Chilled Gas Storage In Mined Caverns Work Shop

THE DEPARTMENT OF ENERGY AND PB-KBB INC.

WELCOMES AND THANKS YOU FOR COMING

PRESENTATION OF PROJECT BACKGOUND, OUTLINE, RESULTS

- Roger Schalge
- Bachelor of Science Degree in Mechanical Engineering
- Polytechnic Institute of Brooklyn
- Graduated 1965
- Employed by PB-KBB inc. Since 1978 (20 years)
- Manager of Projects
- Member of SPE and ASME
- Member of Mechanical Engineers National Honor Society

Doe Advanced Natural Gas Storage Concepts Program

CHILLED GAS STORAGE IN MINED ROCK CAVERNS

Technology Transfer

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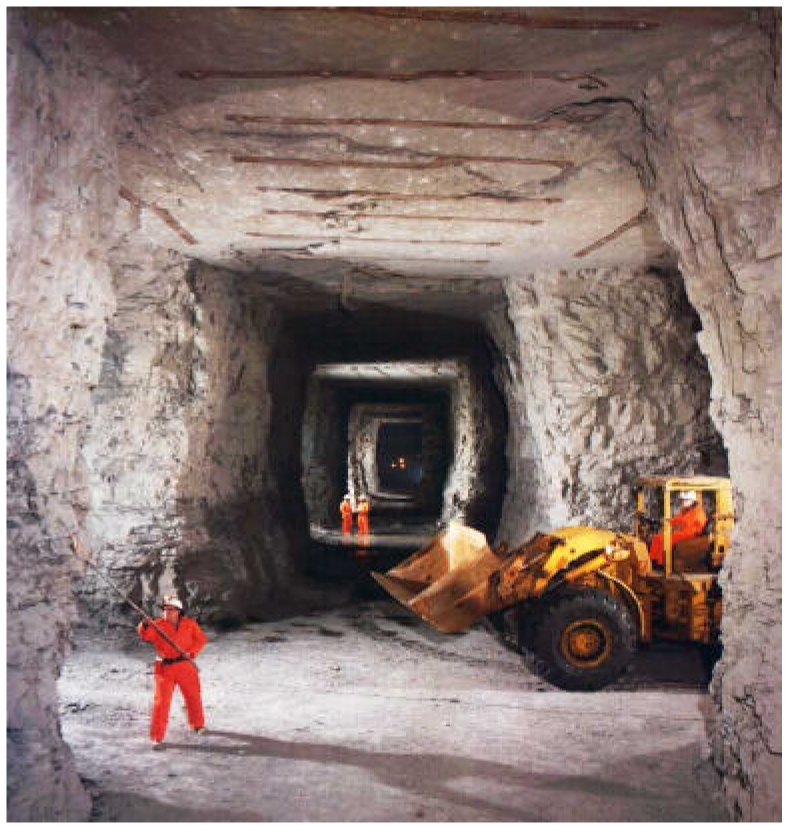

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MORGANTOWN, WV

Department Of Energy Representative

- Mr. Gary Sames
- Project Manager
- Chilled gas storage in mined caverns
- Geologist
- DOE’s Advanced Natural Gas Storage Concepts program description

PB-KBB Representative And Speaker

- Mr. Bruce Russell
- Chief Geologist
- Professional degree in Geological Engineering
- Colorado School of Mines, 1958
- Society of Mining Engineers of AIME
- Employed by PB-KBB since 1972 (26 years)
- Responsible for geological investigation of underground storage caverns
- Has selected sites for many mined storage caverns
- Bruce will present mined gas storage concepts and site selection

PB-KBB Representative And Speaker

- Mr. Walter (Wally) J. Swartz
- Manager of Storage Operations
- B.S. In Chemical Engineering
- University of Detroit, 1973
- Master of Engineering
- University of Detroit, 1974
- Employed by PB-KBB since 1997
- Previously Assistant Facilities Manager - Diamond Shamrock Mount Belvieu Storage Facility
  - 30 salt dome storage caverns and surface facilities
- Wally will present surface facilities design

PB-KBB FACILITATOR

- Mr. Dan Tolleson
- Business Development Manager
- Employed by PB-KBB since 1989
- Dan will direct discussion groups at the completion of the presentation

WORK SHOP ORGANIZATION

- Miss Ginny Wetzel
- Ginny was the publisher for the brochure, prepared the Work Shop programs, arranged the accommodation, meals, travel, and everything else that matters.
- Ginny will be available the rest of the day to assist

PARTICIPATING SUBCONTRACTORS

- Merimack Energy -- Market Analysis
- Frontier-Kemper -- Mining Contractor, Construct-Ability and Cost Estimating
- RE/Spec -- Rock Mechanics and Mine Thermodynamics
- Department of Energy -- Program Management

Doe Advanced Natural Gas Storage Concepts Program
Next Speaker - Gary Sames

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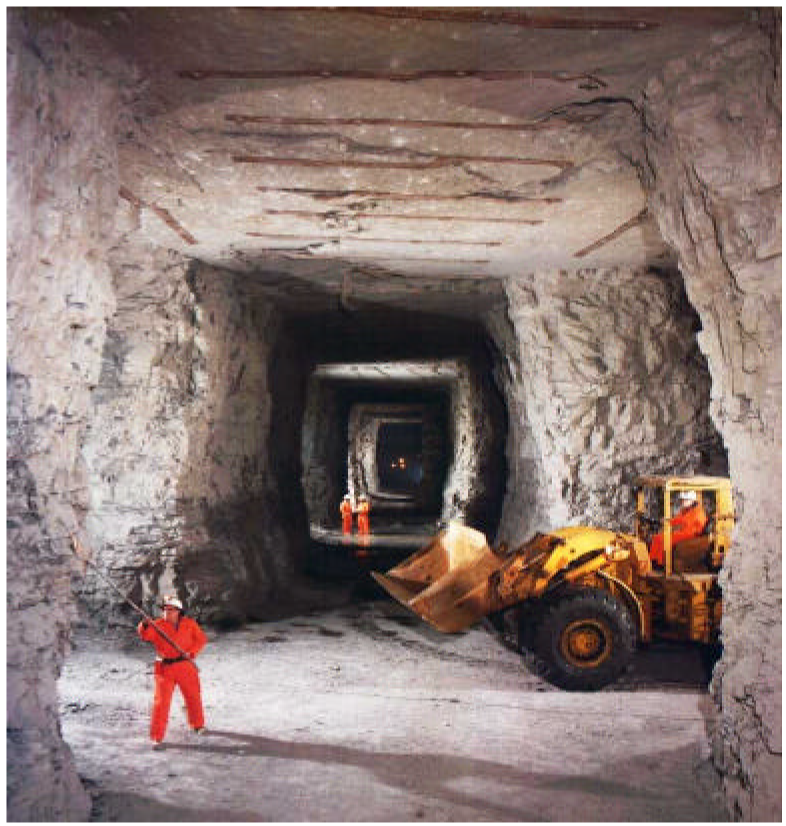
Technology Transfer



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PB-KBB
ENGINEERING CONSTRUCTION OPERATIONS

DEPARTMENT OF ENERGY
FEDERAL ENERGY
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DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA •

PROJECT OBJECTIVES AND OVERVIEW

- Provide storage that is competitive with alternative available high deliverable storage methods
- Available alternatives are salt cavern storage and LNG
- Provide natural gas storage with multiple cycles per year
- Provide high deliverability
- DOE identified five areas that do not have favorable geological conditions of storage such as salt, depleted gas fields, and aquifers
- The areas were New England, Mid-Atlantic (NY/NJ), South Atlantic (DL/MD/VA) South East Atlantic (NC/SC/GA), and the Pacific Northwest (WA/OR)
- Of the five, one was selected for the conceptual design based on pipelines interconnects and future market growth
- The area selected was Howard and Montgomery Counties, Maryland
- The area is near Baltimore and Washington, D.C.

PROJECT SCOPE OF WORK - MINING

- Select area for mined storage cavern
- Conceptual design of cavern and access shafts
- Rock Mechanics evaluation of mine openings and shaft
- Thermodynamics evaluation of stored gas
- Effect of temperature on mined cavern stability
- Conceptual design of surface facilities such as refrigeration equipment, compressor station, and ancillary equipment
- Prepare conceptual design drawings
- Prepare cost and schedule for complete facility
- Complete a final report on all activities
- Conduct Technology Transfer to industry via Work Shops
- The scope did not include a financial model, return on investment

PROJECT CONCEPT

- Chilling natural gas increase it’s density
- The increased density decrease the spatial volume required to storage a cubic foot gas
- Natural gas compressibility decrease to a minimum at temperatures of about -40 ^{o} F and 1,800 psia.
- The Z factor, gas compressibility, at the above conditions is equal to about , Z = 0.5053
- This factor in combination with the reduced temperature can reduce the mined cavern spatial volume by up to 50 %
- Gas has already stored in mined cavern
- PB-KBB has constructed about 80 mined caverns for the storage of LPG which is a combination of vapor and liquid

PROJECTED MARKET AREA STORAGE REQUIREMENTS

Table 2-2
1994 Edition of the Baseline Projection

	New Peaking/Market Area Storage Needs, 2010 (1) (MMCFD)	New Annual Delivery Capacity Needs, 2010 (MMCFD)	Planned or Completed Pipeline & Expansion Projects, 1994-1997 (2) (MMCFD)	Net Requirement (MMCFD)
New England (ME/VT/NH/MA/CT/RI)	269	1,130	978	421
Mid Atlantic (NY/NJ)	1,412	1,158	2,650	(80)
South Atlantic (DL/MD/VA)	450	803	272	981
South Atlantic (NC/SC/GA)	1,190	688	11,197	681
Pacific Northwest (WA/OR/ID)	401	366	695	73

Note: (1) Assumed “high bound” on peak shaving
(2) DOE/EIA Natural Gas 1996 Issues and Trends (December, 1995) and in-house data.

PROJECTED MARKET AREA STORAGE REQUIREMENTS

Table 2-1
Summary of 2010 Peaking and Market Area Gas Storage Requirements of Selected Regions of the US (1994)

Region	Peaking/Market Area Storage Needs (MMCF/day)
New England	269
Mid Atlantic (NY/NJ)	1,352
South Atlantic (DL/MD/VA)	450
South Atlantic (NC/SC/GA)	1,190
Pacific Northwest (WA/OR)	401

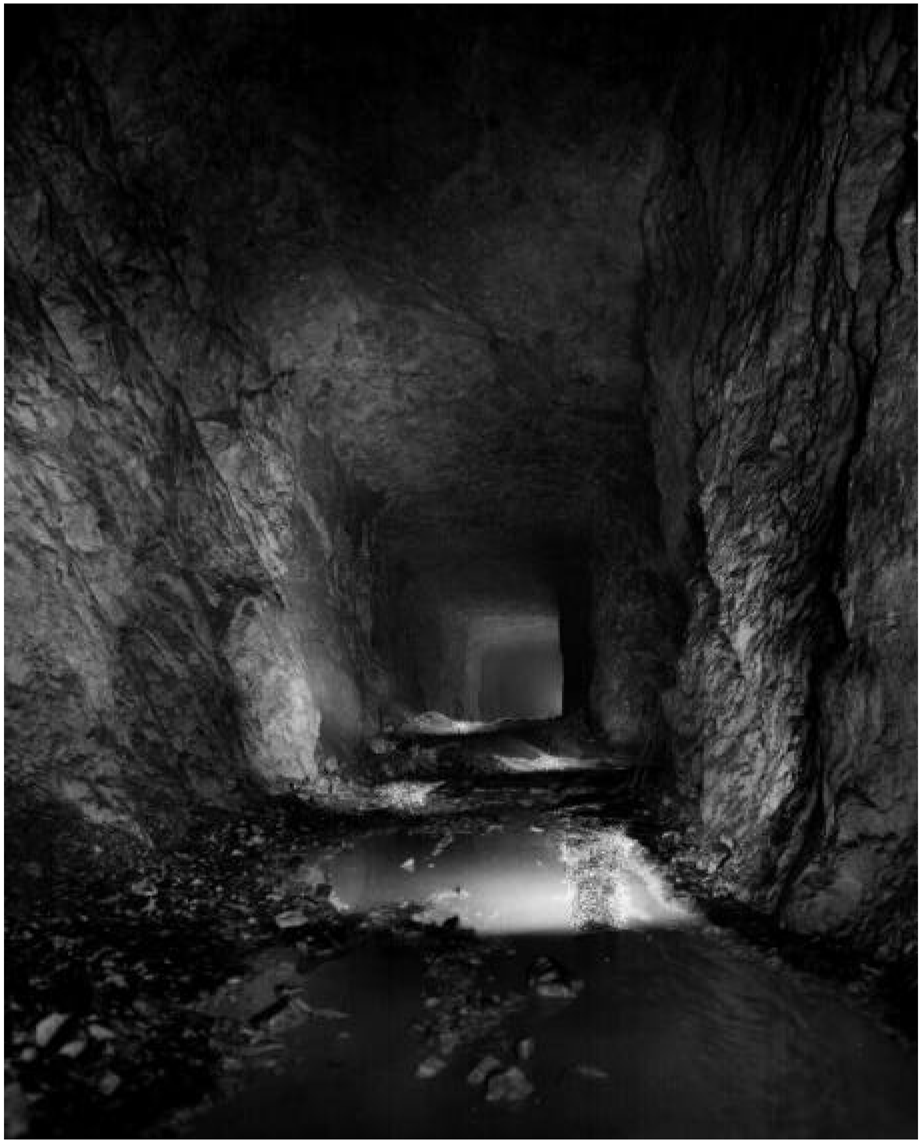
Source: GRI Topical Report – Future Seasonal Natural Gas Loads and Gas Delivery Capacity Requirements in the Lower 48 United States (1/94)

A TYPICAL MINE DRIFT

TYPICAL MINED CAVERN DRIFT OR TUNNEL

A TYPICAL MINED CAVERN DRIFT OF TUNNEL

A TYPICAL MINED CAVERN DRIFT OR TUNNEL



ADVANTAGES OF Z FACTOR AND TEMPERATURE

- Using the equation of state (Perfect Gas Law):
- **pV = n*Z*R*T**
  - Where:
  - p = pressure in psia
  - V = Volume in cubic feet
  - n = moles of gas
  - Z = gas compressibility
  - R = Universal gas constant (10.73)
  - T = Temperature in degrees Rankine
- Substitution using Charles and Boyles Law results in:
- $V_{std} = V_c * [P_c / (T_c * Z_c)] * (T_{std} * Z_{std}) / p_{std}$
  - Where:
  - V_{std} = Standard cubic feet of gas in storage
  - V_c = Cavern volume in cubic feet
  - P_c = Cavern gas pressure in pisa
  - T_c = Cavern temperature in degrees Rankine
  - Z_c = Cavern gas compressibility at cavern temperature and
  - T_{std} , Z_{std}, and p_{std} are condition a atmospheric conditions; constants

ADVANTAGE OF Z FACTOR AND TEMPERATURE

- The term $(T_{std} * Z_{std}) / p_{std}$ is a constant; $C_{std} = 35.3$
- Therefore, to simplify :
- **$V_{std} = V_c * [p_c / (T_c * Z_c)] * C_{std}$**
- The variables that can be manipulated to increase V_{std} are:
- V_c ,cavern volume, p_c ,cavern pressure, and T_c ,cavern gas temperature
- Any increase in the cavern pressure p_c is limited by geology for a mined cavern to the hydrostatic head or possible advantages of chilling the gas to be discussed later
- Increasing V_c is related to economic of construction and also depth; the deeper the cavern the higher the cost
- Since Z_c and T_c are in the denominator of the equation any decrease in these values increase V_{std}
- As an example, if T_c for a normal mined storage cavern is
  - 150º F (610 ºR) then **$Z_c = 0.9046$**,
  - giving **$p_c / (T_c * Z_c) = p_c * 0.0018$**
- Reducing T_c to
  - -20 º F (440 º R) makes **$Z_c = 0.6151$,**
  - giving; **$p_c / (T_c * Z_c) = p_c * 0.0037$**
- **0.0037 / .0018 = 2.0556, increases V_{std} by a factor of 2.0556**

PROJECT CONCEPT BASED ON TEMPERATURE AND COMPRESSIBILITY

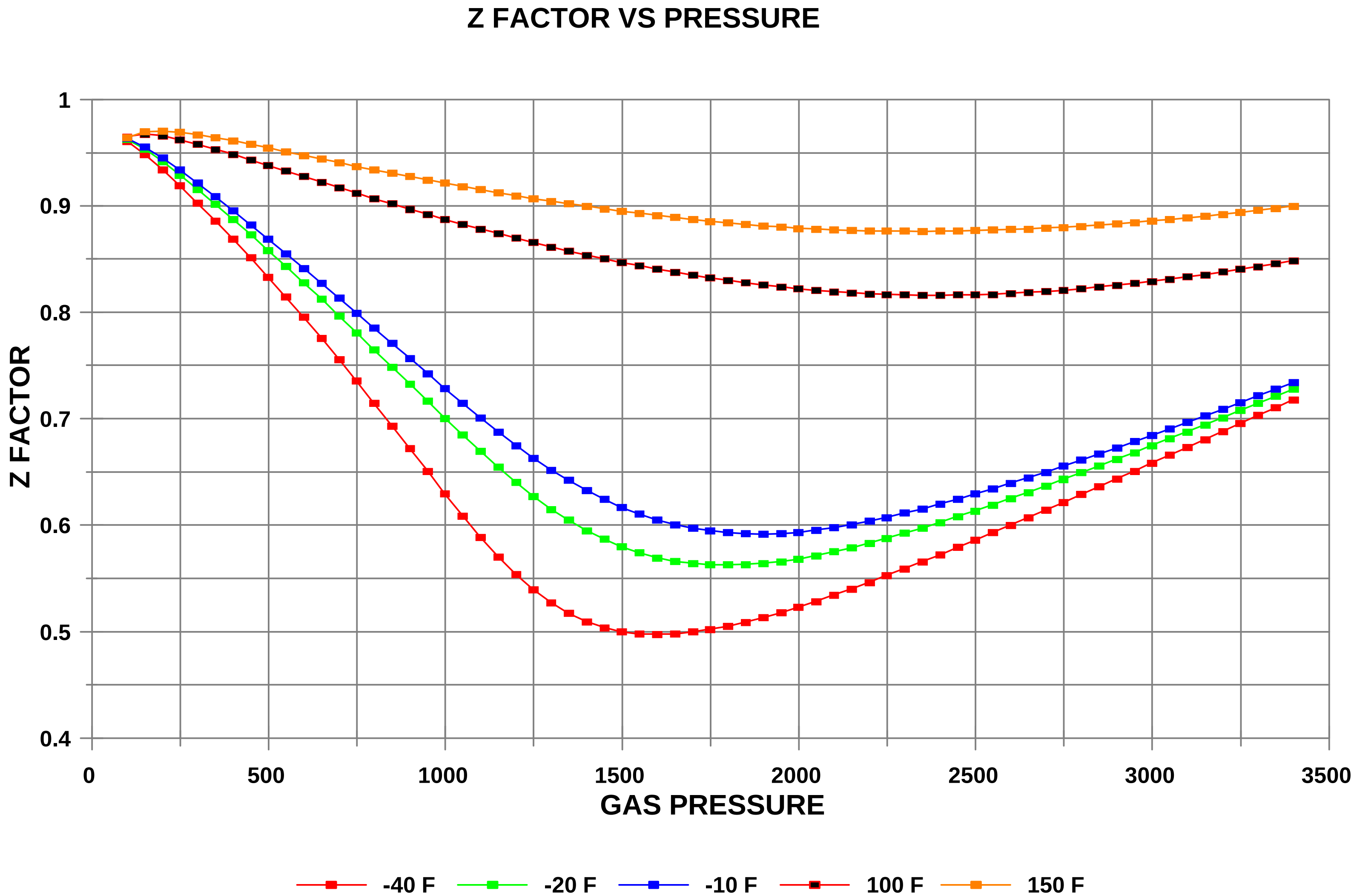


FIGURE 2.0

GRAPH OF GAS VOLUME VS PRESSURE

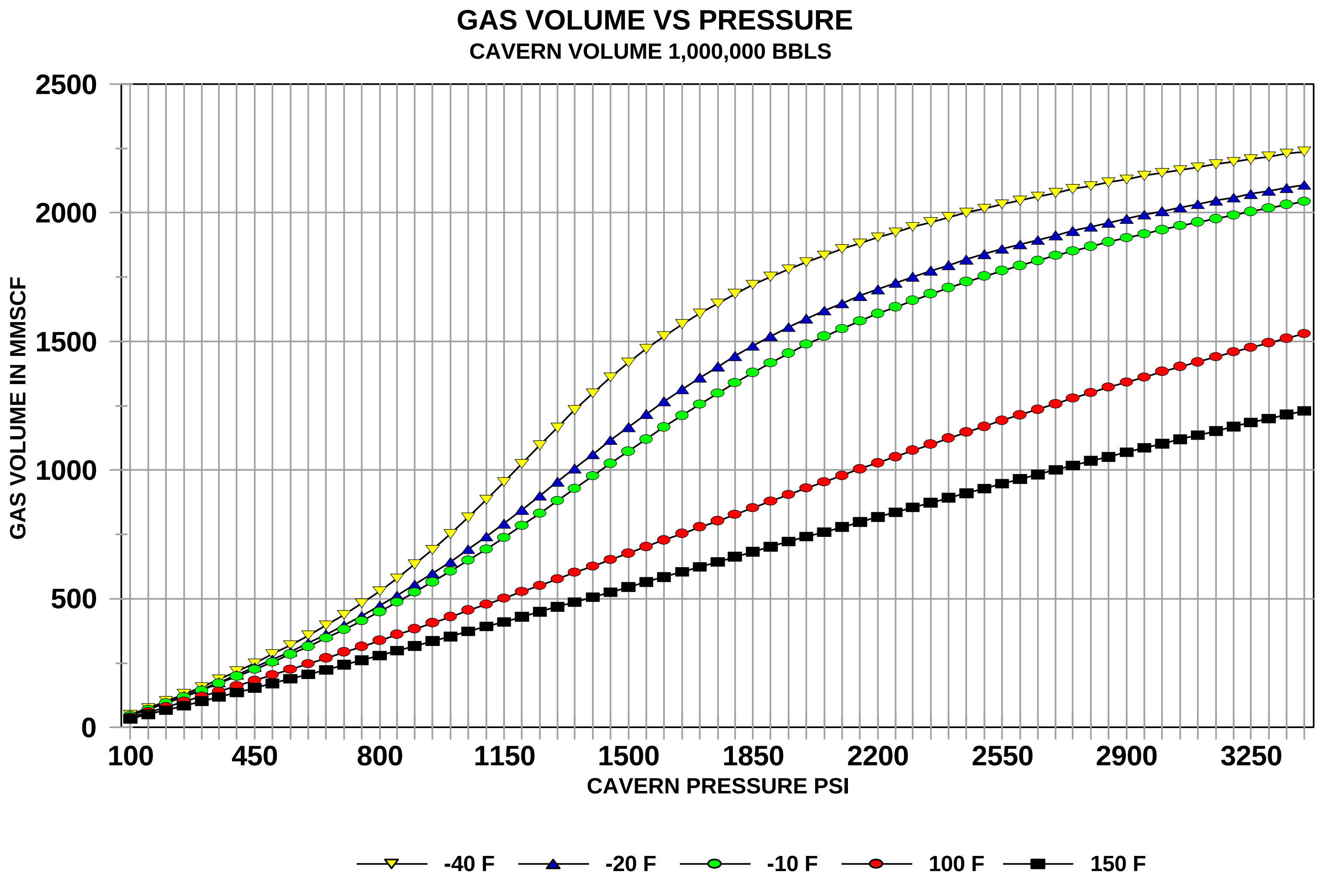


FIGURE 1.0

SELECTED PROCESS AND CAVERN DESIGN PARAMETERS

The process design parameters selected for this study are as follows:

Maximum gas pressures:	1,080 - 1,250 psi
Minimum gas pressures:	250 psig and 100 psig
Operating temperatures:	-20°F, 0°F and +20°F
Cavern depth:	2,500 - 3,000 feet
Operating pressure gradient:	0.433 psi/ft
Working gas volume:	5 Billion Standard Cubic Feet (BSCF)
Gas withdrawal rate:	250 Million Standard Cubic Feet per Day (MMSCFD)
Gas injection rate:	250 MMscfd
Incoming gas temperature:	50°F to 80°F
Dehydration:	Water content reduction from 7 lbm/MMscf to < 1 lbm/MMscf prior to chilling (TEG or Mole Sieve-type)
Production casing diameter:	20 inch OD (0.500" wall)

COMPLETION OF PROJECT OVERVIEW

- It is now time for the Mid-Morning break
- The next speaker will be Mr. Bruce Russell
- Mr. Russell will present site selection, site geology, and some principles on gas storage in mined caverns

Doe Advanced Natural Gas Storage Concepts Program
Next Speaker - Roger Schalge

CHILLED GAS STORAGE IN MINED ROCK CAVERNS

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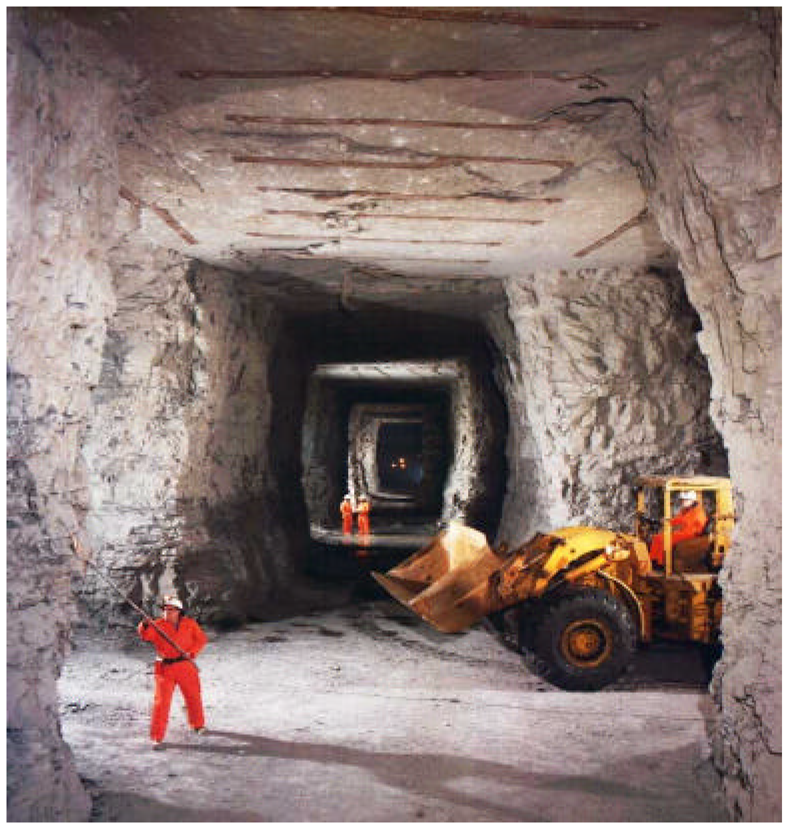

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PRESENTATION ON MINING

- Roger Schalge

GOETECHNICAL ASSUMPTION FOR CONCEPTUAL DESIGN OF CAVERN

Geotechnical Assumptions for Conceptual Design of Refrigerated Natural Gas Storage Cavern

1. Geological Column

0 - 50'	Overburden
50 - 150'	Weathered crystalline rock (igneous or metamorphic)
150 - 3000'	Unweathered crystalline rock (igneous or metamorphic)

2. Rock Properties and Hydrologic Conditions

Unconfined Compressive Strength: . . 2,000 - 20,000 psi (average 10,000 psi)
Tensile Strength: . . . . 700 psi
Young's Modulus . . . . .7,500,000 psi
Poisson's Ratio: 0.27
Bulk Density: . . . . .2.80 g/cc
Porosity: 1%
Hydraulic Conductivity (K): . . . . 10^{-7} cm/sec at 2500-ft. depth
Temperature at 2500' Depth: . . . . 73°F
Temperature Gradient: . . . . .0.64°F/100 feet
Water Table: . . . . ± 30 feet below surface (in gentle hilly terrain); Near surface (in valley bottoms)

Average RQD index value: . . . . 85 at 2500-ft. depth

GEOLOGICAL COLUMN MATERIAL PROPERTIES AND ASSUMPTIONS

Depth	Material
0-50 feet	Overburden
50-150 feet	Weathered crystalline rock
150-3,000 feet	Unweathered crystalline rock

Table 8-2. Properties of Unweathered Crystalline Rock

Property	Value
Unconfined compressive strength	2,000-20,000 psi; Average = 10,000 psi
Tensile strength	700 psi
Young? s modulus	7,500,000 psi
Poisson? s ratio	0.27
Bulk density	2.80 g/cc
Porosity	1%
Temperature at 3,000-foot depth	73 ^{o}F
Average RQD index value	85 at 3,000-foot depth
Water table	Within 30 feet of surface
Hydraulic conductivity	10^{-7} cm/sec at 3,000-foot depth

GAS OPERATING CONDITIONS

Table 8-3. Gas Operating Conditions

Property	Value
Gas storage pressure, maximum	1,370 psi
Gas storage pressure, minimum	250 psi
Refrigerated gas temperature	-20 ^{o}F

Table 8-4. Thermal Properties of Granite

Property	Value
Coefficient of thermal expansion	3.75×10^{-6}
Specific heat	880 J/kg-K
Thermal conductivity	2.51 W/m-K

REQUIRED CAVERN VOLUMES AT VARIOUS DEPTH AND TEMPERATURES

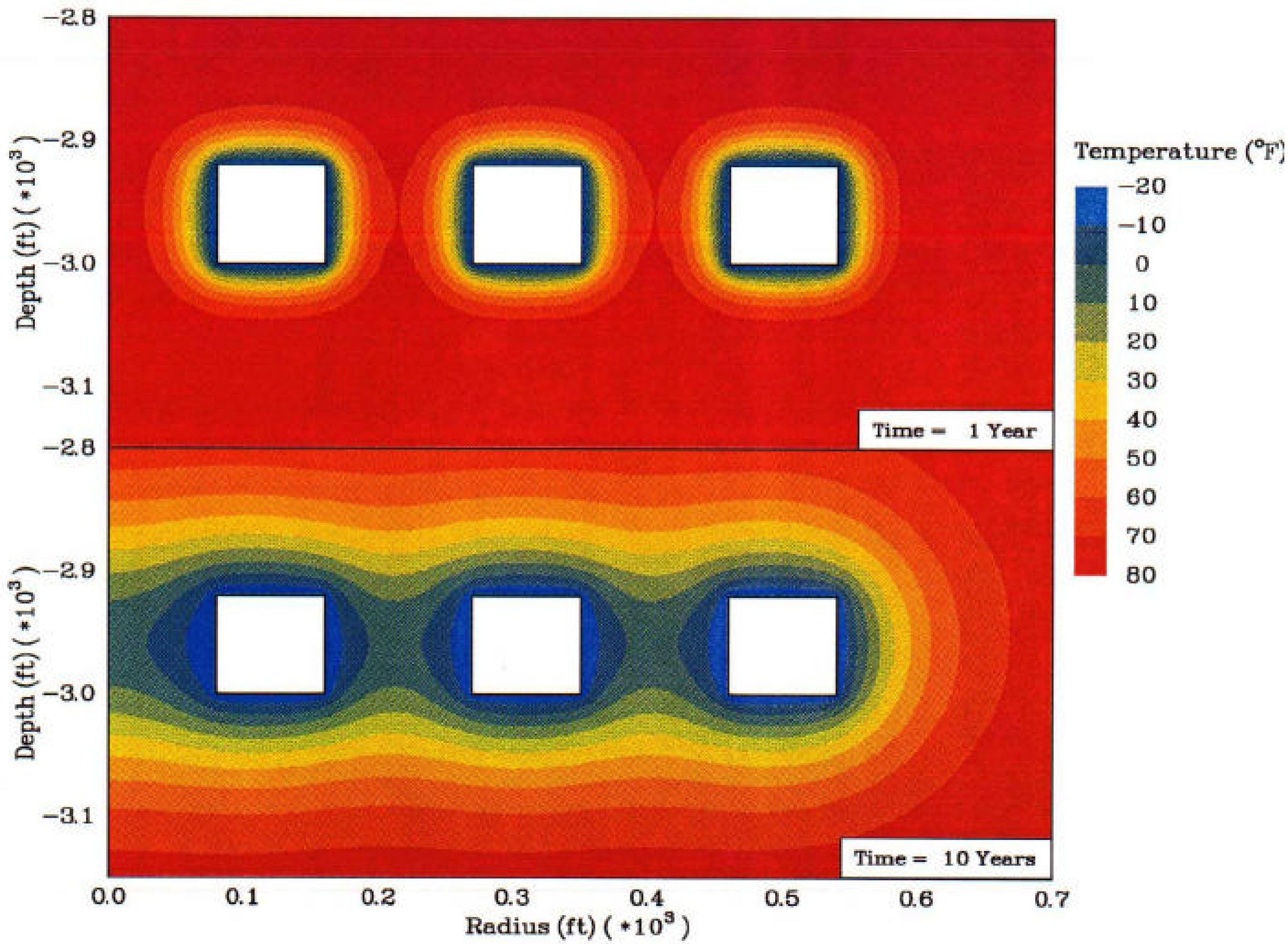
Table 11-2
Required Cavern Volumes at Various Depths and Temperatures

Depth	Cavern Volume at -20°F, million cubic yards	Cavern Volume at-30°F, million cubic yards	Cavern Volume at -40°F, million cubic yards
2500	1.87	1.75	1.56
3000	1.34	1.21	1.08

The process equipment cost was estimated only for chilling the gas to a temperature of -20 °F for the following reasons.

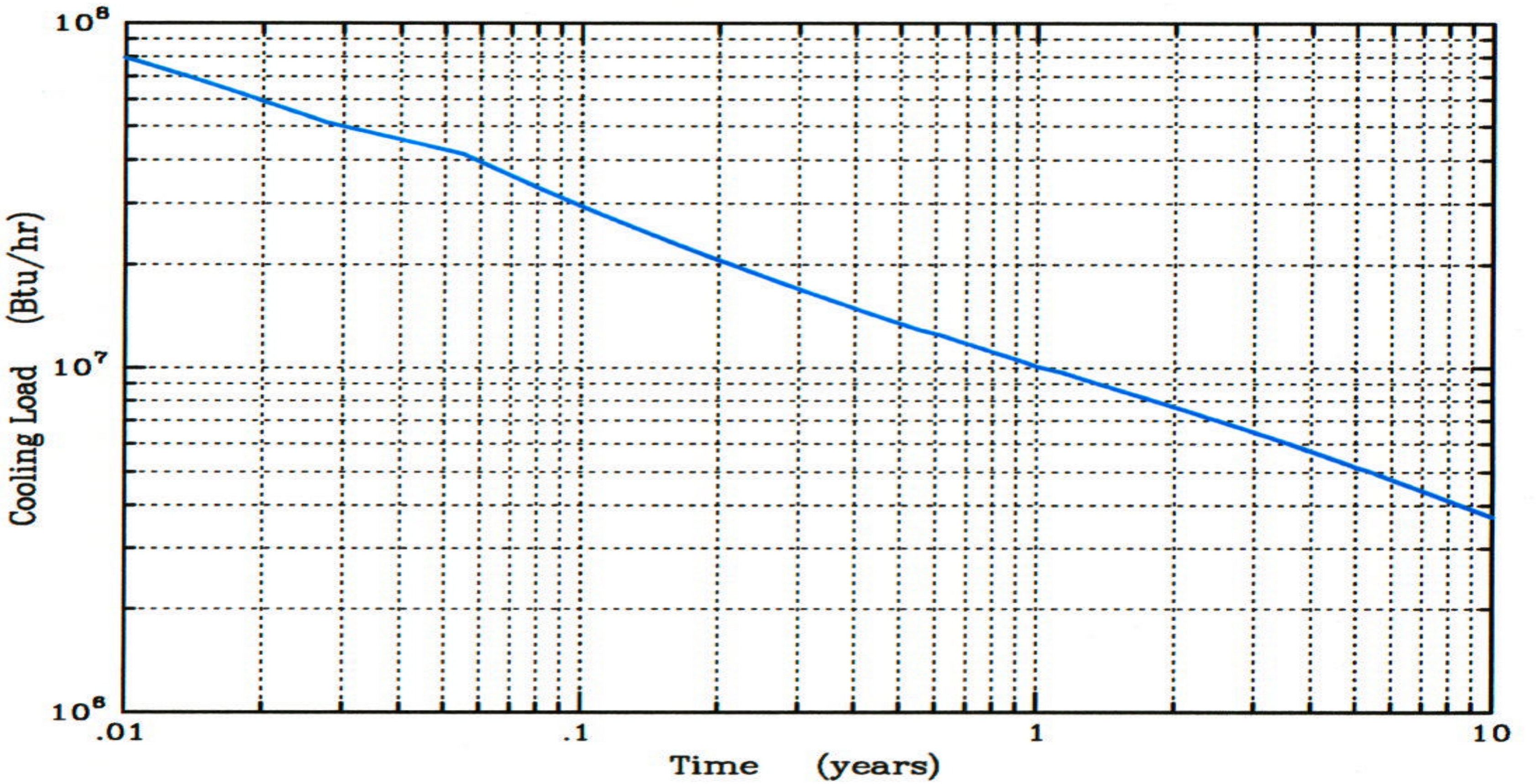
1. A colder temperature would require possible process design changes regarding refrigerant type and equipment design.
2. The metallurgy for the piping and equipment throughout the chilled system would have to be re-evaluated for service below -20 °F, including piping in the mined cavern.

TEMPERATURE DISTRIBUTION IN MINE



COOLING LOAD IN MINE TO MAINTAIN TEMPERATURE

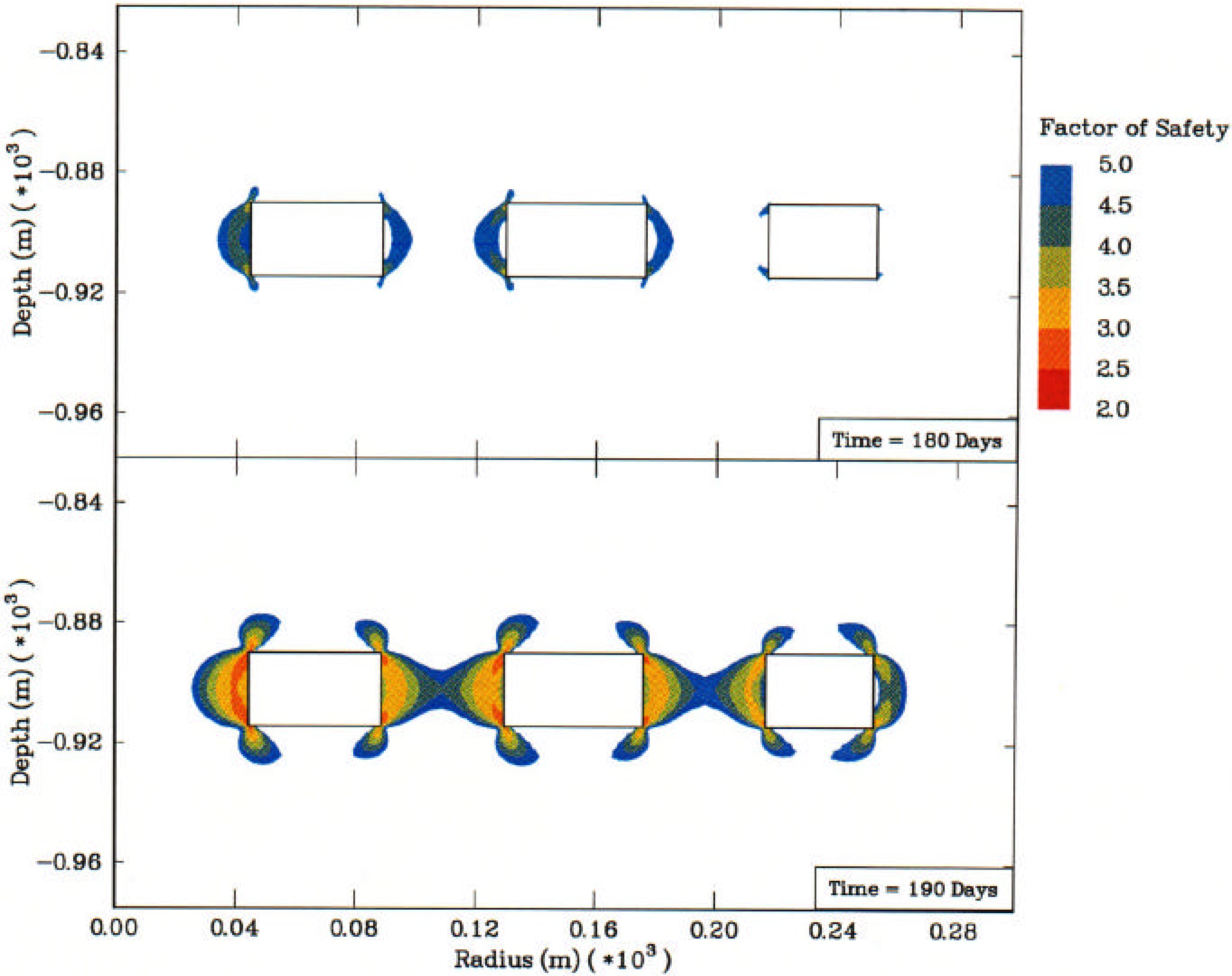
- COOLING LOAD IN BTU's per hour VS TIME IN YEARS



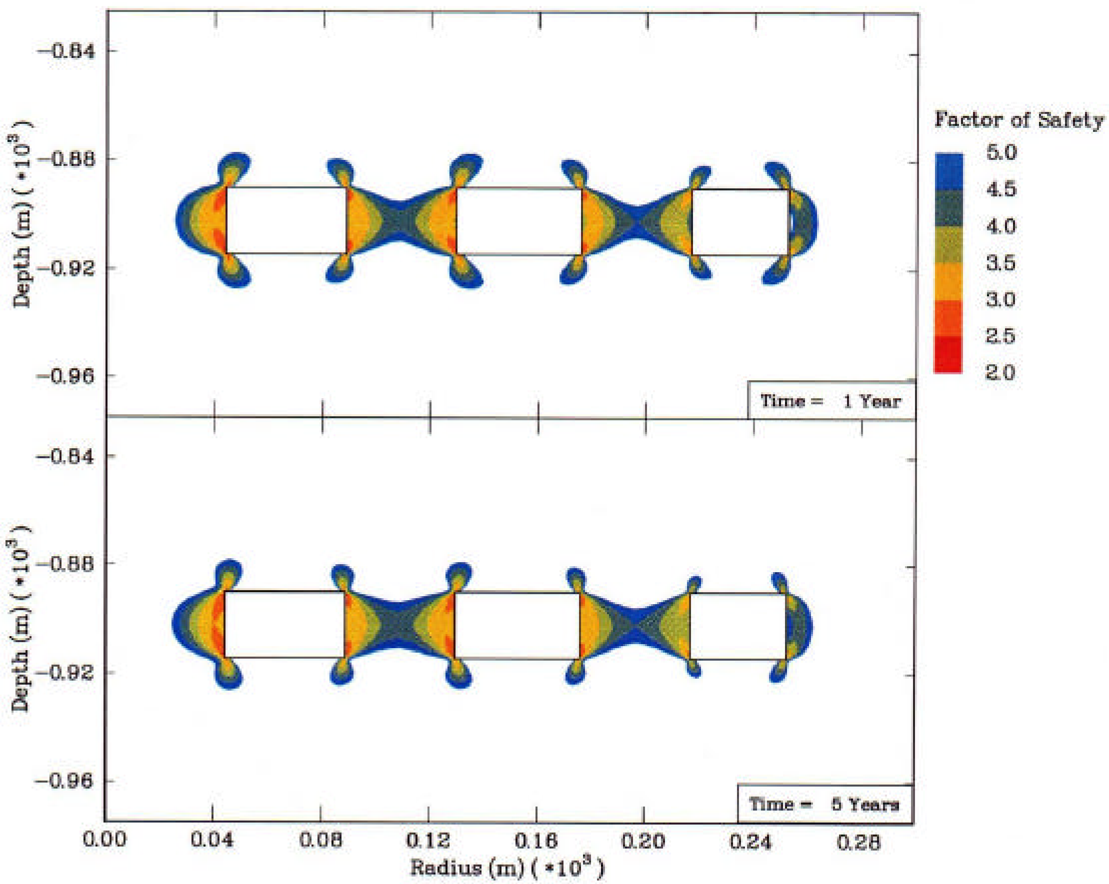
RECIRCULATION COOLING LOAD TO MAINTAIN GAS IN MINE @ - 20 ^{0} F

ONE MONTH	30 MM BTU / HR
ONE YEAR	10 MM BTU / HR
TEN YEARS	3.7 MM BTU / HR

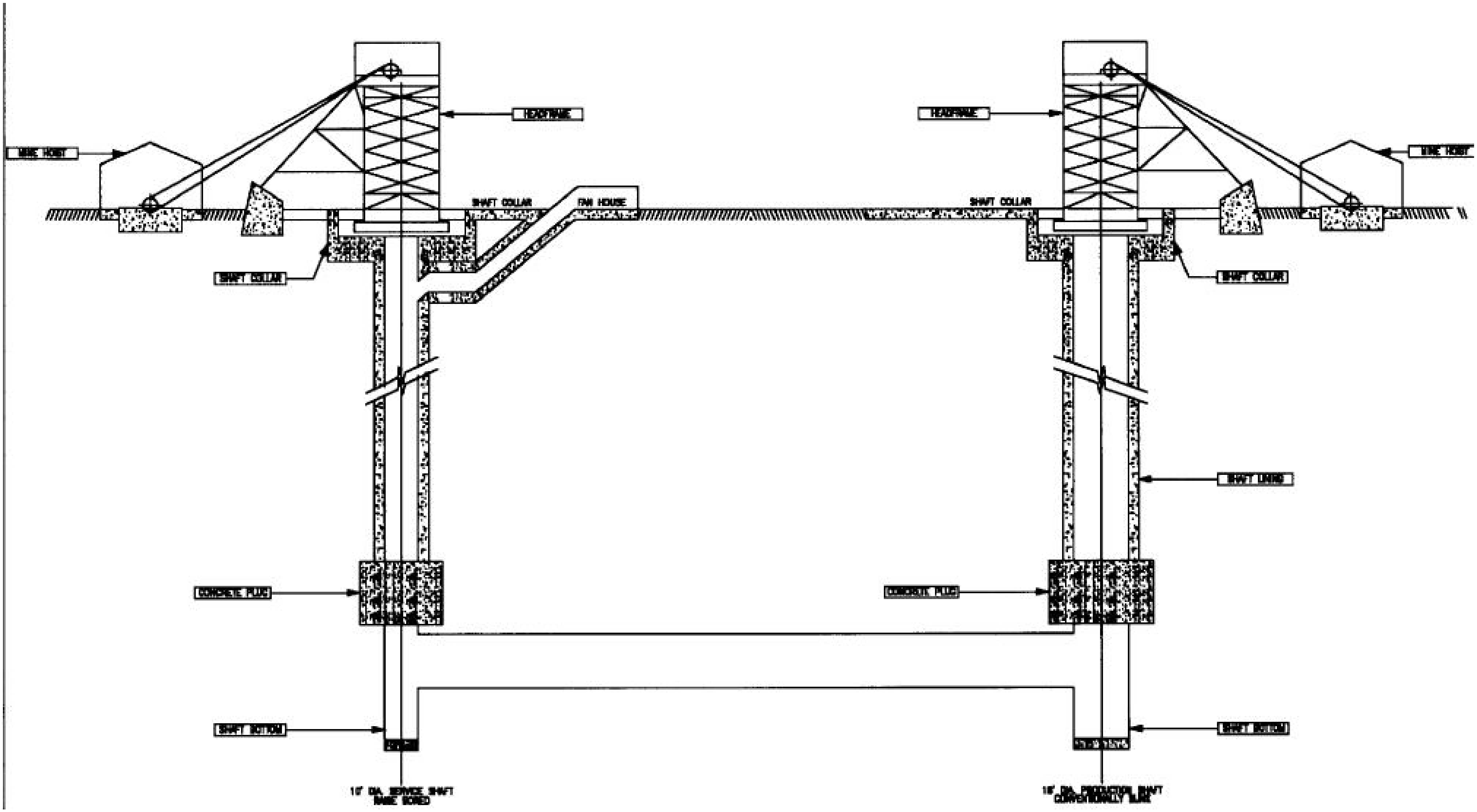
MOHR-COULOMB FACTOR-OF-SAFETY CONTOURS BEFORE AND AFTER DRAWDOWN FROM MAXIMUM TO MINIMUM GAS PRESSURE



MOHR-COULOMB FACTOR-OF-SAFTEY CONTOURS AT 1 AND 5 YEARS AFTER FILLING WITH GAS AT 29 °C



MINE GENERAL LAYOUT



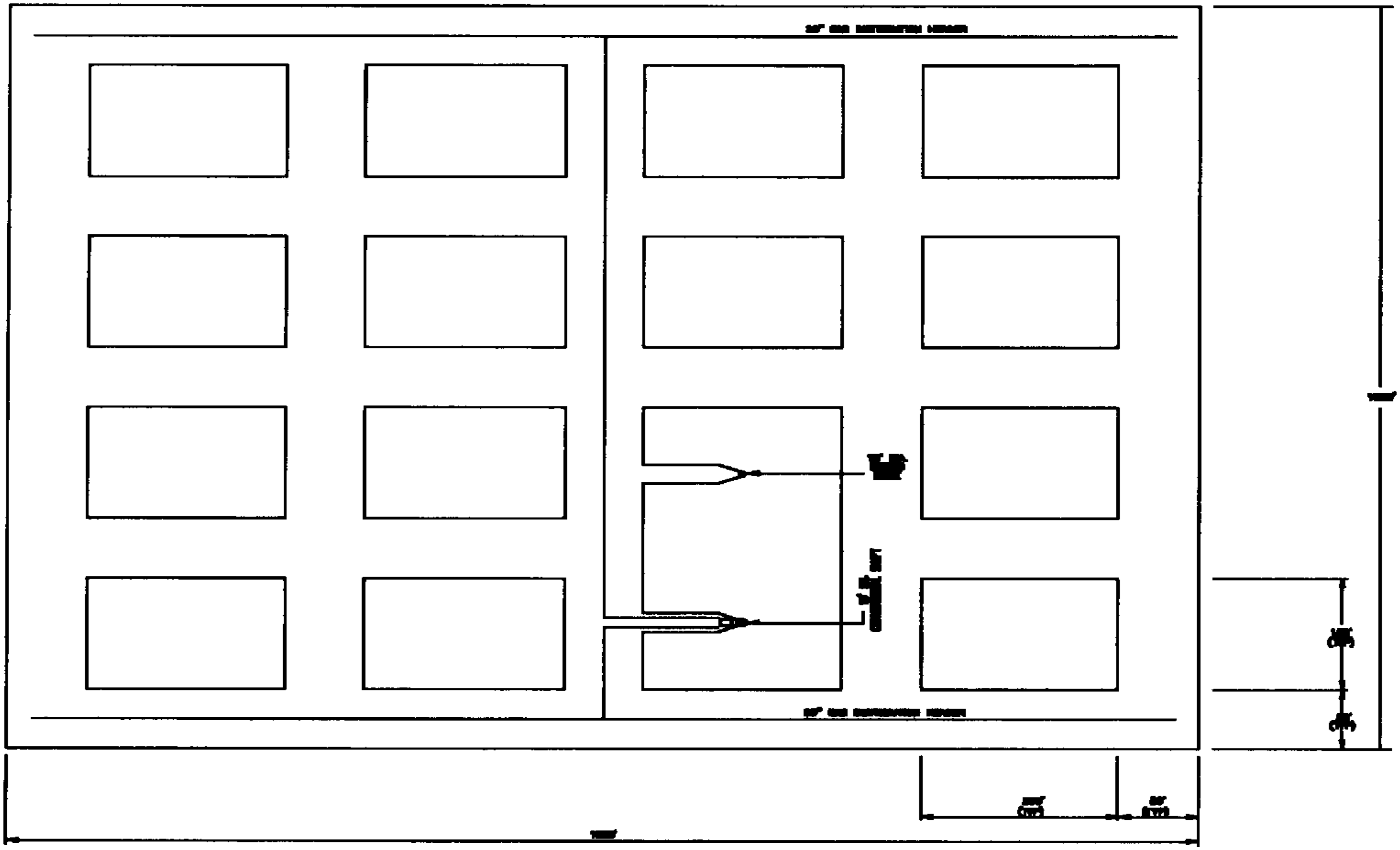
MINING EQUIPMENT REQUIRED FOR CAVERN CONSTRUCTION

Construction Equipment

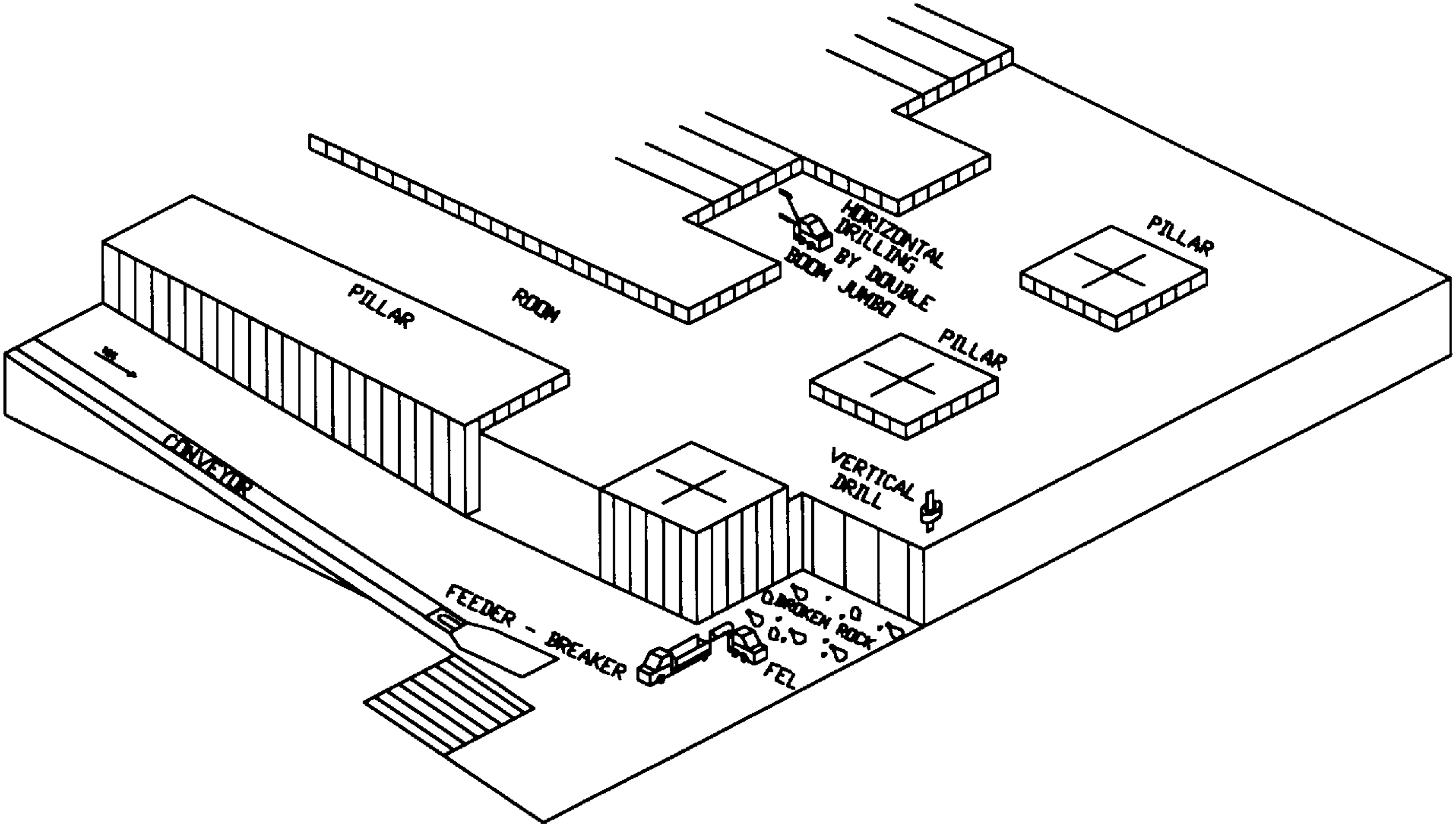
The following construction equipment will be required for the gas storage cavern:

- Double-Drum with Clutch Hoist for Production Shaft
- Single Divided Drum Hoist for Men and Material Shaft
- One Work Stage
- Two 20-ton Skips
- Mancage
- Two Double (or Triple) Boom Electrohydraulic Jumbo Drills
- One Vertical Drill
- ANFO Loading and Blasting Rig
- Two Front-End Loaders (Cat 990 or equivalent)
- Two 40-ton Trucks
- One Roof Bolter
- One Rigid Boom Scaler (Gradall)
- One 80' high Cherry Picker for Handscaling
- Jaw Crusher
- Conveyors and Hoppers
- Power Distribution System
- Compressor and Compressed Air Distribution System
- Dewatering Pump
- Construction Fan with Tubing for Shaft Sinking
- Lubrication Truck
- 300,000 cfm Fan for Cavern Ventilation
- One 5-Stage Centrifugal Compressor (900 HP) for Evacuating Air
- Five Inert Gas Generators (120,000 scfh/unit) with Cooling Towers

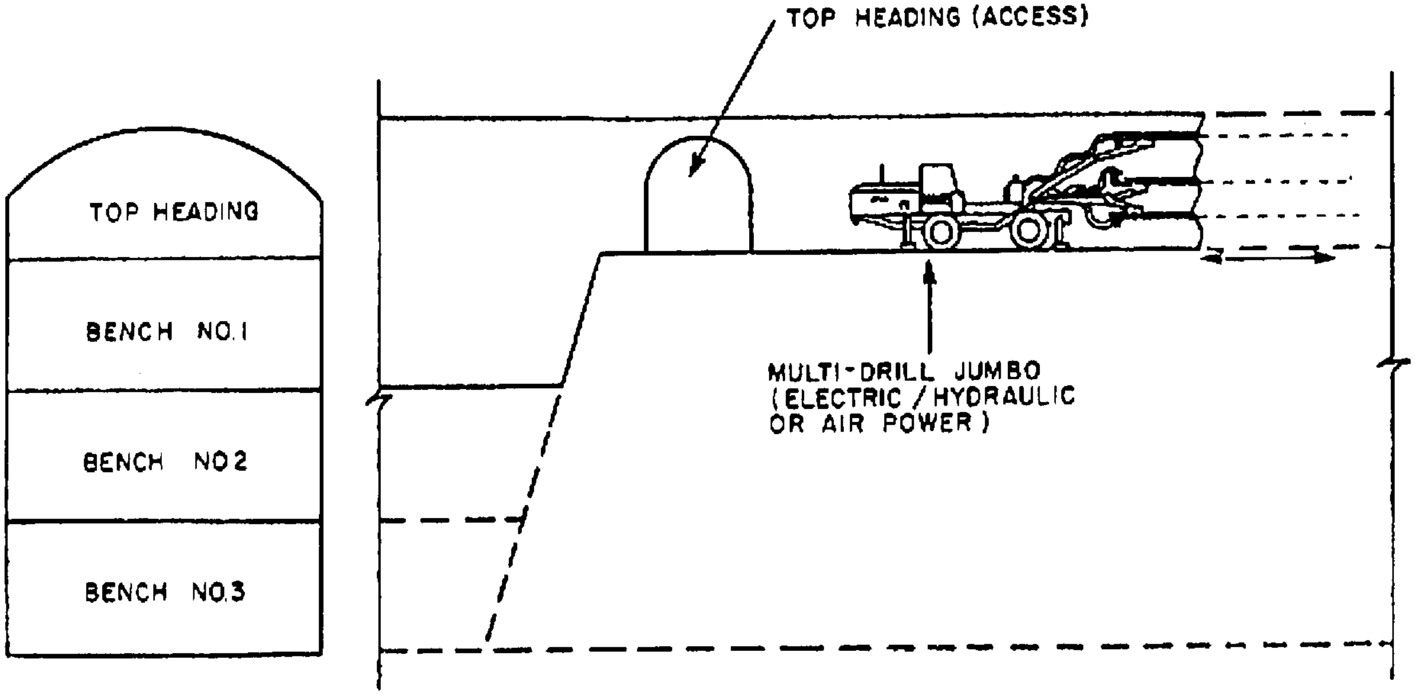
MINED CAVERN AT 3,000 - FOOT LEVEL (ROOM AND PILLAR)



MINE DEVELOPMENT SHOWING BENCHING AND HEADINGS

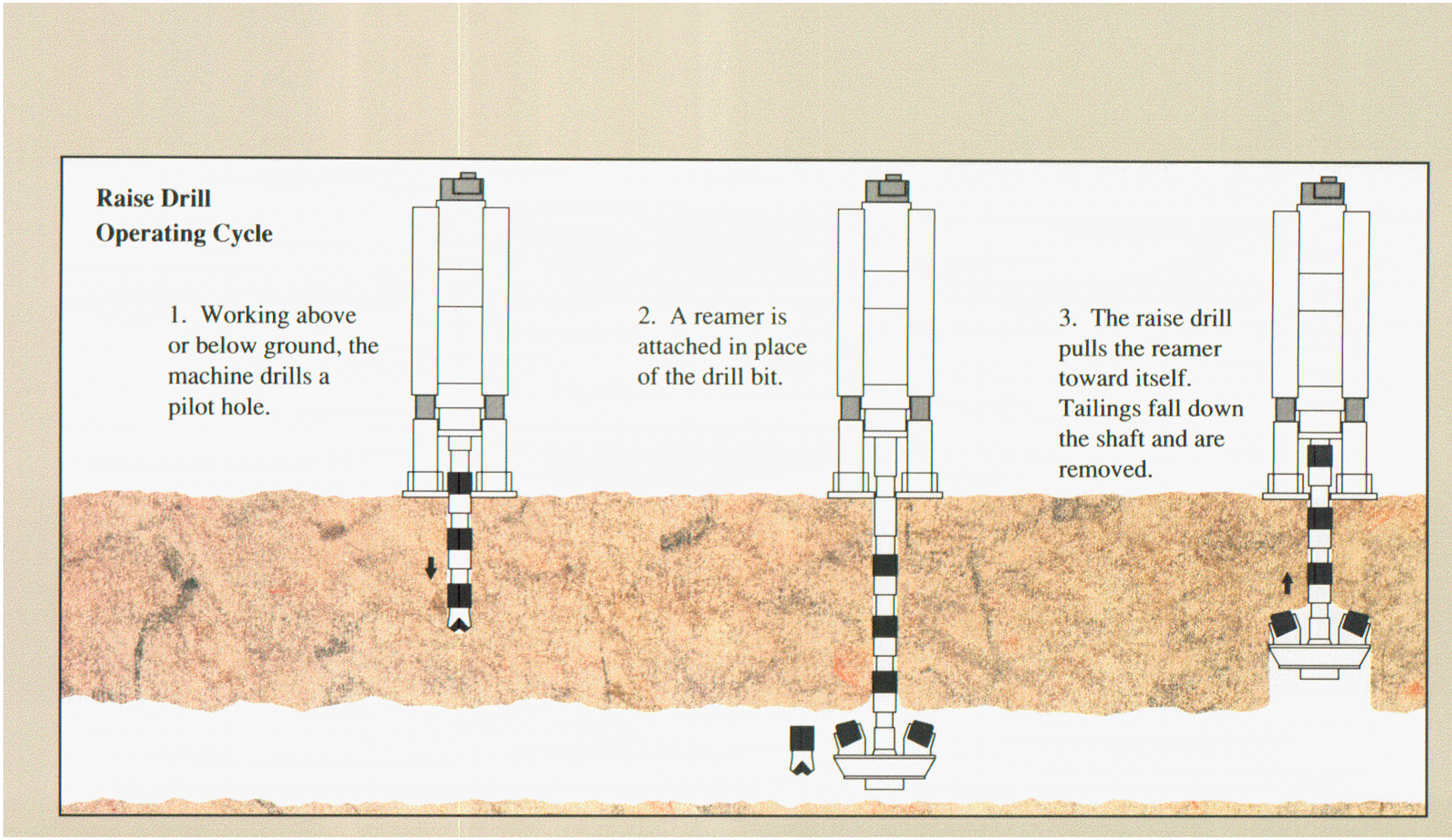


HEADING AND BENCHING MINING METHOD



VIEW OF UNDERGROUND MINING

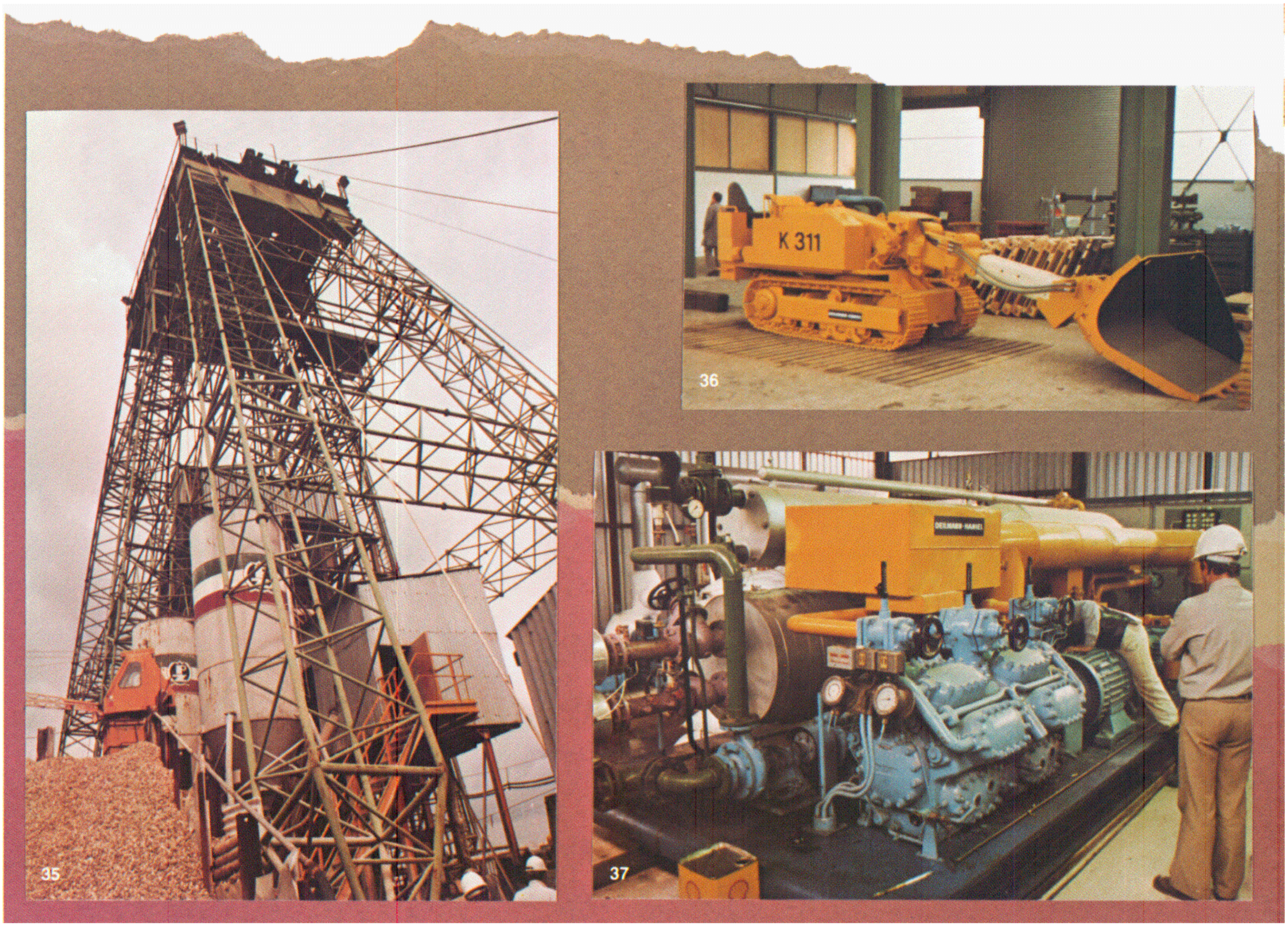
RAISE BORING METHOD



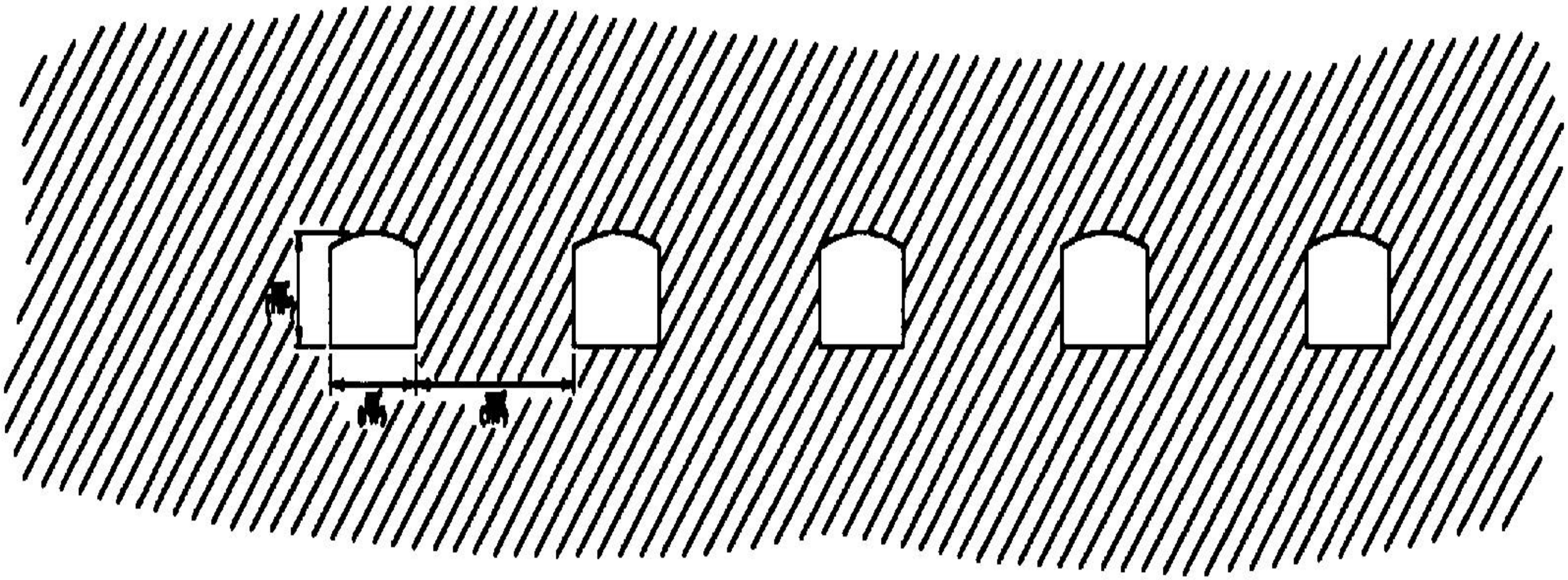
RAISE BORING AT SURFACE AND UNDERGROUND

VIEW UP A LINED SHAFT AND DOWN

MINING HEAD FRAME AND FRONT END LOADER



ELEVATION VIEW OF MINED CAVERN AT 3,000 - FOOT LEVEL



SECTION "A-A" AT 3000' DEPTH

MINED CAVERN CONCEPT PRESENTATION COMPETION

- The next presentation will be on the conceptual design of the surface facilities
- The speaker is Mr. Wally Swartz

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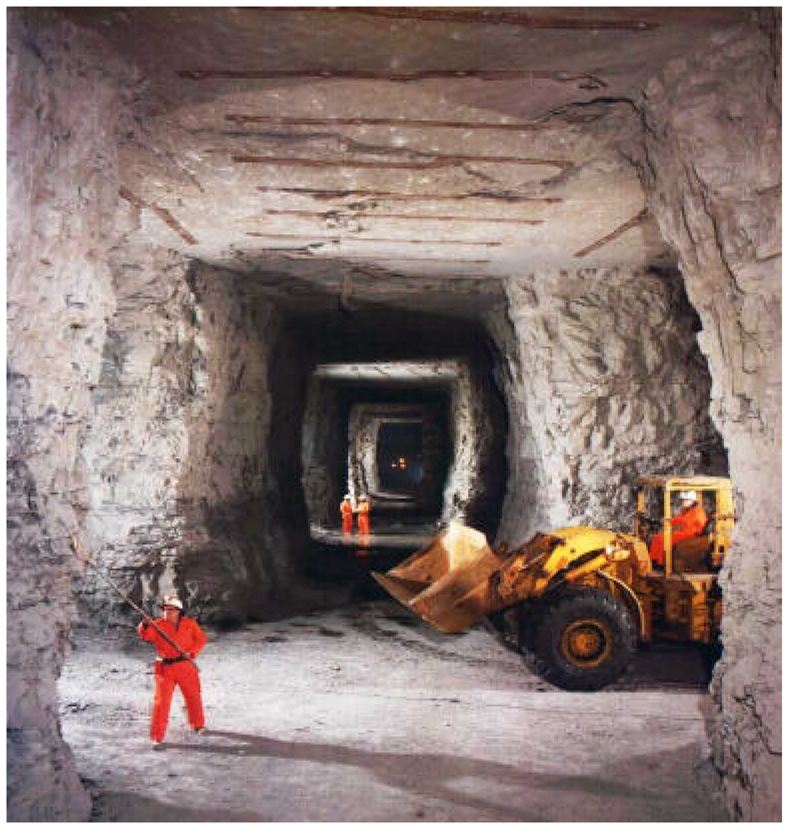

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CONCLUSIONS (COST AND SCHEDULE)

- Mining and surface facilities cost and schedule

MINING LABOR COSTS

Table 10-10

Labor Costs

Position	No.	Hrs/Day	Days/Wk	$/Hr	OH @ 35%	Cost/Yr
Supervisor	1	8	5	35.00	47.25	98,280
Shift Operators	8	12	`4	20.00	27.00	488,808
Relief Operators	2	12	4	18.00	24.30	109,982
Clerical	1	8	5	13.00	17.55	37,315
TOTAL						734,385

- 2190 hrs per year on 12 hr shift schedule
- Overtime figured at 3% of annual schedule at base rate.

ESTIMATED COST OF CAVERN - 1,500 FOOT DEPTH

Table 10-1
Estimated Cost of a Storage Cavern - 1,500-Foot Depth

115.7 Million Cubic Feet Storage
1500 Foot Depth
One 8-20-Ft-Diameter Conventional Shaft
One Ten-Ft-Diameter Raise Bored Shaft
4 Million Cubic Feet Miscellaneous Excavation
Project Duration 80 Months

COST ITEM	QUANTITY	UNITS		UNIT COST	TOTAL
Mobilization	1	LS		7,215,000	7,215,000
Sink & Line Shaft	1500	LF		6,713	10,069,500
Raise Bore & Line Shaft	1500	LF		2,613	3,919,500
Material Handling Equipment	1	LS		4,123,000	4,123,000
Assemble Mining Equipment	1	LS		2,695,000	2,695,000
Excavate Top Heading	1851300	BCY		46.12	85,381,956
Excavate Bench	2581900	BCY		40.21	103,818,199
TOTAL					208,222,155
Contingency					29,101,800
TOTAL PROJECT COST					237,324,000

SUMMARY ESTIMATED COST OF CAVERN - 1,500 FT

Bid Item	Total	Unit Cost
Mobilization	7,212,000	7,212,000
Sink & Line Shaft (per ft)	10,069,500	6,713
Raise Bore Shaft (per ft)	3,919,500	2,613
Material Handling Equipment	4,120,000	4,120,000
Assemble Mining Equipment	2,693,000	2,693,000
Excavate Top Heading(CY)	85,381,956	46.12
Excavate Bench (CY)	103,818,199	40.21
Total Field Cost	208,222,155	
Contingency = 15% of the total field cost	29,101,800	

TOTAL PROJECT COST $237,324,000

ESTIMATED COST OF STORAGE CAVERN - 2,000 - FOOT DEPTH

Estimated Cost of a Storage Cavern - 2,000-Foot Depth

68.7 Million Cubic Feet Storage
2,000 Foot Depth
One 18-20-Ft-Diameter Conventional Shaft
One Ten-Ft-Diameter Raise Bored Shaft
4 Million Cubic Feet Miscellaneous Excavation
Project Duration 59 Months

COST ITEM	QUANTITY	UNITS		UNIT COST	TOTAL
Mobilization	1	LS		7,215,000	7,215,000
Sink & Line Shaft	2000	LF		6,713	13,426,000
Raise Bore & Line Shaft	2000	LF		2,613	5,226,000
Material Handling Equipment	1	LS		4,123,000	4,123,000
Assemble Mining Equipment	1	LS		2,695,000	2,695,000
Excavate Top Heading	1159500	BCY		46.12	53,476,140
Excavate Bench	1385000	BCY		40.21	55,690,850
TOTAL					141,851,990
Contingency					19,577,100
TOTAL PROJECT COST					161,429,100

SUMMARY ESTIMATED COST OF STORAGE CAVERN - 2,000 - FOOT DEPTH

Bid Item	Total	Unit Cost
Mobilization	7,212,000	7,212,000
Sink & Line Shaft (per ft)	13,426,000	6,713
Raise Bore Shaft (per ft)	5,226,000	2,613
Material Handling Equipment	4,123,000	4,123,000
Assemble Mining Equipment	2,693,000	2,693,000
Excavate Top Heading(CY)	53,476,140	46.12
Excavate Bench (CY)	55,690,850	40.21
Total Field Cost	141,851,990	
Contingency = 15% of the total field cost	19,577,100	

TOTAL PROJECT COST $161,429,100

ESTMATED COST OF STORAGE CAVERN - 2,500-FOOT DEPTH

Table 10-3
Estimated Cost of a Storage Cavern - 2,500-Foot Depth

47 Million Cubic Feet Storage
2500 Foot Depth
One 18-20-Ft-Diameter Conventional Shaft
One Ten-Ft-Diameter Raise Bored Shaft
4 Million Cubic Feet Miscellaneous Excavation
Project Duration 48 Months

COST ITEM	QUANTITY	UNITS		UNIT COST	TOTAL
Mobilization	1	LS		7,215,000	7,215,000
Sink & Line Shaft	2500	LF		6,713	16,782,500
Raise Bore & Line Shaft	2500	LF		2,613	6,532,500
Material Handling Equipment	1	LS		4,123,000	4,123,000
Assemble Mining Equipment	1	LS		2,695,000	2,695,000
Excavate Top Heading	791,400	BCY		46.12	36,502
Excavate Bench	1137185	BCY		40.21	45,725,000
TOTAL					119,419
Contingency					15,994,000
TOTAL PROJECT COST					135,413,000

COST ESTIMATE DETAIL FOR 2,500 - FOOT DEEP CAVERN

Table 10-4

Cost Estimate Detail for 2,500-Foot Deep Cavern

Bid Item	Qty.	Unit	Mnhrs.	Labor	Materials	EOE	Total	Ind. Cost	Total	Unit Cost
Mobilization	1	LS	22,000	770,000	3,500,000	52,000	4,322,000	2,996,000	7,212,000	7,212,000
Sink & Line Shaft	2,500	LF	70,000	2,450,000	3,385,000	215,000	6,050,000	11,027,000	16,672,000	6,669
Raisebore Shaft	2,500	LF	25,000	875,000	1,804,000	24,000	2,703,000	3,937,000	6,495,000	2,598
Material Handling Eqpt.	1	LS	22,600	791,000	234,000	127,000	1,152,000	3,079,000	4,120,000	4,120,000
Assemble Mining Eqpt.	1	LS	16,000	560,000	32,000		592,000	2,179,000	2,693,000	2,693,000
Exc. Top Heading	791,400	BCY	151,600	5,306,000	4,462,000	3,728,000	13,496,000	23,884,000	36,502,000	46.12
Exc. Bench	1,137,185	BCY	201,600	7,056,000	3,052,000	2,133,000	12,241,000	31,761,000	45,725,000	40.21
Total Field Cost			938,496	38,172,000	28,925,000	8,784000	106,636,000		119,419,000	
Contingency = 15% of the total field cost									15,994,000	
TOTAL PROJECT COST									135,413,000	

NOTES:

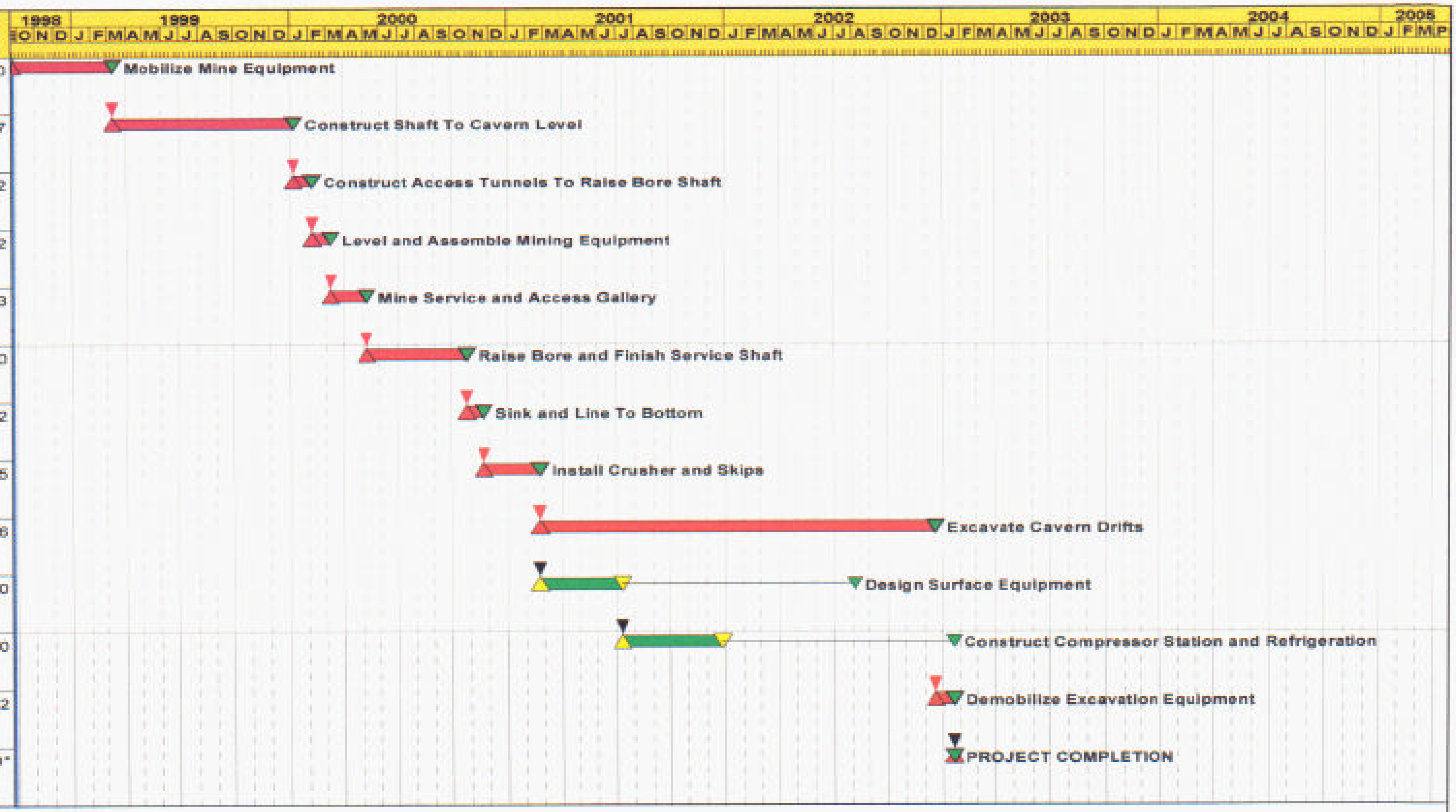
1) Direct burdened labor rate is $35.00 per hour.
2) Salaried labor at rates used in ARSCo Bid.
3) Drill steel & bits @ 0.85 per DLF.
4) Loader and truck EOE @ $40.00 per hour.
5) Dynamite @ $1.50 per pound.
6) ANFO @ $1.00 per pound.
7) Drill EOE @ 0.35 per DLF.
8) Raise bore cutters @ $50.00 per LF.
9) Transit-mix concrete @ $100.00 per yard.
10) Electrical service not included.
11) Work scheduled on seven days per week.
12) No bond premium included.
13) Indirect cost include plant & equip., G&A costs, muck haul and margin.
14) Cavern excavation rate based upon hoisting 400 tons per hour.

SUMMARY COST ESTIMATE FOR 2,500 FOOT DEEP CAVERN

Bid Item	Total	Unit Cost
Mobilization	7,212,000	7,212,000
Sink & Line Shaft (LF)	16,672,000	6,669
Raise Bore Shaft (LF)	6,495,000	2,598
Material Handling Equipment	4,120,000	4,120,000
Assemble Mining Equipment	2,693,000	2,693,000
Excavate Top Heading (CY)	36,502,000	46.12
Excavate Bench (CY)	45,725,000	40.21
Total Field Cost	$119,419,000	
Contingency = 15% of the total field cost	15,994,000	
TOTAL PROJECT COST	135,413,000	

PROJECT SCHEDULE FOR 2,500 - FOOT DEEP CAVERN

Activity ID	Activity Description	Orig Dur
100	Mobilize Mine Equipment	120
110	Construct Shaft To Cavern Level	217
120	Construct Access Tunnels To Raise Bore Shaft	22
130	Level and Assemble Mining Equipment	22
140	Mine Service and Access Gallery	43
150	Raise Bore and Finish Service Shaft	120
160	Sink and Line To Bottom	22
170	Install Crusher and Skips	65
180	Excavate Cavern Drifts	476
210	Design Surface Equipment	100
220	Construct Compressor Station and Refrigeration	120
190	Demobilize Excavation Equipment	22
200	PROJECT COMPLETION	0*



Project Start	23SEP98
Project Finish	20JAN03
Data Date	23SEP98
Run Date	30SEP98

Early Bar
Float Bar
Progress Bar
Critical Activity

MIN2

Sheet 1A of 1B

Department of Energy

ADVANCED UNDERGROUND GAS STORAGE

2,500-ft Cavern Level

Date	Revision	Checked	Approved

REPRESENTATIVE UNIT COSTS FOR NEW GAS STORAGE AND LNG PROJECTS

Table 12-1
Representative Unit Capital Costs for New Gas Storage and LNG Projects

Type of Project	Location	Project Name	Working Gas Capacity (BCF)	Total Cost ($MM)	Unit Cost ($/MCF)	Notes
Depleted Field	California	Putah Sink	15.000	40.000	2.67	(1)
Depleted Field	Colorado	Douglas Creek	10.000	30.000	3.00	(1)
Depleted Field	Utah	Clay Basin Expansion	15.200	49.600	3.26	(1)
Depleted Field	Oklahoma	Manchester	15.000	30.000	2.00	(1)
				Average>>	2.73	
Aquifer	Indiana	Carbon-Calcutta	3.900	12.275	3.15	(1)
Aquifer	Illinois	Hillsborough Expansion	4.500	36.600	8.13	(1)
				Average>>	5.64	
Salt Cavern	Alabama	S. Alabama-McIntosh	2.700	30.000	11.11	(1)
Salt Cavern	Mississippi	Hattiesburg phase 1 & 1A	3.500	47.000	13.43	(2)
Salt Cavern	Louisiana	Napoleonville Phase 1	4.600	45.000	9.78	(1)
				Average>>	11.44	
LNG	North Carolina	Pine Needle	4.000	107.000	26.75	(2)
LNG	Maine	Granite Slate	2.000	44.222	22.11	(2)
				Average>>	24.43	
Refrigerated mined Cavern		Mid-Atlantic	5.000	178.000	35.60	

Notes: (1) EIA/The Value of Underground Storage in Today's Natural Gas Industry.
(2) Brant Energy Data.

SUMMARY OF UNIT COST FOR VARIOUS STORAGE METHODS

TYPE STORAGE	LOCATION	$/MSCF
Depleted Field	California	$2.67
Depleted Field	California	3.00
Depleted Field	Utah	3.26
Depleted Field	Oklahoma	2.00
Aquifer	Indiana	3.15
Aquifer	Illinois	8.13
Salt Cavern	Alabama	11.11
Salt Cavern	Miss.	13.43
Salt Cavern	Napoleonville, La	9.78
LNG	North Carolina	22.11
LNG	Maine	24.43
Chilled Gas	Many Places	35.90

REPRESENTATIVE UNIT CAPITAL COSTS FOR STORAGE

TYPE OF STORAGE		AVG. UNIT COST $ / MCF
DEPLETED GAS FIELD		2.73
AQUIFER		5.64
SALT CAVERNS		11.44
LNG		24.43
CHILLED GAS		35.6
AVOCA & TIOGA		32.00 to 34.00

COST ESTIMATE DETAIL FOR 3,000 - FOOT DEEP CAVERN

Table 10-5

Cost Estimate Detail for 3,000-Foot Deep Cavern

Bid Item	Qty.	Unit	Mnhrs.	Labor	Materials	EOE	Total	Ind. Cost	Total	Unit Cost
Mobilization	1	LS	22,000	770,000	3,500,000	52,000	4,322,000	3,498,000	7,212,000	7,212,000
Sink & Line Shaft	3,000	LF	81,000	2,835,000	3,906,000	258,000	6,999,000	14,439,000	21,813,000	7,271
Raisebore Shaft	3,000	LF	28,200	987,000	2,186,000	64,000	3,237,000	5,026,000	8,393,000	2,798
Material Handling Eqpt.	1	LS	22,600	791,000	234,000	127,000	1,152,000	3,594,000	4,120,000	4,120,000
Assemble Mining Eqpt.	1	LS	16,000	560,000	32,000		592,000	2,544,000	2,693,000	2,693,000
Exc. Top Heading	584,765	BCY	105,300	3,685,500	3,298,000	2,754,000	9,737,500	18,772,000	28,996,500	49.59
Exc. Bench	822,642	BCY	148,000	5,180,000	2,205,000	1,547,000	8,932,000	26,385,000	36,002,000	43.76
Total Field Cost (include P&E and G&A costs)			832,000	34,341,500	25,237,000	7,205,000	97,538,500		109,229,500	
Contingency = 15% of the total field cost									14,629,000	
TOTAL PROJECT COST									123,858,500	

NOTES:
1) Direct burdened labor rate is $35.00 per hour.
2) Salaried labor at rates used in ARSCo Bid.
3) Drill steel & bits @ 0.85 per DLF.
4) Loader and truck EOE @ $40.00 per hour.
5) Dynamite @ $1.50 per pound.
6) ANFO @ $1.00 per pound.
7) Drill EOE @ 0.35 per DLF.
8) Raise bore cutters @ $50.00 per LF.
9) Transit-mix concrete @ $100.00 per yard.
10) Electrical service not included.
11) Work scheduled on seven days per week.
12) No bond premium included.
13) Indirect cost include plant & equip., G&A costs, muck haul & margin.
14) Cavern excavation rate based upon hoisting 400 tons per hour.

SUMMARY COST ESTIMATE DETAIL FOR 3,000 - FOOT DEEP CAVERN

Bid Item	Total	Unit Cost
Mobilization	7,212,000	7,212,000
Sink & Line Shaft (per ft)	21,813,000	7,271
Raise Bore Shaft (per ft)	8,393,000	2,798
Material Handling Equipment	4,120,000	4,120,000
Assemble Mining Equipment	2,693,000	2,693,000
Excavate Top Heading(CY)	28,996,500	49.59
Excavate Bench (CY)	36,002,000	43.76
Total Field Cost	109,229,500	
Contingency = 15% of the total field cost	14,629,000	
TOTAL PROJECT COST	$123,858,500	

COST SUMMARY OF REFIRGERATED MINED CAVERN AT 3,000-FOOT DEPTH

Working Gas Storage of 5.0 Billion Standard Cubic Feet

Maximum Injection Rate of 250 MMSCFD

Maximum Withdrawal Rate of 250 MMSCFD

Injection Cycle - 20 Days

Withdrawal Cycle - 20 days

Conventional Mining and Shaft Sinking (6,292,335 barrels of space)			112,346,209
Refrigeration System, Compressors, and Process			31,971,424
Electrical and Instrumentation Equipment			2,243,333
Compressor Building (210-feet X 50-feet) and Control			903,540
Compressor Building Foundation and Slab			68,064
Concrete Supports for Compressor Station Piping			19,698
Control Building Foundation			153,256
Mechanical Separators Foundations			5,570
Mole Seives Foundations			4,999
Pressure Reducing Station Foundations			4,999
Gas Storage Facility Final Design (Eight Months)			1,078,342
Gas Storage Facility Construction & Commissioning			4,815,600
SUBTOTAL			**153,615,034**
Contingency on All Costs @ 10%			15,361,503
SUBTOTAL			**168,976,538**
Contractors' Profit at 10% on Surface Facilities			3,537,488
TOTAL PROJECT COST			**172,514,026**
COST OF FACILITY PER MMSCF OF BASE GAS STORAGE			**$34.50**
MINING COST PER BARREL OF MINED SPACE			**$20.00**

COST SUMMARY OF REFIRGERATED MINED CAVERN AT 3,000 - FEET

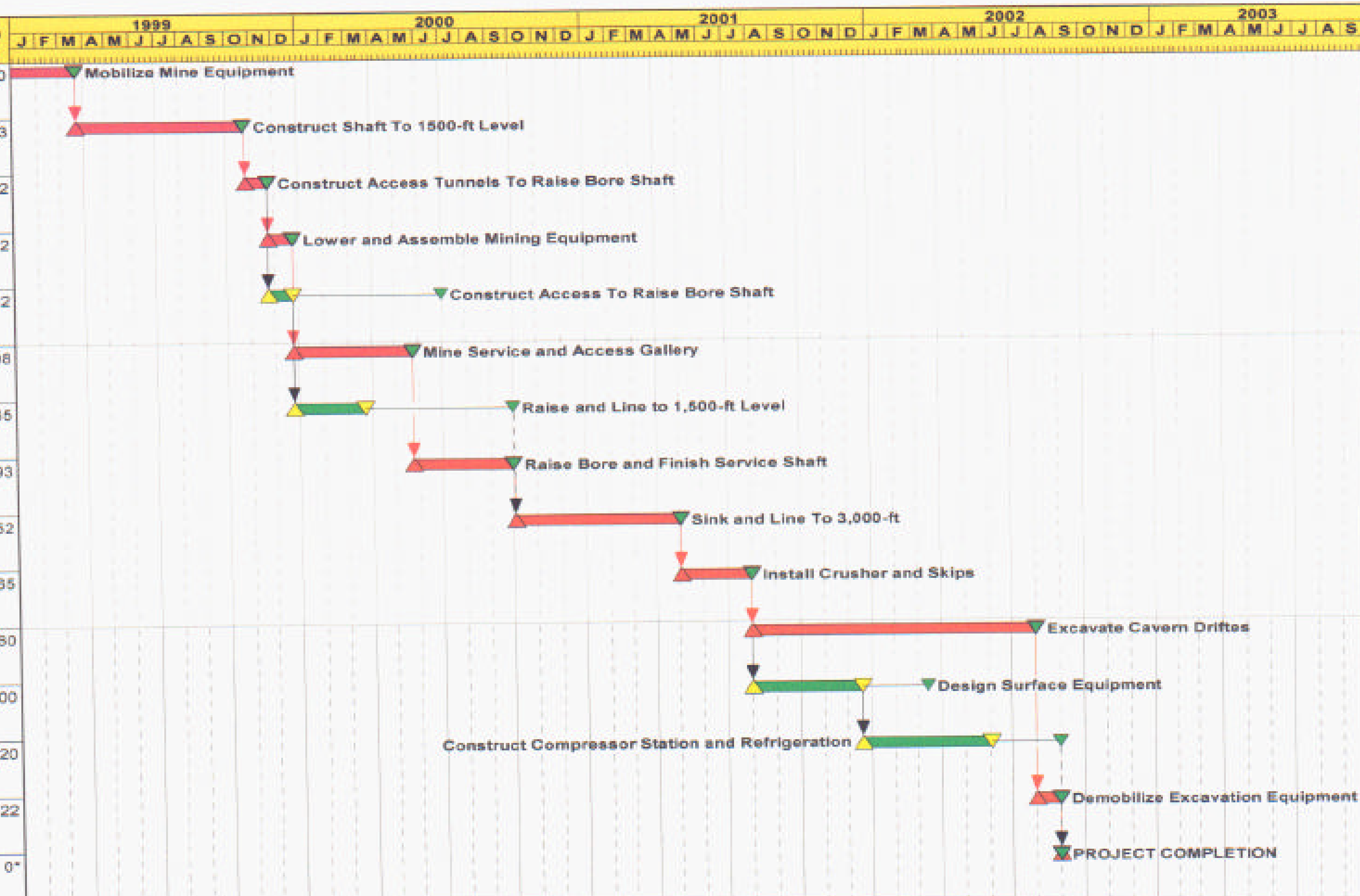
Conventional Mining and Shaft Sinking (6,300,000 BBLS)		112,346,209
Surface Compressor and Refrigeration Equipment		41,268,825
SUBTOTAL		153,615,034
Contingency on All Costs @ 10%		15,361,503
SUBTOTAL		168,976,538
Contractors Profit @ 10%	on Surface Facility	3,537,488
TOTAL PROJECT COST		$172,514,026
COST OF FACILITY PER MSCF STORED		34.50
MINING COST PER BARREL OF MINED SPACE		20.00

Required Cavern Volume (BBLS)

Depth	Cavern Volume @ -20 ^{0} F	Cavern Volume @ - 40 ^{0} F
1500’	21,200,000	Not calculated
2000’	12,000,000	Not calculated
2500’	9,000,000	7,510,000
3000’	6,500,000	5,200,000

PROJECT SCHEDULE FOR 3,000 - FOOT DEEP CAVERN

Activity ID	Activity Description	Orig Dur	Rem Dur
100	Mobilize Mine Equipment	130	130
110	Construct Shaft To 1500-ft Level	153	153
120	Construct Access Tunnels To Raise Bore Shaft	22	22
130	Lower and Assemble Mining Equipment	22	22
230	Construct Access To Raise Bore Shaft	22	22
140	Mine Service and Access Gallery	108	108
240	Raise and Line to 1,500-ft Level	65	65
150	Raise Bore and Finish Service Shaft	93	93
160	Sink and Line To 3,000-ft	152	152
170	Install Crusher and Skips	65	65
180	Excavate Cavern Drifties	260	260
210	Design Surface Equipment	100	100
220	Construct Compressor Station and Refrigeration	120	120
190	Demobilize Excavation Equipment	22	22
200	PROJECT COMPLETION	0*	0*



Project Start	23SEP98
Project Finish	29AUG02
Data Date	23SEP98
Run Date	01NOV98

Early Bar
Float Bar
Progress Bar
Critical Activity

MINE

Sheet 1 of 1

Department of Energy

ADVANCED UNDERGROUND GAS STORAGE

3,000-ft Deep Cavern

Date	Revision	Checked	Approved

COMPARATIVE COST AND SCHEDULE OF CAVERN DEPTHS

Table 11-1
Comparative Cost and Schedule of Cavern Location

	Shaft Depth 1500 ft	**Shaft Depth 2000 ft**	**Shaft Depth 2500 ft**	**Shaft Depth 3000 ft**
Mobilization	7,215,000	7,215,000	7,212,000	7,212,000
Sink & line 18 ft shaft	10,003,500	13,330,000	16,672,000	21,813,000
Rise-bore shaft	3,897,000	5,196,000	6,495,000	8,393,000
Material handling eqpt.	4,123,000	4,123,000	4,120,000	4,120,000
Assembling mining eqpt.	2,695,000	2,695,000	2,693,000	2,693,000
Cavern Exc.	181,714,000	104,197,640	82,227,000	64,998,500
Total mining cost	209,647,500	136,764,640	119,419,000	109,229,500
Contingency	31,447,125	20,514,696	15,994,000	14,629,000
Total cavern development cost	241,094,625	157,279,336	135,413,000	123,858,500
SCHEDULE	80 months	59 months	48 months	47 months

ANNUAL OPERATING COSTS

Table 10-11
Annual Operating Costs

Cost Parameter	Monthly Cost	Annual Cost
Labor		
1 Supervisor	$8,190	$98,280
8 Shift Operators	$40,734	$488,808
2 Relief Operators	$9,165	$109,982
1 Clerical	$3,110	$37,315
Labor Subtotal	$61,199	$734,385
Maintenance Mat'l & Labor	$10,000	$120,000
Operating Supplies	$3,000	$36,000
Energy (as fuel gas)*	$91,202	$1,094,418
TOTAL	$165,400	$1,984,803

* Assumes $2.50 per MMBtu.

ENERGY COST FOR FACILITY

Table 10-9
Energy Costs

	Gas Cost - $/MMBtu:	$ 2.00	$ 2.25	$ 2.50	$ 2.75	$ 3.00
20 Day Injection Period	Fuel Required MMBtu's	Energy Cost	Energy Cost	Energy Cost	Energy Cost	Energy Cost
Compression	$9,864.4	$19,729	$22,195	$24,661	$27,127	$29,593
Refrigeration	$16,491.6	$32,983	$37,106	$41,229	$45,352	$49,475
Dehydration	$1,920.0	$3,840	$4,320	$4,800	$5,280	$5,760
Plant Baseline	$1,221.6	$2,443	$2,749	$3,054	$3,359	$3,665
Total Injection	$29,497.6	$58,995	$66,370	$73,774	$81,118	$88,493
20 Day Withdrawal Period						
Compression	$2,748.6	$5,497	$6,184	$6,872	$7,559	$8,246
Refrigeration	$245.0	$490	$551	$613	$674	$735
Gas Heating	$14,928.0	$29,856	$33,588	$37,320	$41,052	$44,784
Plant Baseline	$1,221.6	$2,443	$2,749	$3,054	$3,359	$3,665
Total Withdrawal	$19,143.2	$38,286	$43,072	$47,858	$52,644	$57,430
	Total Cost per In/Out Cycle	$97,282	$109,442	$121,602	$133,762	$145,922
	Total Energy Cost per Year	$875,534	$984,976	$1,094,418	$1,203,860	$1,313,302

COMPARISON OF STORAGE RATES FOR REFRIGERATED MINED CAVERN VS SELECTED LNG AND OTHER UNDERGROUND STORAGE FACILITIES

Existing LNG Facilities	Days of Withdrawal/ Vaporization	Monthly Demand $/dth/day	Monthly Volume Charge $/dth	Variable Withdrawal Charge $/dth	Variable Injection Charge $/dth	Fuel %	Fuel @ $2.50 $/dth	Single Cycle Unit Cost $/dth	Cost/Cycle @ Max. # of Cycles $/dth
Transco LNG @ Carlstadt, NJ	10	0.9058	0.1745	0.2025	0.2025	7.44%	0.186	3.772	n/a
East Tennessee Natural Gas	10	7.1856	0.0000	0.0000	0.0000	15.69%	0.392	9.015	n/a
Eastern Shore Natural Gas	10	8.6701	0.1745	0.2025	0.2025	7.44%	0.186	13.089	n/a
South Caroline Pipeline Co.	10	5.620	0.0000	0.2500	0.0500	0.00%	0.000	7.044	n/a
Proposed LNG Facilities									
Cove Point LNG (MD)	10	4.940	0.0000	0.0005	0.0005	20.50%	0.513	6.442	n/a
Granite State LNG (ME)	10	6.0600	0.0260	0.0000	0.0546	2.20%	0.055	7.682	n/a
Pine Needle LNG (NC)	10	4.850	0.0000	0.0000	0.0000	0.00%	0.000	5.820	n/a
Existing Salt Cavern Storage									
Hattiesburg Gas Storage (MS)	10	2.6300	0.0000	0.0100	0.0100	1.50%	0.038	3.214	0.321
Proposed Salt Cavern Storage									
Avoca Gas Storage (NY)	10	3.7500	0.0000	0.0100	0.0100	2.00%	0.050	4.570	0.563
Tioga Gas Storage (PA)	10	4.200	0.0000	0.0100	0.0100	1.20%	0.030	5.090	0.602
Refrigerated Mined Cavern	**20**	**9.9190**	**0.0000**	**0.0000**	**0.0000**	**1.16%**	**0.029**	**5.980**	**0.681**

SUMMARY OF COMARATIVE UNIT COST

Existing LNG Facilities	Single Cycle U.C. $/dth
Transco LNG @ Carlstadt, NJ	3.772
East Tennessee Natural Gas	9.015
Eastern Shore Natural Gas	13.089
South Caroline Pipeline Co.	7.044
Proposed LNG Facilities	
Cove Point LNG (NC)	6.442
Granite State LNG (ME)	7.682
Pine Needle LNG NC)	5.820
Existing Salt Cavern Storage	
Hattiesburg Gas Storage (MS)	3.214
Proposed Salt Cavern Storage	
Avoca Gas Storage (NY)	4.570
Tioga Gas Storage (PA)	5.090
Refrigerated Mined Cavern	5.980

CONCLUSIONS

- Store 5.0 BSCF of natural gas
- Multiple cycles per year, 20 days injection and 20 days withdrawal
- Storage is comparable to costs of LNG
- Storage cost is slightly more than two proposed salt cavern projects in the North East (NY/PA)
- The two salt cavern storage facilities were fully subscribed
- Can construct facility for about $172,000,000
- Unit cost is about 34.50 per thousand cubic feet of gas stored
- Can be located in many areas of the United States
- It may be possible to increase the storage pressure after the water around the cavern freezes
- Innovative use of existing technology
- Technically feasible

NEXT SPEAKER

NATURAL GAS STORAGE

Presented by:

Christopher J. Freitas

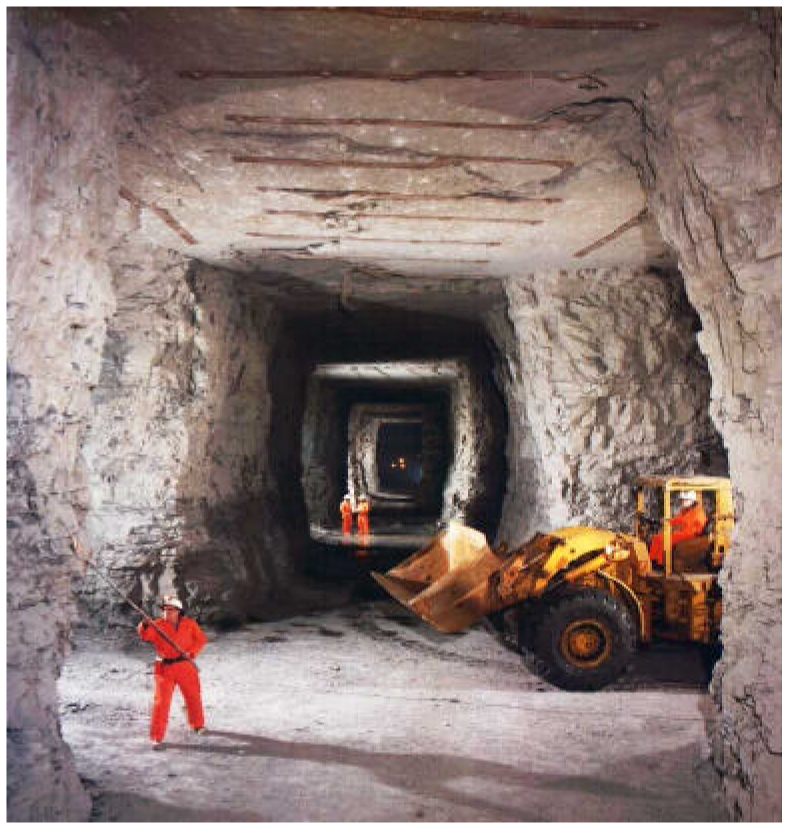
Office of Natural Gas & Petroleum Technology

Doe Advanced Natural Gas Storage Concepts Program
Next Speaker - Dan Tolleson

CHILLED GAS STORAGE IN MINED ROCK CAVERNS

Technology Transfer

PB-KBB INC.
11757 KATY FREEWAY
HOUSTON, TEXAS
281 589-5833



DEPARTMENT OF ENERGY
FEDERAL ENERGY
TECHNOLOGY CENTER
MORGANTOWN, WV

PB-KBB
ENGINEERING CONSTRUCTION OPERATIONS

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BREAK INTO TEAMS FOR DISCUSSION

Mr. Dan Tolleson

- Technical Questions
- Positive / Negative Comments
- Future Possibilities
  - Economics
  - Market
  - Technology

Questions from Houston

- What is the next step? Is there a follow up study?
- Could this technology be used in depleted mines?
- At a lower temperature (less than -20 F) what would the problems be?
- Applicable in CAES?
- Did the schedule include Geotechnical and Environmental schedule or just a construction schedule?
- In determining the depth relative to the safety factor - What are the environmental issues?
- Could you go through the refrigeration process starting from cavern completion?
- How does this compare to traditional LPG costs?
- Is this economically feasible?

Questions from Houston (continued)

- What is the DOE web site address and when will the CD's be available? www.fetc.doe.gov
- Are 9 cycles a year feasible?
- Can you make water tight seals around the shaft?
- With a total project of 6 to 8 years, who would invest?
- How do you get rid of the rock?
- How do you prove mechanical integrity?
- How can you accurately predict the cost estimate?
- Can this work in salt?
- Does the natural gas market support this?
- What is the pay out? How many years?
- How do you get the equipment in the mine?

Questions from Houston (continued)

- What are the effects of freezing on cavern / internal pressure?
- What are the future expansion possibilities?
- How do you purge the cavern?
- Monitor wells?