TESTING OF ENGINES AND ACCESSORY EQUIPMENT

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1.0 SCOPE

This data sheet applies to the construction and protection of engine test facilities that use liquid and gaseous fuels, including but not limited to, the following:

- Jet fuel
- Diesel fuel
- Gasoline
- Natural gas (compressed, liquified, pipeline)
- Petroleum gas(liquefied)
- Hydrogen
- Ancillary liquids such as hydraulic fluids and lubricating oils

Equipment covered by this data sheet includes reciprocating and turbine engines that are used in the motor vehicle, aircraft, marine, locomotive, and power generation industries, among others. This data sheet also covers the testing of accessory equipment such as pumps, fuel tanks, compressors, and generators.

This data sheet does not cover testing facilities for rocket engines or other engines that use special liquid fuels or solid propellants.

1.1 Hazards

Engine test facilities use ignitable liquids or flammable gases, including fuels, lubricating oils, and hydraulic fluids. These liquids and gases are typically stored in bulk quantities and piped to individual test cells to conduct performance testing of engines.

Where ignitable liquids are used, the potential exists for an ignitable liquid pool fire or room explosion if the liquid becomes vaporized. These fires tend to be intense and produce significant heat release rates, which can easily ignite combustibles, damage steel building elements, and destroy equipment if a spray impinges on them.

Where flammable gases are used, the potential exists for a jet fire or a room explosion if the gas is released from the equipment or piping system and is not immediately ignited. For most gaseous fuels, the primary explosion hazard present is a deflagration hazard, which can be mitigated by Damage Limiting Construction (DLC). When hydrogen fuel is used, however, there is the potential for a detonation to occur, which can only be practically addressed by ensuring sufficient space separation to adjacent buildings or equipment to limit the exposure.

Finally, in addition to the typical fire and explosion hazards associated with ignitable liquids and flammable gases, engine test facilities also present the potential for the mechanical breakdown of engines or accessory equipment that is being tested. A mechanical breakdown may be a localized breakdown with small flying debris, representing limited property exposure, or an equipment disintegration in which significant impact damage to the test cell enclosure can be expected unless enhanced construction features are provided.

1.2 Changes

January 2024. Interim revision. The following significant changes were made:

A. Provided guidance on the use of hydrogen

B. Provided guidance on the use of lithium-ion batteries

C. Provided construction and location guidance for detonation-driven room explosion hazards

D. Revised guidance for the location of ventilation in the test cell

E. Clarified guidance for ignition source control related to rated electrical equipment

F. Completed various grammar and editorial revisions

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

2.1.1 For test cells using hydrogen, design the test cells as follows:

2.1.1.1 If the hydrogen flow rate and minimum room volume are within the limitations for Indoor Hydrogen Dispensing (see Table 2.1.3.3) in FM Property Loss Prevention Data Sheet 7-91, *Hydrogen*, design the test cell in accordance with Data Sheet 7-91.

2.1.1.2 If the test cell volume or the hydrogen flow rates are outside the limitations for Indoor Hydrogen Dispensing (see Table 2.1.3.3) in Data Sheet 7-91, design the test cell in accordance with this data sheet.

2.1.2 Treat test cells that are used for lithium-ion battery operated equipment or to evaluate lithium-ion batteries the same as test cells with a hydrocarbon exposure. The fire duration for a lithium-ion battery event is expected to be longer than a hydrocarbon event. See FM Property Loss Prevention Data Sheet 5-33, *Lithium-Ion Battery Energy Storage Systems*, for more information on the expected duration of these events.

2.1.3 Use FM Approved equipment, materials and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide* and RoofNav®, online resources of FM Approvals.

2.2 Construction and Location

2.2.1 General

Apply the recommendations in this section to all test cells. Where a room explosion or severe equipment disintegration hazard exists, enhanced construction features, as listed in Section 2.2.2, may be necessary.

2.2.1.1 Locate engine test cells in buildings of noncombustible construction.

2.2.1.2 Design the test cells as follows:

A. Design the cell walls to have a minimum fire-resistance rating of 1 hour.

B. Construct interior walls using reinforced masonry, concrete, or other wall system that provides resistance to projectile penetration. Ordinary gypsum board walls provide virtually no impact resistance.

C. Construct test cell doors of similar impact resistance as the rest of the test cell, and so hung and latched as to withstand a lateral force equivalent to that for which the cell is designed.

D. Construct observation windows between the control room and the test cells of two thicknesses of heavy impact-resistant glass with air space between.

2.2.1.3 Where dedicated test cells are not provided (e.g., for routine production tests of reciprocating engines), install local protection (i.e., steel plate barricade, blast mat, or chain mail) against projectiles as necessary.

2.2.1.3.1 Locate and arrange all ignitable liquid and flammable gas supply systems as recommended in this data sheet.

2.2.1.4 Do not locate test cells, support rooms, and other equipment containing ignitable liquid or flammable gas in basement areas, tunnels, or other below-grade spaces.

2.2.1.5 Locate ignitable liquid and flammable gas equipment in support rooms separated from the test cell, as shown in Figure 2.2.1.5-1 and Figure 2.2.1.5-2, and in accordance with FM Property Loss Prevention Data Sheet 7-32, *Ignitable Liquid Operations*; FM Property Loss Prevention Data Sheet 7-54, *Natural Gas and Gas Piping*; or other applicable data sheets. Examples of such equipment include the following:

- Fuel and lubricating oil pumps
- Day tanks
- Electrical dynamometers
- Regulators
- Feeders
- Filters
- Heat exchangers
- Gas vaporizers
- Blowers
- Mixers
- Regulators
- Meters

2.2.1.5.1 Where ignitable liquid and flammable gas piping and equipment must be located within the test cell, route the piping to limit exposure from flying debris. Refer to Section 2.5.1.6 for more information.

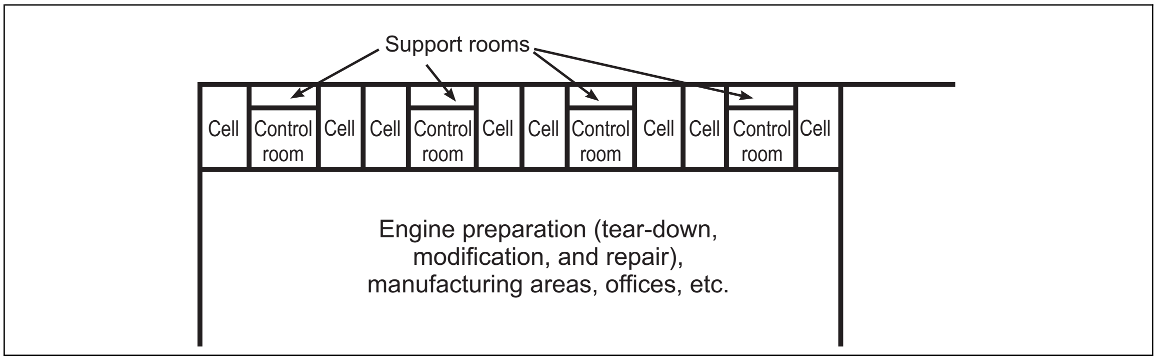


Fig. 2.2.1.5-1. Schematic illustrating internal subdivision for engine test cells

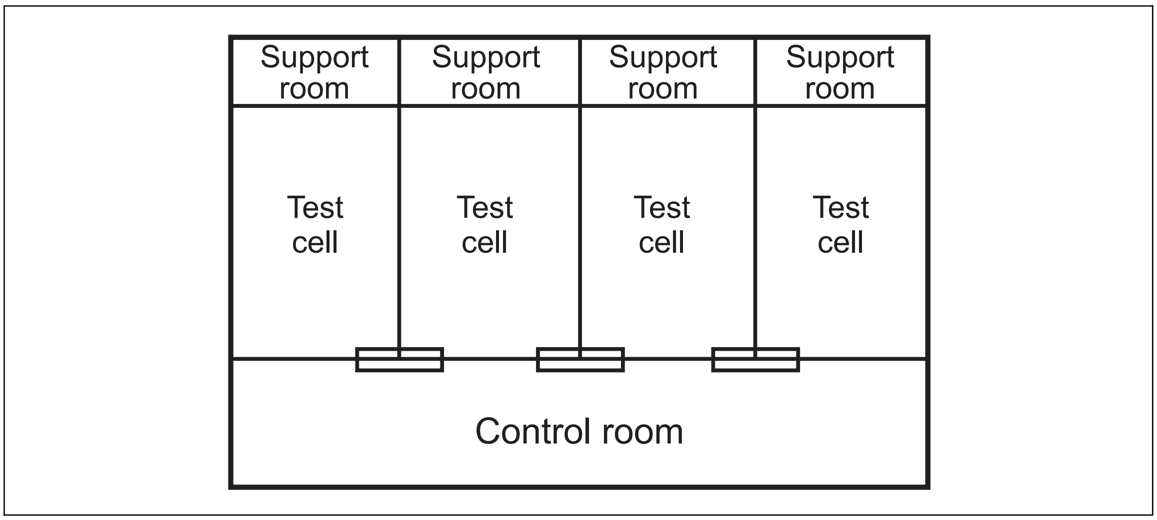


Fig. 2.2.1.5-2. Schematic illustrating alternate test cell arrangement

2.2.1.6 Avoid locating support systems for multiple test cells (e.g., flange piping, fuel processing or handling equipment) in a common support room or fire area.

2.2.1.7 Provide curbing or diking around exterior test facilities to control any liquid release. Alternatively, arrange the surface grade to direct liquid releases away from important buildings, utilities, fire protection equipment, and other critical areas.

2.2.1.7.1 Locate and arrange bulk ignitable liquid storage tanks in accordance with Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*, or Data Sheet 7-32, *Ignitable Liquid Operations.*

2.2.1.8 Locate and arrange bulk ignitable liquid storage tanks in accordance with FM Property Loss Prevention Data Sheet 7-88 or Data Sheet 7-32.

2.2.1.9 Locate and arrange bulk hydrogen storage in accordance with Data Sheet 7-91.

2.2.1.10 Where thermal or sound insulation is installed within the test cell, use noncombustible and nonabsorbent materials.

2.2.2 Room Explosion or Equipment Disintegration Hazards

2.2.2.1 Room Explosion Hazards (Deflagration)

The potential for a deflagration-driven room/building explosion hazard exists where any of the following is used:

A. An ignitable liquid with a boiling point less than, or equal to, 100°F (38°C)

B. An ignitable liquid with a closed cup flash point less than or equal to 425°F (218°C) used at or above its atmospheric boiling point

C. Flammable gas. For test cells using hydrogen, see Section 2.2.2.2.

D. Lithium-ion batteries

If an equipment disintegration hazard exists, refer to Section 2.2.2.3.

2.2.2.1.1 Provide damage-limiting construction for test cells in accordance with FM Property Loss Prevention Data Sheet 1-44, *Damage-Limiting Construction*.

2.2.2.1.1.1 For test cells that use lithium-ion batteries, design damage-limiting construction using propane as the representative gas.

2.2.2.2 Room Explosion Hazard (Fast Deflagration or Detonation)

For test cells that use hydrogen as a fuel, the potential for a fast deflagration- or detonation-driven room/building explosion hazard also exists. If an equipment disintegration hazard exists, refer to Section 2.2.2.3.

2.2.2.2.1 Isolate the test cell using the space separation distances outlined in Table 2.2.2.2.1 to mitigate overpressure exposure to adjacent buildings or equipment.

Table 2.2.2.2.1. Space Separation Distances for Fast Deflagration- or Detonation-Driven Room Explosion Hazard

Test Cell Volume [ft^3 (m^3)]	*Minimum Space Separation [ft (m)]*
≤ 6,000 (≤ 170)	50 (15)
6,001 – 15,000 (171 - 425)	100 (30)
15,001 – 30,000 (426 - 850)	150 (45)
30,001 – 50,000 (851 - 1420)	200 (60)

2.2.2.2.1.1 For locations without the appropriate space separation, provide blast resistant construction for exposed important equipment or structures in accordance with API RP-752, Management of Hazards Associated with Location of Process Plant Permanent Buildings, or ASCE 41088, Design of Blast Resistant Buildings in Petrochemical Facilities. A third-party organization may be needed to appropriately design the containment walls.

2.2.2.2.2 Provide damage-limiting construction for the test cell designed for Fuel Reactivity Group D in accordance with Data Sheet 1-44.

2.2.2.3 Equipment Disintegration Hazards

Where an equipment disintegration hazard exists, either due to the type of engine being tested or the type of test being performed, enhance the test cell design and construction features using one or more of the following. Refer to Section 3.2.3 for additional information regarding the presence of disintegration hazards.

A. Space Separation

Separate the unit under test from other buildings or utilities in accordance with Data Sheet 1-44.

B. Test Cell Construction

Design test cell walls, ceilings, and floors to resist flying debris. Specific test cell construction will vary but will usually necessitate reinforced concrete construction or the installation of steel plating. Design the cell to be as strong as practical to resist flying metal.

2.3 Occupancy

2.3.1 Ventilation

2.3.1.1 Install continuous mechanical exhaust ventilation in areas where any of the following is used:

A. An ignitable liquid with a closed cup flash point less than 100°F (38°C)

B. An ignitable liquid with a closed cup flash point less than or equal to 300°F (149°C) that is heated above its flash point

C. Flammable gas

D. Lithium-ion batteries

2.3.1.2 Install ventilation at floor level and at ceiling level in accordance with Data Sheet 7-32.

2.3.1.2.1 Arrange ventilation to operate at the required flow rate when either floor level or ceiling level ventilation is running.

2.3.1.3 Remove exhaust air through a system of blowers, fans, and ductwork that terminate outside away from equipment, air inlets, doorways, or other openings.

2.3.1.4 Construct exhaust ducts of noncombustible materials.

2.3.1.5 Provide independent exhaust ductwork for each test cell.

2.3.1.6 Design ducts to exhaust as directly as possible to the outdoors and to minimize bends.

2.3.1.7 Design the system so the test cell will not run if the ventilation system is inoperable (e.g., using interlocks with airflow in the ductwork, differential pressure across fans, etc.).

2.3.2 Housekeeping

2.3.2.1 Establish and implement a housekeeping program in test cells, support rooms, and other areas where flammable gas or ignitable liquid is used.

2.3.2.2 Do not store other combustibles in the test cell.

2.3.2.3 Do not store any material in the area that might wash into or plug drains. Refer to Data Sheet 7-32.

2.4 Protection

2.4.1 Provide automatic sprinkler protection over all engine and accessory test cells and support rooms.

2.4.1.1 Design the system to provide 0.3 gpm/ft^2 over 4000 ft^2 (12 mm/min over 370 m^2) or the test cell area, whichever is smaller. Refer to Data Sheet 7-32 for additional information on system design for ignitable liquid use areas.

2.4.1.2 Provide sprinkler protection under any obstruction that exceeds 3 ft (0.9 m) in width or diameter, or 10 ft2 (0.9 m2) in area.

2.4.1.3 Provide a water supply capable of meeting the design sprinkler discharge flow rate, plus 500 gpm (1900 L/min) for hose streams, for a minimum duration of 60 minutes.

2.4.1.4 To limit fire damage in engine and accessory test cells and support rooms, automatic sprinkler protection may be supplemented with an FM Approved fixed special protection system in accordance with Data Sheet 7-32.

2.4.2 An FM Approved water mist system can be used as a supplement to automatic sprinklers or as primary protection within the test cell if the following criteria are met:

A. The system is installed in accordance with the *Approval Guide* listing for protection of machinery in enclosures and Data Sheet 4-2, *Water Mist Systems*, ensuring all system limitations are addressed.

B. Ventilation in the test cell is interlocked to shut down upon system operation.

C. Water supply and compressed gas supply, where provided, are able to provide a 60-minute duration.

2.4.3 Protect bulk, ignitable-liquid storage in accordance with Data Sheet 7-88 or Data Sheet 7-32.

2.4.4 Protect control rooms in accordance with FM Property Loss Prevention Data Sheet 5-32, *Data Centers and Related Facilities*.

2.4.5 Protect ventilation ducts in accordance with FM Property Loss Prevention Data Sheet 7-78, *Industrial Exhaust Systems*.

2.4.6 Protect other areas, such as shops, offices, manufacturing areas, etc., in accordance with applicable data sheets.

2.5 Equipment and Processes

2.5.1 Flammable Gas and Ignitable Liquid Piping

2.5.1.1 Locate, arrange, and inspect fuel and other ignitable liquid transfer equipment, piping, and processes in accordance with Data Sheet 7-32.

2.5.1.2 If natural or manufactured gas is used for testing, locate and arrange storage containers, piping, and associated equipment in accordance with FM recommended practices for natural and manufactured gas. Refer to Data Sheet 7-54.

2.5.1.3 If liquefied petroleum gas (LP gas) is used for testing, locate and arrange storage containers, piping, and associated equipment in accordance with FM recommended practice for liquefied petroleum gas. Refer to FM Property Loss Prevention Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*.

2.5.1.4 If hydrogen is used for testing, do the following:

2.5.1.4.1 Design and install piping, tubing, and fittings in accordance with ASME B 31.12, *Hydrogen Piping and Pipelines*, or equivalent international standard.

2.5.1.4.2 Locate hydrogen mixing operations and flow measurement outside of the building.

2.5.1.4.3 Locate the piping entry above ground and use the shortest route to the dispensing location to minimize the length of piping inside the building.

2.5.1.5 Locate ignitable liquid and flammable gas supply systems outside of the test cell.

2.5.1.6 Arrange ignitable liquid or flammable gas piping to minimize the extent damage by flying debris.

2.5.1.6.1 Locate piping in chases or recesses, behind local protection such as steel plates, or outside the anticipated path of projectiles (e.g., flush against the wall at the corner of the room, at the ceiling, floor, etc.).

2.5.2 Emergency Shutdown

2.5.2.1 Provide safety/emergency shutoff valves and/or an automatically actuated means for shutting down ignitable liquid or flammable gas transfer systems in accordance with Data Sheet 7-32, Data Sheet 7-54, Data Sheet 7-55, Data Sheet 7-91, or other applicable data sheets.

2.5.2.1.1 Arrange the shutoff valves for automatic and manual operation.

2.5.2.1.2 The number and location of shutoff valves will vary depending on the piping system size, complexity, and the potential exposure created by a release.

2.5.2.1.3 Locate shutoff valves outside of the test cell.

2.5.2.2 Provide interlocks so the test cell will shut down and appropriate safety shutoff valves will close upon operation of one or more of the following (an example is provided in Figure 2.4.2.2):

A. Emergency stop button or switch in the control room

B. Fire-actuated devices in the test cell, test stand, or support rooms

C. Automatic sprinkler system or any installed special protection systems

D. Low pressure in the ignitable liquid or flammable gas line downstream of meters

E. High gas or liquid flow

F. High engine vibration or overspeed

G. Low dynamometer pressure

H. Dynamometer overtemperature

I. Low water or coolant flow

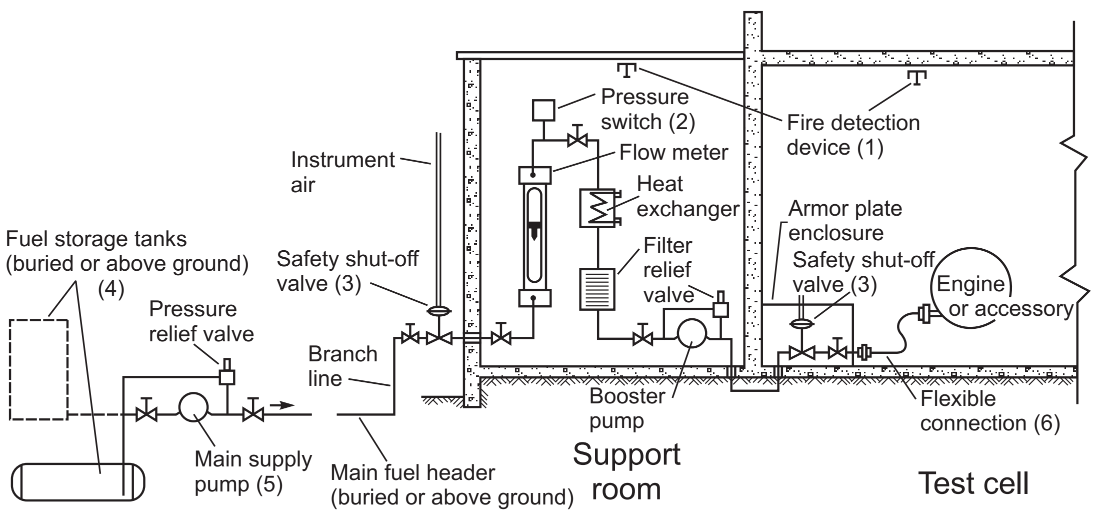
J. Low water or coolant level

K. High water or coolant temperature

L. Opacity meters installed within the test cell

M. Where flammable gas is used, failure of combustion air

Note that the preceding list is not all-inclusive. The provision of automatic interlocks is intended to limit the release of flammable gas or ignitable liquid and/or prevent such a release from occurring. However, the specific interlocks provided will vary with the testing operation and fuel used.



1. Fire detection device. Normally closed contacts.
2. Pressure switch. Contacts closed when operating fuel pressures above minimum.
3. Safety shutoff valve. Normally closed; energized electrically or by air pressure to open. Inlet pressure holds disk in closed position.
4. Fuel storage tanks.
5. Main supply pump. Pump remotely controlled from emergency stop buttons at test area.
6. Flexible connection. Automatic shutoff, quick disconnectors.

Fig. 2.5.2.2. Fuel-supply system

2.5.2.3 Avoid testing without operator presence.

2.5.2.3.1 Where unattended testing is conducted, do the following:

A. Design any installed interlocks to automatically shut down the operation and transmit an alarm to a constantly attended location.

B. Consider the use of additional equipment, such as video cameras or IR flame detection, to verify the presence of abnormal conditions and allow operators to respond remotely.

2.5.2.4 Where flammable gas is used, provide an FM Approved combustible gas detection system in accordance with this section

2.5.2.4.1 Design the gas detection system to complete the actions outlined in Table 2.5.2.4.1 when the specified gas concentrations are detected. Shutting down the test cell includes shutdown of all ignitable liquid and flammable gas transfer systems. Fully exhausting the room may include actions such as, but not limited to, increasing fan speeds and opening dampers.

Table 2.5.2.4.1. Gas Detection System Actions

Fuel	*Gas Concentration Detected*	*Actions*
Hydrogen	25% of the LEL	Sound an alarm, shut down the test cell, close appropriate safety shutoff valves and fully exhaust the room
Flammable gas other than Hydrogen	25% of the LEL	Sound an alarm
	50% of the LEL	Shut down the test cell, close appropriate safety shutoff valves and fully exhaust the room

2.5.2.4.2 Install detectors at floor level, ceiling level and at the inlet of any ventilation.

2.5.2.4.3 Provide accessible local manual activation devices to fully exhaust the test cell.

2.5.2.4.4 Stop recirculation of air within the cell, if applicable.

2.5.3 Provide FM Approved safety containers for the handling of small quantities of ignitable liquids.

2.5.4 Where ignitable liquids are heated, use steam or hot water.

2.5.4.1 If heat transfer fluid is used for heating, arrange the system in accordance with FM Property Loss Prevention Data Sheet 7-99, *Heat Transfer Fluid Systems*.

2.5.5 Use water or water-based coolants to cool equipment.

2.5.6 Design and install hydraulic equipment, piping, and transfer systems in accordance with FM Property Loss Prevention Data Sheet 7-98, *Hydraulic Fluids*.

2.5.6.1 Use an FM Approved industrial fluid in place of a non-FM Approved fluid, such as mineral oil, for hydraulic equipment.

2.6 Operation and Maintenance

2.6.1 Develop safe operating and maintenance procedures in accordance with Data Sheet 7-32.

2.6.2 Where equipment is susceptible to internal damage from foreign objects (e.g., gas turbines), implement a material control program to preclude foreign objects from entering the tested engine.

2.6.3 Provide regular inspections of all ignitable liquid or flammable gas transfer piping and hoses, especially those with frequent connections or disconnections.

2.7 Training

2.7.1 Train employees working in this occupancy in accordance with the appropriate data sheets based on the hazard:

- Data Sheet 7-32
- Data Sheet 7-54
- Data Sheet 7-55
- Data Sheet 7-91
- Data Sheet 7-98
- Data Sheet 7-99

2.8 Human Factor

2.8.1 Establish an emergency response plan in accordance with FM Property Loss Prevention Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*, and the following data sheets, as needed, depending on the specific hazards in the occupancy:

- Data Sheet 7-32
- Data Sheet 7-54
- Data Sheet 7-55
- Data Sheet 7-91
- Data Sheet 7-98
- Data Sheet 7-99

2.8.2 Create documented procedures to expedite response to situations such as fires and explosions in test cells, including the following:

A. Manual shutdown of ignitable liquid and flammable gas systems

B. Availability of provided fire protection features, including identification of sprinkler valve location(s) relative to each test cell

C. Spill response and clean-up procedures

2.9 Utilities

2.9.1 Use only steam, hot water, or indirect hot air heating systems for general room or building heating in areas where ignitable liquid or flammable gas is handled.

2.9.1.1 Locate heaters for all systems outside the test area.

2.9.2 Draw all air for combustion purposes from outside the building.

2.9.2.1 Locate return openings in hot air systems at least 5 ft (1.5 m) from the floor where ignitable liquid or heavier-than-air gas is used.

2.9.3 Use electrical, steam, or hot water heating systems for accessory test cells.

2.9.4 Use direct cooling methods for accessory test cells. Use nonignitable solutions in refrigeration systems.

2.9.5 Insulate inlet and exhaust ducts contained within the test cell with noncombustible or FM Approved Class 1 materials. Refer to Data Sheet 7-78 for details.

2.10 Ignition Source Control

2.10.1 Control ignition sources in accordance with Data Sheet 7-32.

2.10.2 Provide hazardous location rated electrical equipment as outlined in this section and in accordance with FM Property Loss Prevention Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*, and national or local codes.

2.10.2.1 For test cells that use hydrogen, provide Class I, Division 1, Group B electrical equipment within the test cell.

2.10.2.2 For test cells that use flammable gases (other than hydrogen), ignitable liquids with a closed cup flash point at or below 100°F (38°C), or any ignitable liquid heated above its closed cup flash point (including possible ambient temperatures), provide Class I, Division 1, Group D electrical equipment within the test cell.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Engine Test Cells

Internal combustion engines and their accessories for motor vehicles, aircraft, marine vessels, locomotives, stationary power plants, and other uses are subjected to tests at plants where they are manufactured or used. Common types are reciprocating, aircraft turbine and gas turbine engines. Accessories for such engines may include fuel pumps, fuel meters, fuel tanks, superchargers, compressors, hydraulic packs, generators, and starters.

Tests on engines range from routine tests to extensive and severe performance and endurance tests. Accessories are usually tested for performance, tightness, or calibration.

Primary fuels include liquid hydrocarbons such as gasoline, kerosene, diesel oil, and jet fuels. Ignitable liquids such as hydraulic fluids or lubricating oils may also be present. Gases such as propane, butane, and natural and manufactured gases may be used either as fuel for engines or for heating the test cells for environmental tests. Recently, hydrogen has been introduced as potential fuel source for test cells. The use of hydrogen creates the potential for a fast deflagration- to detonation-driven room explosion hazard. Additionally, lithium-ion batteries are being introduced in test cells. Lithium-ion batteries can be expected to cause a longer duration fire event than hydrocarbon fuels.

3.2 Location and Construction

3.2.1 General

Tests may be conducted outdoors or in light, noncombustible, low-value structures where adequate spacing is provided between the test facility and important plant buildings or utilities. However, factors such as simultaneous tests on multiple units, sound control, control of test conditions, and materials handling requirements usually result in substantial engine or accessory test cells and associated facilities being located within main plant areas.

The aircraft engine test facility illustrated in Figure 3.2.1 is also typical of those for other types of engines. The differences might be cell size, the lack of an augmenter section, and the provision of different support rooms for test equipment. The most frequently used accessory test facilities having heavy cell construction are those for turbosuperchargers. Low flash point ignitable liquids are not used in these tests, and the heavy construction is solely for protection against flying metal parts.

In designing internal subdivision of engine testing facilities, the basic consideration is isolation of the unit under test to limit the extent of damage.

This objective is best accomplished by substantial internal cutoffs in the form of:

A. cells for testing that involves a disintegration or other severe hazard.

B. separate enclosures for fuel handling systems and associated hazardous equipment.

C. control rooms for protection of personnel and expensive control instruments.

With regard to the use of support rooms for fuel-handling systems, some components must be inherently located near the unit under test, such as filters, strainers, and piping entering the cell. However, locating ignitable liquid and flammable gas equipment outside of the test cell will limit the quantity of liquid and gas within the cell. Additionally, it will eliminate the potential for impact damage to piping and equipment in the event of disintegration of an engine or accessory equipment during testing.

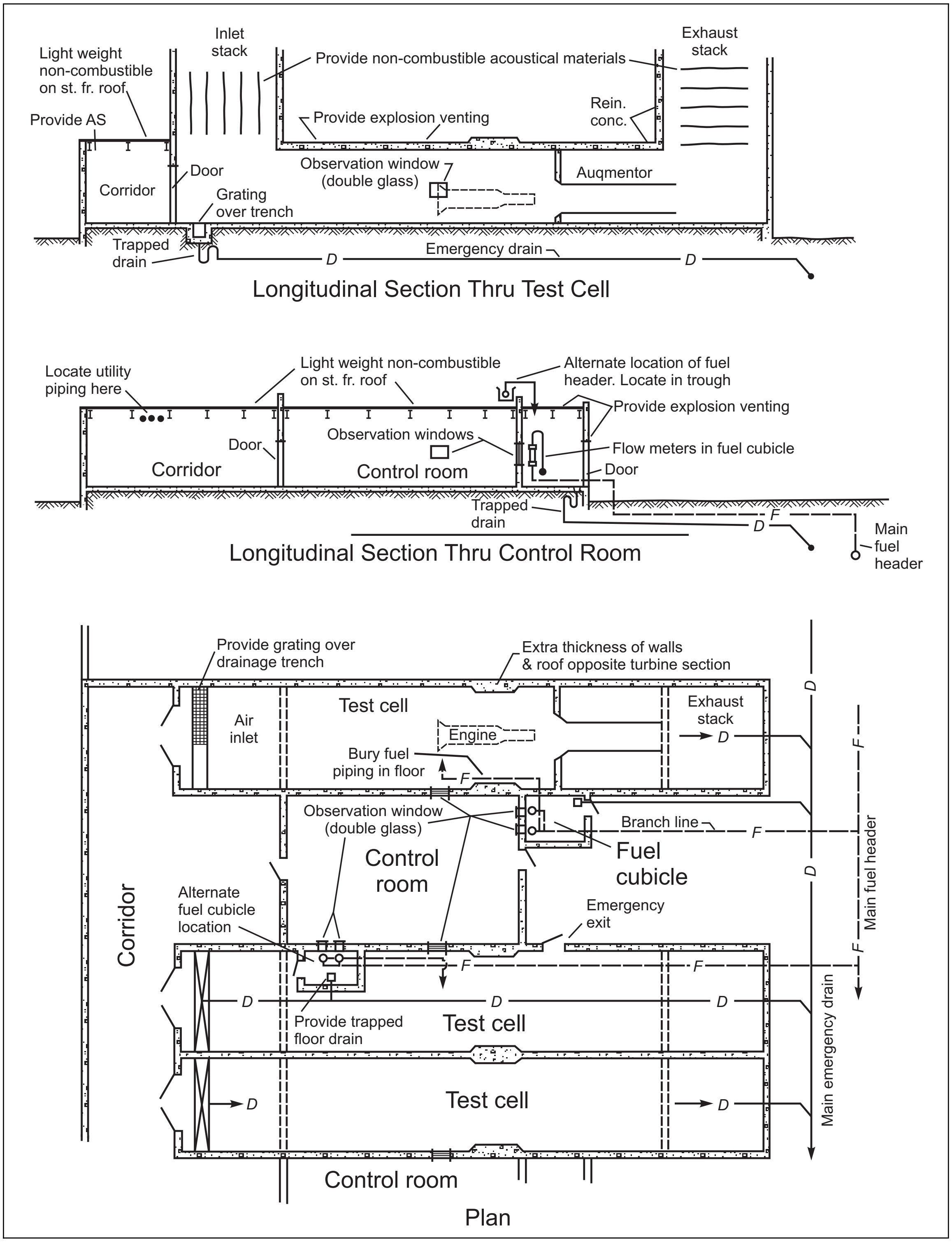


Fig. 3.2.1. *Typical turbine aricraft engine test facility, illustrating recommended cell arrangement and construction*

3.2.2 Room Explosion Hazards

As outlined in Section 2.2.2, a room explosion hazard may exist in some test cells. There are two types of explosions that may occur.

A slow deflagration is an explosion where the flame speed is lower than the speed of sound. In a fast deflagration or detonation, the flame speed is greater than the speed of sound.

The speed and severity of a deflagration event varies depending on the fuel reactivity and level of congestion and confinement. Peak pressures produced by a slow deflagration can be orders of magnitude lower than those produced by fast deflagrations or detonations, and the resulting damage caused by a slow deflagration can be mitigated through the use of damage limiting construction features. Fast deflagrations and detonations are more destructive than deflagrations and cannot be mitigated by damage limiting construction.

3.2.3 Equipment Disintegration Hazards

Where the potential for an equipment disintegration hazard exists, enhanced test cell construction features or other safeguards may be necessary to account for the potential of flying metal parts from destructive testing. The potential for an equipment disintegration hazard will depend on the type of equipment being tested and the type of testing being performed.

3.2.3.1 Equipment Type

The type of engine being tested will influence the presence of a disintegration hazard. For example, a common failure mode for most reciprocating engines involves the connecting rod. In some cases, a thrown rod will puncture the engine block and serve as a projectile within the enclosure. However, this is not considered to be a severe disintegration hazard, even for large reciprocating engines, and should not necessitate additional construction safeguards beyond basic test cell design recommendations listed in Section 2.2.1.

Testing of automotive, small aircraft reciprocating, or diesel engines does not generally present a flying metal hazard unless it includes tests to destruction, extended endurance tests, or tests known to exceed design limitations.

Conversely, testing of dynamic equipment such as turbine aircraft engines, radial reciprocating aircraft engines (e.g., propeller type aircraft engines), and accessory components revolving at high speeds may require increased pressure resistant construction due to the potentially severe mechanical breakdown hazard. Some other larger equipment (gas turbines, turbosuperchargers, compressors) may also necessitate enhanced test cell location or construction features.

3.2.3.2 Test Type

The type of testing conducted may create a disintegration hazard, regardless of the type of equipment being tested. For example, routine testing of equipment in a production process should not create an abnormal disintegration hazard. However, experimental testing where the equipment is subjected to conditions exceeding design limitations (e.g., speed, torque, etc.) or where the equipment is tested to destruction may create a disintegration hazard.

Rotating accessory testing does not present a severe flying metal hazard because of the small size of the accessories and the limited energy available. The type of accessory testing varies widely, however, and tests involving extremes of temperature, pressure, humidity, or motion often make it necessary to use special enclosures such as altitude and temperature cells. The values of these cells make localized flying metal protection desirable if disintegration is possible. With this local protection (armor plate bands), the hazards of the test facility are only those associated with ignitable liquids and flammable gases.

3.2.4 Location of Piping Systems

Data Sheet 7-32 provides detailed information regarding the importance of ignitable liquid piping system integrity. This information also applies to the supply of ignitable liquids and flammable gases in engine test facilities.

Piping located inside buildings that is not accessible for inspection (e.g., in a concealed space) or that is below grade (e.g., basement areas or tunnels) can increase the potential for an uncontrolled ignitable liquid fire. Inaccessible piping cannot be inspected for corrosion or leaking joints. These problems may not be identified before a large quantity of liquid has been released or before the pipe fails. A leak in an unoccupied below grade area may not be noticed. Any leak that is ignited in a basement cannot be effectively attacked by manual firefighting activities. The importance of piping system integrity is especially critical in such unoccupied, below grade spaces.

Several losses have occurred that emphasize the importance of excluding basements, tunnels, and other below grade locations in the design of test facilities, if possible. For example, a serious explosion occurred in a one story and basement building used for testing automotive engines. A new gasoline pumping system had been installed, but piping in the basement for the previous gravity system had been left open. An employee who did not realize that the changeover had been made opened a valve under the gravity tank supply, permitting gasoline to discharge into the basement where its accumulated vapors exploded.

A similar and even more destructive explosion occurred at a jet engine testing facility. Fuel from a flowmeter leaking in a control room in a group of 20 test cells ran down a stairway into a basement, which extended beneath all the cells. The explosive vapor-air mixture filled a large portion of the basement and was ignited by an undetermined source. The heavy concrete construction of all cells in the group was seriously damaged.

3.3 Protection

As most fires in testing facilities involve ignitable liquid spills, flammable gases, or ordinary combustibles, fire protection for the general area is usually provided by water. The water may be supplied from automatic sprinklers, deluge or preaction systems, and from hose streams. The type of protection used will depend on the combustion characteristics of the materials, the probable total quantity involved, the rate and distribution of escaping fuel, and the nature of exposed equipment and structures. Special protection systems such as foam-water sprinkler systems or CAF (compressed air foam) systems may be valuable as a supplement to sprinkler protection in applications where accidents frequently occur, or where emergency drainage problems are encountered.

Test cells and support rooms will have a significant quantity of ductwork, utility piping, overhead cranes, and similar equipment. If these items cannot be located at the perimeter of the room, away from automatic sprinklers, they should be considered potential obstructions to the system.

Engine test facilities typically monitor numerous parameters during the test, including the temperature, pressure, and flow of various components. These measurements may or may not be interlocked to automatically shut down the test and stop the flow of liquid or gas. At a minimum, automatic shutoff of the test and liquid or gas systems should be tied to operation of the fire protection system within the cell. Automatically operated shutoffs are the only reliable means of ensuring the flow of liquid or gas is stopped in the event of a fire. Loss history suggests that, regardless of the presence of supposedly reliable manual shutoff procedures, these methods are not always followed, are not accessible in the event of a fire, or are not performed fast enough.

3.4 Loss History

Engine test facilities typically store bulk quantities of ignitable liquid and/or flammable gas and pump these materials to individual cells to conduct necessary performance or production tests. The fire hazard associated with these supplies of liquids and gases is the same as for similar occupancies using ignitable liquid and flammable gas, for which an extensive loss history base exists. Refer to other data sheets, including Data Sheet 7-32, Data Sheet 7-88, and Data Sheet 7-54 for historical loss data.

A study of losses directly associated with test cells indicated that equipment breakdown (i.e., mechanical or electrical losses) and fire and explosion losses occur at approximately the same frequency. However, fire and explosion losses typically are the result of escaping fuel, and many of these events are preceded by disintegration of engines during tests. As a result, in terms of cost, fire events tend to exceed losses that are strictly mechanical or electrical in nature. This experience shows the value of segregating tests that have a disintegration hazard, and the need for precautions against the sudden release of ignitable liquid and flammable gas.

Most of the fires and explosions were caused by piping or hose failures, spills, or failure of the tested equipment, with subsequent vapor ignition on a hot engine component. Nearly half of the recorded fire and explosion losses were caused by the ignition of ignitable liquids on hot surfaces. For example, a common failure mode for reciprocating engines is a pressurized leak of engine oil (from a loose hose, defective part such as a filter, or similar failure). The oil is released in the form of a mist or spray and is ignited on hot engine components.

Electrical failure (arcing, sparking, etc.) was the ignition source in a third of the reported fire and explosion losses. The ignition source in the remaining losses was unknown.

Limited loss experience exists related to engine test cell fire losses involving flammable gas. The use of hydrogen is fairly new in test cells, but the hazards associated with its use are well documented; so an event involving hydrogen can be expected to be large. As described above, FM has experience with processes involving flammable gas and gas piping. The frequency of flammable gas events within test cells is anticipated to increase as the technology of equipment using compressed natural gas, LNG, LPG, and other gases develops.

With regard to the type of equipment involved, over 60% of FM losses involved dynamic equipment such as jet engines or turbines. Thirty-three percent involved gasoline engines, diesel engines, or other reciprocating engines or accessory equipment. Finally, 6% of the losses involved other equipment such as generators.

4.0 REFERENCES

4.1 FM

Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 4-2, *Water Mist Systems*
Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*
Data Sheet 5-32, *Data Centers and Related Facilities*
Data Sheet 5-33, *Lithium-Ion Battery Energy Storage Systems*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
Data Sheet 7-91, *Hydrogen*
Data Sheet 7-98, *Hydraulic Fluids*
Data Sheet 7-99, *Heat Transfer Fluid Systems*
Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*

4.2 Other

American Petroleum Institute (API), RP-752, *Management of Hazards Associated with Location of Process Plant Permanent Buildings General*.

American Society of Civil Engineers (ASCE), ASCE 41088, *Design of Blast Resistant Buildings in Petrochemical Facilities*.

American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section VIII. ASME B 31.12, *Hydrogen Piping and Pipelines*.

APPENDIX A GLOSSARY OF TERMS

Deflagration: A rapid combustion reaction in which the flame front moves through the unreacted medium (flammable gas and air or combustible dust and air) at a velocity less than the speed of sound in that medium.

Detonation: An extremely rapid combustion reaction in which the flame front moves through the unreacted medium (see deflagration) at a velocity greater than the speed of sound in that medium.

Dynamometer: Commonly referred to as a “dyno,” a device used to measure power, force, or torque. Various types of dynamometers exist, including electrical (e.g., eddy current) and nonelectrical (e.g., water brake) dynamometers. The hazards, applications, and costs associated with each type of dynamometer vary.

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Ignitable liquid: Any liquid or liquid mixture that has a measurable closed cup flash point. The hazard of a liquid depends on its ability to sustain combustion or create a flammable vapor-air mixture above its surface. Flash point is one way of understanding if a liquid can create that flammable vapor-air mixture. For a liquid to burn in a pool, it must have a fire point as well as a flash point. Ignitable liquids include flammable liquids, combustible liquids, inflammable liquids, and any other term for a liquid that will burn.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e. the section numbers are not always the same from version to version).

January 2024. Interim revision. The following significant changes were made:

A. Provided guidance on the use of hydrogen

B. Provided guidance on the use of lithium-ion batteries

C. Provided construction and location guidance for detonation-driven room explosion hazards

D. Revised guidance for the location of ventilation in the test cell

E. Clarified guidance for ignition source control related to rated electrical equipment

F. Completed various grammar and editorial revisions

October 2021. Interim revision. The following significant changes were made:

A. Revised scope to clarify which fuels are covered by this data sheet.

B. Made minor changes to be consistent with Data Sheet 7-32, *Ignitable Liquid Operations*.

C. Added FM Approved water mist systems as an enclosure protection option.

D. Renumbered tables and figures based on section number.

April 2015. The following major changes were made:

A. Changed the title of the data sheet from *Testing Internal-Combustion Engines to Testing of Engines and Accessory Equipment.*

B. Revised terminology and guidance related to ignitable liquids to provide increased clarity and consistency. This includes the replacement of references to “flammable” and “combustible” liquid with “ignitable” liquid throughout the document.

C. Reorganized the document to be consistent with other data sheets.

D. Provided information to assist in evaluating the fire and explosion hazard scenarios associated with test cells.

E. Clarified engine test cell construction. Necessary construction features will vary depending on the type of engine being tested, the presence of an equipment disintegration hazard, and the use of fuels that create a vapor-air explosion hazard.

F. Revised the test cell ventilation recommendations to align with ignitable liquid and flammable gas guidance in other data sheets.

G. Revised the sprinkler protection recommendations for test cells.

H. Updated guidance associated with special protection systems for alignment with current technologies and FM Global recommendations.

I. Expanded guidance on the proper design and location of liquid and gas supply piping and equipment in support rooms and within the test cell. This guidance is intended to minimize the potential for impact damage of the piping and to limit the quantity of fuel within the test cell.

J. Updated the recommendation for interlocks used to monitor conditions within the test cell based on current technologies.

K. Deleted information on the testing of injection carburetors.

L. Added information on the development of an emergency response plan.

September 2000. The document has been reorganized to provide a consistent format.