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In-Process Hazard Classification Of Explosives

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September 2005

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1.0 Scope

A general procedure to classify the hazards of an energetic material at various stages of processing has been developed. A decision tree for energetic substances is presented in Figure 1. A second decision tree for unfinished explosive articles is presented in Figure 2. These outlines incorporate standard DoD and DOT tests where applicable and other tests accepted by industry where needed.

2.0 Background

In the absence of a clear standard, DOT, BATF and DoD classification systems have frequently been applied to manufacturing processes. However, an energetic material will typically provide the same or greater level of hazard in a manufacturing operation than in a shipping or storage configuration. Therefore, the manufacturer or processor of explosive materials may be under assessing the hazard of the energetic materials in their processes by solely using the transportation and storage classifications as a guide.

Alternatively, an explosives manufacturer may assume that in-process operations always represent a high explosive hazard. This approach may lead to unwarranted restrictions or expense for some operations. This blanket approach may also lead to some unsafe practices, when a company has experience with a less hazardous material and then switches to more hazardous material, both of which are identified as having the same level of hazard. Understanding the characteristics of the in-process material ensures that proper safety requirements are addressed early in the designing and planning stages of a production line.

The DOT, BATF and DoD classification systems, when used in combination with other recognized tests can be used to produce a systematic approach to classifying in-process explosive materials. Process simulations may also be used in some instances as noted in the discussion on each test series. These tests and criteria are applied to in-process operations to determine the hazard classification for the hazardous materials used in the process of interest. This protocol is not intended to replace or modify BATF, DoD or DOT classification systems for storage or transportation, but to assist the manufacturer of explosives with proper facility design and siting of modified or new facilities. In-process, refers to stages of manufacture of an original product or an application of that product into another product. The material is considered in-process, if it is in an operation, process or manufacturing stage where it is being used, changed, transported, mixed or otherwise modified or incorporated into the process or product.

In an explosives-manufacturing operation, the reactivity or sensitivity of the material may vary within the process. The in-process material classification and classification requirements may therefore be different for various stages of a process. Therefore, the classification methodology developed should be applied to all stages and/ or configurations of the energetic material.

The two main divisions exist when discussing explosives: substance and articles. Substances refer to the actual energetic material (powders, grains, pellets, etc.) Articles refer to items, which contain explosive substances (detonators, igniters, inflators, etc.) Both substances and articles can mass react depending on the explosive materials they contain and the design configuration

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used. Different tests are needed to evaluate the propagation potential of substances and articles. The remainder of this paper is divided into two main sections addressing these two basic explosive categories. In a manufacturing situation, where the article is unfinished but the substance has been separated into individual units, a combination of the appropriate tests from the two sections is recommended.

When classifying in-process materials or articles, using process simulations, one must be careful to provide a worst-case configuration instead of a normal process upset or minimal-case configuration. It is also generally better to perform an over-test rather than a minimum worst-case test, so that every change in manufacturing procedures does not require a re-test of the energetic substances or articles involved. In addition, adequate training and understanding of how the test results apply to specific stages in the manufacturing process is critical. Otherwise, for example, if testing a specific in-process condition reveals that the substance or article is a 1.4, personnel may misapply the 1.4 to the material regardless of the configuration or stage of manufacture.

For classification purposes, one looks at both the reactivity and sensitivity of the substance or article. Reactivity refers to what type or size of event is produced once initiation occurs. Sensitivity refers to how easily a material or article is initiated due to various stimuli. When the sensitivity and reactivity of a substance or article is properly characterized, the data can also be used to improve the safety and application of the material in addition to in-process classifications as presented here.

For example, sensitivity and reactivity data are used to determine and rank explosive hazards within a process. Sensitivity data, when compared to the in-process potential, can determine the margins of safety and therefore the probability of initiation when manufacturing or using the material in a process. Reactivity data is then used to determine the magnitude of an event should initiation occur.

3.0 Energetic Substances

The testing of energetic substances refers to the explosive substance; whether it be a molecular explosive, a mixture of ingredients, liquids, powders, pastes, emulsions or combinations, etc.; without regard to the handling, storage or transport packaging or loading of the substance into a device or article (see section 4).

There are different techniques used when performing material characterization tests. A common approach is to prescribe screening tests, which provide readily interpreted pass/fail criteria. For process hazard evaluations, more comprehensive testing may be necessary to adequately determine the hazard. The type of technique used determines the degree of testing the material receives and therefore, may limit or increase the applications for which the data is used. Only those tests required for in-process classification of a material have been included below. As a reminder that these test series may differ from the those designated and used for UN/DOT transportation classifications, the words “In-Process” have been used at the introduction of each test series.

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3.1 Energetic Substances Classification Decision Tree for In-Process Operations

Figure 1 is a decision tree for characterizing in-process energetic substances. The flowchart was developed by incorporating the DOT, BATF and DoD tests and/or criteria as well as additional tests recognized as industry standards. Since the DOT and BATF were established for transportation and storage purposes respectively, they do not consider key elements that should be examined in a manufacturing situation. However, some of the test methods used and the resulting data can be applied toward in-process classification. Some DoD and industry classification criteria have included substance classification and characterizations applicable to in-process conditions. These have been incorporated into the decision tree, below.

When using the decision tree to classify in-process energetic substances, if a single test in a test series results in an explosive result, further testing in that series is not necessary. The classification status of that material in a particular state or stage in the process is determined. For example, in Test Series 2 (see Figure 1), if any of the tests is positive (a "go" reaction), the others need not be performed. A positive result in any one of the listed tests results in the determination that the material is an explosive (Class 1 material). Conversely, all of the tests in Test Series 2, must be performed and produce a negative ("no-go") result for the material to be excluded from the explosive class. Of course, one may elect to assume the material is an explosive and thereby avoid Test Series 2 altogether. Similarly, one may assume the worst case result for any of the decision boxes rather than to perform the tests indicated in that box.

As shown in Figure 1, energetic substances in manufacturing operations are either categorized as Class 1.1 or Class 1.3 explosives. A 1.2 designation, which implies a fragmentation hazard, does not apply to a substance. A 1.5 classification, which is designated as an insensitive, yet detonable substance, is difficult to justify in manufacturing scenarios where these materials may experience more initiation hazards than in shipping and storage applications. A 1.4 designation applies only to packaged substances for transport. This designation does not apply to substances.

3.2 In-Process Test Series 1

As shown in Figure 1, Test Series 1 consists of tests that determine material characteristics fundamental in determining processing and handling hazards. These tests have been placed first because impact, friction and ESD sensitivity data must be conducted on materials suspected of having energetic properties prior to handling them in the larger quantities required for the remaining test series.

This type of data, when compared to the in-process potential, can determine the margins of safety and therefore the level of risk achieved when manufacturing or using the material in processing. Material sensitivity data is also essential before one can properly analyze the hazards of a process or clearly determine and rank the most serious hazards. Material Safety Data Sheets (MSDSs), ideally, should contain this type of information.

Other tests may also be appropriate prior to performing larger scale tests. For example, thermal sensitivity tests such as auto-ignition and compatibility may also be conducted on the material. A hazards analysis of the proposed process and handling operations can help determine what

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additional data is needed, if any, before proceeding with the larger scale tests. Furthermore, if it is discovered that the material is very sensitive, yet not very reactive, appropriate handling and manufacturing precautions may be able to further minimize propagation scenarios.

There are different techniques used when performing material sensitivity tests. The DOT tends to require screening tests, which provide a pass/fail criteria. For in-process hazards analysis evaluations, more rigorous testing is typically required. The type of technique used determines the degree of testing the material receives and may limit or increase the applications for which the data is used. Only those tests required for in-process classification of a material have been included below.

Test Series 1, Impact Test

Impact tests are used to determine the response of an energetic material when a moving mass impacts it. This test simulates impact conditions in processing operations, wherein an energetic material is subjected to a collision between moving components of the processing equipment, by normal handling operations, or by the inadvertent dropping of tools or equipment.

The DOT and DoD use the Bureau of Explosives (BOE) impact machine to determine whether a material is too sensitive for transport by conducting a 10-trial screen test. This test is presented as a means used to obtain initial impact data for a manufacturing classification. However, a more thorough test using additional drop heights may be performed as needed in order to conduct a hazards analysis.

The UN prefers the BAM Fallhammer apparatus to determine the sensitivity of substances to impact. The material is forbidden for transport if the lowest impact energy at which at least one "explosion" occurs in six trials is 2 J or less. Using this or a similar impact apparatus, including various weights and heights; a more thorough understanding of the materials behavior to impact stimuli can be obtained as opposed to a screen test only conducted at one height using one weight.

References: *BOE Impact Test*
Recommendations on the Transport of Dangerous Goods, Test 3(a)(i)
Third Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-4 (a), January 1998.

References: *BAM Fallhammer Impact Test*
Recommendations on the Transport of Dangerous Goods, Test 3(a)(ii)
Third Edition, United Nations, New York and Geneva, 1999.

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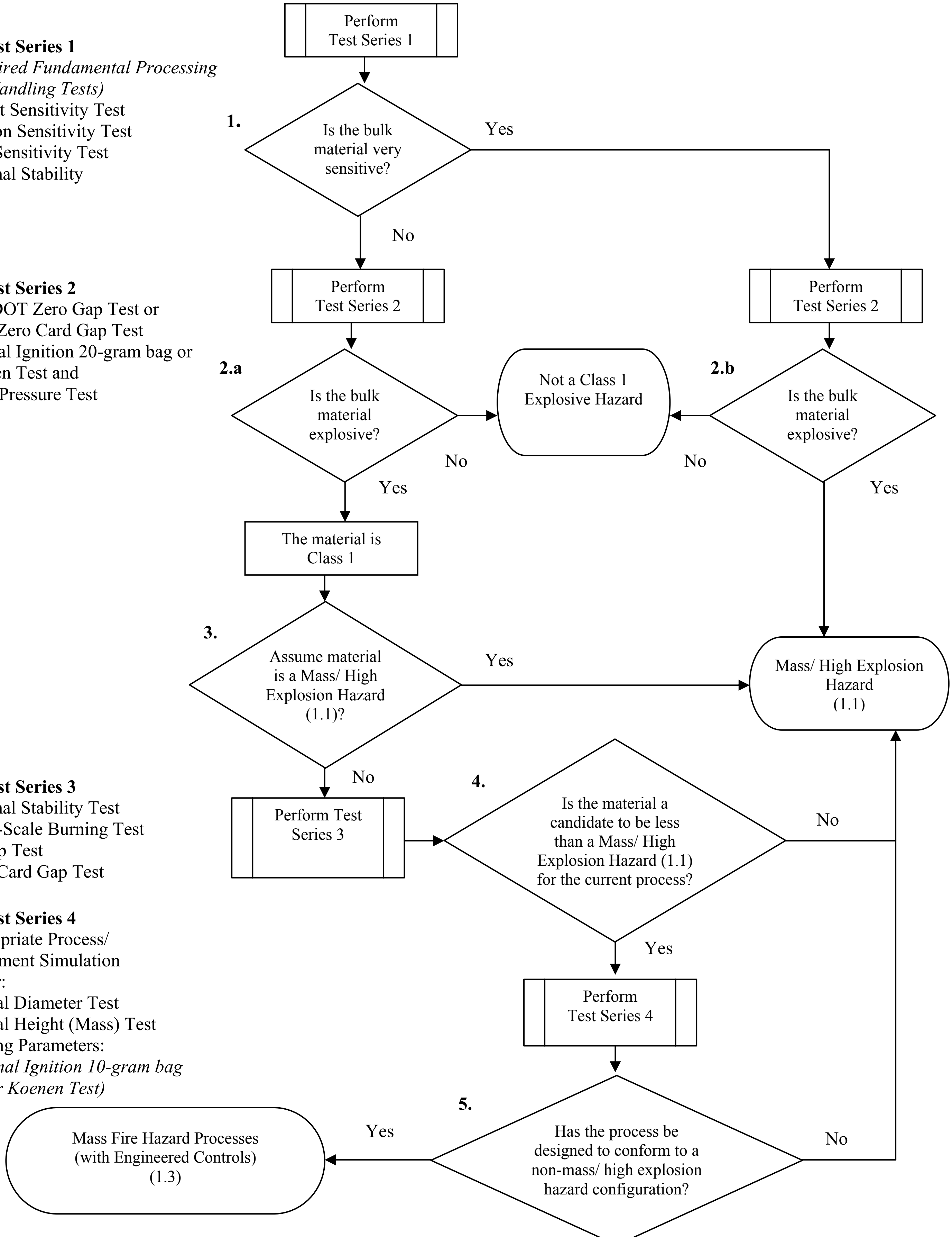
Figure 1. Energetic Materials Classification Decision Tree for In-Process (IP) Operations

IP Test Series 1
(Required Fundamental Processing and Handling Tests)
Impact Sensitivity Test
Friction Sensitivity Test
ESD Sensitivity Test
Thermal Stability

IP Test Series 2
UN/ DOT Zero Gap Test or
NOL Zero Card Gap Test
Internal Ignition 20-gram bag or
Koenen Test and
Time-Pressure Test

IP Test Series 3
Thermal Stability Test
Small-Scale Burning Test
#8 Cap Test
NOL Card Gap Test

IP Test Series 4
Appropriate Process/
Equipment Simulation
and/or:
Critical Diameter Test
Critical Height (Mass) Test
Venting Parameters:
(Internal Ignition 10-gram bag and/or Koenen Test)



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Test Series 1, Friction Tests

Friction sensitivity tests determine the response of an energetic material sample when subjected to frictional forces at a given velocity. This test simulates friction conditions that may occur in a process when an energetic material is subjected to a frictional force between moving components or during material handling.

The ABL and BAM friction tests are the two primary tests of this kind. In the ABL test the sample is placed on an anvil. Force is applied to the anvil through a hydraulic ram attached to a stationary wheel. A pendulum strikes the anvil and slides it under the wheel. In the BAM friction machine, the force is applied to the sample by hanging weights on a lever arm attached to a pin. This pin is set on the plate containing the sample. An electric motor attached to the plate by a connecting rod slides the plate back and forth once under the pin (once forward and once backward). The DoD and DOT use these machines to conduct screen tests to determine whether a material is forbidden for transport. However, these tests may also be used to produce friction profiles for the material.

Reference: *ABL Friction Test*
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-4 (b), January 1998.
or
Mil-Std-1751, "Safety and Performance Test for Qualification of Explosives", Test Method 6.
or
Recommendations on the Transport of Dangerous Goods, Test 3(b)(iii) Second Edition, United Nations, New York and Geneva, 1990.

BAM Friction Test
Recommendations on the Transport of Dangerous Goods, Test 3(b)(i) Third Edition, United Nations, New York and Geneva, 1999.

Test Series 1, Electrostatic Discharge (ESD) Test

The DOT does not specifically require ESD testing for classification of explosives. However, it does require a shipper of explosives to know whether special precautions for ESD are needed. ESD data is critical in a manufacturing operation where parts, clothing or personnel may become charged near exposed material. ESD testing is required by the DoD for handling explosives.

ESD testing is used to determine the response of an energetic material when subjected to various levels of electrostatic discharge energy. The approaching needle method is most commonly used because it best models the common safety issues involved with ESD sensitivity. Electrostatic energy, stored in a charged capacitor, is discharged to the test sample by lowering the discharge needle until a spark is drawn through the sample. An infrared analyzer or sample consumption are means normally used to determine sample initiation.

Reference: *Approaching Needle ESD Test*
Mil-Std-650, "Explosive: Sampling, Inspection and Testing", Test Method T 512.1
or

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Mil-Std-1751, "Safety and Performance Test for Qualification of Explosives", Test Method 4

3.3 In-Process Test Series 2

The DOT includes the zero-gap test, and the internal ignition test using a 20-gram bag, in a series of tests to determine whether a material is an explosive. The zero-gap test determines whether the material can propagate a detonation. The internal ignition test determines if the test material will transition from a deflagration to an explosion under high confinement.

If the material has either of these explosive characteristics, it should be classified as an explosive in a manufacturing operation. If the material is shown not to have these explosive characteristics then the material may be classified as something other than an explosive, even though it may be sensitive to certain stimuli or still exhibit explosive reactions under extreme or rare circumstances. For example, many substances, if finely ground, may produce dust explosions under the proper circumstances, yet these are not considered explosive substances.

Substances, which are both explosive and easily initiated, should be considered a 1.1 for manufacturing applications. This is shown in Figure 1. Therefore, if Test Series 1 identified a material as a forbidden substance according to the DOT or if a material was found to be extremely ESD sensitive, and if Test Series 2 identified the same material as an explosive substance, then the material is considered as a 1.1 for manufacturing applications.

Test Series 2, Zero Gap Test

The sample is loaded into a pipe facing a steel witness plate. A detonator is used to initiate a pentolite booster (50% PETN/50% TNT), which provides a known shock to the sample. The criteria for a "go" reaction are that the pipe is fragmented along its full length and/or a hole is punctured through the witness plate. The test is conducted two or three times unless detonation occurs. The test determines if a material will propagate a detonation when subjected to an adjacent detonation. The UN gap test and the NOL card gap test can both be used for the same purpose when conducted at the zero-gap level.

Reference: *UN Gap Test*
<u>Recommendations on the Transport of Dangerous Goods</u>, Test 1(a)
Third Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-2 (a), January 1998.

NOL Card Gap Test
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-2 (j), December 1989.
or
Naval Ordnance Laboratory Technical Report 74-40, 8 March 1974

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Test Series 2, Internal Ignition (20-Gram Bag)

The sample is loaded into a pipe with 3000 pound pressure tested forged steel end caps. A 20-gram black powder bag igniter is inserted into the center of the pipe, the pipe is filled with test material and the ends capped. After the igniter is fired, if either the pipe or at least one of the end caps is fragmented into two or more distinct pieces then the test result is positive. The test is considered negative (the material passes) if the pipe is merely split open or the caps are sheared off in one piece. Three trials are performed unless a transition from deflagration to explosion occurs earlier. The test determines if a material will explode or detonate when ignited under confinement.

Reference: *Internal Ignition Test*
<u>Recommendations on the Transport of Dangerous Goods</u>, Test 1(c)(ii)
Third Edition, United Nations, New York and Geneva, 1999.

3.4 In-Process Test Series 3

Test Series 3 is a compilation of tests to determine whether or not the material should be considered a high explosive (i.e. Division 1.1) or whether the material may be considered in a lower explosive category (e.g. Division 1.3). The test series contains four different tests: the thermal stability test, the small-scale burning test, the #8 cap test and the card gap test.

The DOT and DoD include the thermal stability test and the small-scale burning test in the test series, which determines whether a material is forbidden for transport. If the material cannot pass these two tests, it cannot be shipped in the tested form. Materials, which fail either of these two tests, should be considered to have a mass explosion hazard.

The BATF and DoD use cap sensitiveness to distinguish between a high and low explosive. If the material fails the #8 cap test, then the BATF requires use of the high explosion table for storage siting and the DoD identifies the material as a 1.1 material in its unpackaged form. In manufacturing operations this type of material should be considered to have a mass explosion hazard. The #8 cap test, as used by the DOT or DoD is a good test for this purpose.

The DoD has used the NOL card gap test as one of the criteria to distinguish whether an explosive material is a 1.1 or a 1.3. Instead of placing the booster right next to the sample, an attenuator is placed between the shock source and the material such that the sample is subjected to a reduced shock event. The attenuation level is varied to determine the 50% probability between detonation and no detonation. For in-process materials, a substance with explosive characteristics is considered a mass explosive (Division 1.1) unless shown to have a detonation sensitivity value of <u>less than</u> 70 cards.

Test Series 3, Thermal Stability Test

This test is used to determine the reaction of samples when subjected to a mildly elevated temperature (75°C) for a specific period of time (48 hours). At the completion of the test, the

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sample is examined for discoloration, weight loss, and dimensional change as evidence of decomposition. Any evidence of explosion is also criteria for a positive result (i.e. fails the test).

Reference: *Thermal Stability Test*
Recommendations on the Transport of Dangerous Goods, Test 3(c)
Third Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-4 (c), January 1998.

Test Series 3, Small-Scale Burning Test , USA

This test is used to determine if unconfined samples, once ignited continue burning or transit to an explosion or detonation. A bed of sawdust, containing small samples of test material, is ignited and monitored. The test is a "go" (positive) if explosion or detonation occurs.

Reference: *Small-Scale Burning Test*
Recommendations on the Transport of Dangerous Goods, Test 3(d)
Third Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-4 (d), January 1998.

Test Series 3, Explosive Cap Testing (No. 8 Cap)

The No. 8 cap test is used to determine susceptibility of energetic materials to detonation from the energy delivered by a standard detonator. Sample detonation is determined by examining the witness plate. The criterion for detonation (positive result) is that the witness plate is torn or penetrated.

Reference: *Cap Sensitivity Test*
Recommendations on the Transport of Dangerous Goods, Test 5(a)
Third Revised Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-6 (a), January 1998.

Test Series 3, NOL Card Gap Test

This test is similar to the UN gap test except that a shorter tube of material is used and a varied attenuator is placed between the test material and the pentolite booster. The attenuators provide a reduced shock source. The criteria for a "go" is that a clean hole is punctured through the witness plate. Typically 12 trials are required to determine the 50% "go/ no-go" level. The test determines if a material will propagate an attenuated detonation.

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Reference: *NOL Card Gap Test*
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-2 (j), December 1989.
or
Naval Ordnance Laboratory Technical Report 74-40, 8 March 1974
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-2 (j), December 1989.

3.5 In-Process Test Series 4

Test Series 4, determines additional material characteristics, in addition to those examined by the DOT and BATF. These characteristics are then used to define in-process parameters. If the process is designed within these parameters, the maximum credible event from a Class 1.3 material or process is a mass fire hazard. This test series includes process simulations, a critical diameter test and a critical height test. The series also includes tests to determine venting parameters, for confined operations. If, however, the process parameters exceed the critical height or critical diameter, then explosion of the material due to self confinement (from a flame initiation), or propagation of a detonation are possible.

Test Series 4, Process Simulation

Where the process is known, appropriate process simulations may be used. However, a change in the process may necessitate re-testing of some or all of the energetic substances used in the process. Appropriate process simulations may consist of modifications to the standard tests below, to represent worst-case confinement, configuration and/or loading in the process.

Test Series 4, Critical Diameter Test

The critical diameter of an energetic material is the largest diameter at which steady-state detonation cannot be maintained. The test uses varying diameter cylinders and a witness plate. A Comp C-4 or similar booster is used to initiate the sample. The test results are considered to be positive if the witness plate indicates detonation. Normally, the test shall be completed after three “no-go” reactions are obtained at a diameter one increment below a diameter that previously yielded a positive result.

Reference: *Critical Diameter Test*
Mil-Std-1751, “Safety and Performance Test for Qualification of Explosives”, Paragraph 5.7.1

Test Series 4, Critical Height (Mass) Test

This test is used to determine the critical height at which a flame initiation transits to an explosive reaction (explosion or detonation). This test is sometimes referred to as a critical mass test because the results are dependent on the self-confinement provided by the mass of material. In this test, a flame initiator (bag igniter) is placed at the bottom of a pipe assembly filled with the test material. Pipes of varying lengths and diameters are used to contain the test material.

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The test is performed by selecting a diameter, and progressively changing the height of the pipe until the material transitions from burning to explosion or detonation. The diameter is then changed and the progressive height variation testing is repeated. Normally, a curve can be fitted using the data, to predict the critical height for other diameters as well. A "go" reaction, for explosion, is one in which the pipe is damaged. The test is concluded at each diameter by running a minimum of three successive trials which produce a "no-go" result at a height below a level which produces a positive reaction (explosion). This level is referred to as the critical height at that diameter.

Reference: *Critical Height (Mass) Test*
Industry Accepted

Test Series 4, Internal Ignition (10-Gram Bag)

This test is similar to the internal ignition test described earlier except that a 10-gram bag igniter is used instead of the 20-gram bag. As stated previously, either the pipe or at least one of the end caps must be fragmented into at least two distinct pieces for a positive result. Three trials are performed unless a transition from deflagration to explosion occurs earlier. The test determines if a material will explode or detonate when ignited under confinement.

Reference: *Internal Ignition Test*
Recommendations on the Transport of Dangerous Goods, Test 2(c)(ii)
Third Edition, United Nations, New York and Geneva, 1999.

Test Series 4, Koenen Test

This test is used to determine the sensitiveness of a material to the effect of intense heat under vented confinement. In this test, the material is placed in a steel container with an orifice plate. The test apparatus is then placed in a protective steel box, and heated at a specified rate. A series of trials is conducted using different sizes of orifices. A "go" reaction is determined by examining the container. Conducting three successive "no-go" reactions with an orifice plate size above that which produced a positive result concludes the test. This orifice is called the limiting diameter. The limiting diameter may be used to evaluate the degree of venting required to avoid an explosion in the process.

Reference: *Koenen Test*
Recommendations on the Transport of Dangerous Goods, Test 2(b) or 1(b)
Third Edition, United Nations, New York and Geneva, 1999.

3.6 Further Testing or Classification

Further delineation is usually made within some of the classifications provided here. Within the 1.1 category for in-process classification, for example, are primary explosives, secondary explosives, blasting agents, booster charges, and others. While such delineation is beyond the scope of this effort, much of the data necessary to identify these subdivisions is included in the tests identified above.

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Some tests in addition to those presented here, which may also be appropriate, include: thermal analysis, compatibility, TNT equivalence and others. Thermal tests provide the auto-ignition temperature, temperature of exothermic reactions, time-to-explosion, etc. Compatibility tests evaluate whether contact with certain chemicals (including such common things as perfume or tape) may cause undesirable consequences. TNT Equivalence evaluates the explosive output (overpressure and/or impulse) of an energetic substance to that of TNT, as used in facility siting and design.

A hazards analysis should apply the known data to proposed processes, before proceeding with larger scale tests or manufacturing operations. It can also be used to identify any additional data necessary to make process design decisions. For example, if a material is very sensitive, but is not very reactive, then appropriate handling and manufacturing precautions may be able to readily minimize propagation scenarios.

4.0 Unfinished Articles

4.1 Unfinished Articles Classification Decision Tree for In-Process Operations

The DOT and DoD use three common tests to determine the hazards of a packaged finished article. These tests include the single package test, the stack test and the external fire test. These tests focus on the hazards of particular shipping and storage configurations. In order to assess unfinished articles in a processing operation or finished articles, which are not in their final shipping configuration yet, modified versions of these tests in addition to others should be conducted. Figure 2 is a decision tree for characterizing unfinished articles. This flowchart was developed by applying DOT and DoD tests to in-process scenarios. These tests evaluate worst-case scenarios which can occur in manufacturing operations more readily than in normal shipping or storage situations.

If an unfinished article fails one of the tests in Series 5, further testing is not required. The classification of that article is a 1.1, mass reaction hazard. However, if the unfinished article passes both tests in Test Series 5, both tests in Series 6 are required to lower the classification further. The classifications of 1.1, 1.2, 1.3 and 1.4 are applied to unfinished articles depending on whether the primary hazard of the articles is mass explosion, fragmentation, mass fire or no mass reaction.

4.2 In-Process Test Series 5

The tests listed in Series 5 are required by the DOT and DoD to determine whether an article is too sensitive for transport. These tests are normally conducted using the packaged article. For in-process classification, these tests are performed on the unpackaged, unfinished article.

Test Series 3, Thermal Stability Test

This test is used to determine the reaction of articles when subjected to a mildly elevated temperature (75°C) for a specific period of time (48 hours). At the completion of the test, the

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article is examined for evidence of reaction. Any evidence of explosion, fire, damaged outer casing, dangerous exudation of explosive visible outside the casing, or a temperature rise greater than 3°C above the oven temperature is criteria for a positive result (i.e. fails the test).

Reference: *Thermal Stability Test*
Recommendations on the Transport of Dangerous Goods, Test 4(a)
Third Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-5 (a), January 1998.

Test Series 5, Drop Test

This test is used to determine if a finished or unfinished article can withstand a free-fall impact without producing any significant fire or explosion hazards. The test is not intended to evaluate whether the unit can withstand the actual impact. The article is dropped at an orientation in which it is most likely to function on impact. Three drops are made on identical units unless a decisive event (e.g. fire or explosion) occurs earlier. A test result is considered positive if evidence of initiation is identified. A rupture of the casing alone is not considered a positive result.

Reference: *Twelve-Meter Drop Test*
Recommendations on the Transport of Dangerous Goods, Test 4(b)(ii)
Third Edition, United Nations, New York and Geneva, 1999,
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-5 (c), January 1998.

4.3 In-Process Test Series 6

Test Series 6 incorporates the criteria the DOT and DoD use to determine the hazards of a packaged finished article, with suitable modification recognizing this series is for unfinished articles.

The tests the DOT and DoD use to examine finished packaged articles include the single package test, the stack test and the external fire test (test series 6 of the UN manual of tests and criteria). The single package test is a smaller version of the stack test. These UN/DOT/DoD tests are conducted on the finished article, as packaged for transport.

In order to assess unfinished articles in a processing operation or finished articles, which are not in their final shipping configuration, modified versions of the UN/DOT/DoD single package test need to be conducted. These tests are termed worst-case propagation tests. Several versions of this test are indicated. Usually at least three configurations, or a semi-confined pile are needed to effectively evaluate all the situations which can be encountered in the manufacturing process.

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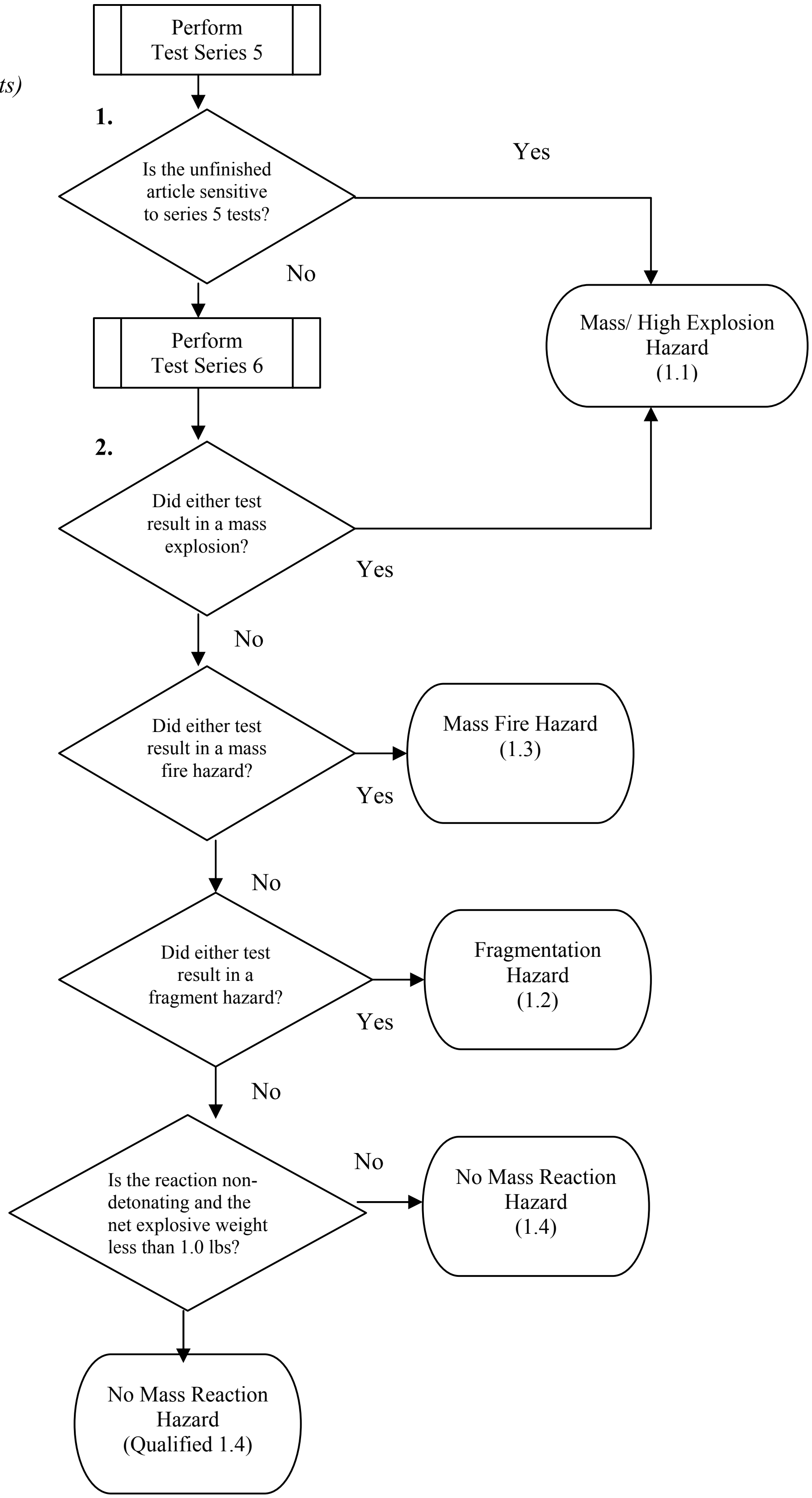
Figure 2. Unfinished Articles Classification Decision Tree for In-Process Operations

IP Test Series 5
(Required Fundamental Processing and Handling Tests)
Drop Test
Thermal Stability Test

IP Test Series 6
Worst-case Propagation Tests
External Fire Test



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In addition, an external fire test, which evaluates how the material reacts when initiated by an external fire, is included in this test series. Together the external fire and propagation tests can determine the final hazard classification of an in-process unfinished article.

If the article passes the IP Series 6 tests, as well as those leading up to this point, and each article is less than 1.0 lb next explosive weight and does not pose a detonation hazard, then the resulting hazard from a number of these articles is similar to that of one pound or less of unconfined 1.3 explosive in storage within the structure where operations are being performed. This is so, because any reactions will be individual, not mass reactions and any single event will involve one pound or less of explosive in a deflagration (including low-level explosions) but not in a detonation. Items which meet these tests criteria and maximum net explosive weight have been termed as “qualified” 1.4 articles.

Test Series 6, Worst-Case Propagation Tests

This test is used to determine whether a reaction from an unfinished article, which was accidentally fired or initiated, would propagate to other articles or parts of the process. This test is conducted by placing articles in a worst-case configuration (e.g. side-by-side, end-to-end, and/or in a pile). This test is similar to the stack test except that the articles are tested without packaging, as they are or may be found in the process, including during process upset. The unfinished or finished articles are placed on top of a steel witness plate. Sand filled inert containers or sandbags may be positioned on the sides and top of the test articles for added confinement. Wire or clamps may be used to hold the articles in place. An article near the center of the unpackaged articles is caused to function (donor). Evidence of propagation or any other observable reaction is recorded. Normally at least two trials are conducted.

Reference: *Single Package Test and Stack Test*
Recommendations on the Transport of Dangerous Goods, Test 6(a) and 6(b)
Third Edition, United Nations, New York and Geneva, 1999.
or
TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-7 (a) and 5-7 (b), January 1998.

Test Series 6, External Fire Test

A stack of unfinished or finished articles as they appear in the manufacturing line is placed on a non-combustible surface (steel grate) above a lattice of dried wood soaked with diesel fuel or equivalent source. A wire basket or clamps may be used to hold the articles in place. Sufficient fuel is used to provide a 30-minute fire. The fire is ignited and the material is observed for: a) Evidence of detonation, deflagration or explosion of the total contents; b) Potentially hazardous fragmentation; and c) Thermal effects (i.e. size of the fireball, etc.).

Reference: *External Fire Test*
Recommendations on the Transport of Dangerous Goods, Test 6(c)
Second Revised Edition, United Nations, New York and Geneva, 1995
or

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TB 700-2, Department of Defense Explosives Hazard Classification Procedures, 5-7 (c), January 1998.

5.0 Protective Enclosures

The use of technology to mitigate hazards is supported in civilian and military practice. Devices can be designed to fully contain or safely direct the deflagration and/or detonation effects of limited quantities of explosive material. Quantities of energetic material may thereby be afforded the same level of isolation and safety as provided by the traditional quantity-distance (Q-D) separations. A blast chimney is an example of these technologies. A blast chimney or other technology must be made to withstand the maximum possible event from the type and configuration of explosive contained within, if used in lieu of (Q-D) separations. Any overpressure discharged must be done so in a manner that safely directs or dissipates the effects thereof. A blast chimney or other technology must be made to withstand the maximum credible event from the type and configuration of explosive contained within, if used as workstation protection in lieu of separated or unattended operations.

6.0 Summary and Conclusions

Tests can be performed to determine in-process hazard classifications. The DOT and BATF have established a classification system for explosives in transportation and storage configurations, respectively. Figures 1 and 2 are decision trees, which have been developed to aid code officials and users in characterizing energetic substances and articles for in-process operations. Energetic substances in manufacturing operations are either categorized as Class 1.1 or Class 1.3 explosives. Substances and articles which would otherwise be classed as a 1.5 for transportation should therefore be considered 1.1 for in-process classifications. The 1.2 and 1.4 designations apply only to articles. The classifications of 1.1, 1.2, 1.3 and 1.4 are applied to finished and unfinished articles depending on whether the primary hazard of the articles is mass explosion, fragmentation, mass fire or a minor event with no mass reaction.

Additional technology such as properly designed protective enclosures is a means to provide added safety or to minimize the effective quantity of an energetic material in an area. Also, further delineation is usually made within some of the classifications provided here. Additional tests may be necessary to obtain an adequate understanding of a material's explosive characteristics for purposes other than this in-process, explosive classification system.

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