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FIRE PROTECTION ENGINEERING SERVICES

REPORT ON FUME HOOD EXHAUST SYSTEM GASKETS

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1.0 Background

1.1 General

Lawrence Livermore National Laboratory (LLNL), in response to clarification requests from the Department of Energy (DOE), has contracted Hughes Associates Inc (HAI) to provide an evaluation of the survivability of several laboratory fume hood exhaust system components, when exposed to elevated temperatures due to fire. This report is neither a full code evaluation report nor quantitative assessment of performance, but instead provides a professional opinion as to the expected performance under the stated operating conditions.

Work process materials from fume hoods in several laboratories are exhausted from the labs, through a ducted system in the 'loft' area (essentially, a mezzanine above the labs), and out of the building through housekeeping High-Efficiency Particulate Air (HEPA) filters located shortly after the duct penetrations into the loft and final stage HEPA filters that are remote from the penetration locations. The ducting system is primarily welded stainless steel and carbon steel; however, several locations contain fittings with neoprene, silicone, or Viton gaskets. This report focuses on the more limiting gasket material (neoprene and Viton). The use of a polymer based gasketing material has led the DOE to question whether the ducts will be able to maintain structural integrity during a fire.

The laboratory locations of concern are the fume hood exhaust ducts from rooms 1378, 1330, and 1322 in Building 332. LLNL has provided the following drawings to assist in the analysis:

- Drawing PLM 66-332-001D0B: Fume Hood Installation, Building 171, Room 1378, Revised 10/28/1967
- Drawing PLM 69-332-005D: Sample Preparation Room, Building 332, Room 1330A, Dated 08/28/1969
- Unknown Drawing #: Building 332 0 Ventilation: Upgrade Ventilation System, Fan Loft Floor Plan, Dated 06/21/1976
- Drawing PLM77-332-024E-0: Plutonium Metallurgy Building 332 Modifications, Building 332, Revised 01/1981

1.2 Operating Conditions

The B332 Documented Safety Analyses (DSA) describes the evaluation basis room fire based on a one hour fire severity event (with a maximum temperature of 1500 °F). For the purpose of this assessment, it is assumed the gaskets are conservatively exposed to this elevated temperature for the entire duration.

The exhaust system capacity is 32,000 cfm. The nominal pressure differentials maintained in the system are as follows:

- Ducts with respect to Loft Space: -1.5 in. w.g.
- Lab Rooms with respect to corridor: -.05 in. w.g
- Corridor with respect to atmosphere: -0.15 in. w.g

1.3 Mechanical Components

There are two types of gasketed fittings. The first is a bolted, flanged connection, with a neoprene gasket seal. The gasket thickness is 1/8" (drawing 332-001D-B), and LLNL has estimated the hydraulic diameter of the gasket to be ¼ in^2. The second is a butt connection. In this fitting, the ducts are joined by a Viton wrap. To secure the gasket, the Viton has been wrapped with a stainless steel band, which is clamped down by adjustable steel tie-down bands. LLNL stated that firestopping (via fire caulking) has been applied to these connections. The butt connections exist at the exit and entrance to the HEPA filters. Flanged connections are elsewhere.

The penetration of the loft floor slab has been sealed with cement grout, and it appears this penetration will survive the 1-hour fire. The loft slab thickness is 10.5".

The exhaust system from all three rooms (1330, 1322, and 1378) is provided with in-duct sprinklers. For the purpose of this evaluation and for conservatism, they were assumed to have no bearing on the assumed temperatures within the ducts and thus gasket performance. It was further assumed that these sprinklers are being properly maintained in accordance with the applicable Codes and Standards.

The ductwork is generally 16 gauge steel, per drawing 332-001D-B. LLNL notes there are a few sections of the ductwork for rooms 1322 and 1330 that are 18 gauge steel. Two sections of carbon steel pipe exist, coated with bisonite for corrosion resistance, with these sections originating from Room 1378. The frame thickness for the housekeeping HEPA filters is 14 gauge steel. The ductwork and HEPA filters for all rooms are braced by a metal framing system (not fire resistance protected) independently connected to the floor slab.

2.0 Historical Context

LLNL has stated that Increment 1 of the facility was operational in 1961. Given this, HAI conducted a review of pertinent documents from the time, which could have guided original design and construction requirements related to fume hood exhaust systems. This includes historical research documents indicative of typical practices as well as possible code requirements.

2.1 Typical Practice

There was no specific design guidance at the time related to the materials used in the exhaust system design. Industry reports, however, indicate that neoprene was commonly used as gasket material for ventilation ducting, and the use of it would have been in accordance with typical practices. No references to Viton were made in any of the reviewed documents.

See references (1), (2), and (3).

2.2 Code Requirements

The code search was limited to documents and guidance published prior to 1985. Documents reviewed after the operational date of 1961 were reviewed for completeness, but would not have had a bearing on the design and construction of the facility. No references were made to Viton in any of the reviewed documents.

2.2.1 NFPA

No NFPA document appears to specifically address the use of combustible materials for items such as gaskets or joints. Generally, they address the use of noncombustible materials, however, DOE Reports (such as those referenced above), suggest that strict adherence to these documents was not always warranted for DOE facilities owing to their unique operations and building configurations.

2.2.1.1 NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals (1975 and 1982 Editions) (4) (5)

The first edition of NFPA 45 did not appear until 1975, well after the facility had been constructed. Neither edition requires specific materials to be used in fume hood exhaust design. Instead, the requirements point to NFPA 91 (1982 Edition, Section 6-2.1), and have generic requirements (e.g. ducts must be noncombustible except for specific conditions, and must have strength and rigidity to meet service conditions). No temperature ratings are mentioned.

2.2.1.2 NFPA 91: Standard for the Installation of Blower and Exhaust Systems for Dust, Stock, and Vapor Removal or Conveying (1949 and 1973 Editions) (6) (7)

The 1949 Edition does not include requirements or specifications of duct materials other than they must be noncombustible. Gaskets, connectors, and other items are not discussed. Note that there was a 1961 Edition, although it was only an editorial revision of the 1949 Edition (according to the code history contained in the 1973 Edition). The 1973 Edition contains no pertinent changes, revisions, or additions relative to this evaluation.

2.2.1.3 NFPA 801: Recommended Fire Protection Practice for Facilities handling Radioactive Materials (1955 and 1970 Edition) (8) (9)

Neither edition contains requirements for ventilation systems, other than recommending non combustible construction.

2.2.2 DOE Guidance Documents

As far as can be determined, the department of Energy did not begin publishing specific complex-wide criteria for ventilation/exhaust design until 1970. The following DOE documents, though not valid during the time of construction, are presented for clarity.

2.2.2.1 ORNL/NSCI-65: Design, Construction, and Testing for High Efficiency Air Filtration Systems for Nuclear Application (1970, 1976) (10) (11)

The 1976 Edition was reviewed, in which the title was changed to ERDA 76-21, *Nuclear Air Cleaning Handbook: Design Construction, and Testing for High Efficiency Air Cleaning System for Nuclear Application* (12). Gaskets are not recommended for all cases, but are recommended for some specific limited cases.

The section regarding fume hoods (Chapter 6, page 146), states that “bolted, gasketed joints…are recommended”; however, no gasket specifications are provided. Other portions of the document recommend ¼ inch-thick gaskets made from ASTM D1056 Grade SCE 43, closed-cell neoprene sponge (pg. 45). A cursory review indicates that ASTM D1056 was not published until 1968, and thus would not be applicable for the original design.

2.2.2.2 DOE Order 6430.1, General Design Criteria Manual (December, 1983) (13)

No specific requirements are provided for materials in ventilation or exhaust systems. Chapter XVII, Section 5.a, provides general guidelines to ensure designs consider the operating environment (e.g., temperature, pressure, vapor chemical makeup, etc.).

3.0 Industry Fire Tests

Industry tests may be indicative of both anticipated conditions and potential performance of a duct component (e.g., gasketed flange, valve) during a fire. The American Petroleum Institute (API) has fire exposure test methods for pipe and duct components. API 6FB, *Specification for Fire Test for End Connections* (1st Edition, May 1, 1985) (14), contains the most relevant test. The test conditions are meant to represent fire exposure conditions in an onshore or open offshore location in the petroleum industry.

The test mandates direct flame exposure on the component for 30 minutes, with average temperature readings within 1400 °F to 1800 °F. In light of the 1-hour, 1500-°F operating condition identified by LLNL, the API test provides comparable conditions. Note, however, that the LLNL exhaust system is negatively pressurized and is exhausting gaseous materials, whereas the conditions for the API 6FB test require a positively pressurized test assembly. As a result, the specific test pass/fail leakage requirements are not applicable to the conditions of the fume hood ductwork.

API Bulletin 6F1, *Performance of API and ANSI End Connections in a Fire Test According to API specification 6FB* (November 1, 1987) (15), tested a variety of gasketed flanges to API 6FB. Table 1.2 of that document shows that all fittings tested contained metallic gaskets (carbon steel, stainless steel, and soft iron), which is indicative of the types of materials required to pass the test. Although not directly pertinent to the investigation, the report notes that at such high temperature, the bolts will expand at such high temperatures. API Bulletin 6F2, *Fire Resistance Improvements of API Flanges, Third Edition, 1999* (18), indicates that bolt expansion may cause leakage if the expansion coefficients of the bolts and bodies are mismatched. Additionally, bolt torque is indicated as a contributing factor in controlling leakage (Section B.3). Appendix D of API 6F2 indicates that specifications for materials in flanges should consider material property changes at elevated temperatures. That appendix shows that low alloy steels can withstand temperatures of up to 800 °F; capabilities of polymeric materials are not listed, however.

The only other fire exposure test located is that performed the manufacturer Swagelok *(Test SEI-00334)*. This test was created to address uneven heating of a valve during fire exposure, leading to a partially failed valve seat. The valve is exposed to direct flame impingement, which is not an anticipated condition for the LLNL fume hoods; however, additional details or specific test procedures could not be located.

4.0 Gasket Performance

The response of polymeric materials to elevated temperatures was investigated to determine if maintaining structural integrity is possible. Test and construction standards followed by anticipated material performance are presented.

4.1 Gasket Material & Fitting Construction Standards & Tests

The following documents outline current test procedures and requirements for elastomeric materials. All tests specified are small-scale and, thus, provide only an indication of potential material performance range; no consideration is given to performance in the end-use application of the material.

4.1.1 ASTM F495: Test Method for Weight Loss of Gasket Materials Upon Exposures to Elevated Temperatures (18)

The test is intended to determine gasket material weight loss following temperature exposures between 600-1500 °F. No pass/fail requirements are given.

4.1.2 ASTM D6909: Standard Specification for High Temperature and Acid-Resistant Fluorocarbon Terpolymer Elastomer (19)

The evaluation considers fluorocarbon terpolymer elastomers used in expansion joints in high temperature industrial applications, where corrosive flue gases are present. Material samples are exposed to air oven aging at 500 °F, and post-exposure material properties are recorded (weight change, hardness, tensile strength, elongation).

4.1.3 ASTM C1166-06: Standard Test Method for Flame Propagation of Dense and Cellular Elastomeric Gaskets and Accessories (20)

For this standard, a material sample of fixed size (1 in. x 18 in.) is exposed to a controlled flame from a burner. The length of the flame is measured to provide a numerical value for flame propagation.

4.1.4 ASTM C864: Standard Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers (21)

This is a specification standard that is referenced in ASTM C1166-06. It contains material property requirements, with the only direct-fire related requirement that of the flame propagation test in ASTM C1166-06.

4.1.5 ASTM C509-00: Specification for Elastomeric Preformed Gasket and Sealing Material (22)

Specifies physical and dimensional properties of gasket materials. Flame propagation test is required (per ASTM C1166).

4.1.6 UL 157: Gaskets and Seals (23)

This test standard specifies material properties based on application environment. The maximum end use temperature specified by the standard is 482 °F, indicating the upper limits of elastomeric gaskets covered by this standard. Standard assumes that re-evaluation of performance must take place in the intended end-use configuration.

4.1.7 ANSI B16.5:1996: Pipe Flanges and Flanged Fittings (24)

ANSI B16.5 provides construction specification which outlines temperature and pressure ratings for fittings. Maximum possible temperature rating in the standard is 1000 °F.

4.1.8 ANSI B16.21: 2005: Nonmetallic Flat Gaskets for Pipe Flanges (25)

Construction specification which contains only dimensional requirements for gaskets. No specific temperature-sensitive or material requirements except that material selection shall be compatible with the fluid and suitable for the pressure-temperature conditions of the service.

4.2 Anticipated Gasket Performance

Based on discussion with industry experts within HAI, it was estimated that Neoprene typically fails around 400-500°F. Viton, a fluoropolymer, has a higher temperature resistance of up to approximately 700 °F.

These numbers are generally supported by those published for Neoprene in the *Ignition Handbook* (16)*:*

- Chapter 13, Table 5 – Autoignition Temperature – 306-317°C (582-602°F) @ 1 atm, 100% Oxygen (NASA Tests, appears to be for cable)
- Chapter 15, Table 15 – Autoignition Temperature – 307-390° (584-734 °F)

The above represent the material autoignition temperature, the temperature at which the material will spontaneously-ignite without an external ignition source. The typical service temperature range is -50 to +250 °F (17).

While it is clear that the assumed operating temperature of 1500 °F at the fittings exceeds the material limitations of the Neoprene and Viton gaskets, the manner in which the failure occurs could affect whether or not structural integrity is maintained. It is the opinion of HAI that, upon exposure to high temperatures, the gaskets will begin to char. For the flanges, this will first occur on the inside surface of the duct; for the butt joints adjacent to the housekeeping HEPA filters, the charring is expected along the exposed inner surface of the gasket. During the predicted 1-hour fire exposure, the flanges and the duct near the butt joints will asymptotically approach the localized temperature of the air within the duct, which decreases with distance from the fume hood, owing to heat transfer from the ducts to the surroundings. As a result, eventually the entire gasket will char. Whether or not the gaskets will stay in place or will become friable and be drawn into the duct after charring was not investigated; however, with the duct at negative pressure relative to the loft area, HAI anticipates partial to full removal of the gasket material.

HAI also notes that material properties of polymers generally decrease with age. The specific compound and manufacturer of the gaskets is unknown, and therefore any reduction in performance since the 1961 operational date does not have any basis for comparison.

Based on the above discussion, HAI has concluded that during an evaluation basis room fire, gaskets will be exposed to conditions outside their typical operating service range, and thus anticipates that the gaskets will fail. Whether structural integrity is maintained depends on additional definition of structural integrity and further analysis. Note that the 2012 International Building Code (IBC) (28), Section 717.5.2, does not require additional protection for ductwork penetrating 1-hr fire-resistance-rated fire barriers (i.e., no fire/smoke dampers are required for ducts in such assemblies); this implies that such ductwork would survive typical exposures for the duration of the fire anticipated by LLNL proximate to the fume hood in the laboratory. This consideration is further supported by NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems* (29), Section 5.3.3.1, and NFPA 91, *Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies* (30), Sections 4.1.12 and 4.1.13.

5.0 Current Practices in Duct & Ventilation System Design

In addition to component level material construction practices and limitations, HAI has investigated current practices for overall duct and ventilation system design, in an effort to provide guidance as to expected system construction.

5.1 California Mechanical Code (CMC)

The CMC (26) contains requirements for construction of exhaust and duct systems. Chapter 5, Exhaust Systems, Section 506.1, states that product-conveying duct systems "shall be of metal". One exception is for Class 5 systems (those conveying corrosives, such as acid vapors), where approved nonmetallic materials make a non-metal construction unsuitable. In this case, the material must possess a flame-spread index of less than 25 and a smoke-developed rating of less than 50, or flame-spread index of less than 25 and an automatic fire-sprinkler system inside the duct. HAI visually verified that sprinklers are present in ducts coming from Rooms 1330, 1322, and 1378. Neither the flame spread index of the gasket materials was able to be confirmed, nor were the contents of the products being conveyed. Although not directly applicable to the region in question, Section 510.3 does require gaskets and sealant for access panels to be rated for 1,500 °F.

Chapter 6, Duct System, Section 602.2, stipulates that exposed materials within ducts shall be noncombustible, or meet the same flame spread and smoke-developing rates as mentioned in section 506.1.

Chapter 13 contains design requirements for ductwork for fuel gas piping. In this application, Section 1309.5.10 states flange gasket materials shall be capable of withstanding design temperatures of the piping system. Acceptable materials mentioned includes primarily references to metallic materials, including aluminum, spiral wound metal, bronze, and cast iron.

5.2 ASHRAE Handbook

The ASHRAE Applications Handbook (27) contains a chapter on laboratory ventilation practices. It is the responsibility of the HVAC engineer to specify appropriate duct materials (pg. 14.11). This includes consideration of the materials flame spread and smoke production ratings.

The document also alludes to the use of neoprene in defining ‘radio isotope fume hoods’. It states as follows:

> *… ductwork should have flanged neoprene gasketed joints with quick disconnect fasteners that can be readily dismantled for decontamination. High Efficiency particulate air (HEPA) and/or charcoal filters may be needed in the exhaust duct.* (ASHRAE Applications Handbook)

Current duct and ventilation design recommendations generally specify noncombustible duct construction. If noncombustible materials are used, the engineer in charge is responsible for selecting materials that meet minimum flame spread and smoke production requirements. In the LLNL exhaust system layout, the specific flame spread properties of the neoprene and the Viton are unknown.

6.0 Conclusions

HAI has evaluated the ability of both neoprene and Viton gasketed joints to withstand thermal insult conditions of 1500 °F for a 1-hour severity room fire for the LLNL fume hood exhaust duct systems for Rooms 1322, 1330, and 1378.

HAI has concluded that, historically speaking, this design was consistent with typical practices of the day. There were minimal authoritative design documents prior to the operational date of 1961, and it has been found that the use of neoprene in other similar fume hood installations was common and expected. Code requirements developed after the facility was built and operated generally recommend noncombustible duct construction.

Several performance tests exist for fire exposure of flanged end connections. The exposure duration of the API 6FA test is 1400-1800 °F for 30 minutes, which is clearly much more severe than the fire exposure in these rooms.

HAI anticipates that the neoprene and Viton gaskets will fail when exposed to the 1500 °F evaluation basis room fire described in the B332 DSA. Although the manufacturer and compound of both gasket material is unknown, recognized material test standards (such as from ASTM and UL) suggest that the limitations of these materials is much less than 1500 °F. Furthermore, the auto-ignition temperature of neoprene is substantially lower than 1500 °F. The gaskets will mostly likely char prior to failure, and whether they stay in place or fall out of place is unknown. HAI recommends assuming that all failed gaskets fall out of place (i.e. by being drawn into the duct).

Current ventilation design practices, such as those detailed by the California Mechanical Code and the ASHRAE handbook, recommend noncombustible exhaust duct construction. In the event noncombustible parts are used, consideration should be given to flame spread and smoke production parameters. HAI could not confirm these properties for the gaskets in question.

Although HAI believes the gaskets will ultimately fail, the determination as to whether structural integrity is maintained depends on the precise definition of the phrase. If the objective is containment of the gases within the duct, it is the opinion of HAI that this is still plausible with failed gaskets based on the following:

- The number of gaskets is limited and the assumed hydraulic diameter of each gasket is only ¼ in^2.
- The duct is maintained at -1.5 in. w.g. with respect to the loft. It can be expected that loft air is drawn into the duct if/when the gaskets fail, thus containing exhaust gases.
- The support system for the ducts, gaskets, and HEPA filters appears to be rigid. HAI does not anticipate bracing failure, thus limiting the amount of physical joint separation that occurs (i.e. fittings are expected to be maintained in place).

HAI suggests further evaluation be conducted to verify that structural integrity is maintained. Possible solutions include:

1. Evaluation of combustible loading in laboratories. This could provide a more realistic approximation of the probable temperature rise within the labs and the exhaust duct systems.
2. The current assumption of 1500 °F for 1 hour is a very severe fire. HAI performed CFD fire modeling for Los Alamos and documented fires that were ventilation controlled verses fuel controlled. A significantly reduced time-temperature curve was documented for identified rooms within a proposed new laboratory complex.
3. Computer fire modeling to determine temperature at gaskets. Heat loss occurs as air migrates from the fire origin to the gasket locations. CFD modeling accounts for factors such as air entrainment and heat losses due to conduction and convection to provide an accurate representation of the temperature at the gasket locations.
4. Review the FLUENT model. LLNL has mentioned a FLUENT airflow model, which could potentially incorporate the loss of the gaskets to determine if structural integrity is maintained.
5. Apply an external solution to maintain structural integrity of the gaskets. This could include a variety of solutions such as wrapping the ducts in ‘3M’ wrap, or providing sealed stainless steel bands with fire caulking over the flanges to prevent leaks if a gasket fails. This would require special attention be made to the design and installation to ensure a leak-free solution.

If there are any questions or comments regarding this report, please direct them to the undersigned.

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