PREFACE TO THE SIXTH EDITION

This edition reflects experience gained in applying the procedures specified in previous editions (particularly the Fifth Edition) to a great number of risk analyses in process plants. This edition incorporates numerous text and application changes including revisions of three penalty charts to make them more representative of actual process conditions.

Improvements embodied in the present edition include:

a) Adjustments to the determination of the Material Factor (MF) to represent the probable effects of temperature and reactivity more accurately.
b) Addition of a Toxicity Penalty to reflect possible emergency response complications.
c) Simplification of the Credit Factor determination.
d) Clearer definition of Process Hazard Penalties to make them more readily applicable to current process situations.
e) Definition of the Risk Analysis Package, including Business Interruption Risks.
f) Use of many examples to demonstrate how the various components of an F&EI calculation are used.

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INTRODUCTION: THE FIRE AND EXPLOSION INDEX SYSTEM

The Fire and Explosion Risk Analysis Program is a step-by-step objective evaluation of the realistic fire, explosion, and reactivity potential of process equipment and its contents. The quantitative measures employed in the analysis are based on historic loss data, the energy potential of the material under study, and the extent to which loss prevention practices are currently applied.

In short, the purpose of the F&EI system is to:

1. QUANTIFY the expected damage of potential fire and explosion incidents in realistic terms.
2. IDENTIFY equipment that would be likely to contribute to the creation or escalation of an incident.
3. COMMUNICATE the F&E risk potential to management.

Beneath all the numbers, graphs, and figures, however, lies the most important goal of the F&EI Program — TO MAKE YOU AWARE OF THE LOSS POTENTIAL OF YOUR OWN PROCESS AREA and to help you identify ways to lessen the severity and resultant dollar loss of potential incidents in an efficient and cost effective manner.

Insurance company assessments of potential exposures are typically based on the worst imaginable incident. They might anticipate, for example, that the complete contents of a reactor dump could vaporize instantaneously and ignite, and their insurance loss estimates, which are determined in part from this kind of analysis, can be extremely large. From a realistic point of view, this kind of situation will seldom, if ever, occur.

The Dow F&EI system attempts to determine the **realistic** maximum loss that can occur to a process plant or related facility — a loss that could **actually** be experienced under the most adverse operating conditions, and the calculation is based on quantifiable data. Finite spill rates, process temperature in relation to material flash points and boiling points, and material chemistry are just a few of the many components of a probable incident that are studied and evaluated.

Although the F&EI system is primarily designed for any operation in which a flammable, combustible, or reactive material is stored, handled, or processed, it may also be used in analyzing the loss potential of sewage treating facilities, distribution systems, pipelines, rectifiers, transformers, boilers, and certain elements of power plants. The system can also be used for risk evaluations of very small processes with small inventories of potentially hazardous materials: its application on pilot plants is strongly recommended.

A WORD OF CAUTION is in order for those planning to use the F&EI system for the risk evaluation of such facilities. Common sense and good judgment must be used during the actual calculation and in the interpretation of its results. Process hazards that contribute to the magnitude of losses have been quantified as "penalties" to provide factors for computation, but not every penalty may be applicable to a specific situation and some may have to be modified. Your Loss Prevention Contact can serve as a valuable resource person who can assist you in the calculations.

Figure 1 — Procedure for Calculating Unit Hazard Factor F&E Index — MPPD & MPDO

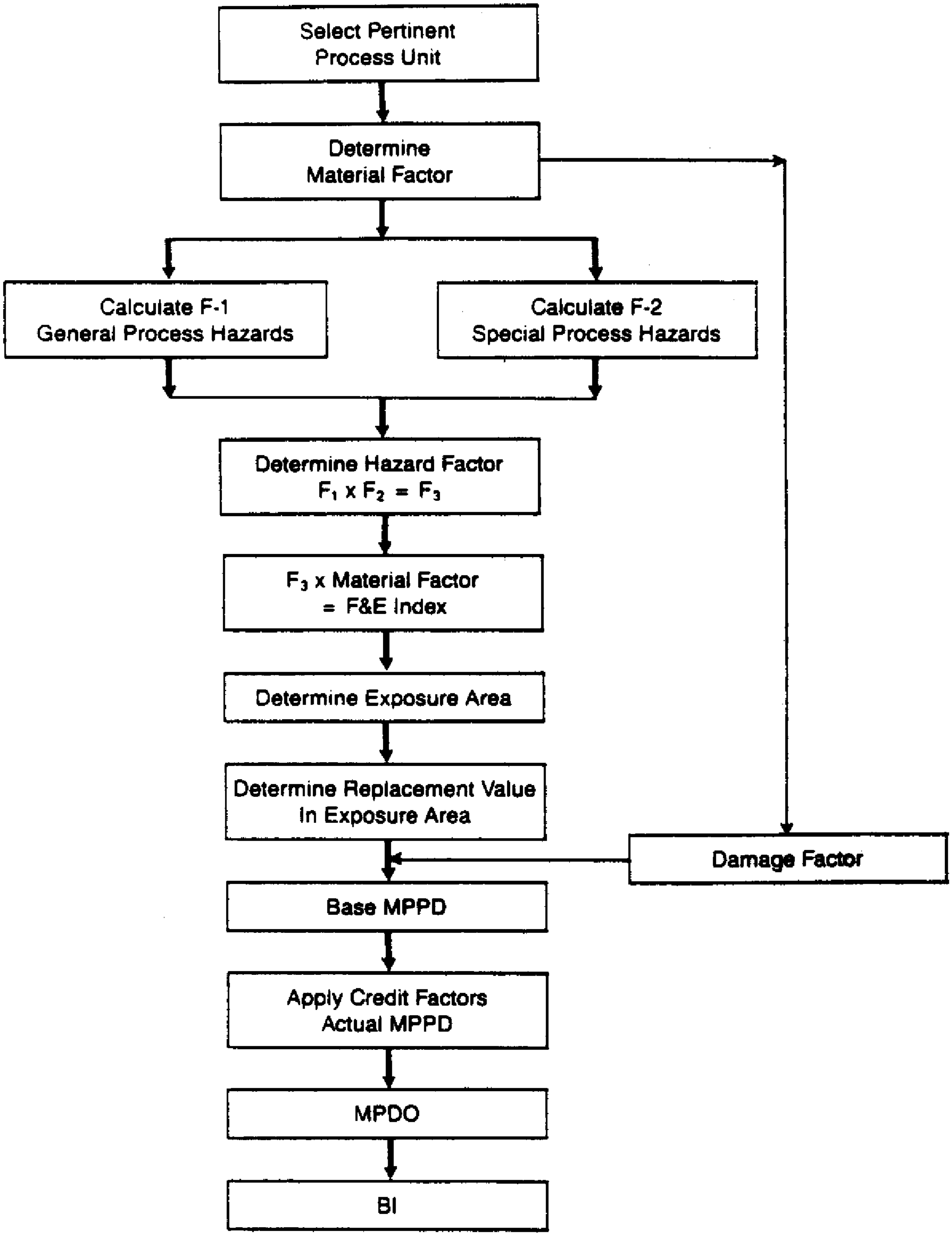

EXHIBIT A

FIRE AND EXPLOSION INDEX

Dow

		LOCATION	DATE
PLANT	PROCESS UNIT	EVALUATED BY	REVIEWED BY

MATERIALS AND PROCESS

MATERIALS IN PROCESS UNIT

STATE OF OPERATION START UP SHUT-DOWN NORMAL OPERATION	BASIC MATERIAL(S) FOR MATERIAL FACTOR

MATERIAL FACTOR (SEE TABLE I OR APPENDICES A OR B) Note requirements when unit temperature over 140°F) →			
1. GENERAL PROCESS HAZARDS	PENALTY	PENALTY USED	
BASE FACTOR →	1.00	1.00	
A. EXOTHERMIC CHEMICAL REACTIONS (FACTOR .30 to 1.25)			
B. ENDOTHERMIC PROCESSES (FACTOR .20 to .40)			
C. MATERIAL HANDLING & TRANSFER (FACTOR .25 to 1.05)			
D. ENCLOSED OR INDOOR PROCESS UNITS (FACTOR .25 to .90)			
E. ACCESS	.35		
F. DRAINAGE AND SPILL CONTROL (FACTOR .25 to .50) ________ Gals			
GENERAL PROCESS HAZARDS FACTOR (F_1) →			
2. SPECIAL PROCESS HAZARDS			
BASE FACTOR →	1.00	1.00	
A. TOXIC MATERIAL(S) (FACTOR 0.20 to 0.80)			
B. SUB ATMOSPHERIC PRESSURE (< 500 mm Hg)	.50		
C. OPERATION IN OR NEAR FLAMMABLE RANGE INERTED NOT INERTED			
1. TANK FARMS STORAGE FLAMMABLE LIQUIDS	.50		
2. PROCESS UPSET OR PURGE FAILURE	.30		
3. ALWAYS IN FLAMMABLE RANGE	.30		
D. DUST EXPLOSION (FACTOR .25 to 2.00) (SEE TABLE II)			
E. PRESSURE (SEE FIGURE 2) OPERATING PRESSURE _____ psig RELIEF SETTING _____ psig			
F. LOW TEMPERATURE (FACTOR .20 to .30)			
G. QUANTITY OF FLAMMABLE/UNSTABLE MATERIAL QUANTITY ________ lbs., H_c = _______ BTU/lb			
1. LIQUIDS, GASES AND REACTIVE MATERIALS IN PROCESS (SEE FIG. 3)			
2. LIQUIDS OR GASES IN STORAGE (SEE FIG. 4)			
3. COMBUSTIBLE SOLIDS IN STORAGE, DUST IN PROCESS (SEE FIG. 5)			
H. CORROSION AND EROSION (FACTOR .10 to .75)			
I. LEAKAGE – JOINTS AND PACKING (FACTOR .10 to 1.50)			
J. USE OF FIRED HEATERS (SEE FIG. 6)			
K. HOT OIL HEAT EXCHANGE SYSTEM (FACTOR .15 to 1.15) (SEE TABLE III)			
L. ROTATING EQUIPMENT	.50		
SPECIAL PROCESS HAZARDS FACTOR (F_2) →			
UNIT HAZARD FACTOR (F_1 x F_2 = F_3) →			
FIRE AND EXPLOSION INDEX (F_3 x MF = F & EI) →			

FORM C-22380 R-4-87 (471-036)

EXHIBIT B

LOSS CONTROL CREDIT FACTORS

1. Process Control (C_1)

a) Emergency Power	98	f) Inert Gas	.94 to .96
b) Cooling	97 to 99	g) Operating Instructions/ Procedures	91 to .99
c) Explosion Control	84 to 98	h) Reactive Chemical Review	.91 to .98
d) Emergency Shutdown	.96 to .99		
e) Computer Control	.93 to .99		

C_1 Total____________

2. Material Isolation (C_2)

a) Remote Control Valves	96 to .98	c) Drainage	.91 to .97
b) Dump/Blowdown	96 to 98	d) Interlock	98

C_2 Total____________

3. Fire Protection (C_3)

a) Leak Detection	.94 to .98	f) Sprinkler Systems	.74 to .97
b) Structural Steel	95 to .98	g) Water Curtains	.97 to .98
c) Buried Tanks	84 to .91	h) Foam	.92 to .97
d) Water Supply	.94 to 97	i) Hand Extinguishers/Monitors	.95 to 98
e) Special Systems	.91	j) Cable Protection	.94 to .98

C_3 Value____________

Credit Factor = $C_1 \times C_2 \times C_3$ = __________ Enter on Line D Below

UNIT ANALYSIS SUMMARY

A-1 F & EI ____________

A-2. Radius of Exposure ____________ ft.

A-3 Value of Area of Exposure $MM ____________

B Damage Factor ____________

C. Base MMPD (A-3 X B) $MM ____________

D. Credit Factor ____________

E. Actual MMPD (C X D) $MM ____________

F Days Outage (MPDO) ____________ days.

G. Business Interruption Loss (BI) $MM ____________

Product of all factors used.

BACK OF FORM C-22380 R-4-87 (471-036)

EXHIBIT

PLANT RISK ANALYSIS SUMMARY

AREA S.

DIV./LOCATION: North Central/Dowville

DATE: 8/26/86

PLANT Visnox

REPLACEMENT VALUE: $50MM

PREPARED BY: Max Adams

Plant Units	Material Factor MF	F&EI $(F_3 X MF)$	Value Area of Exposure $MM	Base MPPD $MM (A-3XB)	Actual MMPD $MM (CXD)	Days Outage MPDO (Figure 9)	B.I. Loss $MM
1. Reactor	29	174	15.000	13.0	6.4	40/110	10.0
2. Furnace	16	96	12.000	7.0	4.0	28/90	7.0
3. Compressor	24	143	15.0	12.5	5.7	35/110	9.0

Three Process Units in a hypothetical plant have been evaluated with results shown above. Assume a total Replacement Value of plant at $50MM. Then from the above recap, the highest Base MPPD is $13MM, and the highest Actual MPPD is $6.4MM with an MPDO range of 40 to 110 days for the Reactor and a Business Interruption Loss of $10MM.

SELECTION OF PERTINENT PROCESS UNITS

The F&EI calculation is intended as a tool to help you determine the areas of greatest loss potential in a particula process. It also enables you to predict the physical damage that would occur in the event of an incident and the losse to be expected from business interruption.

To employ the F&EI calculation effectively, you must first follow an efficient, logical procedure to determine which uni within the plant should be studied.

For the purposes of the F&EI Guide, a **PROCESS UNIT** is defined as any primary item of process equipment. Th following **Process Units** could be identified in a furnace/quench section of a VCM/EDC plant: EDC preheater, ED evaporator, furnace, quench column, EDC absorber, and tarpot.

The process area of an S/B latex plant could have the following **Process Units:** monomer mix feed prep, reactors strippers, monomer recovery, aqueous room, and styrene scrubber.

A warehouse may also be treated as a **Process Unit.** In particular, the materials stored within a fire-walled area, c within the total storage area where fire walls are not provided, would constitute a **Process Unit.**

It is quite clear that most plants have many **Process Units.** To calculate the Fire and Explosion Index, however, onl **Process Units** that could have an impact on the process from a **Loss Prevention** standpoint should be evaluated These are known as "**Pertinent Process Units.**"

Important factors for selecting **Pertinent Process Units** include:

a) Chemical energy potential (Material Factor),
b) Quantity of hazardous material in the **Process Unit,**
c) Capital density (dollars per square foot),
d) Process pressure and process temperature,
e) Past history of problems that could be conducive to a fire and explosion incident.

Generally, the greater the magnitude of any of these factors, the greater the likelihood that the **Process Unit** needs to be evaluated.

The destruction in an incident of scarce, critical, or one-of-a-kind equipment in or near a **Process Unit** could produce many days of downtime. Even with minimal actual fire and explosion damage, this could create high losses due to business interruption. Another valid criterion for selecting **Pertinent Process Units** would be the loss of such critical equipment.

There are no hard and fast rules governing the choice of **Process Units** for evaluation. For help in determining which pieces of equipment have the greatest potential for fire and explosion, you can consult Technology Center manuals, experienced plant engineers, or others with past process experience.

A. Important Considerations

1. The Fire and Explosion Index system assumes that a **Process Unit** handles a minimum of 5,000 pounds, or about 600 gallons of a flammable, combustible, or reactive material. If less material is involved (in a pilot plant, for example), the RISK WILL BE OVERSTATED. As a general rule, F&EI calculations can provide meaningful results for pilot plants only if they handle at least 1000 pounds or about 120 gallons of combustible or reactive material.

2. Careful consideration is needed when equipment is arranged in series and the items are NOT effectively isolated from each other. (An example would be a reaction train without an intermediate pump.) In such situations, the TYPE of process determines whether the whole train or just a single vessel should be considered as the **PROCESS UNIT.**

   In a polystyrene train, for example, where the main hazard is from unreacted material in the first stage reactor, it is inappropriate to apply any penalties for vacuum operation in the flash tank or devolatilizer (which is effectively the third or fourth stage) because IT IS INCONCEIVABLE TO HAVE BOTH HAZARDS OCCURRING AT THE SAME POINT IN THE PROCESS. In this case, it would be reasonable to carry out two separate F&EI calculations, treating the first stage and fourth stage reactors as separate **Process Units.**

   It should rarely be necessary to calculate the F&EI for more than three or four **Process Units** in a single PROCESS AREA of a plant. The number of process areas will vary according to the type of process and the configuration of the plant.

   A separate F&EI form (Exhibits A and B, pages 6 and 7) must be completed for each **Process Unit** evaluated. The results of each calculation must also be listed on the Plant Risk Analysis Summary (Exhibit C, page 8).

3. It is also important to give careful consideration to the state or stage of the operation. By their nature, such normal stages as start-up, steady-state operation, shutdown, filling, emptying, adding catalyst, etc., often created unique conditions having an impact on the F&EI. Generally, good judgment will enable you to select the stage of operation on which to perform the F&EI calculation, but occasionally more than one stage will have to be studied in determining the significant risk.

DETERMINE MATERIAL FACTOR

The Material Factor (MF) is the basic starting value in the computation of the F&EI and other risk analysis values. The MF is a measure of the intrinsic rate of potential energy release from fire or explosion produced by combustion or other chemical reaction.

The MF is obtained from N_f and N_r. The N_f and N_r are NFPA "signals" expressing flammability and reactivity (or instability) respectively, as discussed below under "Unlisted Substances."

Generally, N_f and N_r are for ambient temperatures. It is recognized that the fire and reaction hazards of a material increase markedly with temperature. The fire hazard from a combustible liquid at a temperature above its flash point is equivalent to that from a flammable liquid at ambient temperature. Reaction rates also increase very markedly with temperature. If the temperature of the material on which the MF is based is over 140°F, a certain adjustment may be required, as discussed below under "Temperature Adjustment of Material Factor."

Appendix A provides a listing of MF's for a number of chemical compounds and materials, and these values will be used in most cases. If Appendix A does not list the material, N_f and N_r may possibly be found in NFPA 325M or NFPA 49 adjusted for temperature if appropriate, and used with Table I to determine the MF. If the material is a combustible dust, use the St number rather than the N_f.

A. Unlisted Substances

If neither Appendix A nor NFPA 325 M contains values for the substance, mixture, or compound in question, you will have to determine the flammability value (N_f) or dust class (St). (See Table I, page 13.) First, you will have to establish the parameters shown in the left column of the table. The N_f of liquids and gases is obtained from flash point data and the St of dusts or mists is determined by dust explosion testing. The N_f of combustible solids depends on the nature of the material as categorized in the left column.

The reactivity value (N_r) can be obtained from a qualitative description of the instability (or reactivity with water) of the substance, mixture, or compound at ambient temperature, as follows:

$N_r = 0$ Substance is completely stable, even when heated under fire conditions
$N_r = 1$ Mild reactivity upon heating with pressure
$N_r = 2$ Significant reactivity, even without heating or pressure
$N_r = 3$ Detonation possible with confinement
$N_r = 4$ Detonation possible without confinement

Note that reactivity includes self-reactivity (instability) and reactivity with water.

The reactivity value (N_r) can be obtained more objectively by using the peak temperature of the lowest DTA (Differential Thermal Analysis) or DSC (Differential Scanning Calorimeter) exotherm value as follows:

Exotherm, degrees C	N_r
>400	0
305 to 400	1
215 to 305	2
125 to 215	3
<125	4

There are some exceptions:

1. If the exotherm peak results in $N_r = 4$, but the substance, mixture, or compound is not shock-sensitive, make $N_r = 3$.
2. If the substance or compound is an oxidizer, increase N_r by one (but not over $N_r = 4$).
3. Any shock-sensitive material must be $N_r = 3$ or $N_r = 4$, depending on exotherm temperature.
4. If the N_r obtained seems inconsistent with known properties of the substance, mixture, or compound, additional reactive chemicals testing should be done.

Once you have obtained the N_f or St and determined the N_r, the resulting N_f (or St) and N_r are used with Table I to determine the MF. Make the necessary adjustments as discussed below under "Temperature Adjustment of Material Factor."

B. Mixtures

Mixtures of various kinds can be troublesome under certain conditions. Normally, materials that react violently — fuel and air, or hydrogen and chlorine, for example — are mixed under controlled conditions. The reactions generally take place continuously and rapidly, producing nonflammable, stable products that are safely contained within a Process Unit such as a reactor. The combustion of fuel and air in a furnace is a good example of this sort of controlled reaction. However, since "flame-outs" and other breakdowns can still occur, the MF should be based on the initial reactive mixture, which fits the description of "most hazardous material present during a realistic operating scenario." For additional information see Appendix B, page 57.

Mixtures of solvents or of a solvent with a reactive material can also create troublesome situations. Generally, the MF for such mixtures should be obtained from reactive chemical testing data, as recommended in Appendix B.

If you do not have access to reactive chemical testing data, you can obtain a satisfactory approximation by using the MF of the component with the highest MF value.

One particularly troublesome mixture is the "hybrid." This is a mixture of combustible dust and flammable gas, which can form an explosive mixture in air. The Material Factor must adequately reflect the material hazard present in this UNIQUE SITUATION, and reactive chemical testing data MUST be employed to determine the proper MF.

TABLE 1 — Material Factor Determination Guide

		Reactivity or Instability				
[1]LIQUIDS AND GASES Flammability or Combustibility	NFPA 325M or 49	$N_r = 0$	$N_r = 1$	$N_r = 2$	$N_r = 3$	$N_r = 4$
[2]Non-combustible	$N_f = 0$	1	14	24	29	40
F.P. > 200°F	$N_f = 1$	4	14	24	29	40
F.P. ≥ 100°F < 200°F	$N_f = 2$	10	14	24	29	40
F.P. < 100°F B.P. ≥ 100°F	$N_f = 3$	16	16	24	29	40
F.P. < 73°F B.P. < 100°F	$N_f = 4$	21	21	24	29	40
[3]COMBUSTIBLE DUST OR MIST						
St-1 ($K_{St} \leq 200$ bar m/sec.)		16	16	24	29	40
St-2 ($K_{St} = 201$-300 bar m/sec.)		21	21	24	29	40
St-3 ($K_{St} > 300$ bar m/sec.)		24	24	24	29	40
COMBUSTIBLE SOLIDS						
[4]Dense > 40mm thick	$N_f = 1$	4	14	24	29	40
[5]Open < 40mm thick	$N_f = 2$	10	14	24	29	40
[6]Foam, fiber, powder, etc.	$N_f = 3$	16	16	24	29	40

F.P. = Flash Point, closed cup
B.P. = Boiling Point at Standard Temperatures and Pressure (STP)

Notes:

[1] Includes volatile solids.

[2] Will not burn in air when exposed to a temperature of 1500°F for a period of five minutes.

[3] K_{St} values are for a 16 liter or larger closed test vessel with strong ignition source. See NFPA 68, Guide for Venting of Deflagrations.

[4] Includes wood 2" nominal thickness, magnesium ingots, tight stacks of solids, and tight rolls of paper or plastic film. Example: SARAN WRAP*

[5] Includes coarse granular material such as plastic pellets, rack storage, wood pallets, and non-dusting ground material such as polystyrene.

[6] Includes rubber goods such as tires and boots, STYROFOAM* brand plastic foam and fine material such as METHOCEL* cellulose ethers in dust/leak-free packages.

*Trademark of The Dow Chemical Company

C. Temperature Adjustment of Material Factor

It is important to recognize that the MF represents the hazard of the selected material at **ambient temperature** and **pressure.** The effect of pressure is discussed in detail later under "Special Process Hazards." If the Process Unit temperature is above 140°F (60°C), the MF itself will require adjustment. This is done as follows:

MATERIAL FACTOR	N_f	St	N_r
a. Enter N_f (St — for dusts) and N_r			
b. If temperature below 140°F (60°C), go to "e"			
c. If temperature above flash point, enter "1" under N_f			
d. If temperature above exotherm start (see paragraph below) or autoignition, enter "1" under N_r			
e. Add each column, but enter 4 where total is 5			
f. Using "e" and Table I, determine Material Factor (MF) and enter on F&EI Form — Exhibit A			

NOTE: 140°F. can be reached in storage due to layering and solar heat.

Flash point and autoignition data are generally available and understood, but "**Exotherm Start**" requires explanation. **Exotherm Start** is the temperature at which a heat-generating chemical reaction is first detected in Accelerating Rate Calorimetry (ARC) or similar calorimeter. **Exotherm Start** can be estimated from data secured by Differential Thermal Analysis (DTA) or Differential Scanning Calorimetry (DSC) either by a) subtracting 70°C from the first exotherm start temperature or b) subtracting 100°C from the first exotherm peak temperature. The use of a) is preferred. Of course, if the "real" exotherm start temperature is known from operating experience (with a reactor in a plant, for example), the "real" temperature should be used.

If the Process Unit is a reactor, the exotherm due to the intended reaction is disregarded for purposes of temperature adjustment due to reactivity.

Example:

DOWTHERM*, a heat transfer fluid, has a flash point of 255°F (124°C) and an autoignition temperature of 1150°F (621°C). It has no DSC exotherm below 752°F (400°C) (the usual limit of testing). When in drums in storage it has an MF of 4 (N_f = 1 and N_r = 0). When used, say, as a solvent above 140°F (60°C), the MF is still 4, up to 255°F (124°C). When it is used at temperatures above its flash point of 255°F (124°C), its N_f is increased to 2, making the MF = 10.

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CONTRIBUTING HAZARD FACTORS

After the appropriate Material Factor has been determined, the next step is to calculate the **Unit Hazard Factor** (F_3), which is the term that is multiplied by the Material Factor to obtain the F&EI.

The numerical value of the **Unit Hazard Factor** is determined by reviewing each of the CONTRIBUTING HAZARDS listed on the F&EI form (Exhibit A) under the headings GENERAL PROCESS HAZARD (F_1) and SPECIAL PROCESS HAZARD (F_2). Each item listed as a Contributing Hazard is considered to be a factor contributing to the development or escalation of an incident that could cause a fire or an explosion.

When calculating the penalties comprising the **Unit Hazard Factor** F_3, pick a single specific instant in time during which the material represented by the MF is associated with the **Process Unit** in the most hazardous NORMAL OPERATION STATE. Startup, general operation and shutdown are among the operational states that may be considered.

This rather strict definition is intended to prevent double or triple counting of hazards occurring during the process. Since the MF is taken to be that of the **most hazardous** substance present in the **Process Unit**, you can be certain that your Fire and Explosion analysis will really be based upon a "worst case" when you focus on the most hazardous operational point involving the MF; and this will be a realistic worst case — one that could **actually occur.**

In the F&EI system, only one hazard may be evaluated at a time. If the MF is based on a flammable liquid present in the **Process Unit**, DO NOT TAKE PENALTIES RELATING TO COMBUSTIBLE DUSTS, even though dust may be present at a different time. A reasonable approach might be to evaluate the **Process Unit** once using the MF of the flammable liquid and a second time using the MF of the dust, submitting only the **higher** exposure or higher F&EI calculated.

One **important exception** is the HYBRID, described previously under "Mixtures." If a hybrid mixture is selected as the most hazardous material present, it is penalized both as a dust and as a flammable vapor in the Contributing Hazard Factor sections of this manual.

Some items on the F&EI form have fixed penalty values. For those that do not, determine the appropriate penalty by consulting the text that follows:

REMEMBER — ANALYZE ONLY ONE HAZARD AT A TIME, relating your analysis to a specific, most hazardous time (e.g., startup, normal operation, or shutdown). Keep your focus on the specific **Process Unit** and Material Factor selected for analysis and keep in mind that the results of your calculation are only as valid as the consistency of your penalty assessments.

GENERAL PROCESS HAZARDS

General Process Hazards are factors that play a primary role in determining the magnitude of a loss incident.

The six items listed in this section as CONTRIBUTING HAZARDS are applicable to most process situations. Although it may not be necessary to take penalties for each part of this section, these items have historically played large roles in fire and explosion incidents, and careful evaluation of your particular Process Unit is of **paramount** importance.

REMEMBER, to evaluate the exposure risk of any Process Unit **realistically**, you must apply each GENERAL PROCESS HAZARD PENALTY under the **most hazardous normal operating conditions** that might occur during the association of a specific Material Factor with the Process Unit being analyzed.

A. Exothermic Chemical Reactions

Take this penalty **only** if the Process Unit in question is a reactor in which a chemical reaction takes place.

1. MILD EXOTHERMS require a **penalty of 0.30.** Examples include:
   - a) **Hydrogenation** — Addition of hydrogen atoms to both sides of a double or triple bond.
   - b) **Hydrolysis** — Reaction of a compound with water, as in the manufacture of sulfuric or phosphoric acids from oxides.
   - c) **Isomerization** — Rearrangement of the atoms of an organic molecule such as a change from a straight chain to a branched molecule.
   - d) **Sulfonation** — Introduction of an SO_3H radical into an organic molecule through reaction with H_2SO_4.
   - e) **Neutralization** — Reaction between an acid and a base to produce a salt and water, or of a base and an alcohol to produce the corresponding alcoholate and water.
2. MODERATE EXOTHERMS require a **penalty of 0.50.** Examples include:
   - a) **Alkylation** — Addition of an alkyl group to a compound to form various organic compounds.
   - b) **Esterification** — Reaction between an organic acid and an alcohol.
   - c) **Addition reactions** — Reactions occurring between inorganic acids and unsaturated hydrocarbons. **When the acid is a strongly reactive material, increase the penalty to 0.75.**
   - d) **Oxidation** — Combination of substances with oxygen by combustion, releasing CO_2 and H_2O, or a controlled reaction of some substances with oxygen that does not result in CO_2 and H_2O. For combustion processes and where vigorous oxidizing agents such as chlorates, nitric acid, hypochlorous acids and salts are used, **increase the penalty to 1.00.**
   - e) **Polymerization** — Joining together of molecules to form chains or other linkages.
   - f) **Condensation** — Joining together of two or more organic molecules with the splitting off of H_2O, HCl, or other compounds.
3. CRITICAL-TO-CONTROL EXOTHERMS require a **penalty of 1.00.** These are a class of reactions in which a significant fire and explosion potential would exist if control was lost. Example:
   - a) **Halogenation** — Introduction of a halogen or halogens into an organic molecule.
4. PARTICULARLY SENSITIVE EXOTHERMS, which are quite hazardous exothermic reactions, **require a penalty of 1.25.** Example:
   - a) **Nitration** — The replacement of a hydrogen atom in a compound with a nitro group.

B. Endothermic Processes

A **penalty of 0.20** is taken for any endothermic process taking place in a reactor. NOTE: THIS PENALTY APPLIE ONLY TO REACTORS. When the energy input for the endothermic process is provided by the combustion of solid, liquid, or gaseous **fuel**, the **penalty is increased to 0.40.** Examples include:

1. **Calcination** — Heating a material to remove chemically bonded water or other volatile material. This generall requires a **penalty of 0.40.**
2. **Electrolysis** — Separation of ions by means of an electric current. This generally requires a **penalty of 0.20**
3. **Pyrolysis** or **Cracking** — Thermal decomposition of large molecules by use of high temperatures, hig pressures, and a catalyst. The **penalty is 0.20** for electric or remote hot gas heat or **0.40** for direct fired hea

C. Material Handling and Transfer

This item is evaluated with regard to the potential for fire involving the pertinent Process Unit during the handling, transfer, and warehousing of materials.

1. Any loading or unloading operation involving Class I flammables or LPG-type materials where transfer lines are connected and disconnected receives a **penalty of 0.50.**
2. Where the introduction of air during manual addition of some ingredients into centrifuges, batch reactors or batch mixers may create a flammability or reactivity hazard, a **penalty of 0.50** is applied. NOTE: These penalties apply whether or not the equipment vapor space is inerted.
3. Ranges of penalties based on material fire hazards are applied to warehouse storage or yard storage of various items.
   a) A **penalty of 0.85** is applied for N_f = 3 or 4 flammable liquids or gases. This category includes drums, cylinders, and aerosol cans.
   b) A **penalty of 0.65** is applied for N_f = 3 combustible solids as identified in Table I, page 13.
   c) A **penalty of 0.40** is applied for N_f = 2 combustible solids as identified in Table I.
   d) A **penalty of 0.25** is taken for combustible liquids (closed cup flash point above 100 °F (37.8 °C) and below 140 °F (60 °C)).

   If any of the above are stored on racks without in-rack sprinklers, **add 0.20 to the penalty.**

D. Enclosed or Indoor Process Units

The maintenance of open and freely ventilated construction for areas in which flammable liquids and gases are processed will permit rapid dissipation of any vapors released, thereby reducing the explosion potential of the unit. Dust collectors and filters should also be located in an open area away from other equipment.

An **enclosed area** is identified as any roofed area with three or more sides, or an area enclosed by a roofless structure with walls on all sides.

Even properly designed mechanical ventilation is not as effective as open construction, but if a mechanically ventilated system is designed in such a way that all flammables are collected and dispersed, the penalty can be reduced.

The penalty categories are as follows:

1. When dust filters or collectors are located inside an enclosed area, a **penalty of 0.50** is applied.
2. Any process in which flammable liquids are handled at temperatures above their flash point in an enclosed area receives a **penalty of 0.30.** For quantities of liquid in excess of 10M lb. (≅ 1,000 gallons), a **penalty of 0.45** is used.
3. Any process in which liquefied petroleum gas (LPG) or any flammable liquids are handled at temperatures above their boiling point within an enclosed area **requires a penalty of 0.60.** For quantities of liquid in excess of 10M lbs. (≅ 1,000 gallons), a **penalty of 0.90** is used.
4. Where properly designed mechanical ventilation has been installed, the **penalties** listed in 1. and 3. above may be **reduced by 50%.**

E. Access

Emergency equipment must have ready access to the area housing the pertinent Process Unit. Access from at least two sides is considered the **Minimum Requirement.** STRONG CONSIDERATION should be given to this penalty for major Process Units located in enclosed areas.

At least one of the access approaches must be from a roadway. A monitor nozzle that would remain easily accessible and operational during a fire could be considered a second access.

All **process areas** over 10M sq.ft. (925 sq.m) not having adequate access receive a **penalty of 0.35.**

All **warehouses** over 25M sq.ft. (2312 sq.m) not having adequate access receive a **penalty of 0.35.**

For **areas smaller** than those listed above, judgment must be used in assessing the access requirement. Such areas **may be penalized 0.20** if sound engineering judgment indicates the potential for fire control problems due to inadequate access.

F. Drainage and Spill Control

This section lists penalties for design conditions that could cause large spills of flammable or combustible liquids to be retained around or near process equipment. Inadequate design of drainage has been a contributing factor in a large number of losses involving liquid spills.

These penalties are to be applied **only** if the **material** in the **Process Unit** has a flash point below **140°F**, or if the material is being **processed above** its **flash point.**

To evaluate the adequacy of drainage and spill control, it is necessary to estimate the combined volume of flammable/combustible material as well as firefighting water that would have to be safely drained away or handled in an actual incident.

1. The F&EI calculation of drainage capacity will be based on the following guidelines:
   a) For **Process Units**, use 75% of the unit's capacity, and for **tank farms**, use the entire capacity of the largest tank.
   b) Assume 30 minute flow rate of firefighting water.

Enter the sum of a) and b) above into the appropriate space under GENERAL PROCESS HAZARDS — Item 1.F on Exhibit A.

2. Penalty Selection:
   a) Diking, which is designed to prevent a spill from going to other areas but exposes all the equipment within the dike, receives a **penalty of 0.50.**
   b) Generally, a flat area around the process unit will allow spills to spread out, exposing large areas to fire if ignited. A **penalty of 0.50** is required for this situation.
   c) A diking design that surrounds three sides of an area and directs spills to an impounding basin or non-exposing drainage trench receives **NO penalty** if the following criteria are met:
      i Slope to basin or trench is a minimum of 2% for earthen surfaces, or 1% for hard surfaces.
      ii Distance to equipment from nearest edge of trench or basin is at least 25 feet (8 meters) or, in the case of a large, vertical tank, one tank diameter.
      iii The impounding basin must have the capacity at least equal to the sum of 1.a) and 1.b) above.

      If the above criteria are partially met, a **penalty of 0.25** may be applied.
   d) If the basin or trench exposes utility lines, or does not meet the distance requirements, a **penalty of 0.50** is applied.

      In short, excellent drainage is required if penalties are to be avoided.

NOW THAT ALL GENERAL PROCESS HAZARDS HAVE BEEN EVALUATED, CALCULATE THE SUM OF THE BASE FACTOR AND ALL PENALTIES APPLIED IN THIS SECTION. ENTER THE TOTAL IN THE BOX LABELED "GENERAL PROCESS HAZARDS" (F_1) ON EXHIBIT A, PAGE 6.