Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER
UNCLASSIFIED	510374

TITLE

ACOUSTIC EMISSION INSPECTION OF COMPRESSED GAS CYLINDERS

System Number:

Patron Number:

Requester:

Notes: Paper #31 contained in Parent Sysnum #510343

DSIS Use only:

Deliver to: DK

Acoustic Emission Inspection of Compressed Gas Cylinders

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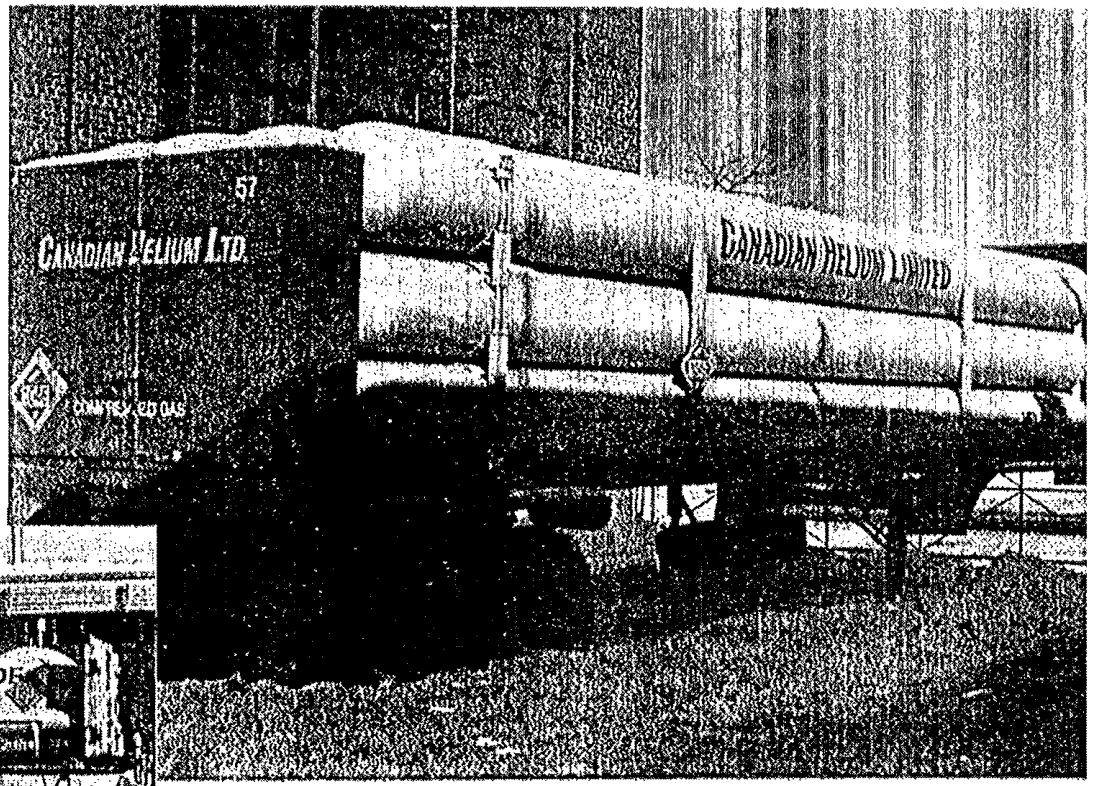
Tektrend International Ltd.

ABSTRACT

Cylinders used to store compressed gases ranging from air and natural gas to hydrogen and inert compositions must be tested periodically usually by a hydrostatic test. In addition to insensitivity of the hydrotest to small service-induced defects, this test involves removal of the vessel from service and contamination of the vessel interior with water. Results of a program that compared acoustic emission testing with the hydrotest will be discussed showing much higher defect sensitivity for acoustic emission. These results combined with the ability to monitor in situ with acoustic emission recommend the latter in a number of applications.

APPLICATIONS

JUMBO
12-TUBE TRAILER



STANDARD
32-TUBE TRAILER

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PROJECT OBJECTIVES

ENHANCED SAFETY

OF

TUBE TRAILERS

THROUGH MORE SENSITIVE AND DETAILED INSPECTION

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COMPRESSED GAS TRANSPORT

COMMONLY TRANSPORTED GASES:

- OXYGEN
- HYDROGEN
- HELIUM
- NITROGEN
- ARGON
- AIR

OTHER GASES:

- NEON
- KRYPTON
- XENON

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TUBE SPECIFICATIONS

STAINLESS STEEL TUBES
DESIGN AND MATERIALS STANDARDS

CANADA: CTC REGULATIONS
UNITED STATES: DOT REGULATIONS

ASME BOILER AND PRESSURE VESSEL CODE SECTION VIII, DIVISION I, CODE CASE 1205, SPECIAL RULING, INTEGRALLY FORCED VESSELS, SA-372, SECTION VIII.

- MATERIAL PROPERTIES
- WALL THICKNESS
- MODES OF TRANSPORTATION AND PACKAGING
- SERVICE PRESSURE AND FILLING LIMITS
- RETESTING AND REINSPECTION INTERVALS AND REQUIREMENTS

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MANDATORY REQUIREMENTS

At the time of manufacture a hydrostatic proof test must be performed. After this test, the cylindrical section of each seamless vessel must be examined using the ultrasonic angle beam technique in accordance with ASTM Standard A-388. DoT Specification 178.45-82 requires that the equipment must be calibrated to detect a notch equal to five percent of the design minimum wall thickness. The following ASTM Standards also are applicable.

E 114-82 Recommended Practice for Ultrasonic Pulse-Echo Straight-Beam Testing by the Contact Method

E 317-82 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments

E 500-82 Definition of Terms Relating to Ultrasonic Testing

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FAILURE EXPERIENCE IN NORTH AMERICA AND EUROPE

GASES: HYDROGEN, NATURAL GAS, CARBON MONOXIDE AND ITS MIXTURES.

ENGLAND: Stress corrosion due to moisture and sulfur impurities and pressure-induced hydrogen environment cracking in a tube made from a chromium-molybdenum steel.

ITALY: Failure of low alloy chromium-molybdenum steel carrying carbon monoxide attributed to stress corrosion attack by hydrogen sulfide.

U. S. A.: Failure of a large seamless steel pressure tube attributed to environmentally assisted cracking due to high concentrations of hydrogen sulfide an sulfur compounds.

Natural Gas: Internal corrosion due to chemical reaction of the acid solution formed by the dissolution of carbon dioxide in water vapour contained in the gas.

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FAILURE MODES

CORROSION AND ENVIRONMENT-ASSISTED CRACKING

- GENERAL CORROSION INCLUDING PITTING
- SULFIDE STRESS CRACKING (SCC)
- HYDROGEN EMBRITTLEMENT

GENERAL CORROSION CAN BE INTERNAL OR EXTERNAL.

EXTERNAL CORROSION IS COMMON TO ALL TYPES OF STEEL CONTAINERS.

SURFACE ROUGHNESS OR SMALL DISCONTINUITIES ON THE INNER TUBE WALL CAN ACCELERATE THE INTERNAL CORROSION PROBLEM.

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FAILURE CHARACTERISTICS

- The fracture initiated on the inner surface in the position where the thin-walled parallel section meets the thicker knuckle region.
- In most of the failures, the fractures initiated at inner wall surface defects about 0.1 mm deep on the inner wall and had propagated in a brittle manner by a mixed intergranular/transgranular mode.
- The cracks tended to follow the distribution of the inclusions which are mainly manganese sulfide.
- The metallurgical structure in the vicinity of the cracks was tempered.
- The quality of the containers met required specifications.
- There was no evidence of any manufacturing defects or defective material
- NDT tests showed that the material quality in the region of the failure was equal to material quality in the parallel wall section. Toughness was at the expected level for quenched and tempered steels at that strength level.
- The absence of gross defects, the good quality of the steel, and the indications on the fracture surface establish that the fractures grew in service and were not manufacturing faults.

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CONVENTIONAL INSPECTION REQUIREMENTS

VISUAL INSPECTION: EVERY TWO (2) OR THREE (3) YEARS

HYDROSTATIC: EVERY FIVE (5) YEARS

HYDROSTATIC TEST IS CARRIED OUT IN A WATER JACKET OR ALTERNATE APPARATUS TO DETERMINE THE EXPANSION OF THE TUBE.

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TEST METHOD OVERVIEW

CANDIDATE METHODS

	ADVANTAGES	DISADVANTAGES
CONVENTIONAL NDT	DETECTION CHARACTERIZATION	100% VOLUME COVERAGE REQUIRED
HYDROTEST ACOUSTIC EMISSION	"REMOTE"	DETECTION ONLY

LABORATORY TESTING PROGRAM

OBJECTIVES:

- Effect a direct comparison of acoustic emission testing with the water jacket test for sensitivity to plastic instability.
- To evaluate the acoustic emission behavior of cylinders.
- To measure crack growth rates.
- To measure crack retardation due to overstressing at the hydrostatic proof load.

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PROOF TEST

PROOF TEST +

FRACTURE MECHANICS

↓

LARGEST FLAW IN THE STRUCTURE

<u>ADDITIONAL DESIRABLE INFORMATION</u>

LOCATE SUBCRITICAL DEFECTS
ASSESS SIZE AND SHAPE
MEASURE GROWTH BETWEEN TESTS

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ADVANTAGES
OF
ACOUSTIC EMISSION TESTING

HIGH SENSITIVITY

FAST
(IN-SITU TUBE TESTING)

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EXPERIMENTAL PROGRAM
LABORATORY TESTS

HYDRO AND AE

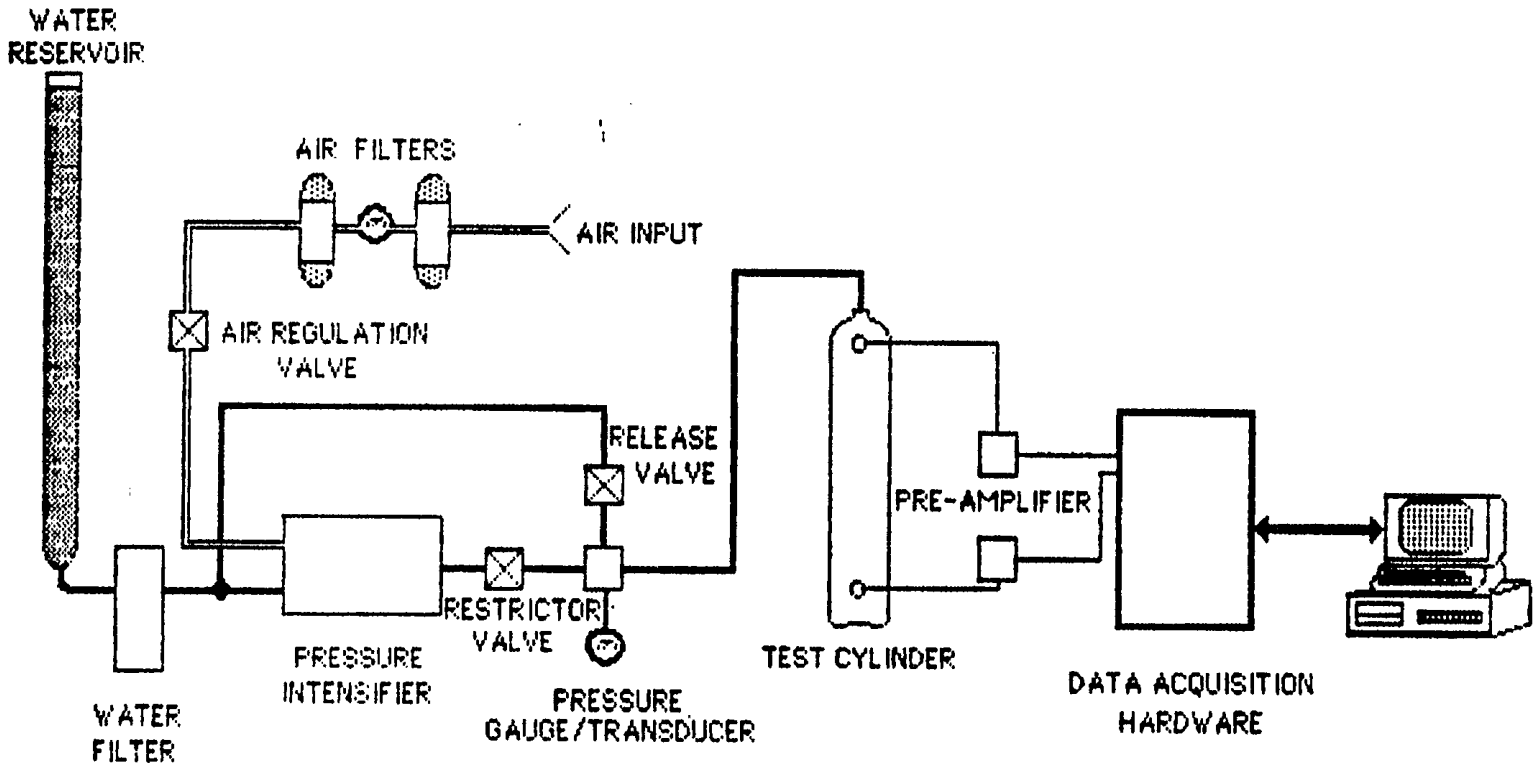
PURPOSE: COMPARE RELATIVE SENSITIVITY
VERIFY COMPUTATIONS

ARTIFICIAL AND NATURAL FLAWS

ARTIFICIAL:	FATIGUED	5
	WELD ARC	3
NATURAL:	GROUND FLAT	5
	SAW CUT (LONG.)	5
VS a/t	SAW CUT (TRANS.)	5
TOTAL SPECIMENS		23

CYLINDER TESTING

LABORATORY SETUP



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TEST CYLINDERS

No.	Flaw Type		Dimensions	No.	Flaw Type		Dimensions
1.	Artificial	Longitudinal Cut	5.08cm x 0.16cm	2.	Artificial	Longitudinal Cut	5.08 x .3175
3.	Artificial	Longitudinal Cut	5.08cm x .477cm	4.	Artificial	Longitudinal Cut	10.16 x .157
5.	Artificial	Longitudinal Cut	10.16 x .3175	6.	Artificial	Longitudinal Cut	10.16 x .477
7.	Artificial	Longitudinal Cut	15.24 x .157	8.	Artificial	Longitudinal Cut	15.24 x .3175
9.	Artificial	Longitudinal Cut	15.24 x .477	10.	Artificial	Longitudinal Cut	.3175
11.	Artificial	Longitudinal Cut	.477	12.	Natural	Arc Strike	
13.	Natural	Arc Strike		14.	Natural	Crack (5400 cycles)	
15.	Natural	Crack (9400 cycles)		16.	Natural	Corroded Crack	
17.	No flaw						

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PRESSURIZATION SCHEDULE

The pressure was increased incrementally by cycling between zero and the following values until failure:

0-10.3 MPa	0-13.8 MPa	0-14.5 MPa	0-15.2 MPa
0-5.9 MPa	0-17.25 MPa	0-20.7 MPa	0-24.8 MPa

0-24.1 MPa, then in 3.5 MPa increments until failure.

This cycling back to zero permitted measurement of the expansion by the direct method for each incremental pressure level.

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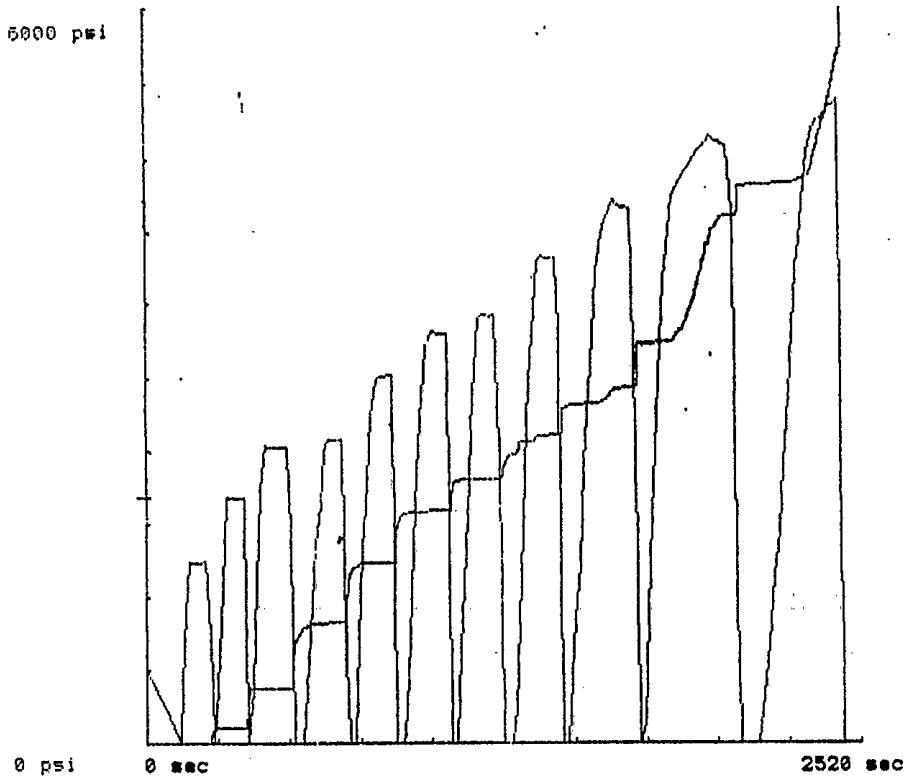
PRESSURIZATION TEST RESULTS

OF THE FOURTEEN (14) CYLINDERS TESTED:

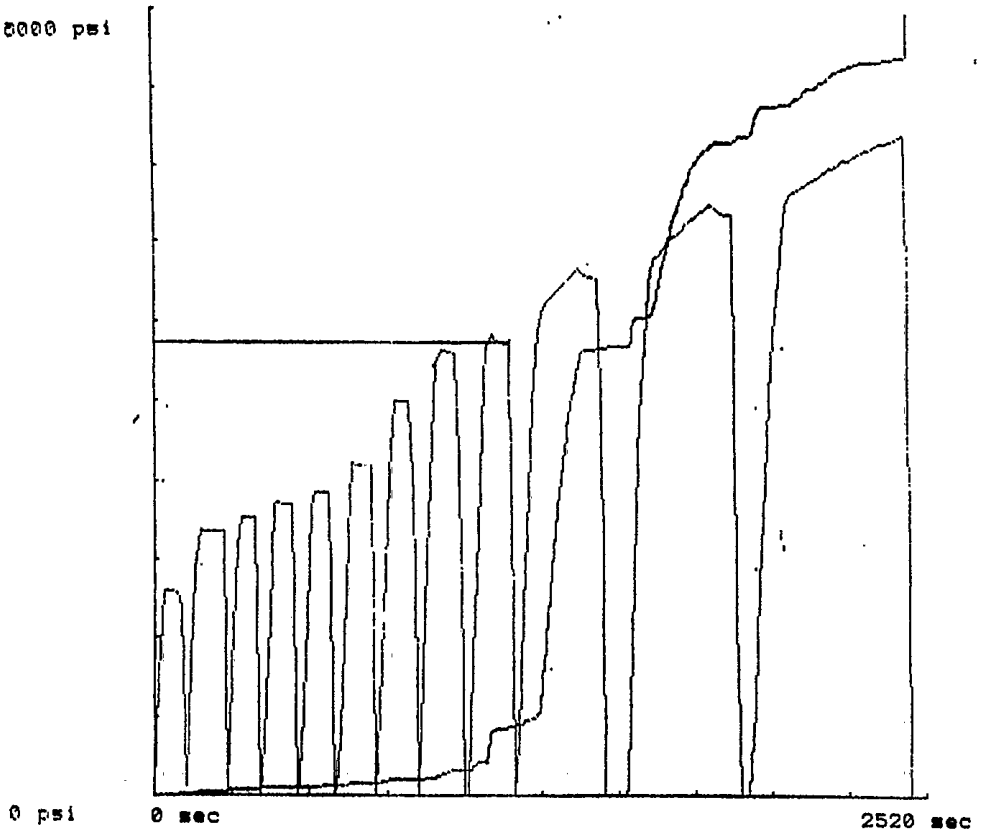
- FIVE (5) WOULD HAVE BEEN DETECTED BY THE HYDROTEST BY BURSTING AND WOULD HAVE BEEN UNDETECTED BY THE WATER JACKET.
- FIVE (5) OF THE CYLINDERS WOULD HAVE BEEN REJECTED BY ACOUSTIC EMISSION AT AN OVERPRESSURE OF 115%.
- NINE (9) OF THE CYLINDERS WOULD HAVE BEEN REJECTED BY ACOUSTIC EMISSION AT AN OVERPRESSURE OF 5/3.
- AMONG THE LATTER NINE (9), THREE (3) WOULD NOT HAVE BEEN DETECTED BY HYDROTEST, BUT AE REVEALED CRACK EXTENSION DURING THE TEST ITSELF.
- VOLUMETRIC EXPANSION DID NOT REVEAL ANY OF THE CRACK-LIKE DEFECTS.

ACOUSTIC EMISSION BEHAVIOR OF CYLINDERS



Starting Pressure : 628
Minimum Pressure : 0
Maximum Pressure : 5270
Total Events recorded : 841

ACOUSTIC EMISSION BEHAVIOR OF CYLINDERS



Starting Pressure : 9
Minimum Pressure : 0
Maximum Pressure : 5004
Total Events recorded : 1070

HYDROTEST AND AE

In this option, the hydrostatic test is retained and acoustic emission testing is used in lieu of the water jacket. This is an extremely conservative approach which retains the high retest pressure of the current testing procedure and simply replaces the water jacket with the more sensitive acoustic emission monitoring. Testing at 5/3 service pressure would excite activity in smaller flaws than the lower pressures in the second option outlined below and this level of test pressure, combined with considerations of crack propagation rates and crack retardation effects induced at this level of pressure provides a margin of safety consistent with a 10-year retesting interval.

This option thus retains the advantages of the currently mandated retest methods, namely, the "proof test" character of the hydrotest and supplements it with the additional sensitivity of acoustic emission monitoring. In the case of vessels that would be rejected by the water jacket due to in-service induced deterioration, such wall thinning is produced by corrosion where cracking of the corrosion products are readily detected by acoustic emission.

IN-SITU ACOUSTIC EMISSION

In this option, compressed gas tubes and cylinders would be pressurized using the product gas normally transported by the vessels as the pressurization fluid and monitored using acoustic emission. For reasons of safety and availability of pressurization pumping equipment at the filling station and the presence of overpressurization safety devices in the system, the test pressure is generally limited to 110% of normal service pressure. Pressurization would be carried out to the highest value deemed reasonable from test practicalities, namely, pressurization capabilities at the filling station and the presence of overpressurization safety devices in the system. This is of the order of 110% to 115% of the service pressure. If there have been accidental overloads or pressure excessions due to temperature cycling to pressures of 110% or over, testing under this option risks being ineffective due to the Kaiser Effect.

Transports Canada / Transport Canada
Marchandises dangereuses / Dangerous Goods

Certificate of Registration

This is to certify that: Tektrend International Inc., Montreal, P.Q. and Canadian Liquid Air, Montreal, P.Q., pursuant to their application on file with Transport Canada have been granted the registration No. 265 in accordance with the provisions of Special Permit No. 3263 and section 25 of CAN/CSA B339-88 for the purpose of performing periodic rainspection and retesting:

a) for the following types of cylinders, tubes or spheres:

CTC cylinders or tubes of specification 3A, 3AX, 3AA or 3AAX or CTC Special Permit 1337 tubes having a water capacity greater than 250 litres and owned by Canadian Liquid Air.

b) by the following test procedure:

The test procedure and operator qualifications shall be as described in Appendix A to this Certificate of Registration notwithstanding the requirements of section 73.34(e) or section 8(b) of Special Permit No. 1337. Retesting shall be performed at least once every 10 years.

c) and under the following limitations:

- The maintenance, filling and use of the cylinders and tubes shall be in complete accordance with all other applicable requirements of the "Regulations for the Transportation of Dangerous Commodities by Rail" and where applicable the terms of Special Permits.
- Cylinders and tubes retested in accordance with paragraph (b) above may be charged to 110 percent of marked service pressure in accordance with section 73.302(c).
- The exterior of the trailer cabinet of the vehicle chassis to which the cylinders are affixed and an exterior tube on each side of a tube module must be marked with letters at least 2 inches high on a contrasting background "CTC SP 3263-265".

d) The following information shall be provided to this Directorate:

- A statement of qualification for each qualified tester and qualified inspectors.
- Location of each facility where testing is conducted.
- A detailed report every 6 months indicating the number of tubes tested and identifying those passing and those failing to pass the test.

Failure to comply with the above mentioned requirements or any applicable regulations may result in the suspension or revocation of this certificate of registration.

This Certificate of Registration shall expire on: January 1st 1992 or on such previous date as this Directorate may decide.

Registration Date: 20 FEB 90 Signed: J.R. Moxley

Director, Regulatory Requirements
Transport Dangerous Goods Directorate

Canada