.00</td>
</tr>
<tr>
<td>&gt;68,950</td>
<td>&gt;10,000</td>
<td>1.50</td>
</tr>
</tbody>
</table>

The above equation and table can be used directly to determine penalties for flammable and combustible liquids with a flash point below 60 C. For other materials the penalty must be adjusted as follows:

1. For highly viscous materials such as tars, bitumen, heavy lubricating oils and asphalts, multiply the penalty by 0.70.
2. For compressed gases used alone or flammable liquids pressurized with any gas above 103 kPag, multiply the penalty by 1.2.
3. For liquefied flammable gases – including all other flammable materials stored above their boiling point, multiply the penalty by 1.3.

There is no penalty for extrusion and molding operations.

The final penalty is adjusted based on the relief pressure set point. First find the penalty associated with the operating pressure from the above equation. Then determine the penalty associated with the pressure steeping of the relief device using the same equation. Divide the operating pressure penalty by the relief pressure penalty to get the penalty adjustment factor. Multiply the operating pressure penalty with just adjustment factor to get the final pressure penalty factor.

Thus, credit is given for having a relatively high relief pressure steeping and vessel design pressure. Note that it is often advantageous to set the relief pressure close to the vessel design pressure. For example, reactions in a volatile solvent, especially in a gassy, unwanted higher temperature reaction can be avoided by setting the relief pressure so that the solvent can boil and remove heat before the higher temperature is reached. Computer simulation is generally used, based on reactive chemicals or other kinetic data, to decide whether a low relief pressure is desirable. However, this is not always desirable in some reactive systems.

For some special situations, it is advantageous to increase the design pressure of a pressure vessel to minimize the likelihood of release and in some special cases perhaps containment of the maximum expected pressure can be obtained.

LOW TEMPERATURE PENALTY FACTOR
The criteria for choosing the low temperature penalty factor are unchanged from those stated in the Dow Guide (1994). This section makes allowances for the possible brittleness
or carbon steel or other metals that may be exposed to temper- 
atures at or below their ductile/brittle transition tempera-
tures. If a careful evaluation has been made and no 
possibility of temperatures below the transition temperature 
exists due to normal or abnormal operating conditions, no 
penalty would be applied. It would be very rare to have a 
vessel designed with this potential. New vessel design 
would avoid the low temperature hazard.

The usual method of determining the transition 
temperature is to test samples of the metal used in the fabri-
cation of the experimental setup, using a standard Charpy 
Impact test to determine that the design, and therefore, oper-
ating temperature is above the transition temperature. 
Proper design should avoid these low temperature process 
conditions.

The following penalties are applied:
1. For experimental setups utilizing carbon steel construc-
tion and operated at or below the ductile/brittle transition 
temperature, a penalty of 0.30 is applied. If no data is 
available a 10°C transition temperature is assumed.
2. For materials other than carbon steel where the operat-
ing temperature is at or below the transition tempera-
ture, use a penalty of 0.20. Remember that no penalty 
is applied if the material is appropriate for the lowest 
possible operating temperature.

**QUANTITY OF FLAMMABLE/UNSTABLE 
MATERIAL PENALTY FACTOR**

*The criteria for choosing the quantity of flammable/un-
stable material penalty factor are changed from those 
quoted in the Dow Guide (1994). This section considers 
additional exposure to an area as quantities of flammable 
and unstable material in the setup is increased. There are 
three categories in this section, each evaluated by a separate 
equation. Apply only one penalty for the entire section, 
based on the material that was selected as the Material 
Factor.*

1. Liquids or Gases in Experimental Setup. This section 
appplies a penalty to a quantity of material that might 
be spilled and create a fire hazard, or that might, on 
exposure to fire, create a reactive chemical event. The 
penalty applies to any operation, including pumping 
into holding tanks, and is valid for the following 
materials when they are selected as the Material Factor:
   a. Flammable liquids and those combustible liquids 
      with a flash point below 60°C.
   b. Flammable gases.
   c. Liquefied flammable gases.
   d. Combustible liquids with closed cup flash point 
      above 60°C when the operating temperature is 
      above the flash point of the material.
   e. Reactive materials regardless of their flammability 
      with NFPA reactivity ratings of 2, 3 or 4.

   In using this section, the first task is to determine the 
   amount of material in the process.
   The penalty is based on the amount of fuel for a fire that 
can be released from the setup or a connected facility 
within 10 minutes. Common sense must be used in 
judging how much material may be released. Experience 
has shown that this amount can be reasonably estimated 
by taking the larger of the following:
   i. The quantity of material in the experimental setup.
   ii. The quantity of material in the largest connected 
      facility.

   Any connected facility that can be isolated by closure 
valves operable from a remote location in times of emergency 
is removed from consideration.

   Before accepting this approximation of the quantity of 
material in the setup, the question to be asked is “What is 
the maximum probable quantity that could be spilled?” 
If using good engineering judgment and familiarity 
with the setup, it is determined that a number which is 
significantly different from the above, use the latter 
number, being sure to document its validity. Remember, 
good judgment and setup familiarity will always lead to 
a more realistic approximation. Note, however, that if 
instability (reactivity) is involved, the quantity of 
concern is the quantity of material normally inside the 
setup.

   To obtain the total heat load in the setup the amount of 
flammable/combustible material is multiplied by the 
heat of combustion, $H_C$ of the material. This value 
may be obtained from Appendix A of the Dow Guide 
(1994) or from reactive chemical test data. The heat of 
combustion of unstable materials, i.e. materials with 
NFPA reactivity ratings of 2 or more, is taken as six 
times the heat of decomposition or the heat of combus-
tion, whichever is larger. Heats of decomposition can 
also be obtained from reactive chemical test data.

   The penalty may be calculated from the following 
equation:

   \[
   \log Y = 0.17179 + 0.42988 \log X - 0.37244 (\log X)^2 
   + 0.17712 (\log X)^3 - 0.029984 (\log X)^4
   \]

   where $X$ is the heat load of the setup in either 10^6 BTU 
or 10^6 kJ. Compared with the Dow Guide (1994) the 
heat load has been reduced by a factor of 1000 to 
reflect the laboratory and pilot plant nature of the 
setups. This means, for example, that a reboiler contain-
ing 400 liters of isopropanol will receive a penalty of 2.35.

2. Liquids and Gases in Storage (Outside Experimental 
Setup Area). Flammable and combustible liquids, 
gases or liquefied gases in storage outside the exper-
imental setup area receive a lower penalty than those 
in the experimental setup area, since there is no involve-
ment in the setup. Experimental setup involvement con-
tributes to the probability of an incident. Material 
Factor materials in this category include raw materials 
in drums or tanks, material in tank farms and material 
in portable containers and other containers.

   This penalty is determined based on the total energy 
content in kJ in any single storage vessel, i.e. the
product of the amount of material and the heat of combustion. In the case of portable containers, use the total quantity of material in all stored containers.

When two or more vessels are located in a common dike which would not drain into an adequately sized impounding basin, use the total energy content of all the tanks within the dike to obtain the required penalty. Unstable materials are evaluated in the same fashion as similar materials in the experimental setup area.

The equation used for estimating the penalty depends on the type of material. For liquefied gases the following equation is used:

\[
\log Y = -0.289069 + 0.472171 \times \log X \\
- 0.074585 \times (\log X)^2 - 0.018641 \times (\log X)^3
\]

and for class I flammable liquid (flash point < 37.8°C) the following equation is used:

\[
\log Y = -0.403115 + 0.378703 \times \log X \\
- 0.046402 \times (\log X)^2 - 0.015379 \times (\log X)^3
\]

and for the class of combustible liquids (37.8°C < flash point < 60°C) the equation is:

\[
\log Y = -0.558394 + 0.363321 \times \log X \\
- 0.057296 \times (\log X)^2 - 0.010759 \times (\log X)^3
\]

where \(X\) is the heat load of the storage in either 10^6 BTU or 10^6 kJ. Compared with the Dow Guide (1994) the heat load has been reduced by a factor of 1000, as for materials in experimental setup area.

3. Combustible Solids in Storage or Dust in Experimental Setup Area. This category covers the penalty requirements for various quantities of stored solids and for dusts encountered in an experimental setup when the solid or dust is the basis of the Material Factor. The measurements used in the penalty assessment are the density of the material and ease of ignition and its ability to sustain flame.

The total weight in kilograms of stored solid or dust contained within the experimental setup is used with the equation given below to determine the penalty. If the materials bulk density is less than 160 kg/m³, the first equation is used, otherwise the second equation is used. For unstable materials, i.e. those with NFPA reactivity rating 2 or higher, use six times the actual weight of material in the experimental setup area and the first equation to determine the appropriate penalty. For solids with bulk density <160kg/m³ the equation is:

\[
\log Y = 0.280423 + 0.464559 \times \log X \\
- 0.28291 \times (\log X)^2 + 0.066218 \times (\log X)^3
\]

and for materials with a bulk density >160kg/m³ the equation is:

\[
\log Y = -0.358311 + 0.459926 \times \log X \\
- 0.141022 \times (\log X)^2 + 0.02276 \times (\log X)^3
\]

where \(X\) is the amount of material in 10^6 kg. Compared with the Dow Guide (1994) the heat load has been reduced by a factor of 500. Notice, that the Dow Guide (1994) use pounds in this calculation.

CORROSION AND erosion PENALTY FACTOR

The criteria for choosing the corrosion and erosion penalty factor are changed from those stated in the Dow Guide (1994). Although good design makes allowances for corrosion and erosion, and indoor equipment are less exposed to weather corrosion, some corrosion/erosion problems may still occur in certain experimental setups.

The corrosion rate is considered to be the sum of the external and internal corrosion rates. Be sure not to overlook the possible effects of minor impurities in the streams that might cause greater than normal internal corrosion. Porosity of bricks and imperfections in plastic linings are likely sites for accelerated corrosion. The following penalties apply:

1. For corrosion rates less than 0.013 mm/year with a risk of pitting or local erosion, the penalty is 0.10.
2. For a corrosion rates between 0.013 mm/year and 0.025 mm/year, the penalty is 0.20.
3. For a corrosion rate higher than 0.025 mm/year the penalty is 0.50.
4. If there is a risk that stress-corrosion cracking might develop, apply a penalty of 0.75. This is common in experimental setups exposed to contamination by chlorine vapor over prolonged periods.
5. Where a lining is required to prevent corrosion, a penalty of 0.20 is applied. However, if the lining is simply to protect a product from developing color, no penalty is taken.

At the 1999 SACHE Faculty Workshop in Freeport, Texas representatives from Dow Chemicals recommended always taking a minimum penalty of 0.10.

JOINTS AND PACKING PENALTY FACTOR

The criteria for choosing the joints and packing penalty factor are changed from those stated in the Dow Guide (1994). Gaskets, seals of joints or shafts and packing can be sources of leaks of flammable or combustible materials, particularly where thermal and pressure cycling occurs. A penalty factor should be selected according to the design of the experimental setup under study and the material being used in the setup. The following penalties should be applied:

1. Where the pump and gland seals are likely to give some leakage or a minor nature, the penalty is 0.10.
2. For experimental setups known to give regular leakage problems at pumps, compressors and flange joints, the penalty is 0.30.

3. For processes in which thermal and pressure cycling occurs, the penalty is 0.30.

4. If the material in the experimental setup is penetrating in nature or is an abrasive slurry which can cause intermittent problems with sealing and if the experimental setup uses a rotating shaft seal or packing, the penalty is 0.40.

5. For any experimental setup that has sight glasses, bellows assemblies or expansion joints, the penalty is 1.50.

At the 1999 SACHE Faculty Workshop in Freeport, Texas representatives from Dow Chemical recommended always taking a minimum penalty of 0.10.

FIRED EQUIPMENT PENALTY FACTOR

The criteria for choosing the fired equipment penalty factor are unchanged from those stated in the Dow Guide (1994). The presence of fired equipment in an experimental setup adds an additional probability of ignition when flammable liquids, vapors or combustible dusts are released. The penalty is applied in one or two ways: 1) to the fired equipment itself when it is the unit subject to F&EI calculations, and 2) to equipment in the vicinity of the fired equipment. The penalty depends on the distance from a probable leak point in the experimental setup to the air intake of the fired equipment. The penalty is determined by entering the distance from a potential leak source to the air intake of the fired equipment using either of the following equations:

For any experimental setup in which the material of the Material Factor could be released above its flash point or in which the material of the Material Factor is a combustible dust, the following equation is used:

\[
\log Y = -3.3243 \cdot (X/64) + 3.75127 \cdot (X/64)^2 - 1.42523 \cdot (X/64)^3
\]

and for any experimental setup in which the material of the Material Factor could be released above its boiling point the following equation is used:

\[
\log Y = -0.3745 \cdot (X/64) - 2.70212 \cdot (X/64)^2 + 2.09171 \cdot (X/64)^3
\]

where X is the distance in meters.

If the fired equipment itself is the unit being evaluated, the distance from the possible leak source becomes zero. If the equipment is heating a flammable or combustible material, the penalty is 1.00, even if the material is not being heated above its flash point. The penalty is not applied to the fire side.

However, any other situation covered by this section involving a material processed below its flash point receives no penalty.

If a piece of fired equipment is located within the process area and there is a possibility that the material in the unit selected as Material Factor could be released above its flash point, a minimum penalty of 0.10 is required, regardless of the distance involved.

Fired equipment with pressure burner design will require only 50% of the penalty specified for standard burner design, provided the air intake is 3 meter or more above grade and is not exposed to potential sources or spills from overhead. However, the 50% penalty cannot be applied when the fired heater itself is the unit being evaluated.

HOT OIL HEAT EXCHANGE SYSTEM PENALTY FACTOR

The criteria for choosing the fired equipment penalty factor are changed from those stated in the Dow Guide (1994). Since most hot oil heat exchange fluids will burn and are frequently used above their flash point or boiling points, they represent an additional hazard in any experimental setup that uses them. The penalties in this section are based on the quantity of the heat exchange fluid used in the setup being evaluated.

No penalty is applied if the hot-oil is noncombustible or, if a combustible fluid, is always used below its flash point. However, the possible formation of mists should be considered.

The quantity used in the table below to determine the penalty taken is the lesser of:

1. A 15-minute spill caused by a break in the line servicing the experimental setup, or
2. The hot oil inventory within the active circulating hot oil system.

The portion of the hot oil exchange system, that can be classified as storage is not used in determining the active capacity unless it is connected much of the time to the setup. It is recommended that the F&EI for the hot oil circulating system itself be determined, including the active (not storage) tank, pumps and distribution/return piping. These determinations have historically led to large F&EI values. If the hot oil exchange system itself is the unit being evaluated, no penalty is taken in this section. However, if a fired hot oil heat exchange system is actually located in the area of the unit being evaluated, the Fired Equipment Penalty Factor will apply.

The hot oil heat exchange system penalty factor is determined from the following table:

<table>
<thead>
<tr>
<th>Quantity of liquid, m³</th>
<th>Liq. above flash point</th>
<th>Liq. at or above boiling point</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.2</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>0.2 to 0.4</td>
<td>0.30</td>
<td>0.45</td>
</tr>
<tr>
<td>0.4 to 1.0</td>
<td>0.50</td>
<td>0.75</td>
</tr>
<tr>
<td>&gt;1.0</td>
<td>0.75</td>
<td>1.15</td>
</tr>
</tbody>
</table>
Compared with the Dow Guide (1994) the quantity of liquid has been reduced by a factor of almost 100.

**ROTATING EQUIPMENT PENALTY FACTOR**

The criteria for choosing the rotating equipment penalty factor are changed from those stated in the Dow Guide (1994). This section recognizes the hazard exposure of experimental setups incorporating large pieces of rotating equipment. Although formulas have not been developed for evaluating all types and sizes of rotating equipment, there is statistical evidence indicating that pumps and compressors beyond a certain size are likely to contribute to a loss incident. For use on experimental setups in laboratories and pilot plants the equipment sizes, which trigger this penalty has been arbitrarily reduced.

A penalty of 0.50 is applied to experimental setups that utilize or are:

1. A compressor with an effect of 100 hp or more.
2. A pump with an effect of 10 hp or more.
3. Agitators (mixers) and circulating pumps in which failure could create an exotherm due to lack of cooling from interrupted mixing or circulation of coolant or due to interrupted and resumed mixing.
4. Other large high speed rotating equipment with a significant loss history, e.g. centrifuges.

Compared with the Dow Guide (1994) the effect limits have been reduced by a factor of 6–7.
APPENDIX B LOSS CONTROL CREDIT FACTORS FOR EXPERIMENTAL SETUPS

EMERGENCY POWER CREDIT FACTOR
The criteria for choosing the emergency power credit factor are unchanged from those stated in the Dow Guide (1994). A credit of 0.98 is given for the provision of emergency power for essential services (instrument air, control instrumentation, agitators, pumps, etc.) with automatic changeover from normal power to emergency power. The emergency power credit should be taken only if it is relevant to the control of an incident in the specific setup being evaluated. For example, maintaining agitation in a rubber slurry tank in the polystyrene process, availability of emergency power is not needed either to prevent or to control possible fire/explosion incident. However, it may be a desirable feature because it permits continued operation when the normal power supply is unreliable. In such cases, no credit should be claimed for the availability of emergency power.

A credit factor of 0.98 is to be given if applicable and else a factor of 1.00 is to be used, which indicates no credit.

COOLING CREDIT FACTOR
The criteria for choosing the cooling credit factor are unchanged from those stated in the Dow Guide (1994). If process cooling systems are designed with the capability of maintaining normal cooling for at least 10 minutes during an abnormal condition, use a credit of 0.99. If a backup cooling system is designed to provide 150% of the cooling requirement for at least 10 minutes, use a credit of 0.97.

EXPLOSION CONTROL CREDIT FACTOR
The criteria for choosing the explosion control credit factor are unchanged from those stated in the Dow Guide (1994). For explosion suppression systems installed on dust or vapor handling equipment or equipment designed to contain a deflagration, use a credit factor of 0.84.

For over pressure relief systems using rupture diaphragms or explosion-relieving vents designed to protect the equipment from possible abnormal conditions, use a credit of 0.84. The credit is applied for any relief device that protects the equipment or building from damage due to rapid over pressure, such as deflagration. This credit is not intended to be applied for typical over pressure relief systems such as safety relief valves that are required for all pressure vessels or emergency relief vents on storage tanks.

EMERGENCY SHUTDOWN CREDIT FACTOR
The criteria for choosing the emergency shutdown credit factor are unchanged from those stated in the Dow Guide (1994). For a redundancy system that activates when conditions become abnormal, initiating a shutdown sequence, use a credit factor of 0.98.

For critical rotating equipment such as compressors, turbines, fans, etc., that are provided with vibration detection equipment, use a credit factor of 0.99 if the equipment only activates an alarm and a credit factor of 0.96 if it initiates a shutdown.

COMPUTER CONTROL CREDIT FACTOR
The criteria for choosing the computer control credit factor are unchanged from those stated in the Dow Guide (1994). When an on-line computer functions as an aid to operators and is not directly in control of key operations, or where the plant is frequently operated without the computer, use a credit factor of 0.99.

When a computer with “fail-safe” logic is in direct control of a process, a credit factor of 0.97 is used. If any one of the following options are used, the credit factor will be 0.93:
1. Redundant critical field inputs.
2. Abort feature on critical inputs.
3. Backup capability for control system.

INERT GAS CREDIT FACTOR
The criteria for choosing the inert gas credit factor are unchanged from those stated in the Dow Guide (1994). When equipment containing flammable vapors is continuously padded with an inert gas, use a credit factor of 0.96.

If the inert gas has sufficient capacity to purge the total volume of the setup automatically, use a credit factor of 0.94. This credit is not applicable if there is an inert purge connection that must be turned on or controlled manually.

OPERATING PROCEDURES CREDIT FACTOR
The criteria for choosing the operating procedures credit factor are unchanged from those stated in the Dow Guide (1994). Adequate written operating procedures and/or fully documented operating discipline are an important part of maintaining satisfactory control of a unit. The following procedures listed with point ratings, are considered to be the most important:
1. Startup – 0.5
2. Routine shutdown – 0.5
3. Normal operating conditions – 0.5
4. Standby running conditions – 0.5
5. Restarting shortly after a shutdown – 1.0
6. Restarting from a post-maintenance condition – 1.0
7. Maintenance procedures – 1.5
8. Emergency shutdown – 1.5
9. Setup equipment/piping modifications and additions – 2.0
10. Foreseeable abnormal fault conditions – 3.0

To obtain a credit factor, add all the points for the conditions that have operating procedures and divide by
150, then subtract result from one, i.e. credit factor is 1 – (Sum of points/150).

Alternatively, engineering judgment may be used to select the value in the range of 0.92 to 0.99, that best represents the completeness and accuracy of operating instruction.

REACTIVE CHEMICAL REVIEW CREDIT FACTOR
The criteria for choosing the inert gas credit factor are changed from those stated in the Dow Guide (1994). The documented use of a total reactive chemical program for reviewing existing and new processes, including process changes and storage and handling of chemicals, is an important loss control function.

When the reactive chemical program is a continuing part of the operations, a credit factor of 0.91 is used. If the review is done only on an occasional basis, use a credit factor of 0.98.

Unless regular orientation in reactive chemicals is provided, no credit can be taken.

OTHER PROCESS HAZARD ANALYSIS CREDIT FACTOR
The criteria for choosing the other process hazard analysis credit factor are unchanged from those stated in the Dow Guide (1994). Several other process hazard analysis tools can be used in addition to the F&EI evaluation. These include quantitative risk assessment (QRA) – credit factor 0.91, detailed consequence analysis – credit factor 0.93, fault tree analysis (FTA) – credit factor 0.93, hazard and operability (HAZOP) studies – credit factor 0.94, failure modes and effects analysis (FMEA) – credit factor 0.94, environmental-health-safety and loss prevention reviews – credit factor 0.96, “what-if” studies – credit factor 0.96, check list evaluations – credit factor 0.98 and management of change reviews – credit factor 0.98.

When any of these process hazard risk analysis programs are done on a regular part of operations the full credit factor is to be used. If these analysis are only done on an occasional basis, a higher factor is to be used based on good engineering judgment. For full credit the results should be shared with employees as appropriate.

REMOTE CONTROL VALVE CREDIT FACTOR
The criteria for choosing the remote control valve credit factor are changed from those stated in the Dow Guide (1994). If the setup is provided with remotely operated isolation valves so that storage tanks, process vessels or major sections of transfer lines can be quickly isolated in an emergency, use a credit factor of 0.98. If such valves are fully stroked at least annually, use a credit factor of 0.96. If partial stroking is used, use a credit factor of 0.97.

DUMP OR BLOW DOWN CREDIT FACTOR
The criteria for choosing the dump or lowdown credit factor are unchanged from those in the Dow Guide (1994). Where an emergency process dump tank can be used directly to receive the contents of the setup safety with adequate quenching and venting, use a credit factor of 0.98. If the dump tank is located outside the setup area, use a credit factor of 0.96.

For emergency venting, if gas/vapor material is piped to a flare system or to a closed vent receiver, use a credit factor of 0.96.

Credit is given for a normal venting system that reduces the exposure of surrounding equipment to released gases or liquids. A vent tied into a flare system or receiver would receive a credit of 0.98. An example would be a lowdown from a polystyrene reactor to a tank or receiver.

DRAINAGE CREDIT FACTOR
The criteria for choosing the drainage credit factor are unchanged from those in the Dow Guide (1994). To remove a large spill from setup or storage area, it is considered necessary to provide a slope of at least 2% (1% on a hard surface) leading to a drainage trench of adequate size, assuming that 100% of the contents of largest vessel plus 10% of the next largest vessel could be released plus 1 hour of sprinkler fire water. Where this requirement is met, use a credit factor of 0.91.

If drainage conditions are good such as to drain contents away from under or near tanks and equipment, a credit factor of 0.91 can also be used.

If the drainage design would allow a pooling of a large spill but could handle small spills (about 50% of the largest tanks contents), use a credit factor of 0.97. Many drains are capable of handling moderate spills, and many areas would quality for a credit factor of 0.95.

Storage tanks that are diked on four sides to retain spills receive no credit. If the dike design directs the spill to an impounding basin located at least 15 meters away and capable of receiving the contents of the largest diked tank plus 10% of the next largest tank plus sprinkler water, a credit factor of 0.95 is used. If the slope is doubtful, or if the impounding basin is closer than 15 meter away, no credit is given for drainage.

INTERLOCK CREDIT FACTOR
The criteria for choosing the interlock credit factor are unchanged from those in the Dow Guide (1994). If a setup is provided with an interlock system which prevents incorrect material flow that could produce undesirable reactions, used a credit factor of 0.98. This credit can also be taken for a burner management system that meets the loss prevention principles and code requirements.

LEAK DETECTION CREDIT FACTOR
The criteria for choosing the leak detection credit factor are unchanged from those in the Dow Guide (1994). If gas detectors have been installed that alarm only and identify a zone in the setup area, use a credit factor of 0.98. When a gas detector both alarms and activates protective systems before the lower flammability limit is reached, use a credit factor of 0.94.
STRUCTURAL STEEL CREDIT FACTOR
The criteria for choosing the structural steel credit factor are unchanged from those in the Dow Guide (1994). The time duration rating of a fireproof coating application is related to the quantity of fuel in the area and the drainage design.

Where fireproofing is used, it should be applied to all load-bearing steel to a minimum height of 5.0 m. Where this has been done, use a credit factor of 0.98. If fireproofing extends above 5.0 m but less than 10.0 m, use a credit factor of 0.97. For fireproofing above 10.0 m used a credit factor of 0.95, but only if such fireproofing is necessary. Fireproofing systems must be in sound repair, or no credit is to be taken.

Reinforced concrete construction qualifies for the fireproofing credit and is the preferred method for fireproofing. Another approach is to install a sprinkler system for cooling the structure only. This should receive a credit factor of 0.98 under this section (although water spray cooling of a structure is not specifically mentioned), rather than a credit factor of 0.97 under sprinkler systems.

FIRE WATER SUPPLY CREDIT FACTOR
The criteria for choosing the fire water supply credit factor are unchanged from those in the Dow Guide (1994). When the water delivery pressure is 690 kPa (approx. 7 atmospheres) or more, use a credit factor of 0.94. If the delivery pressure is less than 690 kPa, use a credit factor of 0.97.

A setup’s supply of fire fighting water should be capable of delivering the maximum calculated demand for a period of four hours. Less than four hours of fire water may be appropriate for low hazard operations. If this requirement is satisfied use a credit factor of 0.97.

Unless the fire water supply can be provided by alternative power sources which are independent of normal electric service and capable of delivering the maximum calculated demand, no credit factor can be applied. A diesel driven fire pump is an example of an alternative power source.

SPECIAL SYSTEMS CREDIT FACTOR
The criteria for choosing the special systems credit factor are unchanged from those in the Dow Guide (1994). Special systems include carbon dioxide, halon, smoke and flame detectors and blast walls or cubicles. The installation of new halon systems is not allowed because of potential harm to the environment. Credit can be given to existing halon system if deemed appropriate for life safety or other special situations.

It is important to be certain that the loss control credits taken for the setup being studied are those that truly apply to that particular setup. A credit factor of 0.91 can be used for special systems.

If a double wall, above ground tank is designed so that the outer wall will contain the total contents after a leak in the primary wall, a credit factor of 0.91 can be used. However, double wall tanks are usually not cost effective and additional integrity in the primary wall is often a better answer to minimizing risk.

Formerly, a credit was given for underground buried and double walled tanks. There is no doubt that from the standpoint of fire protection that a buried tank is safer; however, a more important concern is the possibility for leakage of buried tanks and the difficulty of being able to detect and control leakage. Due to this environmental concern, the construction of new buried tanks is discouraged.

SPRINKLER SYSTEM CREDIT FACTOR
The criteria for choosing the sprinkler system credit factor are changed from those in the Dow Guide (1994). Deluge systems receive a credit factor of 0.97. A deluge system (open head) gets the minimum credit because such systems have many components, any one of which could fail completely or partially, producing a negative effect on the operation and effectiveness of the system. Also the deluge system is used in combination with other loss control features on relatively hazardous operations so its individual benefit is less.

Credit factors for wet pipe or dry pipe systems used in indoor manufacturing areas and warehouses are defined from the following table:

<table>
<thead>
<tr>
<th>Area</th>
<th>Dry Pipe</th>
<th>Wet Pipe</th>
<th>Penalty Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m²</td>
<td>0.74</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>200 m²</td>
<td>0.74</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>300 m²</td>
<td>0.74</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>&gt; 300 m²</td>
<td>1.06</td>
<td>1.09</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Wet and dry pipe sprinkler systems (closed head) are 99.9%–plus reliable, with very few of the variables encountered with deluge systems, which are subject to failure. Multiply the above credit factors by the following penalty factors, which are based on the size of the floor area confined within fire walls:

- Area > 100 m² – use penalty factor 1.06
- Area > 200 m² – use penalty factor 1.09
- Area > 300 m² – use penalty factor 1.12

Note that as the possible fire area is increased, e.g. a warehouse, the credit factor is increased by a penalty factor, which increases the loss control credit factor and increases the MPPD, as it should. Large fire areas offer greater exposure to fire loss than small fire areas.

WATER CURTAINS CREDIT FACTOR
The criteria for choosing the water curtain credit factor are unchanged from those in the Dow Guide (1994). The use of automatic water spray curtains between a source of ignition and a potential vapor release can be effective in reducing the vapor cloud ignition potential.
To be effective, the curtain should be located at least 23 meter from the vapor release point to allow time for detection of the release and automatic activation of the water curtain. A single tier of nozzles at a maximum elevation of 5 meters will receive a credit factor of 0.98. A second tier of nozzles, not exceeding 2 meter above the first tier, will receive a credit of 0.97.

FOAM CREDIT FACTOR
The criteria for choosing the foam credit factor are unchanged from those in the Dow Guide (1994). If the area protection system includes the capability of injecting foam liquid into a standard deluge sprinkler system from a remote manual control station, use a credit factor of 0.94. This credit is in addition to the credit taken for the deluge system itself. A totally automatic foam system receives a credit of 0.92. Totally automatic means the foam valve is automatically actuated when fire is detected.

Manual foam applications systems for the protection of seal rings on open-top floating roof tanks receive a credit of 0.97. Use a credit factor of 0.94 when fire devices are used for actuating the foam system.

Subsurface foam systems and foam chambers on cone roof tanks receive a credit of 0.95. Foam application around the outer shell of a flammable liquid tank receive a credit factor of 0.97 if manually applied, and 0.94 if automatic.

HAND EXTINGUISHERS CREDIT FACTOR
The criteria for choosing the hand extinguisher credit factor are changed from those in the Dow Guide (1994). If there is an adequate supply available of hand and portable fire extinguishers suitable for the fire risk involved, use a credit factor of 0.98. In a laboratory an adequate supply is at least one extinguisher at each entrance/exit to/from the laboratory. Where there is a potential for a large spill of flammable material that, if ignited, could not be controlled effectively with hand extinguishers, do not take a credit. Hand extinguisher credit is not appropriate for areas where large quantities of flammable or combustible liquids can be spilled.

If monitor guns have also been installed, use a credit factor of 0.97. Monitor guns that can be remotely operated from a safe vantage point receive a credit factor of 0.95. Monitors equipped with foam injection capability receive a credit factor of 0.93. Monitors are normally not installed in laboratories and pilot plants.

CABLE PROTECTION CREDIT FACTOR
The criteria for choosing the cable protection credit factor are unchanged from those in the Dow Guide (1994). Instrument and electrical cable trays are very vulnerable to damage from fire exposure when installed in pipe ways and operating structures. The use of 14 or 16 gauge metal sheet below the tray with a water spray directed onto the top side will provide reasonable protection which justifies a credit of 0.98. The use of fireproofing material on the metal sheet in lieu of the water spray also receives a credit of 0.98. If the cable raceway is buried below grade in a trench (either flooded or dry), use a credit factor of 0.94.
APPENDIX C APPLICATIONS OF MODIFIED DOW F&EI TO LABORATORY SETUP

The following pages contain the Dow F&EI forms for application of the modified F&EI to laboratory setups at the Department of Chemical Engineering at Technical University of Denmark.

MODIFIED F&EI FOR PECTINE EXTRACTION EXERCISE

The pectine extraction exercise involve a number of batch operations to extract pectine from fruit peel into warm water, precipitation of the pectine by addition of isopropanol and drying of the precipitate. Isopropanol is added to the extract after it has been allowed to cool.

There is no exothermic or endothermic reaction involved in the pectine extraction process. However, the process does involve the connection and disconnection of transfer lines for isopropanol, which is a class IB flammable liquid, and this according to gives a 0.50 Transfer and Material Handling Penalty Factor. The setup is indoor in a large laboratory hall with a room temperature around 20 deg C, which is higher than the flash point of isopropanol, and hence gives a 0.30 Indoor or otherwise Enclosed Area Penalty Factor. There is access to the area, where this experimental setup is located from two

<table>
<thead>
<tr>
<th>Modified Fire &amp; Explosion Index for Laboratories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BUILDING</strong></td>
</tr>
<tr>
<td><strong>DEPT</strong></td>
</tr>
<tr>
<td><strong>PREPARED BY</strong></td>
</tr>
<tr>
<td><strong>REVIEWED BY</strong></td>
</tr>
<tr>
<td><strong>MATERIALS IN SETUP</strong></td>
</tr>
<tr>
<td><strong>STATE OF OPERATION</strong></td>
</tr>
<tr>
<td><strong>MATERIAL FACTOR</strong> (See Table 1 or Appendix A or B) Note requirements when unit temperature over 50 deg C</td>
</tr>
<tr>
<td>1. General Process Hazards</td>
</tr>
<tr>
<td><strong>Penalty Factor</strong></td>
</tr>
<tr>
<td><strong>Base Factor</strong></td>
</tr>
<tr>
<td>A. Exothermic Chemical Reactions</td>
</tr>
<tr>
<td>B. Endothermic Chemical Reactions</td>
</tr>
<tr>
<td>C. Material Handling and Transfer</td>
</tr>
<tr>
<td>D. Enclosed or Indoor Setup</td>
</tr>
<tr>
<td>E. Access</td>
</tr>
<tr>
<td>F. Drainage and Spill Control</td>
</tr>
<tr>
<td><strong>General Process Hazards Factor</strong> (F_g)</td>
</tr>
<tr>
<td>2. Special Process Hazards</td>
</tr>
<tr>
<td><strong>Penalty Factor</strong></td>
</tr>
<tr>
<td><strong>Base Factor</strong></td>
</tr>
<tr>
<td>A. Toxic Material(s)</td>
</tr>
<tr>
<td>B. Sub-Atmospheric Pressure (&lt; 500 mm Hg)</td>
</tr>
<tr>
<td>C. Operation In or Near Flammable Range</td>
</tr>
<tr>
<td>1. Tank Farms Storage Flammable Liquids</td>
</tr>
<tr>
<td>2. Process Upset or Purge Failure</td>
</tr>
<tr>
<td>3. Always in Flammable Range</td>
</tr>
<tr>
<td>D. Dust Explosion</td>
</tr>
<tr>
<td>E. Pressure</td>
</tr>
<tr>
<td>Relief pressure 101.0 kPag</td>
</tr>
<tr>
<td>F. Low Temperature</td>
</tr>
<tr>
<td>G. Quantity of Flammable/Unstable Material</td>
</tr>
<tr>
<td>1. Liquids or Gasses in Process</td>
</tr>
<tr>
<td>2. Liquids or Gasses in Storage</td>
</tr>
<tr>
<td>3. Combustible Solids in Storage, Dust in Process</td>
</tr>
<tr>
<td>H. Corrosion or Erosion</td>
</tr>
<tr>
<td>I. Leakage – Joints and Packing</td>
</tr>
<tr>
<td>J. Use of Fired Equipment</td>
</tr>
<tr>
<td>K. Hot Oil Heat Exchange System</td>
</tr>
<tr>
<td>L. Rotating Equipment</td>
</tr>
<tr>
<td>Special Process Hazards Factor (F_s)</td>
</tr>
<tr>
<td>Process Unit Hazards Factor (F_p x F_s)</td>
</tr>
<tr>
<td>Fire and Explosion Index (F_e x MF = F&amp;EI)</td>
</tr>
</tbody>
</table>
independent escape routes as well as from adjacent laboratory and a workshop, and hence to Access Penalty Factor is given. The floor in the laboratory hall will allow a spill to spread to other experimental setups, and hence gives a 0.50 Drainage and Spill Control Penalty Factor. This results in a General Process Hazards Factor of 2.30.

Isopropanol has an NFPA Health rating of 1, which results in a Toxic Material Penalty Factor of 0.20. Since operation is not performed at sub-atmospheric pressure no penalty is applied. The extraction step during which a mixture of water and isopropanol is aerated with compressed air is the closest this experiment comes to operations in or near flammable range. The LEL and UEL for isopropanol are respectively 2% and 12.7%. During normal operation the airflow is sufficient to keep the amount of isopropanol in the vent stream from the precipitation vessel below the LEL. In the event of failure of the compressed air supply concentrations of isopropanol above the LEL in the airspace above the precipitation mixture cannot be ruled out, and hence a 0.30 Operations In or Near Flammable Range Penalty Factor is assessed. A penalty factor for the quantity of flammable material in the process need to be applied, since isopropanol is a flammable liquid with flash point below 60 °C. A standard value of the Corrosion and Erosion Penalty factor is also applied. The handout for the pectin extraction setup has several references to leakage problems, and therefore a 0.30 Joints and Piping Penalty Factor is also applied. The special process hazards factor is thus 3.29.

The process unit hazards factor for the pectin extraction setup is 7.57, and hence the modified fire and explosion index is 121, corresponding to an intermediate degree of hazard.

The loss control credit factor calculations for this experimental setup is rather simple. The setup has no emergency power systems, no special cooling systems, no explosion control systems, no computer control systems, no inert gas systems and no reactive chemicals review. However, there is an experimental procedure, which describe pre-startup and normal operations, thus giving a credit for operating instructions and procedures of 1 − (0.5 + 0.5/150) = 0.99. A simple analysis of deviations from normal operations have also been performed using a what-if type of study, thus giving a credit for other process hazard analysis of 0.96, and hence a Process Control Credit C1 of 0.95.

Since there is no remote control valves, no dump / blowdown system, no special drainage system and no interlock system the Materials Isolation Credit Factor C2 is 1.00. Furthermore there is no leak detection systems, no structural steel protection, no special systems, no sprinkler system, no water curtains, no foam system and no cable protection systems, the only factors to be considered in calculation of the fire protection credit factor is fire water supply and hand extinguishers. The fire water supply system of the building in which the experimental setup is located is independent of normal electrical service, but the water supply pressure is uncertain, and hence the Fire Water Credit Factor is 0.97. There is an adequate supply of hand extinguishers available near this experimental setup, and hence the Hand Extinguishers Credit Factor is 0.98. Thus the Fire Protection Credit Factor C3 is 0.95, and the Loss Control Credit Factor is C1 × C2 × C3 = 0.91.

Since the value of the equipment is difficult to assess the Likely Loss-Fire & Explosion Index, LLF&EI (Jensen and Jørgensen, 2006) is applied to determine the level of risk associated with the pectin extraction experimental setup. Based on this work the damage factor is calculated from the process unit hazards factor using a polynomial of the form

\[ DF = a_0 + a_1 \times F_3 + a_2 \times F_3^2 + a_3 \times F_3^3 \]

where the coefficients depends on the material factor, MF. This gives a damage factor MF = 0.66. Then the LL-F&EI is calculated according to the following equation

\[ LL-F&EI = 0.453806 \times \text{SQRT}(DF \times LCCF) \times M-F&EI \]

which gives LL-F&EI = 43, which corresponds to a moderate degree of risk according to Jensen and Jørgensen (2006).

MODIFIED F&EI FOR AMMONIA ABSORPTION SETUP

The ammonia absorption setup involves the adsorption of ammonia into a counter-current stream of water in a packed bed column. The ammonia is evaporated from a pressurized gas cylinder and mixed with to a stream containing approximately 3% ammonia. The LEL and UEL for ammonia are respectively 15% and 28%. Under normal operating conditions the stream of water, into which the ammonia is absorbed is approximately 30 times what is needed to absorb all the ammonia. Nonetheless and after-absorber is used to avoid the release of ammonia gas to the room, which is the largest risk of this experiment. The absorption of ammonia in water at the experimental conditions have very limited influence on the temperature of the streams. Since the students don’t change the cylinder with liquified ammonia no transfer and handling of material penalty factor is assessed, but since ammonia is used above its boiling point an indoor or otherwise enclosed area penalty factor of 0.30 is given. Access to the ammonia adsorption setup is adequate, and hence no access penalty factor is assessed. However, a drainage and spill control penalty factor is given. This results in a general process hazards factor of 1.80.

The only penalties assessed in the special hazards penalty factor is for toxicity, corrosion and leakage resulting the a special process hazards factor of 1.80, and unit process hazards factor of 3.24. Thus the modified fire and explosion index for the ammonia absorption setup is 13, corresponding to a light hazard.

The calculation of the loss control credits for this setup is very simple. The setup has no emergency power systems, no
no special cooling system, no explosion control protection, no emergency shutdown system, no computer control system and no reactive chemical review. However, written instruction for normal experimental procedures do exist, and a what-if type hazard analysis has been conducted by the responsible teacher. This gives a process control credit of 0.95. None of features relevant for material isolation credit apply to this setup, and hence the material isolation credit is 1.00. As far as the features relevant for fire protection credit none apply to this setup, and hence the fire protection credit factor is 1.00. The overall loss control credit factor is therefore 0.95.