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Lawrence Livermore Laboratory

HIGH-PRESSURE SAFETY AT THE LAWRENCE LIVERMORE LABORATORY,
AN ENERGY RESEARCH FACILITY

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MASTER

HIGH-PRESSURE SAFETY AT THE LAWRENCE LIVERMORE LABORATORY,
AN ENERGY RESEARCH FACILITY*

W. A. Burton

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ABSTRACT

The high-pressure safety program at Lawrence Livermore Laboratory, Livermore, California, has been successful in preventing lost-time high-pressure accidents over the past 12 years. Program organization, personnel training and qualification, pressure vessel design criteria and documentation, and pressure testing and inspection are discussed.

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INTRODUCTION

Lawrence Livermore Laboratory (LLL), formerly Lawrence Radiation Laboratory (LRL), is an Energy Research and Development Administration (ERDA) research facility of approximately 5500 employees located in Livermore, California, about 40 miles southeast of San Francisco. We are primarily involved in basic nuclear and energy research, peaceful uses of atomic energy, and the design and testing of atomic weapons for the defense of our country.

In 1964 our Director's Office, apprehensive about the amount of high-pressure work being done, appointed a technical advisor to establish and conduct a pressure safety program. Over 170 people are now directly involved in pressure safety at LLL, and we now have over 500 certified pressure vessels and systems that require periodic attention. This paper is a brief account of our pressure safety program, including organization, personnel training and qualification, design criteria and documentation, pressure testing, and vessel/system certification.

ORGANIZATION AND TRAINING

Our Laboratory is organized much like most fairly large industrial corporations. Our several departments are divided into divisions of one to three hundred employees, and we have smaller sections and groups in each division. Responsibility for pressure safety is vested in the Department

Head. Figure 1 shows the flow of this responsibility down through the Division Leader and authorized individual, to installers and installers-in-training.

An authorized individual is a senior professional person, usually of supervisory status, with a thorough background in mechanical design. He is required to complete a 14-hour pressure safety course, Pressure Seminar for Engineers, HS-506, before being appointed by his Department Head.

A responsible individual is a professional person (chemist or engineer) who is directly responsible for the design of a particular pressure vessel or system and for specifying its operational limitations. He, also, should have completed the Pressure Seminar for Engineers.

Figure 2 shows a technician or craftsman climbing the steps to become a pressure installer. In this position, he is authorized to work directly for a responsible individual in assembling or operating pressure systems and vessels. Until formally qualified, he is an installer-in-training and works closely with a fully qualified installer or inspector designated by his immediate supervisor.

You will notice that there are three steps to installer qualification.

- first, the candidate must complete Pressurized Gas Safety, HS-505, a 14-hour classroom training course.
- Second (or previously), he must have one year's equivalent of closely supervised experience with pressure equipment within the specific range of his tentative qualification. This must be certified by his immediate supervisor and by his Division Leader.

- And third, he must successfully complete a practical pressure installer test.

We have about 80 fully qualified pressure installers.

A limited number of senior technicians and crafts foremen go on to become qualified as pressure inspectors. They are authorized to inspect, pressure test and certify vessels and systems.

Every three years our pressure inspectors are required to attend a 6-hour re-qualification course. Pressure installers and authorized individuals are on a similar 4-year re-qualification schedule.

DESIGN CRITERIA AND DOCUMENTATION

All pressure vessels that are subject to periodic inspection by the State of California are ASME Code stamped, or are covered by a Special Permit to Operate. All other manned area vessels for gas pressures over 1 MPa (145 psi), liquid pressures over 10 MPa (1450 psi), or those containing over 100 kJ (75,000 ft-lb.) of isentropic energy are ASME or DOT stamped or are covered by a Safety Note.

A Safety Note is a document attesting that every practical precaution has been taken in the design of equipment to minimize all severe and unusual operational hazards. It contains a description of the vessel or system, a critical discussion of hazards, all pertinent calculations, directions for testing and labelling, and a complete list of associated procedures. Written by the responsible individual, it must be reviewed and approved by an authorized individual and be finally approved by the Division Leader. Appendix A is a sample safety note, for your reference.

Most manned area vessels for working pressures up to 170 MPa (25 ksi) are designed according to the ASME Code which requires a safety factor of 3 or 4 based on ultimate strength. However, the Code is not always applied to pressure vessels above 170 MPa because complying with these elastic safety factors frequently requires materials that have been heat-treated to such high strength that reliability is appreciably reduced because of low ductility and unacceptable fracture toughness.

Vessels with working pressures between 170 and 270 MPa (39 ksi) usually require the employment of design criteria based on a safety factor of 3 or 4 relative to vessel burst (elastic/plastic) rather than on ultimate strength (elastic).

Vessels for working pressures over 270 MPa are of tougher materials, and are designed to an elastic/plastic safety factor of 3 minimum. At these high pressures, special designs are often required. Vessel bodies that are autofrettaged or are built up of two or more interference-fit shells provide a more favorable stress distribution through the vessel wall. Without exception, the forgings for such vessels are subjected to extensive metallurgical testing.

Carefully prepared and reviewed safety notes and specifications, along with our intensive retest/reinspection program, assure that all non-code pressure vessels designed or used by LLL personnel are safe to operate within their prescribed limits.

PRESSURE TESTING

All pressure vessels for manned area operation are initially pressure tested at 150% of their Maximum Allowable Working Pressure (MAWP) except where analysis by the Maximum Energy of Distortion Theory indicates that combined stresses will theoretically yield the vessel at this test pressure. In this case, the test pressure is reduced to below yield, but never to less than 125% of the MAWP. Manned area pressure systems are tested at the maximum pressure available from their integral pressure sources. This test pressure must equal or exceed the MAWP of the system, and relief protection must be subsequently installed to prevent the operating pressure from ever exceeding the assigned MAWP.

Vessels and systems that are to be operated remotely (where failure could not cause injury) are tested at a pressure sufficiently above the MAWP to assure the functional reliability required.

Without exception, all vessels and systems are reinspected at least every 3 years. With few exceptions, all are retested every 6 years. Where retesting is completely impractical, thorough periodic inspection includes boroscope inspection and/or the application of NDT techniques such as radiography, ultrasonics, acoustic emission, and dye penetrant or magnetic particle examination.

Most pressure testing is conducted in our Mechanical Engineering Department High Pressure Laboratory. This unique facility contains remote test cells designed for hydrostatic, inert gas, and flammable gas testing. Equipment is also available for isostatic pressing to 1 GPa (145 ksi) and gas diffusion bonding to 350 MPa (50 ksi) at up to 1537°C (2800°F).

All pressure tests are conducted or observed by a Pressure Inspector who completes a test report and certifies the vessel or system with an LLL Pressure Tested label (Figure 3). The Lawrence Livermore Laboratory Pressure Inspector, who is assigned full-time to pressure safety work, conducts most of these tests and almost all of the pressure inspections.

Appendix B is an LLL Pressure Test Report form and Appendix C is an LLL Pressure Inspection form. The original copies of these completed forms are filed in the office of the High Pressure Advisor. About 30 days before a pressure vessel or system is due for retesting or reinspection, copies of all previous inspection and test reports are sent to the pressure inspector concerned. The pressure inspector then contacts the responsible individual and arranges for a mutually convenient time to conduct the required preventative maintenance. You will notice that the Pressure Inspection Record directs inspection in detail and the recording of all pertinent observations. A pressure vessel must be inspected both outside and inside, diameter measurements must be taken and compared with those of the original pressure test, and relief devices must be checked and reset if required. Any discrepancies noted are corrected before the required form is signed and returned for review and filing for future reference.

Where remote operation is specified, a Remote Operation Only label (Figure 4) is also affixed to the vessel or system.

The pressure safety program at LLL appears to have proved itself effective in that we have not had a lost-time high-pressure accident since

its inception over 12 years ago. Several other ERDA facilities, including Sandia Laboratories both in Livermore, Ca. and Albuquerque, N.M. and Mound Laboratories in Miamisburg, Ohio, have initiated similar pressure-safety programs with reportedly encouraging results.

APPENDIX A

LAWRENCE LIVERMORE LABORATORY - UNIVERSITY OF CALIFORNIA		FILE NO.	PAGE
ENGINEERING NOTE		ENW 75-999	1 OF 4
SUBJECT	MECHANICAL ENGINEERING SAFETY NOTE		NAME (RESPONSIBLE INDV.)
- PROGRAM 11.2 PRESSURE VESSELS		DATE	OCTOBER 19, 1975

A. DESCRIPTION - FOR THE NEXT 3 YEARS, I WILL BE BE OPERATING 2 TYPE 304 STAINLESS STEEL PRESSURE VESSELS, SERIAL NUMBERS AAA 75-1072 -0A-001 & -002, IN BLDG 231 FOR PROGRAM 11.2.

B. HAZARDS - THESE 50 cm³ VESSELS WILL BE PRESSURIZED AT UP TO 70 MPa OF HELIUM GAS AT ROOM TEMPERATURE UNDER MANHED-AREA OPERATING CONDITIONS. THE MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP) WILL BE 83 MPa.

THE ENERGY OF THE PRESSURIZED VESSEL, ASSUMING REVERSIBLE ADIABATIC (ISENTROPIC) EXPANSION OF THE COMPRESSED HELIUM GAS, PER MARKS' HANDBOOK, 1958 PAGE 4-23, IS :

$$U = \frac{P_1 V_1}{(\gamma - 1)} \left[1 - \left(\frac{P_2}{P_1} \right)^{\frac{(\gamma - 1)}{\gamma}} \right] \quad \text{WHERE: } \gamma = \frac{C_p}{C_v} \text{ FOR } H_2 = 1.68$$

$$P_1 = 83.1 \text{ MPa ABS}$$

$$P_2 = 0.1 \text{ MPa ABS}$$

$$V_1 = 50 \text{ cm}^3$$

$$U = \frac{83.1 \times 50}{1.68 - 1} \left[1 - \left(\frac{0.1}{83.1} \right)^{\frac{(1.68 - 1)}{1.68}} \right] = 6105 \text{ JOULES (4503 FT-LB)}$$

$$\text{WHICH IS EQUIVALENT TO } \frac{4.503 \times 456}{1.55 \times 10^6} = 1.3 \text{ GRAMS OF TNT.}$$

THESE VESSELS WILL BE RIGIDLY MOUNTED TO THE CONCRETE FLOOR WITH 1/8-INCH THICK BY 1-INCH WIDE STEEL BRACKETS AND ANCHORED 3/8-16 MACHINE SCREWS. THEY WILL BE CONNECTED TO THE PROGRAM 11.2 SYSTEM WITH SUPPORTED 1/4-INCH O.D. X 0.125-INCH I.D., 138 MPa WORKING PRESSURE STAINLESS STEEL TUBING PER ALL STANDARD SPECIFICATION MEL 681, USING HIGH PRESSURE CONED, TREADED FITTINGS RATED AT 207 MPa. AN 82 MPa RUPTURE DISC IN EACH VESSEL LINE PROVIDES THE REQUIRED OVERPRESSURE PROTECTION.

LAWRENCE LIVERMORE LABORATORY · UNIVERSITY OF CALIFORNIA ENGINEERING NOTE	FILE NO. ENW 75-999	PAGE 3 OF 4
SUBJECT MECHANICAL ENGINEERING SAFETY NOTE - PROGRAM 11.2 PRESSURE VESSELS -	NAME (RESPONSIBLE INDV.)	DATE OCTOBER 10, 1975

C. CALCULATIONS (CONTINUED) -

4. WELD DEPTH, PER ASME CODE SEC VIII DIV 1 FIG UG 34(g)

$$t_w = 2t, \text{ MIN NOR LESS THAN } 1.25t_s, \text{ BUT NEED NOT EXCEED } t$$

$$\text{OR } t_w = 2 \frac{54.38 - 25.90}{2} = 29 \text{ MM NOR } 1.25 \frac{57.00 - 25.90}{2} = 19.75 \text{ MM,}$$

BUT NEED NOT EXCEED $t = 22.23$, SO MAKE $t_w = 20.00 \text{ MM}$,
TO PROVIDE A 2.23 mm SHOULDER FOR LOCATING PLUG.

D. PRESSURE TESTING - THEY WILL BE PRESSURE TESTED AT 110 MPa, WHICH IS ABOUT 130 % OF THE 83 MPa MAWP. AS SHOWN BY THE FOLLOWING ANALYSIS, THEY WOULD YIELD AT 150% OF THE MAWP (N WOULD BE 0.9 AT 126 MPa). THIS "MAXIMUM ENERGY OF DISTORTION ENERGY" CALCULATION SHOWS THAT 110 MPa TEST PRESSURE IS THE HIGHEST ALLOWABLE.

$$N = \sigma_y / \sqrt{\frac{1}{2} [(s_1 - s_2)^2 + (s_1 - s_3)^2 + (s_2 - s_3)^2]} \dots \left[\text{SEELEY & SMITH ADVANCED MECHANICS OF MATERIALS PG 90, 84 (88)} \right]$$

$$\text{OR } N = \sigma_y / \sqrt{\frac{1}{2} [(s_1 - s_2)^2 + (s_2 - s_3)^2 + (s_3 - s_1)^2]}$$

WHERE: N = FACTOR OF SAFETY BASED ON THE YIELD STRENGTH; MUST BE AT LEAST 1.0

σ_y = YIELD STRENGTH OF MATL = 241.38 MPa

$$s_1 = \frac{P}{K(R-1)} = \frac{110}{1(5.036-1)} = 27.25 \text{ MPa}$$

$$s_2 = \frac{P}{K(R-1)} = \frac{110(5.036-1)}{1(5.036-1)} = 164.51 \text{ MPa}$$

$$s_3 = -P = -110.00 \text{ MPa}$$

ALL EQUATIONS FROM ASME CODE SECTION UA-2

$$N = 241.38 / \sqrt{\frac{1}{2} [(27.25 - 164.51)^2 + (164.51 + 110.00)^2 + (110.00 - 27.25)^2]}$$

$$N = 241.38 / \sqrt{\frac{1}{2} [113034]} = 241.38 / 237.73 = 1.02,$$

WHICH IS SLIGHTLY GREATER THAN 1.0, SO THEY WILL NOT QUITE YIELD AT $1.3 \times 83 = 110 \text{ MPa}$.

LAWRENCE LIVERMORE LABORATORY - UNIVERSITY OF CALIFORNIA		FILE NO.	PAGE
ENGINEERING NOTE		ENW 75-998	2044
SUBJECT	MECHANICAL ENGINEERING SAFETY NOTE		DATE
- PROGRAM 11.2 PRESSURE VESSELS		(RESPONSIBLE INDIV.)	OCTOBER 10, 1975

D. PRESSURE TESTING (CONTINUED) - THE LLL PRESSURE INSPECTOR WHO CONDUCTS THIS TEST WILL RECORD OUTSIDE MEASUREMENTS BEFORE AND AFTER TESTING.

E. LABELLING - THE LLL PRESSURE INSPECTOR WILL CERTIFY EACH VESSEL BY ATTACHING AN LLL PRESSURE TESTED LABEL THAT STATES:

ASSY. (SERIAL NUMBER)
 SAFETY NOTE ENW 75-999
 M.A.W.P. 83 MPa (12 ksi)
 FLUID INERT GAS
 TEMP. -20 TO +100 °C
 REMARKS TEST AT 110 MPa MAX.

F. ASSOCIATED PROCEDURES - M.E. SAFETY NOTE ENW 75-998 COVERS DESIGN OF THE PROGRAM 11.2 SYSTEM, OF WHICH THESE VESSELS ARE A PART. AN OPERATIONAL SAFETY PROCEDURE IS NOT REQUIRED.

PREPARED BY S/(RESPONSIBLE INDIV.)

DISTRIBUTION

(DEPARTMENT HEAD)
 (DIVISION LEADER)
 (PROJECT ENGINEER)
 (AUTHORIZED INDIVIDUAL)
 (RESPONSIBLE INDIVIDUAL)
 (OTHERS CONCERNED,
 INCLUDING BLDG COORDR.)

REVIEWED BY S/(AUTHORIZED IND.)

APPROVED BY S/(DIVISION LEADER)

LLL PRESSURE INSPECTOR L508

APPENDIX B

**Livermore Laboratory
PRESSURE TEST RECORD**

Test No. _____

Test Date _____

BASIC INFORMATION: Enter here and on LLL Pressure Tested label.

LLL PRESSURE TESTED	
ASSY.	_____
SAFETY NOTE _____	
M. A. W. P.	_____ (Per _____ KSI)
FLUID	_____
TEMP	_____ TO _____ °C
REMARKS _____	
TEST NO. _____	
BY _____	DATE _____

Location of vessel (or system): Bldg. _____ Rm. _____

Description: _____

← Leave room for reinspection and retest dates

TEST INFORMATION:

From Test Procedure:

1. Test pressure (maximum) : _____ MPa (_____ psig)
2. Testing fluid (oil, He, etc.) : _____
3. Test temperature : _____ °C (_____ °F)
4. Responsible Individual Name : _____
Dept. : _____
Divn. : _____

From Identification Label:

1. Welded by : _____ on _____
2. Installed by : _____ on _____

Additional Remarks: _____

CERTIFICATION:

The above vessel or system has been successfully pressure tested and labeled, and is herewith approved for operation in a _____ (manned or remote) area. If for remote operation, a Remote Operation Label has been affixed.

LLL PRESSURE INSPECTOR

Send this completed form to the High Pressure Advisor.

APPENDIX C

Lawrence Livermore Laboratory
PRESSURE INSPECTION RECORD

Test No. _____

Test Date _____

BASIC INFORMATION: Enter here and on original (or new) LLL Pressure Tested label. Verify that label information is complete.

LLL PRESSURE TESTED

ASSY. _____

SAFETY NOTE _____

M. A. W. P. _____ Pa (_____ KSI)

FLUID _____

TEMP _____ °C

REMARKS _____

TEST NO _____

BY _____ DATE _____

Location of vessel or system: Bldg. _____ Rm. _____

Is vessel or system still in use? Yes _____ No _____

if not in use, why not refer it to Bldg. 343 for disposition?_____

← Add: RT (for retested) or RI (for reinspected), and date. Example: RT 9/68

REINSPECTION INFORMATION:

Inspect the following points and check appropriate column, explaining as required: (Enter "NA" in remarks column if point is not applicable.)

1. General appearance of system (or vessel) _____
2. Relief devices are: a. Properly set (have them checked; reset as required) _____
 b. Properly sealed _____
 c. Pointed in safe direction _____
3. All fittings are tight, and not obviously over-tightened _____
4. All fittings, gauges, valves, (and piping*) are properly rated _____
5. All system components are secured per H & S supplement 32.05A _____
6. Valve packing nuts are tight, and locked (if locking type) _____
7. Oil is not apparent on or in gas (especially oxygen) systems* _____
8. The vessel diameters have not changed since the last pressure test.
 Measure, record (on back of this form), and check _____
9. The outside surface of the vessel shows no evidence of strain, damage, or corrosion _____
10. The inside surface of the vessel shows no evidence of strain, damage, or corrosion _____
11. Vessel or system seals are leak-tight. Have replaced as required. _____
12. The vessel or system appears to be safe for continuing its operation in a
 (manned or remote) area _____
13. Vessel or system was pressure tested within the last 6 years, or as required by the
 safety note. (If not, and certified for manned-area operation, retest it and submit
 a Pressure Test Record in place of this Pressure Inspection Record). _____

[illegible]

LLL PRESSURE INSPECTOR

CERTIFICATION:

As the professional person responsible for safe operation of this system (or vessel), I certify that, to the best of my knowledge, since last tested at L.L.L. this vessel (or system) has not been critically modified, has not been subjected to temperature or pressure cycling in excess of its design limitations, has not been subjected to temperatures or pressures in excess of those for which it is rated, that all applicable listed conditions are satisfactory, and that I consider this vessel or system safe for operation in a _____ (named or remote) area within the limitations of the L.L.L. Pressure Tested label above for _____ (three or less) more years as required by the safety note for this vessel or system.

RESPONSIBLE INDIVIDUAL

Dept. _____

Divn. _____

*Consider assurance by the Responsible Individual as satisfactory verification.

Send this completed form to the High Pressure Advisor.

FIGURE CAPTIONS

Fig. 1. Pressure safety responsibility.

Fig. 2. Pressure training at LLL.

Fig. 3. LLL Pressure Tested label (silver or black background);
1.5 $\times$ actual size.

Fig. 4. Remote Operation Only label (silver or red background);
1.5 $\times$ actual size.

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*This may be a professional person of equivalent responsibility designated by the Department Head.

**The High Pressure Technical Advisor is in an advisory position in relation to department pressure safety responsibility.

† Each LLL Pressure Installer is directly responsible to the Responsible Individual for whom he is working. An Installer-in-training is responsible, through his supervisor, to the Responsible Individual concerned.

†† Each LLL Pressure Inspector is directly responsible to the Authorized Individuals of his Department on matters of pressure safety.

Burton - Fig. 2

LLL PRESSURE TESTED	
ASSY.	
SAFETY NOTE	
M.A.W.P.	PSI (KSI)
FLUID	
TEMP	TO °C
REMARKS	
TEST NO.	
BY	DATE

Burton -- Fig. 3

FOR
REMOTE OPERATION
ONLY