Report for Brookhaven National Laboratory BNL E951 Liquid Hydrogen Safety Report September 20, 2002

Preface

BNL E951 as proposed requires the use and consumption of the cryogens liquid nitrogen and liquid hydrogen to cool the experiments Pulsed Solenoid Magnet (PSM). The BNL safety requirements, as represented by in-place BNL regulations and broadly accepted standards were searched for applicable sections. The leading applicable national and industrial association standards were identified and acquired.

This note describes the proposed equipment and equipment layout that meet the E951 requirements and addresses, in detail, the referenced siting standards, emphasizing the liquid hydrogen safety issues, as they apply to the proposed layout.

Acronyms

BNL: Brookhaven National Laboratory
CGA: Compressed Gas Association
ESH: Environment, Safety and Health
LH₂: Liquid Hydrogen
LN₂: Liquid Nitrogen
NFPA: National Fire Protection Association
OHSG: Occupational Health Safety Guidelines

Identified References

Liquid Nitrogen

1). BNL ESH, 5.1.0 Non Flammable Cryogenic Liquids, Rev.2

Liquid Hydrogen

2). BNL OHSG, Special Precautions for Locations Containing Flammable Atmospheres, 4.12.0

3). BNL OHSG, Flammable Cryogenic Liquids, 5.2.0

4). NFPA 50B, Standard for Liquefied Hydrogen Systems at Consumer Sites, 1999 NFPA

5). CGA G-5.4-2001, Standard for Hydrogen Piping Systems at Consumer Locations, 2^{nd} Edition

6). CGA G-5.5-1996, Hydrogen Vent Systems, 1st Edition.

Secondary References, referenced by those above

7). CFR 1910.103, Hydrogen, current

8). API Recommended Practice 521, Guide for Pressure-Relieving and Depressuring Systems, 4th Edition, March 1997

Applicable Drawings

The general area layout drawings are those of the A3 beam line. The attached building layout sketch is an excerpt that concentrates on the inside area that includes the beam cave and is bounded by building walls. The beam cave sketch increases the clarity of near PSM connecting cryogenic lines and valves.

The attached cryogen storage and equipment area layout sketch is an excerpt that concentrates on the outside area bounded by building walls to the left and bottom and the experiment's trailer at the top. It includes the Circulator/HE, and the liquid hydrogen and liquid nitrogen dewars and the connecting piping.

Approach

All issues of each identified standard that may apply will be addressed in terms of the layout proposed and the design rationale described.

When a standard requirement applies, compliance will be noted with an "Applied, Applies or Full Compliance" label at the indicated section. When qualifications of any kind are made they are made in RED at the indicated section(s). If an explanation or a qualified response is required, they will be indicated in *RED ITALIC* at the indicated section(s). If lengthy explanations or qualified responses are required the reference to the appended material will be made in RED for easy identification.

Oxygen Deficiency Hazards (ODH) Matters

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Please note that indoor, confined space, ODH matters will be separately addressed and reported by others.

Major Interlocks Recommended

A brief Major Interlock list and discussion of the listed item is appended as Appendix 1.

BNL ESH, 5.1.0 Non Flammable Cryogenic Liquids, Rev.2

Design Comment by section and as appropriate follows. Note that though the original text may be truncated below for readability, the full meaning of the original applies.

- I Introduction
- II Scope
- III Responsibilities
- IV General Requirements
 - A Storage through 7.: Full Compliance
 - B Transfer and Handling through 5.: Full Compliance
 - C Personnel Protective Equipment: Full Compliance
 - D Engineered Systems: Full Compliance
 - E Records and Documentation: Full Compliance
- V Definitions
- Appendix A: N/A
- Appendix B: N/A
- Appendix C: N/A
- Appendix D: N/A
- Appendix E: N/A
- Appendix F: N/A

BNL OHSG, Special Precautions for Locations Containing Flammable Atmospheres, 4.12.0

Design Comment by section and as appropriate follows. Note that though the original text may be truncated below for readability, the full meaning of the original applies.

- I Introduction
- II Scope
- III Definitions
- IV Responsibilities
- V Locations Not Requiring Special Precautions
- VI Locations Requiring Special Precautions
 - A Locations Potentially Requiring Special Precautions
 - 1 Flash point below 40 C. Applies.
 - 2 Flammable Gases or vapors are likely to be present. Applies for the Vent Stack exhaust.
 - 3 Liquids having flash points above 40°C. Does not apply.
 - B Division 1 Location
 - Does not apply.
 - C Division 2 Locations. Applies.
 - D Adequate ventilation and not likely to leak.
 - 1 Applies.
 - 2 2a. Adequately ventilated, can't escape except under abnormal conditions, liquid hydrogen totally contained in a permanent piping system. Applies.
 - 3 Does not apply.
 - 4 Does not apply.
- VII Boundaries of Classified Locations
 - A Determining Boundaries
 - B Boundary Identification
 - Full Compliance
 - C Use of Diagrams

Appendix A, 1 through 11 and 13 through 14 do not apply.

Appendix A, 12. Applies. Defines a 25' diameter within which there must only be Class I Division II Group B electrical equipment.

- VIII Basic Equipment Requirements
 - A Design Based Upon Division Classification

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- 1 Division 1. Does not apply.
- 2 Division 2. Applies.
- B Minimize Equipment in Classified Location Applies.
- C Appropriate Equipment for Classified Locations
 - 1 Applies.
 - 2 Applies.
 - 3 Applies.
- D Approved Equipment

Applies.

E Unapproved Equipment

No unapproved equipment will be used.

- IX Equipment Categories
 - A Explosion Proof:

Applies.

B Purged Enclosures:

Applies.

C Intrinsically Safe: Applies.

D Non-Incendiary Equipment:

Applies.

X Ventilation

1 Does not apply, all piping and equipment locations are out-of-doors.

Appendix A. Addressed above.

Appendix B.

Table B-1: Hydrogen applies.

Table B-2: Does not apply.

Table B-3: Does not apply.

Appendix C.

Application Example

BNL OHSG, Flammable Cryogenic Liquids, 5.2.0

Design Comment by section and as appropriate follows. Note that though the original text may be truncated below for readability, the full meaning of the original applies.

I. Introduction

II. Scope

III. Responsibilities

IV. Required Reviews and Procedures for the Admission and Maintenance of Flammable Cryogenic Fluids in Experimental Areas

A through C: Full Compliance

D. Does not apply.

V. General Precautions for Liquid Hydrogen Areas

A. NFPA 50B:

The referenced NFPA 50B, Liquefied Hydrogen Systems at Consumer Sites document, is addressed in a later section of this report in great detail.

- B. Liquid Hydrogen Area Safety:
- Full compliance. C. Building Requirements
 - No G/LH_2 installation will be made in a building.

A. Equipment

B. Operation of the Equipment

1. Monitored by a qualified operator

A CSC exemption from emptying the LH_2 from the Circulator/HE over night will be sought. It is less safe and counterproductive to empty/warm the HE if the equipment will run again the next morning.

2. Full compliance.

3. Full compliance.

VI. Operating Regulations for Liquid Oxygen

1 A through D: Does not apply.

VII Transportation of Flammable Cryogenic Liquid Containers

A through D: Full Compliance, as they apply.

<u>NFPA 50B, Standard for Liquefied Hydrogen Systems at Consumer Sites, 1999</u> <u>NFPA</u>

Design Comment by section and as appropriate follows. Note that though the original text may be truncated below for readability, the full meaning of the original applies.

- 1 General Information
 - 1.1 Scope
 - 1.1.1 Application
 - 1.1.2 Non-Application
 - 1.2 Retroactivity
 - 1.3 Definitions

2 Design of Liquefied Hydrogen Systems

- 2.1 Containers
 - 2.1.1 Hydrogen Containers shall comply with:
 - a) ASME Section VIII: Full Compliance.
 - b) Portable containers with steel supports in excess of 18". N/A
 - 2.1.2 Permanently installed containers
 - 2.1.3 Container markings: Full compliance.
- 2.2 Pressure Relief Devices
 - 2.2.1 Stationary liquefied hydrogen containers shall be equipped with CGA S-1.3 relief devices. Full Compliance.
 - 2.2.2 Portable liquefied hydrogen containers complying with DOT. Full compliance.
 - 2.2.3 Pressure relief device discharge unobstructed, outdoors without impingement of escaping liquid or gas on the container, adjacent structures or personnel. Full compliance.
 - 2.2.4 Pressure relief devices and vent piping shall be designed so that moisture cannot collect and freeze to interfere with the proper function of the device.

Full compliance.

2.2.5 Pressure relief devices shall be provided in piping wherever liquefied hydrogen could be trapped between closures.

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Full compliance.

- 2.2.6 A sign shall be placed on the container near the pressure relief valve stack, on the vent stack that warms against spraying water on, or in the vent opening. Full compliance.
- 2.3 Piping, Tubing and Fittings
 - 2.3.1 Piping, tubing and fittings, and gasket and thread sealant service, thermal expansion and contraction of piping systems when exposed to temperature fluctuations of ambient to liquefied hydrogen temperatures. Full compliance.
 - 2.3.2 Piping shall conform to ASME B31.3. Piping operating below –
 29°C shall meet impact tests of Chapter III of ASME B31.3 at the minimum operating temperature.
 Full compliance.
 - 2.3.3 Joints shall be welded or brazed or by use of flanged, threaded, socket, slip, or suitable compression fittings. Brazing materials shall have a melting point above 1000°F. Full compliance.
 - 2.3.4 Provide a means to minimize the exposure of personnel to low temperature piping and to prevent air condensates from contacting the piping, structural members, and surfaces not suitable for cryogenic temperatures. Insulation shall be noncombustible with a vapor tight outer seal covering to prevent condensation and oxygen enrichment in the insulation. The insulation material and outer shield shall be adequate to prevent self-attrition in normal operating conditions.

The LH_2 portion of the system will have VJ and MLI and no foam insulation. The vented gas will be warmed by a water-gas heat exchanger before traveling to the vent stack.

- 2.3.5 Uninsulated piping and equipment operating at liquefied hydrogen temperatures shall not be installed above asphalt surfaces or other combustible materials to prevent their contact with liquid air. Full compliance. *The LH2 vaporizer will be fitted with a full sized drip pan for heavy vaporizer duty.*
- 2.4 Equipment Assembly
 - 2.4.1 Valves, gauges, regulators and all other accessories shall be suitable for liquefied hydrogen service pressures and temperatures. Full compliance.

Personnel familiar with their proper installation practices, 2.4.2 construction and use shall supervise the installation of liquefied hydrogen systems.

Full compliance.

Storage containers, piping, valves, regulating equipment and other 2.4.3 accessories shall be readily accessible and protected against physical damage and tampering. A shutoff valve shall be located in the liquid product withdrawal line(s) as close to the container as possible. On containers of over 2000-gal capacity, this shutoff valve shall be able to be operated by remote control with no connections, flanges, or other appurtenances (other than a welded manual shutoff valve) allowed in the piping between the shutoff valve and its connection to the inner container.

Full compliance.

- Cabinets and housings containing hydrogen control equipment 2.4.4 shall be ventilated to prevent any accumulation of hydrogen gas. Full compliance.
- Testing 2.5
 - After installation, all field-erected (all) piping shall be tested and 2.5.1 proved hydrogen (helium) gas-tight at operating pressure and temperature.

Full compliance.

Containers, if out of service in excess of one year, shall be 2.5.2 inspected and tested as outlined in 2.5.1. The pressure relief devices shall be checked to determine if they are operable (repeatable) and properly set.

Full compliance.

- 2.6 Liquefied Hydrogen Vaporizers
 - The vaporizer shall be (suitably) anchored and its connecting 2.6.1 piping shall be sufficiently flexible for the expansion and contraction due to temperature changes. Full compliance.
 - The vaporizer shall be protected on the hydrogen and heating 2.6.2 media sections with pressure relief devices. Full compliance.
 - Heat used in a liquefied hydrogen vaporizer shall be supplied by 2.6.3 utilizing media such as air, steam, water or water solutions. Full compliance.

- 2.6.4 A low temperature shutoff switch or valve shall be provided in the vaporizer discharge piping to prevent the flow of liquefied hydrogen in the event of the loss of the heat source. Full compliance.
- 2.7 Electrical Systems
 - 2.7.1 Electrical wiring and equipment shall be in accordance with Table
 2-7 and Article 501 of NFPA 70, National Electrical Code®.
 Full compliance.
 - 2.7.2 Exception No. 1: Where equipment approved for Class I, Group B atmospheres is not commercially available, the equipment used shall meet the following requirements:
 - i Purged or ventilated in accordance with NFPA 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment.
 - ii Intrinsically safe
 - iii Approved for Class, I Group C atmospheres.
 - Full compliance.
 - 2.7.3 Table 2-7
 - a) Electrical Area Classification
 - b) Regular connections Div. 1 <1 m
 - c) No regular connections Div. 2 1m<L<7m
- 2.8 Bonding and Grounding
 - 2.8.1 The liquefied container and associated piping (e.g., the delivery truck) shall be electrically bonded and grounded. Full compliance.
- 3 Location of Liquefied Hydrogen System
 - 3.1 General Requirements
 - 3.1.1 The storage containers shall be located so that they are readily accessible to mobile supply equipment and authorized personnel at ground level. (Appropriate) Roadways (right of way) or other means of access for emergency equipment, such as fire apparatus, shall be provided.

Full compliance.

- 3.1.2 Systems shall not be located beneath or where exposed by failure of the following.
 - a) Electric power lines
 - b) Piping containing all classes of flammable and combustible liquids
 - c) Piping containing other flammable gases.
 - d) Piping containing oxidizing materials

Full compliance.

3.1.3 Where a liquefied hydrogen container is installed on ground level with or lower than the adjacent storage of all classes of flammable and combustible liquid or liquid oxygen, suitable protective means shall be taken to prevent accumulation of liquids within 15.2 m of the liquefied hydrogen container. Protective means shall include diking, diversion curbs, or grading of the flammable and combustible liquid storage or liquid oxygen.

Full compliance.

3.1.4 Storage sites shall be fenced and posted to prevent entrance by unauthorized personnel. Sites also shall be placarded as follows:

LIQUEFIED HYDROGEN FLAMMABLE GAS NO SMOKING – NO OPEN FLAMES

Full compliance.

3.1.5 If liquid hydrogen is located (as specified in table 3-2.1) in a separate building, in a special room, or inside a building where not in a special room or exposed to other occupancies. Containers shall have the pressure relief devices vented unobstructed to the outdoors at a minimum elevation of 7.6 m above grade to a safe location as required in 2-2.3

Full compliance.

- 3.2 Specific Requirements
 - 3.2.1 The location of liquefied hydrogen storage, as determined by the maximum total quantity of liquefied hydrogen, shall be in the order of preference indicated by in Table 3-2.1

Table 3-2.1

- a) This table is limited to liquefied hydrogen capacities of up to 600 gallons.
- b) The 200-gallon E951 Circulator/HE is limited by the requirements of this Table to Outdoor, Separate Building or Special Room locations.
- c) Table 3-2.1 Note: Note that this table does not apply to storage in dewars used in laboratories for experimental purposes.
- d) Full compliance.
- 3.2.2 The maximum distance in feet from liquefied hydrogen of indicated storage capacity located either outdoors, in a separate

building, or in a special room to any specified exposure shall be in accordance with table 3-2.2

- a) Exception: The distances in (line) numbers 1,4,6,7,8 and 11 shall be permitted to be reduced by 2/3, but not to less than 1.5 m for insulated portions of the system. For uninsulated portions of the system, the distances shall be permitted to be reduced by the use of protective structures having a minimum fire resistance rating of 2 hours. The protective structure or of the insulated liquefied hydrogen tank shall interrupt the line of sight between uninsulated portions of the liquefied hydrogen storage system and the exposure.
- b) Table 3-2.2 Minimum Distance from Liquefied Hydrogen Systems to Exposures (in feet)
 - i Buildings and structures

Wall(s) adjacent to system constructed of non-combustible materials

Sprinklered building or structure with combustible contents or structure or unsprinklered building or structure having non-combustible contents.

39.63-3500 gal: 5 feet (Applies)

3501-15,000 gal: 5 feet (Applies)

Unsprinklered building or structure with combustible contents.

Adjacent wall(s) with fire resistance rating less than 3 hours.

39.63-3500 gal: 25 ft (16.7 ft) (N/A)

3501-15,000 gal: 50 ft (34 ft) (N/A)

Adjacent wall(s) with fire resistance rating of 3 hours or more.

39.63-3500 gal: 5 feet (Applies)

3501-15,000 gal: 5 feet (Applies)

Walls adjacent to the system constructed of combustible materials.

Sprinklered building or structure. 39.63-3500 gal: 50 feet (34 ft) (N/A) 3501-15,000 gal: 50 feet (34 ft) (N/A) Unsprinklered building or structure.

39.63-3500 gal: 50 ft (34 ft) (N/A)

3501-15,000 gal: 75 ft (50 ft) (N/A)

Wall Openings

Openable (doors, vents)

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39.63-3500 gal: 75 ft (N/A) 3501-15,000 gal: 75 ft (N/A)

Unopenable

39.63-3500 gal: 25 ft (N/A) 3501-15,000 gal: 50 ft (N/A)

There are no wall openings in the structure (assembly of shielding blocks) that are within 75 feet face any building/structure. The nearby building structure wall openings (doors) are completely line-of-sight shielded from the liquefied hydrogen storage containers and 32 ft (man door) and 28 ft (rollup door) away from the nearest LH_2 storage/delivery point as-the-crow-flies. The positive position layout argument made here is one of shield block (blockhouse) containment.

iii Air Compressor intakes or inlets for air conditioning or ventilating equipment.

39.63-3500 gal: 75 feet (N/A)

3501-15,000 gal: 75 feet (N/A)

A survey will be made and any offending intakes or inlets in adjacent building walls will be closed if inactive or relocated if active.

iv All classes of flammable and combustible liquids (above ground and vent or fill openings if below ground)(see 3-1.3)

39.63-3500 gal: 50 ft (34 ft) (N/A) 3501-15,000 gal: 75 ft (50 ft) (N/A) *There are no, or will be no, flammable and combustible liquids within these limits.*

- v Between stationary liquefied hydrogen containers 39.63-3500 gal: 5 feet (Applies) 3500-15,000 gal: 5 feet (Applies)
- vi Flammable gas storage other than hydrogen 39.63-3500 gal: 50 feet (34 ft) (N/A) 3501-15,000 gal: 75 feet (50 ft) ((N/A)
- vii Liquid Oxygen and other oxidizers (see 3-1.3)
 39.63-3500 gal: 75 feet (50 ft) (N/A)
 3501-15,000 gal: 75 feet (50 ft) ((N/A)
 There are no Oxygen or other oxidizers within these limits.
- viii Combustible solids 39.63-3500 gal: 50 feet (34 ft) (N/A)

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3501-15,000 gal: 75 feet (50 ft) ((N/A)

No combustibles are located within the liquefied hydrogen storage structure (the shielding block, i.e., "blockhouse", assembly). Exposed combustibles (e.g., experimenters trailer) within the specified distance limit can be removed. There is (or can be) no line-of sight to the electrical cables run high and outside on the adjacent building wall, but they are within ca. 25 ft at the closest point of the 14,000 gallon dewar. The blockhouse position argues separation through the interposed shield block walls.

- Open flames and welding 39.63-3500 gal: 75 feet (N/A) 3501-15,000 gal: 75 feet ((N/A) There will be no open flames or welding within the specified distance limit.
- x Places of public assembly

ix

39.63-3500 gal: 75 feet (N/A) 3501-15,000 gal: 75 feet (N/A) *There will be no places of public assembly within the specified distance limit.*

- xi Public ways, railroads and property lines 39.63-3500 gal: 25 feet (16.7 ft) (N/A) 3501-15,000 gal: 50 feet (34 ft) ((N/A) There will be no places of public ways, railroads and property lines within the specified distance limit.
- xii Inlet to ground sewers 39.63-3500 gal: 5 feet (N/A)

3501-15,000 gal: 5 feet ((N/A)

There are, will be, no inlet to ground sewers within the specified distance limit.

- 3.2.3 Unloading connections on delivery equipment shall not be positioned closer to any of the exposures cited in the Table 3-2.2 than the distances given for the storage system. See 3-2.2, 2 and 8.
- 3.2.4 The minimum distance of the fill container connections from parked vehicles shall be 25 ft. Full Compliance
- 3.3 Handling of Liquefied Hydrogen Inside Buildings Other Than Separate Buildings and Special Rooms.

The listed items (a) through (h) do not apply. All liquefied hydrogen containers and lines are outside.

- 4 Design Considerations at Specific Locations
 - 4.1 Outdoor Locations
 - 4.1.1 Roadways and Yard surfaces located below liquefied hydrogen piping as well as areas under fill connections and delivery vehicles uninsulated hydrogen piping (vaporizer) from which liquid air can drip shall be constructed of noncombustible materials. For the purposes of this standard, asphalt and bitumastic paving shall be considered combustible. If expansion joints are used, fillers also shall be of noncombustible materials.

Full Compliance

4.1.2 If walls, roofs, weather shelters, or canopies are provided, they shall be constructed of noncombustible or limited combustible materials.

Full Compliance

- 4.1.3 Electrical wiring and equipment shall comply to Section 2-7. Full Compliance
- 4.1.4 Lighting shall be provided for nighttime transfer operation.
- 4.2 Separate Buildings There are no separate buildings containing liquefied hydrogen.
- 4.3 Special Rooms

There are no special rooms containing liquefied hydrogen.

- 5 Operation
 - 5.1 Operating Instructions
 - 5.1.1 For installations that require any operation of equipment by the user, instructions shall be maintained at operating locations. Full compliance.
 - 5.2 Qualification of personnel
 - 5.2.1 A qualified person shall be in attendance at all times while the mobile supply is being unloaded. Full compliance.
 - 5.3 Securing Equipment
 - 5.3.1 Each mobile liquefied hydrogen supply unit used as part of as hydrogen system shall be secured to prevent movement. Full compliance.

5.4 Grounding

- 5.4.1 The mobile liquefied hydrogen supply unit shall be grounded. Full compliance.
- 6 Maintenance
 - 6.1 Inspection
 - 6.1.1 Each liquefied hydrogen system installed on consumer premises shall be inspected annually and maintained by a qualified representative of the equipment owner. Full compliance.
 - 6.2 Clearance to Combustibles
 - 6.2.1 Weeds or similar combustibles shall not be permitted within 15 ft of any liquefied hydrogen equipment. Full compliance.
- 7 Fire Protection
 - 7.1 7-1 Cautionary Information
 - 7.1.1 Personnel shall be cautioned that hydrogen flames are practically invisible. Full compliance.
- 8 Referenced Publications
 - 8.1.1 See original text. Not a part of the requirements of this NFPA document.

Appendix A Explanatory Material

See original text. Not a part of the requirements of this NFPA document.

Appendix B Physical Properties of liquefied Hydrogen See original text. Not a part of the requirements of this NFPA document.

Appendix C Referenced Publications See original text. A list of referenced materials.

Formal Interpretation *See original text*.

<u>CGA G-5.4-2001, Standard for Hydrogen Piping Systems at Consumer Locations,</u> 2nd Edition

Design Comment by section and as appropriate follows. Note that though the original text may be truncated below for readability, the full meaning of the original applies.

- 1 Introduction
- 2 Scope
- 3 Properties of Hydrogen
 - 3.1 Flammability
 - 3.2 Temperature Impact
 - 3.3 Diffusion
 - 3.4 Asphyxiant
 - 3.5 Liquid hydrogen
 - 3.6 Embrittlement
- 4 Piping System Criteria: Full Compliance
 - 4.1 General
 - 4.2 Piping materials
 - 4.3 System components
 - 4.4 Electrical equipment
- 5 Cleaning: Full Compliance
 - 5.1 General
 - 5.2 Cleaning Procedure
 - 5.3 Inspection tests for cleanliness requirements
- 6 Installation: Full Compliance
 - 6.1 General
 - 6.2 Aboveground installation
 - 6.3 Underground installation

Specifically not allowed for liquid hydrogen piping.

- 6.4 Electrical Installation:
- 6.5 Electrical grounding and bonding
- 7 System start-up: Full Compliance
 - 7.1 Inspection
 - 7.2 Testing
 - 7.3 Purging
 - 7.4 Operation
- 8 Maintenance and repair: Full Compliance
 - 8.1 Inspection
 - 8.2 Grounding system

- 8.3 Maintenance
- 8.4 Records

CGA G-5.5-1996, Hydrogen Vent Systems, 1st Edition.

Design Comment by section and as appropriate follows. Note that though the original text may be truncated below for readability, the full meaning of the original applies.

- 1 Introduction
- 2 Definitions
- 3 Properties of hydrogen
- 4 General considerations: (Full Compliance)
 - 4.1 Vent system design: Full compliance
 - 4.2 Operational venting
 - 4.3 Emergency venting
 - 4.4 Mechanical considerations
 - 4.5 Fire considerations
 - 4.6 Deflagration/detonation considerations
- 5 Design: (Full Compliance)
 - 5.1 Codes
 - 5.2 Sizing
 - 5.3 Design considerations
 - 5.4 Design

6

- 5.5 Materials
- 5.6 System Components
- Installation: (Full Compliance)
 - 6.1 Installation supervision
 - 6.2 Inspected tested to the code
 - 6.3 Siting requirements
 - 6.4 Piping joints
 - 6.5 Vent piping joints
 - 6.6 Threaded joints
 - 6.7 Brazed connections
 - 6.8 Mechanical fittings
 - 6.9 Mechanical joint conductivity
 - 6.10 Mechanical joint location
 - 6.11 Mechanical joint electrical conductivity
 - 6.12 Uninsulated piping
 - 6.13 Vent pressure test
- 7 Operation: (Full Compliance)
 - 7.1 Manual venting

- 7.2 Knowledgeable operators
- 7.3 Vent system visual inspection
- 7.4 Vent rates
- 7.5 Venting cold gas
- 7.6 Vaporize before venting
- 8 Maintenance: (Full Compliance)
 - 8.1 Personnel protective equipment
 - 8.2 Visual Inspection
 - 8.3 Physical inspection
 - 8.4 Field repairs
- 9 References:

Figure

Figure 1

Secondary References, cited in the primary references

Secondary Reference 7

CFR 1910.103, Hydrogen, current

Cited as a reference in references 5 and 6, see Identified References presented earlier.

CFR 1910.103 provides a slightly different view of storage siting than is available 50 B, but makes no requirements beyond, i.e., more demanding than, NFPA 50 B that I can find.

Secondary Reference 8

API Recommended Practice 521, Guide for Pressure-Relieving and Depressuring Systems, 4th Edition, March 1997.

Cited as a reference in reference 6, see Identified References presented earlier.

The Scope of RP521 states, "This recommended practice is applicable to pressure relieving and vapor depressuring systems." As such it deals with vent and flare stacks for those circumstances and generally assumes that the effluent is a hydrocarbon.

Both pressure relieving and vapor depressuring are binary, on-off, flow actions with relatively narrow (4:1) flow ranges. In the E951 flammable gas venting case the flow peaks when the magnet is pulsed and decays exponentially to a minimum flow ca. 30/1.6 = 18.8 times smaller.

The RP521 high discharge velocity vent sizing approach¹, however, is in conflict with the reference 6, CGA G-5.5-1996, Hydrogen Vent Systems, L/D < 60 vent stack sizing for long stacks to minimize the possibility of stack deflagration and detonation². The 63' vent stack³ proposed details provided elsewhere, would follow the CGA G-5.5 recommendation until the issue can be studied in greater depth.

¹ High velocities enhance air mixing and reduce the plume length necessary to reach the lower flammability limits.

² See CGA G-5.5, Section 5.3 Design Considerations.

³ Necessary to accommodate the 58" adjacent building roof height.

Appendix 1.

Major Interlocks

It is anticipated that the ODH matters to include those interlocks will discussed separately.

It is anticipated that reporting fire alarms and hydrogen and motion detectors will monitor the balance of the experimental area. A hood assisted hydrogen detector should be located at two locations: 1). Above and covering the business end of the liquid hydrogen dewar (to 14,000 gallons) and 2). above and covering the Circulator HE (to 200 gallons), the only two places of significant quantities of liquid hydrogen.

The source dewars should be isolated, the air removed from the actuators of the normally closed liquid nitrogen (RV602) and liquid hydrogen (RV502) dewar valves and an auto dialer inform the necessary authorities immediately if any of the following occur:

1). Any Panic button pushed (buttons locations TBD).

2). Any area Fire Alarm or that of an adjacent area.

3). Any Cryogen level above the alarm condition.

4). Any vessel pressure above the alarm condition.

5). Any measured temperature above the alarm condition.

6). Any process pressure above or below the alarm condition.

7). To include such other interlocks as may be required/specified by the reviewing committees.

The system will be designed and constructed to fail safe in the case of utility failure and that provision fully tested. The appropriate system and on-call responses will be discussed with the experimenters and the appropriate laboratory designees in the case of each possible utility failure, and a response plan created and implemented.

