Design Analysis Cover Sheet

Complete only applicable items.

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2. DESIGN ANALYSIS TITLE

MOL.19951101.0017

North Portal Surface-Based Compressed Air System Analysis

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7. SYSTEM ELEMENT

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	Print Name	Signature	Date
8. Originator	C. L. Mellen	<i>C. L. Mellen</i>	1/18/95
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12. REMARKS

Complete only applicable items.

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[illegible]

1. PURPOSE

The purpose of this analysis is to capture the design requirements and analyze equipment performance relevant to the Surface-Based Compressed Air System (CAS) design at the Yucca Mountain Site Characterization Project (YMP) Exploratory Studies Facility (ESF).

2. QUALITY ASSURANCE

The CAS is a temporary utility and as such has not been identified with an interface to the potential repository.

- | The quality assurance (QA) classification of this analysis is NONE; no QA controls are applicable.

3. METHOD

The method used in this design analysis involves capturing data and requirements, modifying or developing conceptual design criteria (Title I), then developing final design criteria (Title II). Design data and requirements are captured from the following sources:

- | 3.1 Local Records Center, searches for records associated with work previously done on the ESF CAS.
- 3.2 The Title I Design Summary Report (DSR) for the ESF provides a preliminary conceptual design basis for the CAS.
- | 3.3 The ESF Design Requirements Document (ESFDR) and Basis for Design (BFD) provide criteria and requirements compiled from upper tier documents.
- 3.4 Meetings with project participants involved with the design, construction, and testing of the YMP ESF.
- 3.5 Discussions with equipment vendors to evaluate available equipment and suitability for incorporation within the design.
- | 3.6 Reserved.
- 3.7 Design reviews of the CAS, generating a wide variety of requirements and constraints.

4. CODES AND STANDARDS

- 4.1 AMERICAN NATIONAL STANDARDS INSTITUTE, INC. (ANSI)/INSTRUMENT SOCIETY OF AMERICA (ISA):

S7.3-1975

Instrument Air Standard

4.2 CODE OF FEDERAL REGULATIONS (CFR):

29 CFR 1910 Occupational Safety and Health Standards

4.3 NATIONAL FIRE PROTECTION ASSOCIATION (NFPA):

NFPA 70 National Electrical Code, 1993

4.4 UNDERWRITERS LABORATORIES (UL):

UL 142 Standard for Steel Above Ground Tanks for Flammable and Combustible Liquids, April 1, 1994.

4.5 U.S. CODE:

RCRA Resource Conservation and Recovery Act of 1976. Title 42, Sec. 6901.

4.6 U.S. CODE OF FEDERAL REGULATIONS (CFR):

10 CFR 436 Federal Energy Management and Planning Procedures, January 1, 1994.

30 CFR 57.11052 Safety and Health Standards - Underground Metal and Nonmetal Mines - Escapeways - Underground Only - Refuge Areas, July 1, 1993.

4.7 U.S. DEPARTMENT OF ENERGY (DOE):

6430.1A General Design Criteria, April 6, 1989

5. DESIGN INPUTS

5.1 Design Review Comment (response) DA-TR-ESF-S-14, J. Lathrop regarding ST-ME-011, August 12, 1991. Re: Requirement for 9000 CFM of Compressed Air.

5.2 U.S. Geological Survey (USGS) Memorandum, B. Craig to A. Yang, November 3, 1989, Re: Gas-tracer Concentration, NNA.891226.0205 (GS.89.A.001669).

5.3 InterOffice Correspondence (IOC), L. Engwall to J. Naaf, LV.ESSD.LGE.5/93-099, Re: May 12, 1993. Re: Requirement for 4000 CFM of Oil-Free Compressed Air.

5.4 IOC, C. Mellen to distribution, LV.ESSD.CM.9/93.516, September 17, 1993, Re: Outline Scope, Requirement for Oil-Free Compressed Air and Air-Cooled Equipment.

- | 5.5 IOC, C. Mellen to distribution, LV.ESSD.CM.9/93.527, September 30, 1993, Re: Meeting findings, requirement for 2560 CFM compressed air at 125 psig; instrument quality air; skid-mounted equipment; chemical injection skid.
- | 5.6 IOC, R. M. Sandifer, LV.SE.SB.10/93-089. Re: Excess CAS Equipment.
- | 5.7 IOC, D. F. Vanica to L.G. Engwall, LV.ESSB.DFV.5/93-075, May 14, 1993, Re: Requirement for 2200 CFM Compressed Air.
- | 5.8 IOC, D. Parker to distribution, LV.ESSD.DHP.11/93.545, November 17, 1993, Re: CAS Piping.
- | 5.9 IOC, C. Mellen to D. Parker, LV.ESSC.CLM.8/93-253, August 17, 1993, Re: ESF 1C Package Mechanical Scope Outline.
- | 5.10 IOC, C. Mellen to R. Dresel, LV.ESSD.CM.12/93.558, December 2, 1993, Re: Excess CAS Equipment,.
- 5.11 Teleconference with Tom Leonard of REEC0: Request for 4 inch CAS line to shop, October 4, 1993.
- 5.12 Teleconference with Tom Leonard of REEC0: Request for 4 inch CAS line to shop - verified, January 21, 1994.
- | 5.13 Title I Design Summary Report for the Exploratory Studies Facility (DSR), YMP/92-40 Rev. 1. May 6, 1992.
- | 5.14 Exploratory Studies Facility Design Requirements (ESFDR), YMP/CM-0019 Rev. 1, November 1994.
- | 5.15 Design Analysis: BABFAG000-01717-0200-00161 Rev. 00, Compressed Air Distribution Design Analysis, D. F. Vanica, December 7, 1993. Re: Refuge Chamber Requirements, Requirement for 2500 CFM (3000 peak) Compressed Air.
- | 5.16 Design Analysis: BABFAG000-01717-0200-00161 Rev. 00, Compressed Air Distribution Design Analysis, D. F. Vanica, March 29, 1994. Re: Requirement for 2376 CFM Compressed Air.
- | 5.17 Design Analysis: ST-ME-011, Underground Support Systems, D. A. Veronica Raytheon Services Nevada (RSN), July 18, 1991. Re: Requirement for 2200 CFM, 100 psig Compressed Air.
- | 5.18 Determination of Importance Evaluation (DIE) for ESF North Portal Pad BABB00000-01717-2200-00001, REV 05. Re: Tracers, Fluids, and Materials (TFM) Controls for the CRS and CAS.
- 5.19 Letter, R. Sandifer to J. Replogle, LV.MG.RMS.12/93.191, December 1, 1993, Re: Nevada Test Site (NTS) Surplus Equipment.

- 5.20 IOC, J. J. Salchak to A. Segrest, LV.ESSD.Ref.3/94-177, March 25, 1994, Re: CAS - Package 1C 90 Percent Design Revised Requirements.
- 5.21 Waste Isolation Evaluation: Tracers, Fluids, and Materials for Use in the Package 2C Exploratory Studies Facility Construction, BABE00000-01717-2200-00007, Rev. 03, August 23, 1994, Re: Organic Deposition Rate Limits.
- 5.22 Letter, A. Segrest to J. Replogle, LV.ESSD.REF. 3/94-.099, March 4, 1994, Re: Revision of CAS Requirements from 90% Design Review.
- 5.23 Letter, C. T. Statton to N. Z. Elkins. #LV.SC.BWD. 2/94-208, February 2, 1994, Re: Request for Exemption of Tracers.
- 5.24 Los Alamos National Laboratory IOC LA-EES-13-LV-02-94-054, N. Z. Elkins to C. T. Statton. February 22, 1994, Re: Support for Exemption from Use of Tracers.
- 5.25 IOC, C. Mellen to D. Parker, LV.ESSD.CM.12/93.556, December 6, 1993, Re: Results of Field Inspection.
- 5.26 Letter, R. Sandifer to R. Pritzheit, LV.MG.RMS.11/93.169, Re: Request for Information About NTS Surplus Air Compressors.
- 5.27 IOC, C. Mellen to R. Dresel, LV.ESSD.CM.12/93, 560, December 7, 1993, Re: Excess Equipment Procurement.
- 5.28 Design Analysis: Life-Cycle Cost Analysis for the Condensate Receiving System, BABBDF000-01717-0200-00025 REV 00. Re: Selection of Condensate Removal System.
- 5.29 ESF Basis for Design (BFD) Document, BAB000000-01717-6300-00002 REV 05, November 28, 1994, Re: CAS requirements.
- 5.30 ESF Package 1D 90% design review comment: ID-064; Re: Refuge Chamber Air Supply Requirements.
- 5.31 Specification Section 13046, Refuge Chambers, BABEC0000-01717-6700-13046, REV 00; Refuge Chamber Requirements: Provide compressed air, emergency illumination (power) for 48 hours. (TBV-044)
- 5.32 Yucca Mountain Site Characterization Project Surface Air Compressors and Generators Safety Analysis, BABBD0000-01717-0200-00001, REV 00.
- 5.33 DIE for ESF Surface Compressed Air and Standby Power Systems, BABBD0000-01717-2200-00022, REV 00. Re: Tracers, Fluids, and Materials (TFM) Controls for the CRS and CAS.

6. CRITERIA

6.1 APPLICABLE CRITERIA FROM THE DSR, SECTION 3.4.6 (REFERENCE SECTION 5.13)

"The compressed air system supplies compressed air for ESF construction, testing, and operation. The surface compressed air system consists of pad-mounted compressor units producing the compressed air, as well as auxiliary equipment conditioning the compressed air (Reference Design Analysis ST-ME-011). The compressed air system will contain an approved tracer gas metered for control."

"The conditioning equipment includes oil separators and aftercoolers to provide a product safe for personnel use. The surface compressed air system supplies compressed air to meet the 100-psig demands of subsurface construction and testing. Booster compressors will be provided for the 200-psig pressure requirements of the large diameter drills."

6.2 APPLICABLE CRITERIA FROM THE ESFDR SECTION 3.2.5.2.6 COMPRESSED AIR SYSTEM (REFERENCE SECTION 5.14)

6.2.1 "The compressed air system shall provide compressed air throughout the designated areas of the ESF with flow rates and pressures to support construction and operations of the facilities, site characterization testing requirements, and drilling requirements including additional drift excavation."

6.2.2 "Compressed air shall be conditioned as required and a quantity maintained to meet drilling and test apparatus requirements (Reference ESFDR Appendix B). Suitable filtering shall be provided where oil-free air is required."

6.2.3 "The air compressor(s) shall be of a size to meet the requirements of ESF construction, testing, and operations. Modularity of the system to accommodate variable loads and system maintenance shall be considered."

6.2.4 "All compressed air used during operation and construction of the ESF shall not be provided with chemical tracers unless requested by the ESF Test Coordinator. All tracers and substances added shall be approved per Section 3.2.1.M.3."

6.2.5 "As an energy conservation measure, designers will examine the use of electrical and/or electrohydraulic drives for underground construction equipment as an alternative to compressed air wherever possible and feasible."

6.3 APPLICABLE CRITERIA FROM THE BFD, SECTION 7.2.4.6 IV.D. (Reference Section 5.29):

6.3.1 "The surface-based CAS shall support subsurface construction, testing and surface based maintenance by providing compressed air at the quantity, quality, and pressure required. CAS requirements will support the documented present and future needs of users. The CAS shall support the design requirements as described in ESFDR Appendix B.3.5 for testing." (BFD 7.2.4.6 IV.D.1.)

- 6.3.2** Provide for the initial installation of three (3) compressors with provisions in the future for a total of six (6) skid-mounted packaged air compressors. Each compressor is to have a nominal capacity of 1500 scfm. Provide compressed air to support subsurface testing and construction as well as surface-based maintenance of equipment. (BFD 7.2.4.6 IV.D.3.)
- 6.3.3** A coalescing filter will remove oil particulates and mists. Filters shall be modular skid mounted units utilizing lifting aids for installation and servicing. (BFD 7.2.4.6 IV.D.5.)
- 6.3.4** The pressure of compressed air supplied to the North Portal interface will be a minimum of 125 psig to support subsurface testing and construction requirements. (BFD 7.2.4.6 IV.D.6.)
- 6.35** To ensure subsurface operational reliability, the CAS shall be designed with approximately 50% excess capacity. (BFD 7.2.4.6 IV.D.7.)
- 6.3.6** The CAS will be designed to withstand the natural conditions and hazards at the ESF. Natural hazards must not interfere with provisions within the CAS for worker safety. Operation of the CAS must not be affected by the following hazards: (BFD 7.2.4.6 IV.D.8.)
- 6.3.6.1** Combinations: The CAS must be capable of withstanding a combination of natural hazards present at the ESF described below.
- 6.3.6.2** Temperature: The CAS must be capable of operating in ambient temperatures from -14 degrees F to 108 degrees F. Piping must be insulated and heat traced to prevent condensate from freezing.
- 6.3.7** Air/water separators will be installed at points in the system where condensate could occur. The condensate (oil and water) will be drained into a storage system and transferred offsite for processing. (BFD 7.2.4.6 IV.D.9.)
- 6.3.8** An electronic control system (ECS) shall utilize panels mounted on each skid to control and monitor CAS operations. The ECS shall interface with the site facility management system for remote monitoring, control, and fault detection. Manual switching and indication will be provided for local control of the panel. Control panels to be National Electrical Manufacturers Association rated, Underwriter's Laboratories, Inc. listed, and installed in accordance with NFPA-70. Lockout/tagout protection as required by 29 CFR 1910.147 shall be integrated into the CAS equipment controls. Provide for electronic detection of supply air hydrocarbon levels to indicate major compressor seal failures. (BFD 7.2.4.6 IV.D.16.)
- 6.3.9** The CAS shall utilize excessed oil-injected rotary-screw compressors available at the NTS. Provide for drain pans placed under compressors to contain normal leakage. (BFD 7.2.4.6 IV.D.18.)

6.3.10 Provide the CAS with a condensate removal/oil separation/oil storage system in accordance with the RCRA. [ESFDR Appendix J] (BFD 7.2.4.6 IV.D.20.)

7. ASSUMPTIONS

7.1 Stated volumetric values (scfm) are assumed at standard temperature and pressure (STP) unless stated otherwise. The STP is 70 degrees F and 14.7 psia, since values are corrected for actual temperature and elevation in Attachment II, no verification required.

7.2 Reserved.

7.3 The ambient temperature data source citing a maximum of 108 degrees F and minimum of -14 degrees F will not be exceeded for the life of the ESF North Portal Pad utilities. If actual temperature exceeds this range, the time spent outside the range is expected to be minimal with nominal effects to the operation of the CAS. Therefore, no verification required. (Reference Sections 5.3 and 8.2).

7.4 A 4 inch compressed air line to the Shop Building provides no additional load to the total CAS quantity. Items using compressed air in the shop are the same items (hand tools, drills, etc.) that would normally be used for subsurface excavation. Therefore, the compressed air used to maintain these items at the shop is not added to the subsurface supply. Since the net total is the same overall quantity required for subsurface operations, no verification required. (Reference Sections 5.11 and 5.12).

7.5 Moisture content of ambient air and compressed air is estimated from Tables 4.6 and 4.7 (Reference Section 8.1) for multiples of 10 degrees F, 5 percent relative humidity, and 10 psig. Since conditions are rounded to nearest table values and bounded within tabular ranges, no verification required.

7.6 Current operations philosophy for subsurface excavation is a normal work week of 5 days.

1st Shift	07:00-15:00	Maintenance and Operations (M&O)
2nd Shift	15:00-23:00	M&O
3rd Shift	23:00-07:00	M&O

(Verification required TBV-041)

8. REFERENCES

8.1 Compressed Air and Gas Handbook, fifth ed., Prentice-Hall Inc. 1989.

8.2 17-year Climatological Summary for Yucca Flat, Nevada. January 1962-April 1978. Provided to the Management and Operating (M&O) Contractor by B. Anzai of RSN. (Attachment I)

8.3 Reserved.

8.4 Mechanical Engineering Reference Manual, eighth ed., Michael Lindeburg, P.E.

8.5 Manchester Tank Catalog 4954-2/91.

9. COMPUTER PROGRAMS

| LOTUS 1-2-3 spreadsheets are used for portions of this analysis. As described in NLP-19-1 Rev. 0, 5.1.1, spreadsheet software does not require qualification for work subject to Quality Assurance Requirements Document (QARD) requirements.

10. DESIGN ANALYSIS

The body of this analysis is divided into three sections consisting of CAS requirements, CAS design, and CAS equipment analysis. The requirements section captures relevant information in chronological sequence to illustrate the evolution of requirements. Later requirements often supersede previous ones as part of the normal design development process. The documented evolution of requirements provides traceability, a requirement of the QARD.

10.1 CAS REQUIREMENT EVALUATION

The following requirements capture the evolution of the CAS. Some may no longer be applicable but are captured in this analysis to provide a traceable history of development. The latest and most current requirements are summarized in Section 10.2.

10.1.1 CAS General Requirements (Reference Section 6.2)

10.1.1.1 The CAS shall provide compressed air at the flow rates and pressures required to support construction, operations, site characterization testing, and additional drift excavation. (ESFDR 3.2.5.2.6 A).

10.1.1.2 The compressed air shall be conditioned and filtered to meet testing and drilling requirements (ESFDR 3.2.5.2.6 B).

10.1.1.3 The air compressors shall be of a size to meet the requirements of ESF construction, testing, and operations. Modularity of the system and maintenance shall be a consideration (ESFDR 3.2.5.2.6 C).

10.1.1.4 All compressed air used during operation and construction shall be injected with approved chemical tracers (ESFDR 3.2.5.2.6 D).

10.1.1.5 To conserve energy, the subsurface designers shall examine the use of electrical drives for subsurface construction equipment where applicable (ESFDR 3.2.5.2.6 E).

| 10.1.1.6 The CAS will provide air for life support to the subsurface refuge chambers. The refuge chambers will provide the necessary air filtration

equipment to allow the respiration of the CAS air. The CAS must be able to supply air contingency for up to 48 hours. The total quantity of air required for this service is 170 scfm at 100 psig (Reference 5.16, 5.30, 5.31, and 30 CFR 57.11052).

Provisions in the standby power generation system shall provide that power is available for the CAS to supply air to the refuge chambers.

10.1.2 CAS Design Volume Requirements

- 10.1.2.1** Original air volume requirement: 2200 cfm (125 psig discharge pressure) and 100 psig to tools. A total of six (6) 1500 cfm compressors, three (3) at each portal entrance was planned. A grand total of 9,000 cfm was to be installed with 3000 cfm of this available as standby capacity. (Reference Sections 5.1 and 5.17) These requirements were based on the simultaneous operation of two tunnel boring machines at each portal.
- 10.1.2.2** Interim air volume requirement: Based on conversation with subsurface engineers on the potential for expansion, 4,000 cfm was identified as a future operating requirement (Reference Section 5.3).
- 10.1.2.3** Interim air volume requirement: Request from D. F. Vanica to revise requirements to 2200 cfm (Reference Section 5.7).
- 10.1.2.4** Interim air volume requirement: Volumetric requirements established at 2560 cfm based on meeting with subsurface engineers and the testing and performance assessment community (Reference Section 5.5).
- 10.1.2.5** Interim air volume requirement: Design air volume requirement established at 2500 cfm, with a peak demand of 3000 cfm (Reference Section 5.15).
- 10.1.2.6** Final air volume requirement: Design air volume requirement established at 2376 scfm from subsurface design analysis (Reference Section 5.16).

10.1.3 CAS Pressure Requirements

- 10.1.3.1** The original air pressure requirement was 125 psig discharge pressure allowing a conservative 100 psig for tools (@2200 cfm) (Reference Section 5.17).
- 10.1.3.2** The final pressure requirements established at 125 psig to North Portal entrance (Reference Section 5.5).

10.1.4 CAS Air Quality Requirements

10.1.4.1 Oil-free air is identified as an operating requirement (Reference Section 5.3).

10.1.4.2 DIE analysis indicates that the CAS be oil-free (Reference Section 5.4).

10.1.4.3 ANSI/ISA-S7.3 was determined as a reference for air quality (Instrument Air Standard). Nominal filtering of particulates established at 3 microns. Dewpoint established at least 18 degrees F below ambient. Hydrocarbons established at less than one (1) ppm concentration (Reference Section 5.5).

10.1.4.4 Comments from B. Anzai at the 90 percent design review for Design Package 1C questioned the need for air quality up to the ANSI/ISA standard as determined in Reference Section 5.5. Reassessment by the testing and performance assessment community determined that the requirement for air drying and hydrocarbon vapor removal could be deleted. This decision resulted in the removal of the air dryer skid, carbon adsorption filters, and chemical injection system (Reference Sections 5.20, 5.22, 5.23 and 5.24).

10.1.4.5 Waste Isolation Analysis suggests that the minimum recommended level of organic deposition within the fourth segment of the tunnel be limited to 10 grams per meter of total excavation (Reference Section 5.21).
NOTE: This recommendation is shown for information only, and is not a requirement. The purpose of this information is offered as consideration for the determination of importance evaluation.

10.1.5 Equipment and Piping Requirements

10.1.5.1 Originally, the equipment specified for the CAS would be new equipment. However, DOE program budgetary constraints have forced YMP to use excess NTS equipment for the CAS. Several compressor units are identified as candidates (Reference Sections 5.6, 5.10, 5.25, 5.26, 5.27).

10.1.5.2 Originally, six (6) rotary-screw compressors rated at 1500 cfm, 125 psig, and 300 hp were proposed (Reference Section 10.1.2.1). Three units located at each portal shall allow for system maintenance and reliability (Reference Sections 5.17 and 5.1).

10.1.5.3 Piping for the surface portion of the CAS will be supported from beneath the muck conveyer (Reference Section 5.8).

10.1.5.4 Provide a 4 inch line to the Shop Building for supporting maintenance of underground equipment (Reference Sections 5.11 and 5.12).

- 10.1.5.5** DIE analysis indicates that the CAS utilize air-cooled equipment (Reference Sections 5.4 and 5.18).
- 10.1.5.6** Oil-free air-cooled rotary screw (ACRS) compressors are required based on meeting with the subsurface design group and the testing-performance assessment community. The compressor module size approximates 750 cfm. Electrical requirements are 480 V, 3 ph, 200 hp, for each of five (5) compressors. Redundancy established at one (1) module. Compressors to be mounted on oil-field type skids, not requiring a pad (Reference Section 5.5).
- 10.1.5.7** Three (3) excess oil-injected ACRS compressors are identified at NTS and are set aside for use by YMP M&O in designing the ESF CAS. The excess equipment is skid mounted and will require a concrete slab for installation (Reference Sections 5.10 and 5.19).
- 10.1.5.8** Two (2) ACRS compressor units were purchased with YMP funds and never installed. These units were manufactured by Ingersoll-Rand (I-R) in 1983 and are rated at 1500 scfm @ 125 psig. The I-R compressors are field-mounted on skids along with motor control centers. Assembly drawings and procurement specifications are reported missing and presumed lost at NTS. These units have been in storage for approximately 10 years. Conversation with the manufacturer's representative indicates that these units will require refurbishment of the seals, shafts, and bearings. Also, recalibration to 1365 scfm @ 150 psig by a factory authorized service center will be required (Reference Sections 5.10, 5.26).
- 10.1.5.9** One (1) compressor unit is a "Quincy" model Q-1500, rated at 1500 scfm @ 125 psig and manufactured by Colt Industries in 1981. The unit has been in operation at the NTS having logged 12,000 hrs. Refurbishment to ensure reliability is required as well as recalibration to 1365 scfm @ 150 psig by a factory authorized service center during refurbishment (Reference 5.10, 5.25).

10.1.6 CAS Interfacing Requirements

- 10.1.6.1** Interface point with the subsurface compressed air piping is established at the base of the conveyer tower and in proximity of the CAS pad (Reference Section 5.9).
- 10.1.6.2** Interface point with the subsurface compressed air piping established at the chemical injection skid located in proximity of the conveyer tower. A 4 by 6 foot concrete slab and 110V electrical power will be required for the injection system and will be shown by electrical surface design. Subsurface designers will be responsible for the design of the tracer injection system (Reference Section 5.5).

10.1.6.2.1 The gas-tracer injection system shall inject a nominal concentration of six parts per million of sulfur hexafluoride (SF6) into the compressed air system provided to the ESF portal (Reference Section 5.2).

10.1.6.3 The surface-based tracer injection system has been deleted. CAS tracers (where required) are to be administered underground near the required testing apparatus (Reference Sections 5.20, 5.22, 5.23 and 5.24).

10.1.6.4 Coordination with civil designers determines the following interfaces for CAS piping. The future interface for the continuation of compressed air piping is anticipated to occur at:

10.1.6.4.1 The 8 inch main CAS supply interface established at coordinates: N765192.24, E570042.44. (TBV-043)

10.1.6.4.2 The 4 inch CAS supply to shop interface established at coordinates: N765188.43, E570055.58. (TBV-043)

10.2 CAS DESIGN

From Section 10.1, the design requirements for the CAS are as summarized:

10.2.1 Reference Sections 5.1 and 5.17 assume two tunnel boring machines, one approaching from each portal and meeting in the middle. Current philosophy is to use only one machine to do the main tunnel excavation. This change requires that the supporting utilities be sized for the entire tunnel excavation. Therefore, provisions are to be made to add three (3) more 1500 cfm compressors (excess equipment) to the North Portal in the future.

10.2.2 The design volume and pressure requirements are 2376 acfm and 125 psig provided to the North Portal entrance. The discharge pressure of the compressors will be 150 psig to overcome the pressure drop associated with ancillary equipment.

10.2.3 To satisfy the requirements of Section 10.1.4.3 and the testing and performance assessment requirements of the project (Reference Section 5.5), the following compressed air system accessory components are required (as skid mounted packaged modules). The following will be located in built-up trains of in-line components:

10.2.3.1 External aftercoolers - sized to cool the discharge air to within 3 degrees F of ambient.

10.2.3.2 Moisture separator - Automatically purges condensate produced by the aftercooler. Protects air tools from excessive gumming.

10.2.3.3 Air receivers - sized to serve each compressor. Protects system components from oil slugs possible when oil-injected screw compressors suffer a massive failure. Improves equipment life by providing a reservoir to prevent compressor short cycling. Provides additional refuge air capacity under emergency situations.

10.2.3.4 Coalescing filter - captures hydrocarbon particulates and aerosols to protect downstream piping from excessive oil buildup.

10.3 EQUIPMENT ANALYSIS

10.3.1 Definitions

acfm: Actual cubic feet per minute corrected for temperature and pressure.

scfm: Standard cubic feet per minute @14.7 psia, 70 degrees F (528 degrees R), dry air.

10.3.2 Compressors - The compressors are nominally rated for applications at STP. Corrections for altitude and temperature are calculated to predict actual performance.

For low temperatures and pressures, air can be considered an ideal gas. By definition, ideal gases behave according to the ideal gas laws. The general ideal gas law shows the relationships between pressure, volume, and temperature (Reference Section 8.4):

$$\frac{P_1 V_1 T_2}{T_1} = P_2 V_2$$

and

$$V_2 = \left(\frac{P_1}{P_2}\right) \left(\frac{T_2}{T_1}\right) V_1$$

where:

P= pressure in lbs./sq. ft. absolute

V= volume in cu. ft.

T= absolute temperature (°R)

The ratios P_1/P_2 and T_2/T_1 can be represented as correction factors for pressure and temperature. Attachment II shows these correction factors in tabular format.

The manufacturer (I-R) estimates a rerating for 150 psig operation at STP of: 1365 scfm. Applying correction factors from Attachment II to the rerated standard condition yields the following:

$$1365 \text{ scfm} \times 0.811436 = 1107.6 \text{ say } 1110 \text{ acfm}$$

$$1110 \text{ acfm} \times 3 \text{ compressors} = 3330 \text{ acfm}$$

Given that the demand requirement of 2376 scfm (10.1.2.6) represents the actual tool demands from the corrected supply of 3330 acfm, the actual compressor loading factor is:

$$\frac{2376}{3330} = .7135 \text{ or } 71\%$$

10.3.3 Compressed Air Receiver Sizing

A common approach to sizing receivers is to select one to provide one minute's storage. The following formula is normally used (Reference Section 8.1, Page 237):

$$T = V \frac{P_1 - P_2}{P_0(C - S)}$$

T = Time (minutes)

P_1 = initial pressure, psig

P_2 = final pressure, psig

P_0 = atmospheric pressure, psia

V = receiver capacity, ft^3

C = air requirement out of receiver, acfm

S = air charging receiver, acfm

Rearranging,

$$V = T \left[\frac{P_0(C - S)}{P_1 - P_2} \right]$$

Receiver size must be evaluated for the expected site conditions. These conditions provide a range of operating temperatures from -14 degrees F to 108 degrees F and at an elevation of 3680 ft. Table 1 lists the variables at STP and at the ambient extremes. Correction factors are found in Attachment II.

Table 1. Variables at STP and at the Ambient Extremes.

VARIABLE	STP	108°F	-14°F
Corr. Factor	0	0.811	1.033
T = minute	1	1	1
P ₁ = psig	0	0	0
P ₂ = psig	150	150	150
P _o = psia	14.7	11.9	15.2
C = acfm	0	0	0
S = acfm	1365	1110	1410

For 108°F:

$$V_{108} = (1) \left[\frac{11.9 (0-1110)}{(0-150)} \right] = 88.0 \text{ ft}^3$$

$$88.0 \times 7.46 \text{ gal/ft}^3 = 656 \text{ gallons}$$

For -14°F:

$$V_{-14} = (1) \left[\frac{15.2(0-1410)}{(0 - 150)} \right] = 142.9 \text{ ft}^3$$

$$142.9 \times 7.46 \text{ gal/ft}^3 = 1065 \text{ gallons}$$

From Reference 8.5, choose a 1060 gallon (142 ft³) Receiver Tank.

Time to fill receiver at -14 degrees F is 1 minute. At 108 degrees F the time to fill is:

$$T = V \left[\frac{(P_1 - P_2)}{P_o (C-S)} \right]$$

$$= 142 \left[\frac{(0-150)}{11.9 (0-1110)} \right] = 1.6 \text{ minutes}$$

10.3.4 Oil Entrainment Calculation

(NOTE: The following calculation is offered as consideration for the determination of importance evaluation.)

One purpose of injecting oil into a rotary screw compressor is to provide a seal between the helical rotors. Some of this "seal oil" is entrained in the discharge air and is mostly removed by the integral oil separator. Of the small amount of oil left, most is condensed from the discharge air along with water as the airstream cools, some is removed by the coalescing filter, and the remainder ends up at the end user.

Depending on the age of the compressor, the discharge air oil concentration can be between two (2) and six (6) parts per million. Because of the potential for interference with ESF characterization procedures, the amount of oil entrained in the compressor discharge air needs to be accounted for. Attachment IV calculates the amount of oil expected to be entrained in the air or removed by filters in the system.

The following data used for calculation of oil entrainment is based on engineering judgement and the most current information available:

- Discharge from the compressor air end is estimated at 4 ppm (average between 2 and 6 ppm). Reference Attachment V for determination of gallons of oil produced.
- A total of 25,000 feet of excavation is expected to be accomplished within two years.
- The deposition rate of oil on the tunnel walls originating from the CAS is assumed at 80 percent.
- The efficiency of the coalescing filter, initially rated at 99.99 percent (at 35 degrees F), is estimated to fall to 68 percent at the 108 degrees F summer extreme.
- The estimated density of oil used by the air compressors is 54.9 lb/ft³. (Attachment V)

The maximum amount of oil entrained at the compressor discharge is estimated by the following equation (see Section 7 and Attachment IV):

$$\left[\frac{2.46 \text{ Gal}}{1000 \text{ HR} \times 1000 \text{ CFM}} \right] \times \left[\left(\frac{3 \text{ Shift}}{\text{Day}} \right) \left(\frac{8 \text{ Hr}}{\text{Shift}} \right) \left(\frac{5 \text{ Day}}{\text{Week}} \right) \left(\frac{52 \text{ Week}}{\text{Yr}} \right) \right] \times$$

$$\left[\left(\frac{54.9032 \text{ lb}}{\text{cu ft}} \right) \left(\frac{\text{cu ft}}{7.48 \text{ Gal}} \right) \right] \times \left[\frac{2376 \text{ cu ft}}{\text{Min}} \right] = 267.7 \text{ lb/yr (TBV-041)}$$

with the coalescing filter rated at 68% removal efficiency, the remainder is:

$$[1.00 - 0.68] 267.7 = 85.67 \text{ lb/yr} \quad \text{say} \quad 85.7 \text{ lb/yr}$$

$$\left(\frac{85.67 \text{ lb}}{\text{Yr.}}\right)(0.80)\left(\frac{2 \text{ Yr}}{25,000 \text{ ft}}\right)\left(\frac{453.59 \text{ gm}}{\text{lb}}\right)\left(\frac{3.28 \text{ ft}}{\text{m}}\right) = 8.16 \text{ gm/m say } 8.2 \text{ gm/m (TBV-041)}$$

Estimated deposition rate:

The results of the oil entrainment calculation on Attachment IV indicate that the coalescing filter will remove at least 121 lbs of oil annually from the compressed air supply. Under actual operating conditions, the coalescing filter will remove more oil as the average ambient temperature is much less than the summer extreme used for design.

After the coalescing filter, the annual amount of entrained oil in the supply air is a maximum of 85.7 pounds. This translates into an estimated deposition of oil on the tunnel surfaces of 8.2 grams (TBV-041) per meter of excavation. The 10 gram per meter limit suggested by Reference Section 5.21 is thereby accomplished.

10.3.5 Condensate Removal System

Liquid condensate produced by the CAS must be controlled as described in Section 2.1.2. These controls indicate that a receiver is required to hold the condensate. This section shall size the receiver.

The method of sizing a condensate receiver is as follows:

- Determine the amount of condensate produced.
- Combine water and coalesced oil amounts to determine the total volume of receiver required.
- Select and size a condensate receiving/removal system, based on life-cycle cost analyses (Reference 5.28).

10.3.5.1 Calculations

10.3.5.1.1 Determine the Average Ambient Condensate Production

From Attachment I and Table 4.6 (Reference Section 8.1) the following values have been tabulated.

Table 2. Ambient Moisture Values

Month	Avg Dry Bulb Temp (°F)	Relative Humidity					Ambient Moisture (Gal/1000 ft³)
		Hour				Avg	
		04	10	16	22		
Jan	35.8	71	53	39	65	57	.0215
Feb	41.3	69	45	32	57	51	.0238
Mar	44.6	61	34	25	47	42	.0190
Apr	50.9	53	27	19	38	35	.0244
May	61.3	48	22	15	32	29	.0301
Jun	69.6	39	18	13	25	24	.0356
Jul	76.8	39	19	14	27	25	.0498*
Aug	75.4	43	22	15	29	27	.0498*
Sep	66.7	45	22	18	33	30	.0427
Oct	55.9	52	27	21	41	35	.0351
Nov	44.3	62	39	30	53	46	.0314
Dec	36.9	68	48	39	63	55	.0215

*July and August have the highest average ambient moisture values of .0498 gallons/1000 ft³. The average ambient temperature plus 3 degrees superheat (aftercooler approach temperature) yields 79.8 degrees F, or say 80 degrees F. Comparison with the value in Table 4.7 (Reference Section 8.1) of moisture content of saturated air at 80 degrees F and 150 psig gives .0177 gallons of water/1000 ft³ air.

The estimated average amount of condensate produced for three compressors is:

$$[2376 \text{ scfm} \times (.0498 - .0177) \text{ Gal}]/1000 \text{ ft}^3$$

$$= .0763 \text{ Gal/Min}$$

$$= 4.58 \text{ Gal/Hr}$$

$$= 110 \text{ Gal/Day (24 Hr Operation)}$$

10.3.5.1.2 Determine Estimated Peak Condensate Production

The peak estimated amount of condensate produced will most likely occur within the three months shown with the highest average ambient moisture content shown in Table

3. Further expansion is needed to establish peak loads. Using the peak monthly temperature along with the relative humidity occurrence in hour 1600 will give a better estimate of the peak load.

Table 3. Peak Ambient Moisture

Month	Peak Temp of	R. H. @ 1600 hr. %	Interpolated Moisture Content Table 4.6 (Ref. 8.1)
Jul	108	14	.06680
Aug	108	15	.07162
Sep	105	18	.07918*

*The estimated peak ambient moisture content is: .07918 gal/1000 ft³

Comparison with the value shown in Table 4.7 (Reference Section 8.1) estimated for an ambient of 110°F and 150 psig gives .0447 gallons water/1000 ft³ air.

$$[2376 \text{ scfm} \times (.07918 - .0447) \text{ Gal}]/1000 \text{ ft}^3$$

$$= 4.91 \text{ Gal/Hr}$$

$$= 117.9 \text{ Gal/Day (24 Hr Operation)}$$

Comparison with average ambient conditions as shown in Section 10.3.5.1.1, indicates that peak conditions dominate condensate production over average conditions.

10.3.5.1.3 Condensate Receiving Tank Sizing

From Section 10.3.5.1.2, the peak condensate productions estimated at 118 gallons daily. From Attachment IV, oil removed by the coalescing filter and accessories and transferred to the condensate receiving system is:

$$267.7 \text{ lb/yr} - 85.7 \text{ lb/yr} = 182 \text{ lb/yr}$$

conventional to a daily amount,

$$(182 \text{ lbs/yr}) \left(\frac{1 \text{ Yr-Shift}}{2080 \text{ Hr}} \right) \left(\frac{1}{3 \text{ Shift}} \right) \left(\frac{\text{ft}^3}{54.9 \text{ lb}} \right) \left(\frac{7.48 \text{ Gal}}{\text{ft}^3} \right) = .00397 \text{ Gal/Hr}$$

$$= .095 \text{ Gal/Day.}$$

Compared to the peak daily production of condensate at 118 gallons, oil addition to the condensate receiver is insignificant and not a factor for sizing.

To size the receiver, use average condensate production rates as determined in 10.3.5.1.1 for three shifts.

Table 4. Daily Condensate Total

SHIFT	AIR DEMAND (SCFM)	CONDENSATE PRODUCTION RATE (Gal/Hr)	CONDENSATE FOR SHIFT (Gal)
1st	2,376	4.58	36.64
2nd	2,376	4.58	36.64
3rd	2,376	4.58	36.64

Total Daily Condensate: 110 Gallons/Day

Allowing for the tank to be pumped out by a tanker truck with capacity for 1150 gallons (Attachment III) allows for a service interval of $1150 \div 110 = 10.5$ days.

Sizing the tank using UL-142 (Reference 4.4), the minimum volume required is $1150 / .90 = 1280$ gallons. The nearest nominal size for a condensate receiving tank is 1500 gallons.

The life-cycle analysis for the Condensate Receiving System supports (Reference 5.28) the selection of a 1500 gallon as the most cost effective alternative.

10.3.5.1.4 Determine Oil Disposal Amount

(NOTE: The following calculation is offered as consideration for the determination of importance evaluation.)

From Section 10.3.4 the discharge of oil from the CAS is estimated at 267.7 lb/yr. Of this amount, 85.7 lb is fully entrained and discharged in the final air stream. (Reference 10.3.4) The remainder,

$$268 - 86 = 182 \text{ lb/yr}$$

is lost by the compressor and captured in the Condensate Receiving System.

11. CONCLUSIONS

The following conclusions are provided for capture by the BFD for the CAS.

- 11.1 The air volume requirement needed to support the initial subsurface and surface needs is calculated to be 2376 scfm at 150 psig.
- 11.2 The current CAS design uses three (3) compressors to support current requirements. A total of 3330 acfm is available providing a 71 percent loading factor.
- 11.3 The CAS design can accommodate future unspecified needs with up to three (3) additional compressors (six [6] total).
- 11.4 The CAS design supports compressed air requirements by providing suitable filtering, storage, and condensate containment accessories.
- 11.5 Excessed compressors at NTS have been identified to be refurbished to supply the needs of the CAS.
- 11.6 Coalescing filtration is the only technology needed to meet air quality requirements. The estimated maximum subsurface oil deposition rate is 8.2 grams per meter. (TBV-041)
- 11.7 Surface-based injection of tracers in the compressed air is not required.
- 11.8 The estimated peak condensate production is approximately 118 gallons per day and the average condensate production is estimated at 110 gallons/day.
- 11.9 The air receiver volume for each compressor is sized at 1060 gallons.
- 11.10 The condensate receiving tank volume is sized at 1500 gallons.
- 11.11 The maximum service interval for draining the condensate receiving tank is 10 days.
- 11.12 The CAS will provide 170 scfm to each subsurface refuge chamber for a continuous period of not less than 48 hours during an emergency.

12. ATTACHMENTS

ATTACHMENT

TITLE

I	I	17-Year Climatological Summary
	II	Combined Air Density Correction Factors
I	III	REECO Condensate Disposal Summary
	IV	Oil Entrainment Calculation Spreadsheet
	V	Oil Content of Compressed Air
I		(Atlas Copco Industrial Compressors, Inc.)

Title: North Portal Surface-Based Compressed Air System Analysis

MONTH		JAN	FEB	MAR	APR	MAY	JUN		JUL	AUG	SEP	OCT	NOV	DEC		ANN
P R E C I P I T A T I O N (Inches)	AVERAGE	0.87	1.05	0.65	0.41	0.33	0.31		0.53	0.45	0.81	0.40	0.59	0.68		6.88
	GREATEST MONTHLY	4.02	3.60	3.50	2.57	1.62	2.66		1.87	2.52	2.38	1.69	3.02	2.66		4.02
	YEAR	1969	1978	1978	1965	1971	1972		1976	1977	1969	1976	1965	1965		1/69
	LEAST MONTHLY	0	0	0	T	0	0		0	0	0	0	0	T		0
	YEAR	1972/76	1972/77	1972	1962/77	1976	1974/76		1963	1962	1968	1967	1962/76	1969/72		2/77#
	GREATEST DAILY	1.25	1.51	0.99	1.08	0.86	1.03		1.10	2.18	2.13	1.65	1.10	1.31		2.18
	YEAR	1969	1976	1978	1965	1971	1972		1976	1977	1969	1976	1970	1965		8/77
	AVERAGE	2.9	1.3	1.9	0.4	*	0		0	0	0	*	0.7	2.1		9.3
	GREATEST MONTHLY	29.1	17.4	9.0	3.0	0.2	0		0	0	0	T	6.6	9.9		29.1
	YEAR	1974	1969	1969	1964	1975						1971	1972	1971		1/74
R E L A T I V E (%)	S N O W	GREATEST DAILY	10.0	6.2	7.5	3.0	0.2	0	0	0	0	T	6.6	7.4		10.0
		YEAR	1974	1969	1969	1964	1975					1971	1972	1971		1/74
	H O U R (PST)															
		04	71	69	61	53	48	39	39	43	45	52	62	68		54
		10	53	45	34	27	22	18	19	22	22	27	39	48		31
		16	39	32	25	19	15	13	14	15	18	21	30	39		23
		22	65	57	47	38	32	25	27	29	33	41	53	63		42

* One or more occurrences during the period of record but average less than 0.5 day.

Most recent of multiple occurrences.

↑ Data period from January 1962 to December 1971.

(a) Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy and cloudy are defined as average daytime cloudiness of 0-3, 4-7 and 8-10 tenths, respectively.

Title: North Portal Surface-Based Compressed Air System Analysis

MONTH		JAN	FEB	MAR	APR	MAY	JUN		JUL	AUG	SEP	OCT	NOV	DEC		ANN
W I N D (Speeds in MPH)	AVERAGE SPEED	6.0	6.8	8.6	9.1	8.0	7.9		7.5	6.8	6.7	6.5	6.0	6.2		7.2
	PEAK SPEED	58	60+	56+	60+	60+	60		55	60+	60	60	60+	53		60+
	YEAR	1965	1976	1975	1967/70	1967	1967		1971	1968	1976	1971	1973	1970		2/76#
	23-02 (PST)	233/01	275/01	240/02	250/02	260/02	272/02		278/01	222/02	281/01	286/01	234/01	288/02		261/01
	11-14 (PST)	135/03	118/03	186/05	198/05	179/07	185/08		185/12	182/12	183/06	138/04	152/04	109/01		174/06
S T A T I O N (Inches)	AVERAGES	26.09	26.06	25.98	25.95	25.93	25.93		26.00	26.00	26.00	26.05	26.08	26.08		26.01
	HIGHEST	26.54	26.47	26.43	26.39	26.39	26.26		26.22	26.22	26.36	26.40	26.58	26.59		26.59
	LOWEST	25.42	25.31	25.47	25.50	25.42	25.42		25.67	25.71	25.56	25.52	25.31	25.49		25.31
(a) AVERAGE SKY COVER SUNRISE TO SUNSET		4.9	5.2	5.1	4.4	4.2	3.0		2.7	2.7	2.3	3.1	4.7	4.5		3.9

* One or more occurrences during the period of record but average less than 0.5 day.

Most recent of multiple occurrences.

↑ Data period from January 1962 to December 1971.

(a) Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy and cloudy are defined as average daytime cloudiness of 0-3, 4-7 and 8-10 tenths, respectively.

Title: North Portal Surface-Based Compressed Air System Analysis

MONTH			JAN	FEB	MAR	APR	MAY	JUN		JUL	AUG	SEP	OCT	NOV	DEC		ANN		
A V E R A G E N U M B E R O F D A Y S	S U N R I S E	T O S U N S E T	CLEAR	13	11	12	13	15	18		20	21	21	20	13	15		192	
			PARTLY CLOUDY	8	7	8	9	9	8		8	7	6	7	8	7		92	
			CLOUDY	10	10	11	8	7	4		3	3	3	4	9	9		81	
	P R E C I P I T A T I O N		.01 INCH OR MORE	3	4	4	3	2	2		3	3	2	2	3	3		34	
			.10 INCH OR MORE	2	2	2	1	1	1		1	1	1	1	2	1		16	
			.50 INCH OR MORE	1	1	*	*	*	*		*	*	*	*	*	1		3	
			1.00 INCH OR MORE	*	*	0	*	0	*		*	*	*	*	*	*		1	
		1.0 INCH OR MORE OF SNOW		1	1	1	*	0	0		0	0	0	0	*	1		4	
		THUNDERSTORMS		*	0	1	1	2	2		3	3	2	1	*	*		15	
		T E M P E R A T U R E	M A X I M U M	90° F OR MORE	0	0	0	0	4	15		29	25	11	1	0	0		85
				OR 32° F OR LESS	1	0	0	0	0	0		0	0	0	0	0	1		2
	M I N I M U M		32° F OR LESS	29	24	23	13	2	0		0	0	1	9	24	30		155	
			0° F OR LESS	1	0	0	0	0	0		0	0	0	0	0	0		1	

* One or more occurrences during the period of record but average less than 0.5 day.

Most recent of multiple occurrences.

↑ Data period from January 1962 to December 1971.

(a) Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy and cloudy are defined as average daytime cloudiness of 0-3, 4-7 and 8-10 tenths, respectively.

Title: North Portal Surface-Based Compressed Air System Analysis

COMBINED AIR DENSITY CORRECTION FACTORS
(COMPRESSOR INLET CONDITIONS)

Date: 04/04/94

Revision: 0

By: C. Mellen

Page: 1 of 1

REFERENCE DENSITY 0.075 lb/cu. ft.

REFERENCE TEMP. = 70° F

Elevation
(Feet) Elevation
Factor

5000	0.822846	0.991155	0.977821	0.96913	0.948061	0.92789	0.908559	0.890017	0.872217	0.855114	0.83867	0.822846	0.807608	0.792924	0.778765	0.767796	0.765102
4800	0.829932	0.999691	0.986242	0.977475	0.956226	0.935881	0.916383	0.897682	0.879728	0.862478	0.845892	0.829932	0.814563	0.799753	0.785471	0.774408	0.771691
4600	0.837018	1.008226	0.994663	0.985821	0.96439	0.943872	0.924208	0.905346	0.887239	0.869842	0.853115	0.837018	0.821518	0.806581	0.792178	0.78102	0.77828
4400	0.844104	1.016762	1.003084	0.994167	0.972555	0.951862	0.932032	0.913011	0.894751	0.877206	0.860337	0.844104	0.828473	0.81341	0.798884	0.787633	0.784869
4200	0.85119	1.025298	1.011504	1.002513	0.980719	0.959853	0.939856	0.920675	0.902262	0.88457	0.86756	0.85119	0.835428	0.820238	0.805591	0.794245	0.791458
4000	0.858277	1.033833	1.019925	1.010859	0.988884	0.967844	0.94768	0.92834	0.909773	0.891935	0.874782	0.858277	0.842383	0.827067	0.812298	0.800857	0.798047
3800	0.865363	1.042369	1.028346	1.019205	0.997048	0.975835	0.955505	0.936005	0.917285	0.899299	0.882004	0.865363	0.849338	0.833895	0.819004	0.807469	0.804636
3600	0.869615	1.04749	1.033398	1.024213	1.001947	0.980629	0.960199	0.940603	0.921791	0.903717	0.886338	0.869615	0.853511	0.837992	0.823028	0.811436	0.808589
3400	0.872449	1.050904	1.036767	1.027551	1.005213	0.983825	0.963329	0.943669	0.924796	0.906663	0.889227	0.872449	0.856293	0.840724	0.825711	0.814081	0.811224
3200	0.879535	1.05944	1.045188	1.035897	1.013377	0.991816	0.971153	0.951334	0.932307	0.914027	0.896449	0.879535	0.863247	0.847552	0.832417	0.820693	0.817813
3000	0.886621	1.067976	1.053608	1.044243	1.021542	0.999807	0.978978	0.958999	0.939819	0.921391	0.903672	0.886621	0.870202	0.854381	0.839124	0.827305	0.824402
2800	0.893707	1.076511	1.062029	1.052589	1.029706	1.007798	0.986802	0.966663	0.94733	0.928755	0.910894	0.893707	0.877157	0.861209	0.84583	0.833917	0.830991
2600	0.900794	1.085047	1.07045	1.060935	1.037871	1.015789	0.994626	0.974328	0.954841	0.936119	0.918117	0.900794	0.884112	0.868038	0.852537	0.840529	0.83758
2400	0.90788	1.093583	1.078871	1.069281	1.046035	1.023779	1.002451	0.981992	0.962353	0.943483	0.925339	0.90788	0.891067	0.874866	0.859243	0.847141	0.844169
2200	0.914966	1.102118	1.087291	1.077627	1.0542	1.03177	1.010275	0.989657	0.969864	0.950847	0.932561	0.914966	0.898022	0.881694	0.86595	0.853753	0.850758
2000	0.922052	1.110654	1.095712	1.085973	1.062364	1.039761	1.018099	0.997322	0.977375	0.958211	0.939784	0.922052	0.904977	0.888523	0.872657	0.860366	0.857347
1800	0.929138	1.119189	1.104133	1.094318	1.070529	1.047752	1.025924	1.004986	0.984887	0.965575	0.947006	0.929138	0.911932	0.895351	0.879363	0.866978	0.863936
1600	0.936224	1.127725	1.112554	1.102664	1.078693	1.055743	1.033748	1.012651	0.992398	0.972939	0.954229	0.936224	0.918887	0.90218	0.88607	0.87359	0.870525
1400	0.943311	1.136261	1.120975	1.11101	1.086858	1.063733	1.041572	1.020316	0.999909	0.980303	0.961451	0.943311	0.925842	0.909008	0.892776	0.880202	0.877113
1200	0.950397	1.144796	1.129395	1.119356	1.095022	1.071724	1.049396	1.02798	1.007421	0.987667	0.968674	0.950397	0.932797	0.915837	0.899483	0.886814	0.883702
1000	0.957483	1.153332	1.137816	1.127702	1.103187	1.079715	1.057221	1.035645	1.014932	0.995031	0.975896	0.957483	0.939752	0.922665	0.906189	0.893426	0.890291
800	0.964569	1.161867	1.146327	1.136048	1.111351	1.087706	1.065045	1.04331	1.022443	1.002395	0.983119	0.964569	0.946707	0.929494	0.912896	0.900038	0.89688
600	0.971655	1.170403	1.154658	1.144394	1.119516	1.095696	1.072869	1.050974	1.029955	1.009759	0.990341	0.971655	0.953662	0.936322	0.919602	0.90665	0.903469
400	0.978741	1.178939	1.163078	1.15274	1.12768	1.103687	1.080694	1.058639	1.037466	1.017124	0.997563	0.978741	0.960617	0.943151	0.926309	0.913262	0.910058
200	0.985828	1.187474	1.171499	1.161086	1.135845	1.111678	1.088518	1.066303	1.044977	1.024488	1.004786	0.985828	0.9675720.97	0.949979	0.933015	0.919874	0.916647
0	0.992914	1.19601	1.17992	1.169432	1.144009	1.119669	1.096342	1.073968	1.052489	1.031852	1.012008	0.992914	4527	0.956808	0.939722	0.926486	0.923236
0	1	1.204545	1.188341	1.177778	1.152174	1.12766	1.104167	1.081633	1.06	1.039216	1.019231	1	0.981481	0.963636	0.946429	0.933099	0.929825

Temperature Factor =

1.204545

1.188341

1.177778

1.152174

1.12766

1.104167

1.081633

1.06

1.039216

1.019231

1

0.981481

0.963636

0.946429

0.933099

0.929825

-20

-14

-10

0

10

20

30

40

50

60

70

80

90

100

108

110

TEMPERATURE (DEGREES F)

elevation factor

 $\frac{\text{ref. pressure} - (\text{ref. density} \times \text{actual elevation})}{144}$

ref. pressure

temperature factor:

 $\frac{\text{ref. temp.} + 460}{\text{actual temp.} + 460}$

actual temp. +460

OIL ENTRAINMENT CALCULATION SPREADSHEET

COMPRESSED AIR OIL ENTRAINMENT CALCULATION Rev. 01

FN: CASANL01.WK3

Date: 11/03/94

Page 1 of 1

Status: FINAL

By: C. Mellen

ASSUMPTIONS:

** = based on Atlas-Copco data for 4 ppm; 2.46 gallons/1000 hrs-1000cfm

Density: Air = 0.075 lb/cuft Oil = 54.9032 lb/cuft

Operations: 3 shifts for 5 days / wk 52 weeks/year 6240 annual hours (total)
 25000 feet of total excavation 80.00% HC deposition rate
 2 year excavation lifespan

Flow Schematic	Air Flow Rate	Air Stream HC entrained	Underground HC deposition rate	Remarks
Air compressors 150 psig each @ 1500 scfm req'd units 1.584 load fact 0.792 HC ave 4 ppm 2.46E-06 gal/hr-cfm Integral aftercooler est. coolin 50 degrees F	2376	267.7085 lb/yr *	25.49057 gm/m	oil entrained in air
External aftercooler and Moisture separator	2376			
Coalescing filter eff. = 68.00% HC	2376	85.66673 lb/yr *	8.156981 gm/m	HC left in air est. removal eff. @ 108F
182.0418 lb/yr				oil removed by filter
Component Demands Surface maint. LF. 1 0 scfm	2376	0 lb/yr *	0 gm/m	est. load factor no concurrent demand identified
Leakage @ 10.00% 216 scfm	2376	7.787884 lb/yr *	0.741544 gm/m	est. leakage rate of 10%
TBM 0 scfm	2160	0 lb/yr *	0 gm/m	
Mapping 400 scfm	2160	10.81651 lb/yr *	1.029922 gm/m	
Shotcreting 400 scfm	1860	10.81651 lb/yr *	1.029922 gm/m	
Core drill 400 scfm	1560	10.81651 lb/yr *	1.029922 gm/m	requires subsurf filtration
Hand tools 1500 scfm	1260	40.5619 lb/yr *	3.862207 gm/m	
Alcove test 180 scfm	135	4.867428 lb/yr *	0.463465 gm/m	requires subsurf filtration
Total Air Stream		HC entrained	Total Underground	HC deposition rate
		85.66673 lb/yr *		8.156981 gm/m

OIL CONTENT OF COMPRESSED AIR

WORLD TECHNOLOGY
AMERICAN KNOWHOW

Atlas Copco Industrial Compressors, Inc.

2.46

Atlas Copco