D0, E740
LAr Dewar

Technical Appendix to
Cryogenic Pressure Vessels
(5032TA, July 27,1984)

D0 ENGINEERING NOTE
3740.512-EN-244

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Technical Appendix to Cryogenic Pressure Vessels; E740 LAr Dewar

1.0 Documentation

1.1.1 System Equipment and Operation

The 20,000 gls. Liquid Argon dewar stores up to 15,000 gls. of high purity (<1.0 ppm O_2, 0.999995) LAr for use in the Liquid Argon calorimeters of E740, the D0 collider detector, at elevation 707'. The dewar provides for the total detector volume of 11,000 gls and a 4,000 gls. storage inventory. The large gas volume ($\geq$ 5,000 gls.) serves operational needs and guards against overfill concerns.

The LAr dewar functions in two modes; 1) low pressure (16 psi relief) storage, and liquid and gas transfer operations to and from the low pressure (13 psi relief) detector cryostats, and 2) high pressure (65 psi relief) liquid transfer operations to and from a delivery trailer at elevation 743'.

The storage function is intended to be long term and non-venting. The dewar is equipped with a 40 kW LN_2 condenser that operates to maintain the pressure constant in the storage mode. This service exactly parallels the NeH_2 and D_2 storage dewar services provided at the 15' bubble chamber for its operation.

1.1.2 Flow Sheets

The flow sheets (current revision) are included in the appendix. 3740 ME 222394 S, sht 1,2

1.1.3 Preliminary Operating Procedures

The previously submitted preliminary procedures, section 5.0 Argon Dewar, indicated the expected use of the dewar. Please note that these were representative, in a current state of development, and were not offered as final.

1.1.4 Qualification and Training

The initial operators (D0 cryo experts) of this system have the following areas of experience and years of experience;

Operators	Experience	Years
G. T Mulholland	H_2,Ne,D_2 Bubble Chambers	
	Large, small He Systems	
	100 T/d Nitrogen Reliquifier	
	Accelerator Cryogenics	
	LAr Calorimeters	30
Kelly Dixon	H_2,Ne,D_2 Bubble Chambers	
	Large He Systems	
	Large LAr Calorimeter	10
John Urbin	H_2,Ne,D_2 Bubble Chambers	
	Large He Systems	
	Large LAr Calorimeter	10
Ernie Ramirez	Large He Systems	
	Accelerator Cryogenics	10
Dan Markley	H_2,Ne,D_2 Bubble Chambers	
	Large He Systems	10

The above people are posted through out DAB as the D0 cryoexperts by means of the list included in the appendix.

1.1.5 Chapter 5032 Documentation

Provided under separate cover as the "14.1 document"._ It may also be found as EN 219 in the D0 note file._

1.1.6 Active Component List

The active components are listed in the D0 EN 193, Piping Components List in the D0 files.

2.0 Analysis Requirements

2.1 Failure Mode and Effects Analysis (FMEA)

Reference the formatted FMEA which appears in the appendix. Included at the end of the appendix is a flow sheet 3740 ME 222394 S, sht 1 which shows the boundary of the components included in the FMEA

2.2 What-if Analysis

Reference the formatted "What if" analysis which appears in the appendix.

3.0 Engineering Calculations

Important engineering calculations for the D-Zero project are given Engineering note numbers. An index to these notes which are relevant to the cryosystem is in the appendix.

3.1 Relief System Adequacy

The adequacy of the relief system is addressed in EN 232. The treatment is general, well referenced, and has application well beyond this work.

3.2 Stress Calculations

The stress calculations for component parts will be found in the EN describing each part design or analysis. See the D0 EN index.

4.0 Maintaining Safe Operation

4.1 Updating Documents

D0 has a mature file of component, system and schematic drawings, a checked and approved mode of operation, a large and current engineering note file, and a substantial and developing operating procedures manual. All these documents are improved and kept current by periodic review, upgrading and updating.

Operations logbooks and historical trend analysis provide the basis for system improvement and upgrade.

4.2 Operating Procedures

Operating procedures have been written for;

- Instrument Air
- Vacuum
- Nitrogen Storage Dewar
- Argon Storage Dewar
- Test Cell Operation
- CC Cryostat
- EC Cryostat
- Emergency Procedures
- Special Procedures

4.3 Operator Training and Qualification Records

A set of cryogenic operators will be trained and identified (see Qualification and Training). That list will be keep current, by addition and retraining, and augmented with the RD/CRYO personnel as systems are commissioned and the operating procedures are tested and become well established.

5.0 Inspections

5.1 Review inspections

Inspections have been performed when and as deemed necessary.

5.2 Operations Inspections

Inspections of the operating system are encouraged.

APPENDIX TO

D0 ENGINEERING NOTE

3740.512-EN-244

D0 CRYOEXPERT CALL LIST

	LAB EXT.	PAGE NUM.	HOME PHONE
DIXON, Kelly	2634	334	(708) 741-8747
MARKLEY, Dan	2849	992	(815) 741-1521
MULHOLLAND, George T.	3287	850	(708) 653-2443
RAMIREZ, Ernie	2670	491	(708) 377-5187
URBIN, John	2638	357	(708) 859-8829

Component				Failure or Error Mode	Hazard/Effect	Hazard Class	Remarks/Recommendations
CV	455	N		Open	Normal	Safe	
CV	455	N		Closed	Stops N2 venting	Safe	RD458E Relieves outside of building
MV	456	A		Open	Normal	Safe	
MV	456	A		Closed	Stops Argon purge	Safe	
MV	457	A		Open	Normal	Safe	
MV	457	A		Closed	Stops Argon Sampling	Safe	
MV	462	A		Open	Normal	Safe	
MV	462	A		Closed	Stops Argon fill	Safe	Supervised Ar fill procedure
MV	469	A		Open	Bypasses DPI470A	Safe	Lose indication of pressure drop across F467A
MV	469	A		Closed	Normal	Safe	
MV	603	A		Open	Normal	Safe	
MV	603	A		Closed	DPI606A & DPT637A Blocked	Safe	Lose Ar dewar level indication
MV	604	A		Open	Normal	Safe	
MV	604	A		Closed	DPI606A & DPT637A Blocked	Safe	Lose Ar dewar level indication
MV	605	A		Open	Lose level indication	Safe	Bypasses DPI606A & DPT637A
MV	605	A		Closed	Normal	Safe	
MV	607	A		Open	Normal	Safe	
MV	607	A		Closed	PI608A & PT653A Blocked	Safe	Lose electronic Argon dewar pressure indication
MV	610	A		Open	Permits flow	Safe	With MV664A open
MV	610	A		Closed	Normal	Safe	
MV	616	A		Open	Permits flow	Safe	
MV	616	A		Closed	Normal	Safe	
MV	617	A		Open	Normal	Safe	Permits flow to Argon dewar reliefs
MV	617	A		Open	Normal	Safe	Permits flow to Argon dewar reliefs
MV	624	A		Open	Permits pressure behind a cap	Safe	
MV	624	A		Closed	Normal	Safe	
MV	627	V		Open	Permits vacuum behind a cap	Safe	
MV	627	V		Closed	Normal	Safe	
MV	628	V		Open	Normal	Safe	
MV	628	V		Closed	TG629V Blocked	Safe	Lose indication of Argon vacuum jacket pressure
MV	632	A		Open	Permits flow	Safe	Vents Ar dewar outside of building
MV	632	A		Closed	Normal	Safe	
MV	633	A		Open	Normal	Safe	Ar dewar test port
MV	633	A		Closed	Stops Ar sampling	Safe	
MV	635	A		Open	Normal	Safe	Ar dewar test port
MV	635	A		Closed	Stops Ar sampling	Safe	

				Failure or		Hazard	
Component				Error Mode	Hazard/Effect	Class	Remarks/Recommendations
MV	639	A		Open	Normal	Safe	
MV	639	A		Closed	PT653A Blocked	Safe	Lose electronic Ar dewar pressure indication.
MV	640	E		Open		Safe	Locked cap after valve
MV	640	E		Closed	Normal	Safe	
MV	643	A		Open		Safe	Cap after valve
MV	643	A		Closed	Normal	Safe	
MV	646	A		Open		Safe	Cap after valve
MV	646	A		Closed	Normal	Safe	
MV	648	A		Open	Normal	Safe	
MV	648	A		Closed	Stops Ar flow	Safe	
MV	656	N		Open	Normal	Safe	
MV	656	N		Closed	Blocks PT655N	Safe	
MV	658	A		Open		Safe	Cap after valve
MV	658	A		Closed	Normal	Safe	
MV	660	A		Open	Normal	Safe	
MV	660	A		Closed	Stops Lar flow to calorimeters	Safe	
MV	661	A		Open		Safe	Cap after valve
MV	661	A		Closed	Normal	Safe	
MV	664	A		Open	Permits flow	Safe	
MV	664	A		Closed	Normal	Safe	
MV	667	A		Open	Bypasses DPI669A	Safe	Lose indication of pressure drop across F672A
MV	667	A		Closed	Normal	Safe	
MV	668	A		Open	Bypasses DPS666A & DPT665A	Safe	Lose indication of pressure drop across FM671A
MV	668	A		Closed	Normal	Safe	
MV	674	A		Open		Safe	Cap after valve
MV	674	A		Closed	Normal	Safe	
MV	677	A		Open	Bypasses DPI676A	Safe	Lose indication of pressure drop across F670A
MV	677	A		Closed	Normal	Safe	
PV	601	A		Open	Permits flow	Safe	
PV	601	A		Closed	Normal	Safe	
PV	611	A		Open	Permits flow	Safe	With several other valves open.
PV	611	A		Closed	Normal	Safe	
PV	612	N		Open	Normal	Safe	
PV	612	N		Closed	Stops LN2 flow to Ar dewar	Safe	
PV	615	N		Open	Normal	Safe	
PV	615	N		Closed	Stops LN2 flow to Ar dewar	Safe	

Component				Failure or Error Mode	Hazard/Effect	Hazard Class	Remarks/Recommendations
PV	625	A		Open	Normal	Safe	Supervised filling operation
PV	625	A		Closed	Stops LAr fill	Safe	
PV	638	A		Open	Normal	Safe	
PV	638	A		Closed	Stops LAr flow from dewar to Calorimeters	Safe	
PSV	609	A		Open	Vents Argon	Safe	Vents inside building
PSV	609	A		Closed	Overpressurize piping	Mech. damage	Mean time between failures=274 years
PSV	614	N		Open	Vents Nitrogen	Safe	Vents inside building
PSV	614	N		Closed	Overpressurize piping	Mech. damage	Mean time between failures=274 years
PSV	619	A		Open	Vents Argon	Safe	Vents outside of building
PSV	619	A		Closed	Dewar pressure increases to 95 psi max.	Safe	RD618A relieves Ar dewar at 95 psi
PSV	620	A		Open	Vents Argon	Safe	Vents outside of building
PSV	620	A		Closed	Dewar pressure increases to 25 psi max.	Safe	RD621A relieves Ar dewar at 25 psi
PSV	623	A		Open	Vents Argon	Safe	Vents inside building
PSV	623	A		Closed	Overpressure piping	Mech. damage	Mean time between failures=274 years
PSV	626	V		Open	Vent insulating vacuum space	Safe	See LAr dewar relief valve sizing
PSV	626	V		Closed	Normal	Safe	
PSV	630	A		Open	Vents Argon	Safe	Vents inside building
PSV	630	A		Closed	Overpressure piping	Mech. damage	Mean time between failures=274 years
PSV	633	A		Open	Vents Argon	Safe	Vents inside builing
PSV	633	A		Closed	Overpressure piping	Mech. damage	Mean time between failures=274 years
PSV	642	A		Open	Vents Argon	Safe	Vents inside builing
PSV	642	A		Closed	Overpressure piping	Mech. damage	Mean time between failures=274 years
PSV	647	A		Open	Vents Ar	Safe	
PSV	647	A		Closed	Overpressure piping	Mech. damage	Mean time between failures=274 years
PSV	657	A		Open	Vents Argon	Safe	
PSV	657	A		Closed	Overpressure piping	Mech. damage	Mean time between failures=274 years
SV	673	A		Open	Vents Argon	Safe	
SV	673	A		Closed	Overpressurize piping	Mech. damage	Mean time between failures=274 years
RD	458	E		Open	Vents Nitrogen	Safe	Vents outside of building
RD	458	E		Closed	Normal	Safe	
RD	618	A		Open	Vents Argon	Safe	Vents outside of building
RD	618	A		Closed	Normal	Safe	
RD	621	A		Open	Vents Argon	Safe	Vents outside of building
RD	621	A		Closed	Normal	Safe	

DØ Liquid Argon Dewar "What-If"

"WHAT - IF"	CONSEQUENCE / HAZARD	CONCLUSION / RECOMMENDATIONS
Leaks occur?	Oxygen Deficiency Hazard may occur due to cryogens leaking into the building.	Leaks of reasonable size have been anticipated by the ODH analysis and appropriate provisions made so they present no personnel or equipment danger (i.e. the ODH class is 0).
The Ar dewar is overfilled?	Dewar will completely be filled.	The dewar volume has been sized with a 5,000 gallon ullage to preclude this from occurring. If an overfill occurs however due to human error, the dewar may fill only to its maximum and the source pressure head (≈46 psig). The relief is set at 65 psig.
The Ar dewar is filled with a delivery pump?	The Dewar relief valve will relieve at it's 65 psig setting.	The operating procedures prevent this event from occuring. Personnel involved with the filling operation know that the pump is not to be operated. The filling of the Ar dewar will be a highly supervised event. In the event this does occur, however, the 65 psig relief valve is of adequate size to vent vapor displaced from a pump liquid fill at 200 gpm.
The Ar dewar is overfilled with a delivery pump?	Dewar will be filled with liquid and will blow it's reliefs.	This is an unlikely two failure mode case. Operating procedures will prevent either failure mode from occurring. See the above two "What if" cases for the singly occurring failure mode. Should this occur, the rupture disc blows and the dewar vents to the vent line. The dewar pressure would be the vent line head plus the pressure drop due to the flow.
The vacuum of the LAr dewar fails?	Loss of vacuum.	Safe. This case was covered in D0 Engineering Note 219. Vacuum failure of the dewar or any associated lines will impede or seriously hamper operations, but not provide a personnel or equipment danger.
There is a fire?	Dewars will relieve and possible loss of signal or valve operators.	Fire exposure of the dewar is covered in D0 Engineering Note 232. The implication of the loss or signals of valve operators is that trapped liquid volumes could occur and cause trapped volume reliefs to relieve.

"WHAT - IF"	CONSEQUENCE / HAZARD	CONCLUSION / RECOMMENDATIONS
There is an earthquake?	Damage to the piping system could occur.	The ANSI B31.1-1986 piping code under par. 101.5.3 states that "The effect of earthquakes, where applicable, shall be considered in the design of piping, piping supports..." The effect of earthquakes are not applicable to the region of Illinois where Fermilab is located. The Uniform Building Code shows that Fermilab is in a Class 0 seismic zone which means no design provisions for earthquakes are required.
There is a loss of electrical power?	Backup power will be required to maintain operation of the system.	Sustained loss of electrical power will result in critical equipment running on the Emergency Power Generator. The instrument air, vacuum pumps and controls are (will) all be EPG powered. Should the EPG fail before the return of commercial power the equipment is lost, see below.
There is a loss of instrument air?	Valves will close.	Safe. The primary system is backed up for several hours with a tube trailer. All valves are failsafe, i.e. they close on the loss of instrument air. Reference the failure mode and effects analysis.
There is a loss of cooling water?	The main cooling water supply might be in jeopardy if a system was not designed properly.	The vacuum and Instrument air equipment have a primary, emergency powered, immediate start, closed loop, fan blown radiator, redundant pump, glycol stream to put the heat load on the building system and provide lower summertime coolant temperatures. Loss of the secondary system, or commercial power if the emergency generator functions, does not effect the cooling provided to the rotary equipment.
There is a loss of Liquid nitrogen?	Cooling will be lost and will cause the Argon vessels to warm, boil off, and vent.	The loss of liquid nitrogen denies the detector its necessary coooling and it will pressurize and vent. The rate of loss is calculated to be only 0.45 gpm of liquid argon on average, which is very slow. The loss of liquid nitrogen does not provide a personnel or equipment danger.
Some kind of contamination occurs?	The contamination could restrict flows.	Continued or serious one-time contamination of the coolant stream with frozen solids will result in a loss of liquid nitrogen, see above.

"WHAT - IF"	CONSEQUENCE / HAZARD	CONCLUSION / RECOMMENDATIONS
There is some kind of equipment failure?	A piece of equipment will stop working.	100% redundancy in mechanical forepumps provide for vacuum equipment failure in the operating mode. The insulating vacuum can function with either the cryostat diffusion pump or the blower. Instrument air is backed up by 8 or more hours of high pressure gaseous nitrogen. All valves close on air failure. Expected equipment modes do not provide a personnel or equipment danger.
An operator makes a procedural error?	Upset of the system may occur.	Any one operator procedural or console error can cause any one component to act improperly which is comparable to a component failure. Failure of equipment is covered above and failure of valves was covered in the FMEA. A single operator error cannot cause a safety problem.
A U-tube falls during removal or insertion and strikes the following vulnerable components?		NOTE: A survey of the area around the U-tubes was made to determine which components were vulnerable.
A. 3/8"pilot line to 16 psig relief valve.	Line could bend with possibility of small argon leakage from dewar.	No safety hazard exists due to low flow rates which could exist.
B. Instr. air supply solenoids, air sets (regulators/filters), I/P transmitters and positioners.	Erroneous signals/pressure from instr. air manifold could open large pneumatic valves causing ODH and other cryo dangers.	Supply air to pneumatic valves will be shutoff procedurally by manual or solenoid valves. Both solenoid and pnuematic valves fail CLOSED.
C. Pressure, level gages and/or 1/4" copper tubing.	Tubing within or leading to gages could shear adding to any concurrent ODH situation.	Close protected shutoff valves at dewar.
D. 1/2" copper tubing vaporizer liquid shutoff valve.	Tubing could shear leading to ODH situation.	Line has been reinforced by well supported aluminum channel.

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"WHAT - IF"	CONSEQUENCE / HAZARD	CONCLUSION / RECOMMENDATIONS
E. 1/4" cast bronze test valves at relief inlets.	Tubing/valves could shear adding to any concurrent ODH situation.	Relief selecting valve, MV617A, should be switched temporarily to other position until any necessary repairs are complete.
The deired rate of rise (1 psi/15 min) can not be achieved?	This ROR criterion is set very conservatively for an ODH guideline. However it still should be followed, otherwise the purity of the argon within the dewar could be jeopardized.	Valve leakage criteria should include operational as well as ODH considerations. Nonetheless, instructions to operators shall specifically state that ALL procedures should be followed exactly as written unless approval has been granted by the cryo supervisor for deviation. If the usual seating methods (valve stroking, packing tightening) have failed, it is likely that the only option available is to drain the dewar, vent it to atomosphere, and make repairs to the valve.
The U-tube gets stuck during removal?	Piping could be bent if excessive force is used. Trolley, hoist, and rail have large factors of safety and can not be subjected to unsafe loads.	All u-tubes have been field fitted to their counterparts. Piping damaged due to the lack of good common sense will have to be repaired as needed.

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INDEX TO D-ZERO ENGINEERING NOTES

RELEVANT TO THE CRYOSYSTEM

(February 20, 1990)

I. OXYGEN DEFICIENCY HAZARD

EN-50	Spill provisions of DO LAR Calorimeter
EN-129	D-Zero Vent stacks
EN-229	ODH Analysis method and conclusions
EN-231	Leak analysis- Bayonnet + Flange
EN-233	U-tube/Filter change ODH considerations
EN-235	DAB, South side, ODH analysis
EN-242	D-Zero Cryo Ventillation Fan Controls and Monitoring

II. VESSELS

EN-111	Argon dewar required relief flow
EN-115	High pressure source, Cryostat relief solution
EN-121	ASME Code design calculations for CC Cryostat
EN-204	Cooling system expansion tank safety note
EN-219	D-Zero LAr Dewar pressure and vacuum vessel safety notes
EN-221	D-Zero LN2 Dewar pressure and vacuum vessel safety notes
EN-234	LAr Dewar condensor coil considerations
EN-244	LAr Dewar Technical Appendix to Cryogenic Pressure vessels

III. PIPING

EN-25	Central Calorimeter piping flexibility
EN-59	Specification for fabrication, installation and testing of pipe
EN-162	Pipe stress analysis
EN-172	Analysis of rotary bayonnets/piping
EN-193	D-Zero Piping components
EN-220	Storage dewar U-tube design

IV. MISCELLANEOUS

EN-4	Stress analysis End Calorimeter cryo
EN-9	End Cap Cryostat
EN-22	Central Calorimeter nozzles
EN-23	Central Calorimeter/ cryo support
EN-24	Cryostat stiffening rings (cent)
EN-26	Central Calorimeter Vessel Calculations
EN-36	End Cap Calorimeter Vessel Calculations
EN-42	Summary stress analysis of CC Cryostat
EN-54	Design review of DO Cryostats
EN-63	D-Zero vent piping
EN-65	Battelle design review CC vac.
EN-68	Design summary of CC cryo vessels
EN-232	Fire Relief value determination

FMEA ANALYSIS

Definition of Hazard Classes

Safe	=	No mechanical damage or personnel injury.
ODH	=	Releases argon or nitrogen to atmosphere, possibly threatening personnel. This possibility is taken into account in ODH Analysis, area classification, and procedures. See ODH Analysis and Safety Manual, Chapter 15.1 for further details.
Mechanical Damage	=	Possible damage to equipment, most likely due to over pressurization. Personnel injury is considered sufficiently unlikely and as such, constitutes an acceptable risk. ODH is possible if piping, pressure vessels or components rupture.
Unsafe	=	More than negligible possibility of personnel injury even if standard ODH procedures are followed.

Note: Mean time between failures taken from Fermilab Standard 5064TA, Table III.