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UNDERGROUND GASIFICATION FOR STEEPLY DIPPING COAL BEDS

Phase I Report: Feasibility Study and Program Plan

September 30, 1977—February 28, 1978

May 1978

Work Performed Under Contract No. EF-77-C-03-1472

Gulf Research and Development Company
Pittsburgh, Pennsylvania

and

TRW Energy Systems Planning Division
McLean, Virginia

MASTER

U. S. DEPARTMENT OF ENERGY

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ABSTRACT

The first phase of the DOE project for gasification of steeply dipping coal beds consisted of site selection activities, a concept feasibility study and program planning.

A test site was selected at North Knobs near Rawlins, Wyoming. This site has the best potential for a successful first UCG-SDB test.

Analysis of the concept suggests air emission and aquifer degradation as possible areas of environmental impact. A monitoring plan has been established to determine the environmental effect of the tests.

The detailed technical approach for the project is being developed based on present DOE field experiences and previous Russian work. Emphasis will be on resolving technical areas where the DOE experience is not transferrable (i.e., process modeling, well configuration, and installation).

Using a proprietary cost estimating model, the parameters of greatest sensitivity were product gas quality, gas leakage, and yield of product gas per unit volume of injection air.

A facility and equipment design was established for cost projection and to serve as a basis for detailed design work during the second phase.

A cost analysis of the project indicated that the original costs projections still hold but that the spending curve will require revision.

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EXECUTIVE SUMMARY

This Gulf Research & Development Company/TRW Project, Underground Gasification for Steeply Dipping Coal Beds, is the first commercial project for underground coal gasification (UCG) funded by the Department of Energy (DOE). Although several underground coal gasification projects have been carried out by DOE in horizontal coal beds, this will be the first experiment in the United States for gasification of steeply dipping ($\geq 45^\circ$) coal beds (SDB). One objective of this project is to assess the economic viability of UCG in SDB. A second objective is to develop and demonstrate this technology through Government/Industry cost shared venture. The government technology developed for use in gasifying horizontal coal beds is to be transferred as effectively as possible for application to the steeply dipping bed problem.

From a national perspective, considerable additional energy sources must be found during the next twenty years to satisfy projected energy demand. Underground coal gasification has the potential to contribute significantly to the overall energy picture in the time frame mentioned. Development of these beds is not economically feasible by conventional techniques. It is estimated that as much as 100 Billion tons of coal lies in steeply dipping beds. It is possible that much of this coal could be utilized through underground or in situ gasification.

In situ gasification presents a number of advantages over conventional mining and combustion methods. No equipment or staff is needed to mine the coal, no trains are required to haul the coal to the combustion site, no combustion need take place near large urban centers. The process gas produced by underground gasification can be utilized in several ways: directly for generation of power at the gasification site; the upgraded gas could be transmitted to consumers via gas pipeline; the gas could be used as feedstock for chemical production.

This project represents a major step toward commercialization of underground coal gasification. The sequence of steps of which it is a part is shown below.

- Develop and demonstrate in situ gasification technology in horizontal beds. This is also being done by DOE via projects at Lawrence Livermore Laboratory and Laramie Energy Research Center.
- Develop and demonstrate in situ gasification technology in steeply dipping beds.
- Transfer this technology to industry and demonstrate the above technology in a coal environment which is representative of significant national resource.
- Develop reliable economic data for estimation of scaled-up operating costs.
- Demonstrate large (multi-module) burns.
- Demonstrate pilot scale plant usage of UCG process gas from a multi-module burn. Determine economic viability of full-scale commercialization.
- Construct and demonstrate a full-scale plant.

In order to develop the necessary cost data for a pilot scale UCG demonstration, this project incorporates the execution of several test "burns." The first burn serves the purpose of developing the necessary skills and procedures for demonstrating gasification using the simplest module configuration. The second burn develops the relationship of the process gas quality to programmed changes in the process variables. The third burn demonstrates the expansion of these operations to a

process unit which consists of more than one linked module. Collectively these operations will provide a data base which can be used to develop pilot-scale facility cost estimates. At the same time, demonstration of the UCG technology in steeply dipping beds and transfer of this technology to industry will have taken place.

Implementation of the above activities has been broken into four sequential phases. The content of these phases is given below.

- Phase I -- The critical elements of the program which must be performed at the outset are contained in this phase. Among these are selection of a gasification site, evaluation of any environmental and permit acquisition problems which might be associated with gasification at the site, development of a test plan for execution of the three burns, definition of the facilities and instrumentation required to support the burn, evaluation of any special problems (such as extinguishing the fire or drilling the slant wells) which might be associated with project activities.
- Phase II -- A detailed geological and hydrologic characterization of the test site is performed. The facility and instrumentation system are designed, and items requiring a long lead time are ordered. Associated problems are evaluated. Baseline environmental monitoring is initiated, and appropriate permits are secured. The process holes associated with the first burn are drilled and the air permeability between them is measured. Equipment footings, roads, and other appurtenances necessary to support the later installation of the facility are emplaced. Plans and procedures for operation of the site and execution of the burns are produced.
- Phase III -- The facility and instrumentation are installed. The test site is staffed. All necessary systems are checked

out and calibrated. Burn No. 1 is initiated. The modules for Burns 2 and 3 are installed, tested, and ignited. Collected data are analyzed and interpreted in terms of experiment objectives. Environmental monitoring continues. After completion of Burn No. 3, the site is restored to its original condition.

- Phase IV -- Using the data collected in Phases I through III, the cost of constructing and operating a pilot unit is estimated.

The activities of Phase I have resulted in significant accomplishments. Of major importance is the selection of a test site, definition of plans for operations to be performed at the site, as well as scheduling and costing the activities of Phases II, III, and IV. These accomplishments and others achieved in Phase I are tabulated below.

General

- General Technical Approach - The overall method for implementing the UCG in steeply dipping beds project was defined.
- Activity Network - A network was developed to interrelate project tasks along a time base.
- Cost Review - A detailed analysis of the projected costs through completion revealed that the original cost estimates were still valid.
- Parametric Cost Estimate - The GR&DC mathematical model was employed to perform a sensitivity analysis showing the effects of key process parameters on the anticipated sale price of gas generated by a conceptual UCG commercial plant.

Site

- Site Selection - A site at North Knobs, near Rawlins, Wyoming, was found to satisfy the site selection criteria set up for this project. Preliminary site characterization revealed the presence of water above the gasification region. This was one of the site selection criteria.

Operations

- Test Plan -- A plan was developed for execution of the three burns. Ranges were established for the significant process parameters.
- Facility Design -- A conceptual design for the facility was established. This design calls out the location of structures, piping, and major pieces of support equipment.
- Instrumentation -- Instrumentation needs to support the three burns were evaluated.

Support

- Site Support -- A plan was developed for support of the site operations.
- Permits -- The state and federal permits necessary for operation of the site were reviewed. No extraordinary difficulties were foreseen in obtaining these.
- Quenching -- An assessment was made of the difficulties to be encountered in extinguishing the burns. No exceptional problems are anticipated as long as the burns take place below the water table.

- Environmental Analysis -- The most likely environmental impacts of the project's operation were assessed. No major areas of concern were found. A plan was developed for environmental monitoring in Phases II and III.

A number of observations are drawn from the learning experience resulting from the Phase I activities and are listed below:

- Gasification in steeply dipping beds involves technical uncertainties not previously addressed. In order to complete this project within budget, it is mandatory that maximum use be made of the existing UCG data base developed by LLL, LERC, and Sandia.

The existing data base relates only to the subbituminous coals of semiarid Wyoming. Our site maximizes the ability to transfer the existing UCG knowledge into the SDB program.

- The planned approach to the burns forces us to face two uncertainties:
 - a) operation in a new resource (steeply dipping coal beds)
 - b) application of a high-angle slant drilling approach

In order to minimize the uncertainties involved in b), an examination of slant drilling technology is currently being undertaken. This assessment results in a recommendation to perform a slant drilling test operation early in Phase II. Such an effort is not funded under the present contract.

- It is imperative that sufficient instrumentation be emplaced in the vicinity of the burn area to allow an ongoing estimate to be made as to the location of the burn front. It is desirable to know that the burn front is developing "properly." This information is also necessary for validation of the

predictions of the process model. The complete array of UCG diagnostic instrumentation currently employed on a burn would probably be too expensive for use on a commercial operation. This project occurs during a transition period in the horizontal bed effort between an early stage of intensively instrumented burns and a second stage of development in which the burn configuration will be followed primarily from the predictions of a mathematical model. At present, neither the instrumentation nor the model has been demonstrated to yield the desired degree of predictive accuracy in horizontal beds. Steeply dipping beds present a whole new array of problems in both areas. Unfortunately, the SDB project cannot begin on the second stage of the overall instrumentation and predictive modeling development process. It is imperative that this project be highly instrumented and accompanied by a significant effort to develop an appropriate SDB process model. Each of these activities will require additional support.

- Backup sites are required to be in a high state of readiness in the event that gasification operations cannot be performed at the North Knobs site. Among the reasons for such a move would be: unfortunate hydrologic conditions, discovery of heavy fracturing in the coal seam, observation of unusually low permeability along the linkage path. Work is currently under way to locate at least two candidate backup sites.
- A characterization of the nation's steeply dipping resource should be made. This resource characterization would expand the existing work that defines the size and distribution of the SDB resource to determine the applicability of existing experience and the results of the program to that resource. The results of this study would define for potential participants the specific technical problems which might be encountered in the commercialization of a particular SDB coal.

- There is considerable commercial interest in the production of high Btu gas. This requires injection of oxygen. Development of cost factors for an oxygen burn requires that the burn extend over a significant period (as much as 80 days). The absence of these data dictates that funds should be allocated for such an exercise as part of this project.

1.0 INTRODUCTION

The purpose of this document is to provide Department of Energy (DOE) with the results of the feasibility study and program planning for the underground gasification of steeply dipping coal beds (UCG-SDB). It is limited to a discussion of the work performed during Phase I of the project.

Information is provided on site selection, rationale, a description of the selected site including its relationship to the SDB national resource, an environmental analysis and environmental monitoring plan, a parametric cost estimate, and a detailed project and cost plan for Phases II, III, and IV.

The goal of energy independence for the United States requires the increased use of our largest energy resource, coal. Research and development for improving the efficiency and environmental acceptability of coal combustion is in the national interest.

Underground coal gasification utilizes the coal in situ. The gas produced from underground combustion can be used for various markets, including electric power, substitute natural gas, and chemical feedstocks for products such as ammonia and methanol. The general public should find UCG more acceptable than strip and conventional underground mining techniques. The environmental impacts of UCG are considerably less and the dangers to underground laborers in conventional deep mining are eliminated.

In addition, underground coal gasification promises economic recovery of coals that are economically or technically unminable with conventional mining techniques. The Soviet Union during its five decades of underground coal gasification has reported considerable success in gasification of steeply inclined seams. A review of their technology leaves the impression that SDB was their preferred resource for UCG.

An estimated 100 billion tons of coal in the U.S. occurs in steeply dipping beds (SDB). About 25% of this coal is suitable for in situ gasification.

DOE is sponsoring research on coal conversion. One major program is underground coal gasification research and development. The project for gasification of steeply dipping coal beds is one part of that test program.

Gulf Research & Development Company (GR&DC), along with TRW as a major subcontractor, has begun a five-year program to evaluate the technical and economic feasibility of UCG in SDB. The primary objective of the project is to establish process feasibility and provide data on the economics of the system. This information will be used to produce a design concept and a cost estimate for the design, construction, and operation of a pilot plant--the next step toward commercial development of the UCG process for SDB.

Secondary objectives are:

- To install a module and ignite, sustain, and extinguish underground coal gasification in steeply dipping beds.
- To optimize values for injection gas flow rate, reactor pressure, and amount of water in the reaction.
- To establish effects of subsurface subsidence on the process.
- To determine resource utilization in a single module.
- To establish overall economics of the process.
- To determine the effects of operating two modules at the same time in communication with one another.
- To establish the resource recovery potential.
- To determine the impact of the process on the environment.

The following constraints govern the project:

- All tests will be conducted under the water table level to assure the ability to quench the process.
- All site work will be conducted in a manner to minimize the impact on the environment.
- The site must be restored to its original condition to the extent possible.
- The three tests will be performed using process modeling, instrumentation design, and operational computer software supplied by DOE.

2.0 REPORT ON PHASE I ACTIVITIES

2.1.0 SUMMARY OF PHASE I ACTIVITIES

The purpose of the Phase I effort was to establish the overall approach to move UCG technology into steeply dipping coal seams. This was accomplished by selecting a site, integrating existing technology into the project, identifying the problem area precisely, and establishing programs to resolve the problem areas.

During Phase I, the following were completed:

- The overall technical approach was established. The arrangement of the burn areas on the site, drilling, permitting, environmental monitoring, testing, quenching, instrumentation, and facilities plans for the project were established.
- The North Knobs site near Rawlins, Wyoming, was selected; it satisfies the criteria better than any other site.
- An environmental analysis of the conceptual design was performed that establishes several areas which the Phase II design must address specifically. Additionally, a plan was prepared for environmental monitoring for baseline data before, during and after operations.
- A quench mode analysis was performed that pointed out that the tests should be conducted below the water table and that more work must be done during Phase II to investigate additional techniques.
- A test plan was laid out that estimates the optimum value for each of the three major variables (reactor pressure, injection flow rate, and water content) as they relate to the fourth variable, time. The real optimum values will be established by varying each variable over a range of values while holding the other two constant. Additionally, the depth of the module, drilling configuration, and linking techniques were established.

- The instrumentation needs were estimated and existing instrumentation systems were reviewed to determine their applicability to the project needs. Some instrument systems were selected for use; some were rejected; and some will be investigated further in Phase II.
- A facility was designed to a level of detail sufficient to facilitate cost estimating and provide a basis for a Phase II detailed design.
- A parametric cost analysis was performed using the GR&DC proprietary mathematical model for a conceptual commercial plant for UCG in a horizontal coal seam. Gas heating value, outlet gas pressure, air and gas leakage, and production rate per well were found to have the greatest effect on sales gas price. Effects which appear to be pertinent in SDB were identified.
- A detailed cost review was performed based on more information than was available at the proposal stage. The review indicates that the project can be completed for the original estimated amount of money. Some transfers of funds between WBS's and phases are required.
- A subcontract with TRW was signed by GR&DC and TRW. Government approval was obtained.
- The permitting plan involves two stages. The first stage is to obtain permits for site evaluation early in 1978. The second stage is to obtain permits for site construction and testing in early 1979.
- A schedule that shows the known interaction between various tasks was developed. The schedule will be updated periodically as the various tasks and their interaction with one another

become more and more understood and defined. As the schedule develops, the critical path items will become visible to project personnel.

During Phase I, the overall technical approach to accomplish the project goal and objectives was established and is divided into four phases as outlined below:

- Phase I Feasibility Study and Program Plan have been completed and are described in this report. This includes:
 - Site Selection
 - Environmental Activities
 - Parametric Cost Estimate
 - Detailed plans and costs for Phases II, III, and IV
- Phase II Site Evaluation and Experimental Design will include:
 - Geological/hydrological field program
 - Environmental baseline monitoring
 - Experimental test design
 - Investigation of special problems
 - Facility design and some construction
 - Detailed planning for the field tests in Phase III
- Phase III Field Test of UCG of SDB will be attempted for the first time in the United States. This is a three-burn program that will:
 - Demonstrate the ability to link, ignite, sustain, and terminate a UCG-SDB process module (Burn No. 1).
 - Operate a process evaluation burn to study the relationships between process parameters and resource recovery (Burn No. 2).

- Operate a twin parallel module experiment to determine the feasibility of multimodule operation and resource utilization (Burn No. 3).
 - Monitor water and air quality before, during, and after the test program to estimate the effects of UCG on the environment.
 - Provide improved economic projections of commercial UCG of SDB.
- Phase IV will develop a Conceptual Pilot Plant Design and Cost Estimate for a facility of sufficient size to fully demonstrate the feasibility of underground gasification of steeply dipping coal beds.

2.2.0 STUDIES PERFORMED

2.2.1 TECHNICAL APPROACH

2.2.1.1 Introduction

Gulf Research & Development Company (GR&DC), with TRW as a major subcontractor, have begun a five-year program to evaluate the technical and economic feasibility of UCG-SDB. The primary objective of the project is to establish process feasibility and provide data on the economics of the system. This information will be used to produce a design concept and a cost estimate for the construction and operation of a pilot plant--the next step toward commercial development of the UCG process for SDB.

Secondary objectives are:

- To install a module and ignite, sustain, and extinguish underground coal gasification in steeply dipping beds.
- To optimize values for injection gas flow rate, reactor pressure, and the amount of water required in the reaction.
- To establish the effects of subsurface subsidence on the process.
- To determine resource utilization in a single module.
- To establish the overall economics of the process.
- To determine the effects of operating two modules simultaneously in communication with one another.
- To establish the resource recovery potential.
- To determine the impact of the process on the environment.

The following constraints govern the project:

- All tests will be conducted under the water table level to assure the ability to quench the process.
- All site work will be conducted in a manner to minimize the impact on the environment.
- The site must be restored to its original condition to the extent possible.
- The three tests will be performed using Process Modeling, Instrumentation Design, and Operational Computer Software supplied by DOE.

An overall technical approach has been developed to achieve the stated objectives within the established constraints. The approach maximizes utilization of existing experience while resolving the new untried areas. The major effort must be to resolve the untried areas, not rejustify the existing experience. Development of this approach is, by necessity, an iterative process since the elements of the project exhibit a high level of interdependency. The nature of the interdependencies is shown in the functional flow diagram as Figure 2-1.

2.2.1.2 Utilization of Existing Experience

Gasification of steeply dipping coal seams is a reality in Russia, but it is yet to be demonstrated in the United States. A large amount of information on this subject is available in the Russian literature but not in the desired detail. Some of the field experience in the gasification of horizontal beds can be transferred to the SDB process, but the extent of the transferability has not been fully determined. The overall technical approach is to use existing experience and minimize the risk in the unknown areas. There is reason to believe that the relationship between various process parameters and product gas yield and composition is significantly different in the steeply dipping UCG process.

Figure 2-1. FUNCTIONAL FLOW OF TECHNICAL APPROACH

State of the art in UCG in the U.S. is the linked vertical well (LVW) technique utilized at Hanna and Hoe Creek. A coal rubble bed is replenished during the process. This rubble bed serves as the reduction zone in the process where CO_2 reduction and the water gas processes occur. This rubble bed zone appears to be essential to maintenance of gas quality during the process. When the UCG process is applied to SDB, a change in the process occurs. The rubble falls to the bottom of the reactor away from the product gas outlet. To maintain the necessary gas quality, the injection well must be maintained at the bottom of the reactor. The Russian experience supports this concept. Their preferred configuration for SDB shows the injection well installed through the footwall and a production well installed down the seam. Implications of dip on the overall process chemistry are discussed in detail in "In Situ Gasification Reactions" (Section 2.2.3.1).

2.2.1.3 Development of the Technical Approach

A preliminary test plan was developed to establish project site selection criteria. These criteria are discussed in "Site Selection Activities" (Section 2.2.2) and in Appendix A. The test plan was used to review the original RFP site requirements. The project site selection criteria represent stricter requirements than the RFP and enhance the probability of providing a technical success. The stricter project site selection criteria are:

- limitation of rank to subbituminous
- establishment of an upper limit of dip to 75°
- seam thickness range of 3-10 meters
- simple geology
- site accessibility

In addition to the above, the contract for this project implicitly imposed the additional criteria that the selected site must use the experience gained in underground coal gasification at Lawrence Livermore Lab (LLL), LERC, MERC, and Sandia to the maximum extent possible.

Potential sites were evaluated utilizing the project site selection criteria. Data available at the time of contract award were supplemented with additional field data for the selection of a test site meeting these criteria with the lowest level of risk. The North Knobs site near Rawlins, Wyoming, is considered to be the best site for the first field test.

A site-specific test plan was developed for the North Knobs site. Boundary values for process parameters were established for design purposes based upon Hanna data (0.8 lithostatic pressure, burn front advance of 0.6 m/d (2 feet/day) optimum water 0.3 kg/kg coal). Areas where dip may introduce complicating factors were defined and will be evaluated further. Among these are reactor growth patterns (rate and shape), process model applications, instrumentation well configurations, and instrument arrays and data interpretations. Areas where technology transferability is logical are surface facilities, process and product analysis, instrumentation, and process control systems.

Studies of the interactions of process parameters of air flow rate, reactor pressure, process water volume, reactor volume, and reactor shape are required to define optimum process conditions. As a result of the effect of gravity on the process, reactor volume may have a much greater effect on the process than in horizontal beds. Process parameter matrices were developed for the design of the experiments.

The test plan provides for three burns which are designed to obtain the data required to establish the feasibility of the process and to provide input into the SDB economic projects. The three burns are each described in more detail below.

Burn No. 1

The primary differences between horizontal and SDB gasification are related to configuration and method of installation of the process module. Systems and techniques for horizontal gasification are being utilized in this program, although the technology may not be totally

transferable. Burn No. 1 will provide a check-out of the various systems and experience in the operation of a field burn.

Burn No. 2

An economic analysis of UCG indicates that yields of product gas per unit volume of air and gas quality are the more significant process parameters for cost projections. The cost of air or oxygen overrides the drilling or surface piping costs for horizontal beds and the same may be true for inclined beds.

The Burn No. 2 process evaluation will deal primarily with the effect of air injection rates and pressures on product volumes and product composition. Enhancement of product gas quality can be achieved to a limited degree with water injection. The effective range of water levels for product enhancement must be investigated. The effect of reactor volume on product yield and product quality must also be investigated.

Results from Burn No. 2 must give indications of product yield, product composition, and reactor stability as measured by yield and composition data. Data will be utilized in the Gulf Modified Economic Model to obtain economic projects based upon an actual field test of UCG-SDB.

Burn No. 3

Resource utilization is of concern when evaluating any fuel conversion process. Projections as to the shape of a single UCG-SDB process module suggest that a bridging effect may be observed. Sweep-out of coal between modules would be desirable to improve resource utilization with a realistic well spacing. Burn No. 3 must attempt to accomplish this in a non-streaming mode. The results of this test will be useful for preparing the Phase IV Pilot Plant Estimate.

Process instrumentation specifications must be determined by the test plan and data interpretation requirements. The process instrumentation must be procured from off-the-shelf sources. Transferability of certain items from DOE to this project must be evaluated.

The ability to control and terminate the underground gasification process is required. To date, DOE tests have allowed the process to quench itself by means of shutting off the air supply and letting groundwater seep in and cool the reactor. This technique must be considered the prime technique for this project; however, quenching in SDB may present more of a problem. A failure mode analysis of UCG of SDB defined three possible types of reactor failure:

- faulting
- pressure blow-out
- leakage up the production well

The results of the failure analysis have altered the information needed from the geotechnical program and may affect process module and equipment design. Various options for termination of the process have been proposed and must be evaluated further.

A facility must be designed to support the field test program set forth in the test design. The final design must consider the test plan requirements, geology, climate, and site restoration requirements.

A parametric analysis of the gasification process in horizontal beds suggests that overall process efficiency, leakage, and product quality are the major factors in determining economics of a conceptual UCG process. Surface piping and drilling costs are secondary factors. Impact of the steeply dipping bed configuration on process economics may occur through all of these factors. Certainly it can impact on process efficiency, leakage, and consistency of gas production. Arrangement of surface facilities and drilling costs may assume greater importance in

SDB. Drilling costs for the slant wells required for the process are not well defined.

The economic model for UCG must be revised to provide a parametric cost estimate specific for SDB. The test program must supply data on process efficiency, leakage, product gas quality, facility configuration, and slant drilling capabilities. Then viable economic projections can be made on conceptual commercial processes for UCG-SDB.

A detailed picture of the site geology is needed as input into test design, facility design, drilling, process data analysis, and environmental activities. The available technical data for the North Knobs site are inadequate for the development of a detailed test plan that can install, operate, and terminate a field UCG experiment. Such a field experiment must provide the data needed to satisfy the project objectives. The technical program must provide information on the coal seam geometry and composition, presence of faulting, groundwater flow, and boundary strata composition. Surface and subsurface mapping of the proposed site must provide information for selection of the optimum burn locations on the site with respect to coal seam attitude and thickness, hydrology, access, and terrain. The subsurface geology must provide input for the subsidence studies, development of the drilling program, and hydrology program. The input required is detailed data on lithologic, stratigraphic, and structural properties of the involved strata.

Hydrologic studies must provide input data on subsurface hydrologic characteristics of the site. The input data required are the water table level, aquifer identification and its accompanying transmissivity and groundwater flow rate and direction.

Air permeability of the seam must be measured in the first process module which will be installed during the latter part of Phase II.

These geologic studies must integrate the subsurface data, the surface characterization data, and the hydrologic data into a detailed

picture of the entire site. This will be used as a basis for final acceptance of the site and the on-site burn locations. Specifically, this detailed picture must include:

- Depth of seam
- Thickness of seam
- Lithology
- Structure
- Aquifer identification
- Aquifer characteristics
- Cleat orientation
- Anomalous conditions
- Seam dip
- Porosity and permeability of the seam
and its enclosing rock formations

An important project objective is to determine the impact of the process on the environment. This is enforced by the project constraint to minimize the impact on the environment. Analysis of the design concept has defined air and groundwater quality as areas where possible impacts on the environment may occur. Environmental effects are also a concern of the government agencies that approve the permit requirements for the field test.

Ambient air quality must be monitored for both EPA criteria pollutants and for those pollutants which are thought to be specific to this project. The EPA criteria pollutants are sulfur dioxide, nitrogen oxide, carbon monoxide, ozone, non-methane hydrocarbons, and total suspended particulates (TSP). Pollutants specific to UCG are identified in Appendix B, Environmental Analysis of Concept Design. These data must be correlated with wind speed and direction to determine the effects of project activities upon air quality in the area.

The baseline water quality monitoring program must determine the concentrations of selected parameters in the coal seam waters and in adjacent underlying and overlying zones before the UCG tests. The data

obtained from baseline monitoring must be compared with data obtained from subsequent project phases to determine the changes in the selected parameters. Water samples must be analyzed in accordance with EPA recommended procedures.

The monitoring must continue during the field test activities and for one year after the test activity. The data collected must be correlated with field activities to properly evaluate the impact of the project activities on the environment.

An Environmental Impact Assessment (EIA) for the selected site, in accordance with DOE "Guidelines for Environmental Review" (39 FR 5020, as amended by 42 FR 711) is required. The EIA must evaluate the expected environmental impacts of the proposed project on the site based on the environmental analysis of the process conceptual design and available baseline monitoring data. The EIA is necessary for DOE environmental review and permit requirements.

The test plan will be revised from time to time as required based upon process parameters, economic factors, coal characterization, and site characterization data. Process parameters such as module configurations, gas pressure, flow rate, and process water content must be considered in conjunction with an economic analysis for experimental design to arrive at a suitable test plan.

Laboratory bulk coal studies must be performed on several coal corings from the site to obtain gasification and pyrolysis behavior, compositional makeup, and certain physical characteristics (thermal conductivity, density, heat capacity). Gasification characteristics must be determined from combustion tube studies and will be primarily concerned with identifying the composition and relative amounts of gasification products obtained under certain conditions of pressure, temperature, and feed composition. These data, besides being incorporated into the test design plan, must be suitable for computer modeling efforts.

Revisions to the test design plan may directly impact upon the design functions for facilities, process equipment, quenching operations, instrumentation design activities, and the detailed test procedure definition.

Using the information gained from the mapping and exploratory drilling activities (discussed earlier), the task of defining the final site layout plan must be undertaken. After establishing access road and site grading requirements of the general site, the location of the process and instrumentation wells must determine equipment locations (compressors, piping, portable buildings, etc.). In choosing surface facility locations, the effects of possible subsidence resulting from the burns must be considered.

The facility design must provide compressed air for linking and gasification at pressures and flow rates specified in the test plan. The injection compressor design must also provide for flow variations over the ranges specified in the test plan. A separate linking compressor must supply air during the initial linking operations at flow rates and pressures specified in the test plan. A detailed cost comparison between electric and diesel-powered compressors must be made. The piping design must accommodate measurement of temperatures, pressures, and flows of both the injection and production gases.

The instrumentation system can be divided into four major categories: process control instrumentation, product analysis instrumentation, reactor definition instrumentation, and data acquisition and reduction system.

Process control instrumentation must monitor the temperature, pressure, and flow rate of the injection air, production gases, and water injection with conventional "off-the-shelf" items such as orifice meters and mass flow meters.

The product analysis instrumentation system must provide chemical composition data for both the product gas and the gases obtained from

affected areas within the coal seam. Product composition data are used to calculate basic process characteristics such as product heat value and thermal efficiency and aid in determining the best end use of the UCG products (boiler feed, synthetic gas feed, chemical plant feedstock, etc.). In-seam gas analysis provides input for modeling the chemical reactions occurring within the seam. A combination of analytical instruments (gas chromatographs, cold traps, calorimeters, and hygrometers) is used to analyze all of the products except tars. Due to its great effect on UCG product distribution, redundant water analyses must be made with two independent analytical instruments.

Reactor shape definition is also of great commercial importance because it allows well utilization and coal resource utilization efficiencies to be calculated. Well utilization efficiency is defined here as the amount of coal which can be gasified per well and is directly related to the shape/size of the reactor. Coal resource utilization efficiency is the amount of coal gasified in a given area divided by the amount of coal present in that same area and multiplied by one hundred. For the UCG process, there are many questions still to be answered concerning the degree of control the operator really has over the shape/size of the reactor. Control of reactor shape/size implies the ability to control the direction of the gasification front. A "second best" alternative might be the ability to at least predict the movement of the gasification front under certain operating conditions, well configurations, and coal bedding conditions. This type of information would permit a commercial developer to determine the areal sweep of certain well patterns and/or coals, thereby allowing much more efficient well and coal utilization.

The only way to determine if the direction of the gasification front can be controlled is to obtain a three-dimensional "picture" of the reaction chamber via reactor definition methods during a UCG field test. Since the distance between the production and injection well bases is only 18 m (60 feet) in this project, a reactor definition method should provide a real time three-dimensional picture with a resolution of ± 1.5 m (5 feet), at least. Furthermore, the data collected

by this method should be amenable to further interpretation after the burn (through correlation with events in the burn) to increase the resolution to ± 0.6 m (± 2 feet). Post-burn reactor definition activities such as coring, seismic methods, or others are recommended to confirm the accuracy of the chosen reactor definition methods but are presently not funded.

Various methods will be used to determine the size and shape of the in situ reactor. These include subsurface thermal, mass balance, and helium tracer methods. Other methods such as resistivity, seismic, and subsidence monitoring will be further evaluated. Thermal data will be obtained from thermocouples placed in instrumentation wells which extend into and below the coal seam. The thermocouples placed above and below the seam will be used to calculate heat loss to the surrounding strata. Interpretation of the thermal data obtained from above the reactor may also help define subsidence events. The proper placement of these instrument wells will be an important design variable, since placement determines to a large extent the amount of useful data obtained by this method. DOE have used their process models to plan instrument well placement. This will be needed for this project. The existing models must be modified to provide the needed capability.

Design of the data acquisition system must be based upon DOE-supplied software, the Sandia/LERC experience at Hanna, and the LLL experience at Hoe Creek. Due to the variety of hardware used and the two independent systems used at Hanna, problems may be encountered when attempting to integrate the two systems. Software implementation must only involve generating a software performance specification that will be used in the procurement of the system hardware. Procurement of the system hardware can proceed only after the software is provided. A cost evaluation of the DOE computerized process control system must be made.

The test plan must provide criteria from which drilling programs can be prepared. The drilling programs are instrumentation wells, injection and production wells for Burns Nos. 1, 2, and 3, and the

geotechnical program. Discussions with people in the drilling field indicate that slant well drilling requires development during Phase II.

2.2.2 SITE SELECTION

2.2.2.1 Introduction

Site selection activities during Phase I involved detailed review of available information on the North Knobs and Johnny Moore Syncline areas, and reevaluation of several of the more promising backup sites. In addition, a small amount of exploratory drilling was done on the North Knobs site to confirm available information. After review of the U.S. SDB resources, the North Knobs site was considered the best site for the first UCG-SDB test; it offers the best chance for a successful first U.S. SDB test.

The site selection criteria utilized for site selection were:

- Dip greater than 45°, less than 75°
- Subbituminous rank
- Seam thickness 3-10 meters
- Below the water table
- Accessible
- Relatively simple geology
- Available to GR&DC for lease

These criteria are explained more fully in Appendix A of this report, "Site Selection." The North Knobs site has:

- Seam dip of 64°
- Subbituminous coal
- Two seams of adequate thickness
- Water table at 30 meters (100 feet)
- Located 3 km (2 miles) from an interchange of I-80
- GR&DC has a lease

The data used for selection of this site and rejection of other sites were collected by:

- reviewing available federal and state geotechnical publications;
- reviewing consulting reports prepared on the area;
- discussions with geotechnical personnel from the federal, state, and county levels, academia, and local consulting firms; and
- field observations made on the site.

2.2.2.2 North Knobs Discussion

The site is located in the North Knobs area, approximately 11.5 km (8 miles) west of Rawlins, Wyoming (Figure 2-2). The particular site investigated in this area is in Section 11, T21N, R89W (Figure 2-3).

There are three coal seams in the area with sufficient outcrops to verify the trend shown in Figure 2-3. These seams are:

<u>Coal Seam</u>	<u>Thickness</u>
Wally Bed	0-4 m (0-13 ft)
Interval	47-72 m (155-250 ft)
G Bed	2-7.5 m (7-25 ft)
Interval	43-64 m (140-210 ft)
I Bed	1.7-4.8 m (5.6-16 ft)

A fourth coal seam, the Nebraska Bed, is over 1220 m (4000 ft) below the I bed and is not exposed in Section 11. The intervals between the coal seams are composed of sandstone, siltstone, and shale.

The coal lease in Section 11 is held by Rocky Mountain Energy Company. An agreement between RME and Gulf has been completed whereby UCG tests must be conducted at depths below 250 feet.

An exploration program was previously conducted in Section 11 by Energy Development Company. The main purpose of this program was coal resource evaluation. Thirty holes were drilled along the coal outcrop to approximately 45 m (150 ft). In addition to cores obtained from a few holes, geophysical logs were run in all holes. Much of the data obtained during this exploration program were available for review.

Figure 2-2. INDEX MAP OF NORTH KNOBS AREA, CARBON COUNTY, WYOMING

Figure 2-3. LOCATION OF HYDROLOGIC TESTING WELLS IN SECTION 11

In the area north of the valley (Figure 2-3) the G bed has been burned to a maximum depth of about 30 m (100 ft). Whether this is a result of natural or man-made causes is not known. However, the presence of clinker material could make this area less desirable for a UCG test. Therefore, the prime area available for testing is that portion south of the valley.

The beds in the prime area dip uniformly to the southwest at about 64°. Both the G and I beds outcrop at the surface. However, the G bed is covered in many places by soil and alluvium. (See Appendix A for the stratigraphic column.)

In early December, 1977, three hydrologic test wells were drilled in Section 11 (see Figure 2-3). Piezometers were installed in these holes to monitor the water level in the stratigraphic units near the "G" and "I" coal seams. The construction of the wells is shown in Figure 2-4.

The water level in these wells was monitored on a bi-weekly basis. From measurements taken to date, the potentiometric surface is apparently about 30 m (100 ft) below the land surface.

In December 1977, water samples were collected from the three hydrologic wells. Laboratory analyses of the samples indicate selenium and lead contents which are much greater than the State of Wyoming allowable limits. The analyses are for general information only since the samples were not collected in accordance with accepted sampling procedures. The detailed analyses may be found in Appendix A.

2.2.2.3 Johnny Moore Syncline Discussion

The location which was rejected actually involves two possible test sites in the Johnny Moore Syncline area, approximately 11.5 km (8 mi) east of Walden, Colorado (Figure 2-5). These sites are: 1) 243 ha

Figure 2-4. THE HYDROLOGIC TESTING WELLS IN SECTION 11

Figure 2-5. INDEX MAP OF JOHNNY MOORE SYNCLINE AREA, JACKSON COUNTY, COLORADO

(600 acres) in Section 16, T9N, R78W; and 2) 97 ha (240 acres) in Sections 25 and 26, T9N, R78W. These areas are shown, respectively, in Figures 2-6 and 2-7.

The following is a summary of the data which led to the rejection of the site in Section 16:

- The Colorado Land Board leased the acreage to Gulf three years after it had awarded a 10-year lease for the same acreage to a coal mining company. Therefore, the Gulf lease is invalid.
- Much of the coal outcrop is covered by 6-30 m (20-100 ft) of terrace gravels or soils. Therefore, the actual location of the syncline cannot be confirmed by field mapping. An expensive seismic or exploratory drilling program would have to be initiated to determine the coal location and dip.
- Where the coal seam is exposed in an existing mine east of Section 16, measured dip approaches 90°. The near verticality of the coal seam would present possible subsidence problems as a result of UCG.
- The measured thickness of the coal seam has been reported to be as much as 15 m (50 ft). This is considered too thick for initial testing UCG of SDB.

The following is a summary of the data which led to the rejection of the sites in Sections 25 and 26:

- The coal seam in Section 26 is presently being strip mined to 60 m (200 ft). This means that UCG operations would have to be conducted either in the bottom of the strip mine or on top of a reclaimed area. Rock falls and poor air circulation due to the strip mine configuration would make operations in the bottom of the strip mine hazardous. Adequate control of drill holes would be extremely difficult in the reclaimed areas.

Figure 2-6. SITE 1--JOHNNY MOORE SYNCLINE AREA (Section 16)

Figure 2-7. SITE 2--JOHNNY MOORE SYNCLINE AREA (Sections 25 & 26)

All drill holes would have to be cased throughout the reclaimed interval. In addition, the reclaimed material would be undergoing compaction/subsidence. This would affect any surface facility placed on the reclaimed material.

- A potential site in the same coal seam but further south (in Section 35) will be mined in the next two years to a depth of 122 m (400 ft).
- With the exception of one drill hole in a fracture zone, there is no water standing in existing drill holes in the area. There is no ground water flow into the bottom of the existing strip mine.
- The coal seam in Section 25 dips 85-90°.
- The coal seam in Section 25 has a measured thickness of 15 m (50 ft).
- An existing county road runs very near the coal seam for about 100 m (300 ft). In order to provide a sufficient area for UCG surface operations, this road would have to be relocated. This would be an added expense.
- Strip mining operations are scheduled to begin prior to 1980 in Section 25. It is undesirable to run a UCG test in close proximity to a commercial mining operation.

A search was conducted for additional sites as possible alternates for testing UCG of SDB. A summary of alternate site selection activities may be found in Appendix A.

2.2.2.4 Further Work Planned

To assist in making a final decision as to the suitability of the North Knobs site, further site evaluation studies have been initiated.

These studies may be broken down as follows:

- geologic characterization
 - surface mapping; aerial photographs
 - geologic map
 - geologic cross sections
 - geologic column-rock composition
 - core drilling
 - lab testing
- hydrologic characterization
 - drilling
 - piezometer installation
 - drawdown tests
- seismic studies; may not be necessary, depending on other data

2.2.3 TEST PLAN

The development of a site-specific test plan requires several steps:

- Chemical processes of gasification
- In situ gasification process
- SDB effects on the gasification process
- Implications on process parameters
- Module configuration options
- Design of experiments

Process and instrumentation requirements will be determined by the site-specific test plan. The test plan establishes the criteria for all of the other activities in the project except the environmental monitoring. This includes geologic, hydrologic, quenching, instrumentation, and facility requirements.

2.2.3.1 In Situ Gasification Reactions

The test plan must first consider the complex combination of chemical reactions occurring in all coal gasification processes whether above or below ground.

The reactions of the process can include the following groups of reactants:

- Reaction of char (C) with free oxygen
- Reactions of char with bound oxygen (i.e., H_2O , CO , CO_2 , etc.)
- Thermal decomposition of coal to form char plus volatile matter
- Reaction of partially decomposed coal CH_xO_y with free oxygen or bound oxygen
- Effect of the chemical and physical properties of the specific coal on the above reactions

Reactions of char or coal with free oxygen are referred to as combustion reactions and are highly exothermic.

- $C + O_2 \longrightarrow CO_2 + \Delta \quad (4.09 \times 10^5 \text{ kJ/k mole})$
- $2C + O_2 \longrightarrow 2CO + \Delta \quad (2.46 \times 10^5 \text{ kJ/k mole})$
- $2CO + O_2 \longrightarrow 2CO_2 + \Delta \quad (5.71 \times 10^5 \text{ kJ/k mole})$

These serve to produce heat and some of the reactants for the gasification and coal pyrolysis reactions to follow.

Reactions of char or coal with bound oxygen are termed gasification reactions and, except for the last reaction shown, are endothermic.

- $H_2O + C \longrightarrow CO + H_2 - \Delta \quad (1.19 \times 10^5 \text{ kJ/k mole})$
- $2H_2O + C \longrightarrow CO_2 + 2H_2 - \Delta \quad (7.53 \times 10^4 \text{ kJ/k mole})$
- $CO_2 + C \longrightarrow 2CO - \Delta \quad (1.62 \times 10^5 \text{ kJ/k mole})$
- $CO + H_2O \longrightarrow CO_2 + H_2 + \Delta \quad (4.35 \times 10^4 \text{ kJ/k mole})$

The first two reactions above are probably the most prevalent in UCG.

Thermal decomposition of coal (pyrolysis) occurs as the hot product gases permeate through the unaffected coal and also occurs through simple thermal conduction from the combustion zone to the seam.

The initial organics (volatile matter) formed from pyrolysis can further partially crack to carbon compounds in the C_1 to C_4 range.

The reaction of partially pyrolyzed and unaffected coal with free or bound oxygen can also occur as broken coal falling from above the oxidation zone reacts with the turbulent air flow.

- $CH_xO_y + zO_2 \longrightarrow uCO_2 + vCO + wH_2O$
- $CH_xO_y + zH_2O \longrightarrow mC_uH_z + nCO_2$

According to the former definitions, the first is a combustion reaction and the second is a gasification reaction.

When gasifying horizontal beds, the combustion and gasification reactions can be visualized as occurring on a fairly continuous coal seam where the products formed by combustion encounter hot char immediately in the gasification zone. This continuous burning pattern promotes generally smooth steady state product formation. As the lower zone of the seam burns away, some coal subsidence from the upper zone will occur and possibly disrupt steady state conditions at times, but due to the seam's horizontal attitude most of the burn front established prior to subsidence will still be intact to provide continuity for the reactions.

Due to the subsidence-prone nature of steeply dipping beds, the reaction scheme postulated for horizontal beds may not hold in SDB gasification. As the reaction zone grows, subsidence will occur either in a steady state fashion (continuous minor falls of coal into the reaction zone) or as major random events. The steady state process could produce: (1) oxidation and reduction in two areas (i.e., the bottom of the reaction zone and the updip combustion face), (2) oxidation only in the bottom of the cavity with reduction occurring on the updip face, or (3) oxidation in the bottom and oxidation and reduction on the updip face. Preliminary evaluation indicates that a high-heating value product can probably be obtained with any of these steady state modes. But if the process occurs as major random subsidence events, it may increase to a point where most of the updip combustion front will fall into the bottom of the reactor void. This would temporarily result in essentially all of the combustion and gasification occurring at the base of the well with essentially no reactions occurring at the updip coal face. Eventually, this coal face would reignite as the fallen coal burns out and oxygen reaches the face. These subsidence events will certainly affect the steady state reactions occurring by drastically upsetting such variables as coal surface area, combustion/gasification location, water content, and possibly others. Major subsidence events may therefore hinder obtaining steady state data and create considerable data point spread.

Much of Phase II Test Design Planning will be spent in evaluating the system in terms of what may happen, how to detect it, their effects, and how to deal with them in order to maintain high quality gas production. For example, major random subsidence will probably be accompanied by an increase in the CO_2/CO ratio and a sharp increase in injection well/production well pressure ratio. The increase in CO_2/CO ratio is the result of the large sudden increase in coal permeability which promotes channelling rather than permeation of the combustion products through the reduction zone. This rapid addition of unaffected and carbonized coal to the bottom of the reaction zone may also disrupt the water and thermal equilibriums as well, resulting in even more CO_2 . The increase in the pressure ratio will result from fallen coal blocking the injection well.

2.2.3.2 Controllable Process Parameters

One of the project objectives is to vary the process variables to determine the optimum values for maximum energy production.

The rate of production and composition of the product gas is a direct function of:

- The imposed conditions of gasification, including pressure, flow rate, and composition of the injection gas (oxygen content, water content).
- The particular chemical and physical characteristics of the coal being gasified.
- The specific geologic conditions prevailing at the site.
- Conditions created locally during linkage and gasification, e.g., fracturing and drying of the coal.

Using air injection for a given site and linking method, the controllable process parameters become:

- Injection air pressure
- Water content of injection air

- Rate of air injection
- Temperature of reaction (controlled by injection rate, pressure, and water content)

Injection air pressure and volume will be controlled by choking the production well and adjusting compressor output. Water will be added into the injection air stream to assist in controlling the temperature and therefore the reaction rates and the heating value of the production gas. Water is also a reactant in the gasification reactions.

In UCG, time and reactor growth are almost synonymous since the reactor grows irreversibly as gasification time increases. To a minor extent, however, reactor growth can also be considered a controllable parameter, in that reactor volume will be taken into account in the sequencing of the air injection rate tests, water injection rate tests, and reactor pressure tests.

Based on the above considerations, the experimental Burns No. 1 and No. 2 test matrices (Figures 2-16 and 2-21) were developed. These show the range of variables to be used in each burn.

Another important factor to be determined is the response time between adjustment of injection air, water content, and pressure, on the production gas quality. This will determine to a large extent the number of experiments which must be performed.

Probably one of the most important factors needed for economic projections is the useful life of a module. The useful life is defined as the length of time an acceptable product can be produced in a cost effective mode. In the horizontal UCG projects, it is generally agreed that an optimum module life exists. Past that point, increased costs of compressors exceeds the cost of module construction. Hanna IV is a six-month burn to determine module life for a LVW system. Our longest burn in a single module is 80 days. Budgetary constraints have limited Burn No. 2 to 80 days. That is not long enough to define the module life in the SDB process. Extension of the burn to 120 days should allow determination of single module life.

2.2.3.3 Uncontrollable Variables

Because the in situ reactor exists in a geologic environment, gasification will encounter certain uncontrollable variables including possible ground water influx, coal seam discontinuity including shale partings and sandstone channels, and roof falls. Although the sweep pattern of the reactor zone can be partially controlled via air injection rate, it is also subject to local geologic conditions.

Ground water may be introduced into the reaction zone as a result of subsequent communication with both overlying and underlying aquifers.

2.2.3.4 Data to be Monitored

The following data must be collected during the gasification process to establish the optimum values for the process variables.

- Air injection flow rate
- Water content of the injection air
- Pressure drop between the injection and production wells
- Production gas flow rate
- Production gas composition
- Particulate concentration in product gas

Table 2-I shows how these field data will be used to calculate the major process performance parameters: coal resource utilization, production gas heating value, water influx rate, leakage rate, and percent energy recovered.

2.2.3.5 Data Evaluation

The evaluation of test results will include:

- Time required for linking
- Amount of coal affected during the linking process
- Amount of air injected per linear meter of linkage
- Configuration and rate of movement of the burn front during linking and gasification

Table 2-I

FIELD DATA FOR PROCESS PARAMETER CALCULATION

<u>Process Performance Parameter</u>	<u>Method of Calculation</u>	<u>Field Data Needed</u>
Amount of coal gasified	Carbon, Hydrogen and oxygen balance	Gasifying fluid and product gas flow rate and composition
Water influx rate	Hydrogen balance	Gasifying fluid and product gas flow rate and composition
Gasifying fluid leakage rate	Nitrogen balance	Gasifying fluid and product gas flow rate and composition
MJ/m ³ of product gas, rate of MJ production	Sum of MJ of individual components of product gas	Product gas flow rate and composition
Percent energy recovered	Ratio of MJ production rate to total MJ avail- able from coal consumption rate	Gasifying fluid and product gas flow rate and composition

- Effects of variation in injection air flow rate, pressure, and water content on product quantity and quality
- Variation in gas production rate and product gas composition as a function of time
- Variation in the gross heating value and temperature of the product gas and the total gas production per day
- Total amount of coal gasified
- Extent of roof falls
- Extent of surface subsidence
- Gas leakage rate
- Thermal efficiency and overall process efficiency

2.2.3.6 Possible Well Configurations

There are several different module configurations possible in the SDB process. Due to the dip, entry into the coal seam can be through the roof, down the seam at the outcrop, and through the floor of the seam. Options considered for the SDB field test are shown in Figures 2-8 through 2-12.

The α configuration is simply the linked vertical well design utilized in most U.S. field tests of UCG involving horizontal beds. The β , γ , and π configurations have appeared in the Russian literature. The τ option is a modification of the β configuration that moves the injection well away from a subsidence zone.

The five options are compared in Table 2-II, in regard to drilling, linking, subsidence, leakage, and surface facility implications. Only one (α) utilizes conventional vertical drilling as employed at Hanna and Hoe Creek on horizontal beds. The other four require slant drilling at varying degrees. When considering the high subsurface subsidence characteristics of most steeply dipping beds, however, slant wells offer several advantages.

Figure 2-3.

Figure 2-9.

Figure 2-10.

Figure 2-11.

Figure 2-12.

Table 2-II

<u>Configuration</u>	<u>Drilling Requirements</u>	MODULE CONFIGURATION OPTIONS				
		<u>Angle from Horizontal</u>	<u>Linking</u>	<u>Subsidence</u>	<u>Leakage</u>	<u>Surface Facilities</u>
α	Conventional vertical	(90°) (90°)	Backward burn linking (BBL)	Interference with injection and production well	Same as horizontal beds	Same as horizontal
β	Down seam and vertical	(65°) (90°)	BBL or drilled borehole	Injection well	leakage up the production well	Large run of piping
γ	Down seam foot wall	(65°) (45°)	BBL or drilled borehole	Minimal possible physical blockage of injection well	Leakage up the production well	More compact no facilities over subsidence area
π	2-foot wall wells	(50°) (50°)	BBL	Possible blockage of injection well by rubble	Minimal	Most compact facilities located away from subsidence area
τ	Slant drilling down seam	(65°) (65°)	BBL or borehole	Some pinching of injection well, but less than α or β	Leakage up the production well	Covers greatest area longest runs

- Freedom from subsurface subsidence effects. Russian work in SDB has shown that roof fall can pinch-off vertical wells resulting in process termination in an extreme case or variation in flow rates or reactor pressure in lesser cases.
- Alternate linking options. To date, backward burn linking is the preferred method of establishing communication between injection and production wells. Downseam drilling does allow borehole linking, however.
- Footwall entry of air. The movement of the rubble bed to the bottom of the reactor makes footwall entry necessary.
- Simplicity of surface facilities. The injection and production wells are located away from the reactor zone areas and areas of potential subsidence. This should be favorably reflected in the projected economics of a commercial facility.

There are also disadvantages to the slant well configurations, mostly in the installation of the modules.

- Difficulty in drilling. Drilling experts feel that the slant drilling required for the process modules can be achieved. However, the process will be tedious and time consuming. The angle, depth, hole diameter, and target constraints all present operational problems that need further definition.
- Well completion. Installation of the well casings in the slant configuration will be more difficult, due to the drag on the casing as it is inserted. Cementing will also be complicated by this configuration.
- Leakage up the production well. In all cases of slant configuration, the production well is up the coal seam. Well head temperatures of 325-550°C are reported at Hanna. The hot casing will cause local heating in the coal seam. Subbituminous

coal exhibits a 2-3% shrinkage on heating. This shrinkage away from the production well could provide a leakage path to the surface for the product gas.

Slant drilling requirements were established and drilling experts were consulted as to the feasibility of the drilling program. Most of the consultants felt that, although technically feasible, the installation of the slant wells could present problems. The major obstacle is the lack of field experience in this type of geology. Slant drilling will be required for the eventual commercialization of UCG - SDB. This is an area where experience early in Phase II is needed to improve confidence in the systems.

2.2.3.7 Planned Well Configuration

The planned well configuration (modified γ) is shown in Figure 2-13. This configuration was chosen for two reasons: (1) the DOE contract specifies that two vertical wells not be used (α configuration) in all burns, and (2) of all the slant well configurations discussed in the previous section, this one is the most advantageous. Shown here is one module, i.e., one production well and two injection wells. Two injection wells are preferred because it offers an alternative well in case of well plugging and also offers the opportunity to determine gasification behavior through an open well bore. The first burn which will mainly be a "system checkout" burn will not have two injection wells. The π configuration (Figure 2-11) may be used if leakage around the periphery of the production well and its grouting becomes excessive. Leakage may be a problem because, as the production pipe and its environs heats up during the gasification phase, the coal may shrink away (2-3%) from the production pipe grouting. The modified configuration prevents this from occurring since the production well is completed in the heat stable silty sandstone strata below the coal seam.

In the modified γ configuration, injection wells are drilled through the footwall to protect them from the possible effects of subsidence, and the production well is drilled through the coal seam along the footwall.

Figure 2-13. THE MODIFIED Y WELL CONFIGURATION CONSISTING OF ONE PRODUCTION WELL AND TWO INJECTION WELLS

The injection wells will intersect the bottom of the coal seam at a point ≤ 182 meters (≤ 600 feet) below the surface. The base of the first-stage injection well and the production well will be 18 meters (60 feet) apart. The base of the second-stage injection well will be near, but may not intersect the production well base. The lower 69 m (228 feet) of the production well will be uncased.

Early Phase II activities in this regard will set criteria on the following aspects of well configuration:

- The injection and production well points of entry into the coal seam footwall
- The distance between the production well and the coal footwall
- The distance the injection well must penetrate the coal footwall
- The allowable drilling variances from the target point in all degrees of freedom

2.2.3.8 Well Linking and Gasification Events

The planned well configuration permits the effects of two linking methods on the UCG process performance to be determined. These are linking through a reverse burn technique and linking through a borehole. The reverse burn method of linking will be evaluated first followed by gasification through an open borehole.

After the wells have been drilled, the coal is ignited at the base of the production well (Figure 2-14, Event 1). (For the sake of simplicity, only a single injection well is shown.) Air is pumped into the production well only during coal ignition. After ignition, the linking process begins with high-pressure (estimated to be 21 kPa/meter of depth), low-volume (estimated to be 7080 standard m^3/day max) air being pumped into the injection well and through the coal to the production

EVENT 1 - COAL IGNITION, BEGIN LINKAGE

EVENT 2 - COMPLETE LINKAGE

EVENT 3 - BEGIN GASIFICATION

EVENT 4 - GASIFICATION COMPLETE, BEGIN QUENCH

Figure 2-14. SEQUENCE OF EVENTS IN UCG-SDB

well (reverse burn linking). During linking, the burn front advances from the base of the production well toward the source of air at the bottom of the injection well. The link is completed when the burn front reaches the bottom of the injection well and the pressure of the system suddenly drops. This is shown in Figure 2-14, Event 2. Due to the dipping coal seam, thermal override during the linking phase will probably not occur.

The seam is now ready for gasification which is accomplished using low-pressure, high-volume air with water injection if the formation water is inadequate for gasification. Gasification progresses from the base of the injection well to the base of the production well, as shown in Events 3 and 4. Quench operations begin when gasification is complete. Table 2-III shows preliminary project design values for linking and gasification, plus the estimated composition and production rate of the low product gas.

2.2.3.9 Burn Schedule and Location Plan

The test plan discussed above will involve three burns. The schedule for the burns is shown below.

Figure 2-15 is included to illustrate the location plan for the three burns. The distance between the burns is a minimum of 46 m (150 feet).

Table 2-III

PRELIMINARY PROJECT DESIGN VALUES FOR A SINGLE-MODULE BURN

Coal Properties (in place subbituminous coal)

Density: 1.4 SG 1400 kg/m³ (87.4 lb/cu ft)
 13 973 tonnes/hectare m (1900 tons/acre ft)
 Heat Content: 18.6 MJ/kg (8000 Btu/lb)
 18.6 x 10³ MJ/tonne (16 x 10⁶ Btu/ton)

Linking - Backward Burn Technique

Air Required: 475 sm³/meter (50 M SCF/linear ft)
 Injection Rate: 7080 sm³/day (250 M SCF/day)
 (maximum rate) (24-hour day)
 Linking Rate: 1.5 m/day (5 ft/day)
 Linking Pressure: up to 21 kPa per meter of depth
 (1 psi per foot of depth)

Gasification

Air Required: 5.7 x 10⁴ sm³/day (2 MM SCF/day)
 (Burn No. 1) 39 sm³/min (1.4 M SCF/min)
 Gas Produced: 9.9 x 10⁴ sm³/day (3.5 MM SCF/day)
 69 sm³/min (2.3 M SCF/min)

Gas Composition:

Component:	H ₂	CH ₄	C ₂ H ₆	CO	N ₂	CO ₂	Ar	H ₂ S
Volume Percent:	18	5	.5	18	48	10	.5	.08

Heating Value: 6.33 MJ/m³ (170 Btu/SCF)
 6.28 x 10⁵ MJ/day (595 MM Btu/day)

Figure 2-15. LOCATION PLAN FOR BURN NOS. 1, 2, 3
 1 cm = 12 m (1" = 100')

2.2.3.10 Burn No. 1

During this initial burn, the process instrumentation and equipment will be checked out and the ability to ignite, control, and extinguish the process will be established. During the length of the burn, which will last about 20 days, limited experiments to optimize the major independent variables as described by the matrix shown in Figure 2-16 are planned. Figures 2-17 and 2-18 show the plan view and cross sectional well configuration for Burn No. 1. The dimensions shown were solely for the costing exercise and are subject to change. This also holds for the dimensions in Burns No. 2 and No. 3. Additionally, a test will be conducted whereby the injection air is stopped and restarted to determine its effect on performance. The facility design is required to provide maximum air injection rates of 5 MM SCFD at 125 psig and water injection rates of 10 gpm during this burn. The completion of all the tests required depends on the number and severity of the process and equipment problems encountered. Process performance will be monitored as a function of each of the independent variables (R_I , W_I , P_R , and t), but due to the short gasification period involved, the tests will principally be conducted to determine trends rather than to obtain hard process data. For example, the injection rate (R_I) tests which are scheduled to last for four days may just be run at two different rates and held for shorter periods than in Burn No. 2. Process performance versus reactor volume tests will be made intermittently throughout the burn rather than as a single series.

Although highly desirable, no subsurface reactor definition measurements will be made during this burn due to lack of funding.

2.2.3.11 Burn No. 2

Figure 2-19 shows a plan view and Figure 2-20 shows the cross sectional well configuration for Burn No. 2. This test burn will be concerned mainly with optimizing process parameters on a one-module configuration consisting of two injection wells and one production well. Both process and reactor definition instrumentation will be utilized.

$$R_I \leq 5.7 \times 10^4 \text{ sm}^3/\text{day}$$

$$(R_I \leq 2 \text{ MM SCFD})$$

$$W_I \leq 8 \text{ kg/min}$$

$$(W_I \leq 2 \text{ gpm})$$

$$P_R$$

$$P_R \leq 0.8 P_H$$

$$t$$

$$t \leq 20 \text{ days}$$

R_I	$0.708 \times 10^4 \text{ sm}^3/\text{day}$ to $5.7 \times 10^4 \text{ sm}^3/\text{day}$ (0.25-2 MM SCFD)	6 kg/min (1.5 gpm)	$0.5 P_H$	4 days
W_I	$2.8 \times 10^4 \text{ sm}^3/\text{day}$ (1 MM SCFD)	0-8 kg/min (0-2 gpm)	$0.5 P_H$	4 days
P_R	$2.8 \times 10^4 \text{ sm}^3/\text{day}$ (1 MM SCFD)	6 kg/min (1.5 gpm)	$0-0.8 P_H$	4 days
t	$2.8 \times 10^4 \text{ sm}^3/\text{day}$ (1 MM SCFD)	6 kg/min (1.5 gpm)	$0.5 P_H$	$\Delta t = 2 \text{ days}$ between each of above test series

R_I = rate of air injection

P_R = pressure in reactor

W_I = rate of water injection

P_H = hydrostatic pressure

W_C = mole % of water in injection air

V_R = reactor volume

t = time (days). Time must be included as an inherent variable of the process, since reactor volume is a direct function of the gasification time. For this reason, V_R is replaced by t .

Figure 2-16. Burn No. 1 Test Matrix

Figure 2-17. BURN NO. 1 WELL CONFIGURATION

Plan View

Scale 1 cm = 12 m (1" = 100')

Figure 2-13. BURN NO. 1 WELL CONFIGURATION

Section AA

Scale 1 cm = 12 m (1" = 100')

Figure 2-19. BURN NO. 2 WELL CONFIGURATION

Plan View

Scale 1 cm = 12 m (1" = 100')

Figure 2-20. BURN NO. 2 WELL CONFIGURATION

Section BB

Scale: 1 cm = 12 m (1" = 100')

In this 80-day burn, a systematic study relating process performance to the controllable variables will be made according to the test matrix shown in Figure 2-21. The effects of process variables will be sequenced taking irreversible reactor growth into account. The facility design is required to provide air injection capability of 5 MM SCFD at 125 psig and water injection capability of 10 gpm during this burn. Another test involves determining the feasibility of gasifying through an open borehole rather than a porous link. After the gasification zone reaches the base of the production well, gasification behavior through an open wellbore rather than a porous link will be evaluated. Air injection will begin in the secondary well after contact or near contact between it and the reactor zone is established. At this point, the primary injection well will be shut in. Particulate content and heating value may be affected during open borehole gasification.

The final length along dip of the gasification zone should be approximately 49 m (160 ft).

2.2.3.12 Burn No. 3

Burn No. 3 involves a two-module parallel configuration (four injection, two production wells) which will operate for up to 80 days using the optimum conditions for flow rate, pressure and water injection rate found from Burn No. 2. The facility design is required to provide air injection capability of 10 MM SCFD at 125 psig and water injection capability of 15 gpm during this burn. Figure 2-22 shows the plan view for this burn, and Figure 2-23 shows the cross-sectional well configuration. Linkage between two injection wells across the strike will be accomplished with a reverse burn. The modules will then be operated simultaneously with a sweep of the combined area while maintaining a high-quality production gas. The sweep will be controlled by choking or closing the various wells to provide maximum air flow past the desired burn front. The test burn will utilize both reactor definition instrumentation to monitor the progress of the burn and the required process instrumentation. Gas tracer studies will be used to estimate the degree of communication between the wells.

$$R_I \leq 14.1 \times 10^4 \text{ sm}^3/\text{day}$$

$$(R_I \leq 5 \text{ MM SCFD})$$

$$W_I \leq 16 \text{ kg/min}$$

$$(W_I \leq 4 \text{ gpm})$$

$$P_R \leq 0.8 P_H$$

$$t \leq 80 \text{ days}$$

R_I	$1.4 \times 10^4 \text{ sm}^3/\text{day}$ to $11.4 \times 10^4 \text{ sm}^3/\text{day}$ (0.5-4 MM SCFD)	12 kg/min (3 gpm)	$0.5 P_H$	$\Delta t = 15$
W_I	$5.7 \times 10^4 \text{ sm}^3/\text{day}$ (2 MM SCFD)	0-16 kg/min (0-4 gpm)	$0.5 P_H$	$\Delta t = 20$
P_R	$5.7 \times 10^4 \text{ sm}^3/\text{day}$ (2 MM SCFD)	12 kg/min (3 gpm)	$0 - 0.8 P_H$	$\Delta t = 20$
t	$5.7 \times 10^4 \text{ sm}^3/\text{day}$ (2 MM SCFD)	12 kg/min (3 gpm)	$0.5 P_H$	$\Delta t = 5 \text{ days}$ between each of of above test series

R_I = rate of air injection

P_R = pressure in reactor

W_I = rate of water injection

P_H = hydrostatic pressure

W_C = mole % of water in injection air

V_R = reactor volume

t = time (days). Time must be included as an inherent variable of the process, since reactor volume is a direct function of the gasification time. For this reason, V_R is replaced by t .

Figure 2-21. Burn No. 2 Test Matrix

Figure 2-22. BURN NO. 3 WELL CONFIGURATION

Scale 1 cm = 12 m (1" = 100')

Plan View

Figure 2-23. BURN NO. 3 WELL CONFIGURATION

Section CC

Scale: 1 cm = 12 m (1" = 100')

The next two sections, 2.2.4 and 2.2.5, describe the instrumentation and equipment required to control and evaluate the process in accordance with the test design.

2.2.4 PROCESS INSTRUMENTATION

2.2.4.1 Introduction

The test plan has established requirements for the process instrumentation in the project. These requirements are closely related to the project objectives of establishing the feasibility and potential for commercialization of UCG in SDB. Based on the technical approach discussed in Section 2.2.1, there are four distinct areas of instrumentation needs: process control, product analysis, reactor definition, and data acquisition and reduction.

Based on the test plan and project constraints, instrumentation for the various burns will be as follows:

- Burn No. 1
 - There will be no reactor shape/size definition instrumentation.
 - There will be instrumentation to analyze the composition of the gasification products.
- Burn No. 2
 - There will be eight (8) wells for reactor definition.
 - There will be instrumentation to analyze the composition of the gasification products.
- Burn No. 3
 - There will be sixteen (16) wells for reactor definition.
 - There will be instrumentation to analyze the composition of the gasification products.

2.2.4.2 Instrumentation System Design

Figure 2-24 is a preliminary P&ID of the instrumentation system. The data acquisition and analysis system are depicted in very generalized block diagram form, as are the process control and product gas analysis inputs. Preliminary plans call for product gas analysis using a gas chromatograph, an automatic balance, a hygrometer, and a continuous calorimeter. The reactor definition methods to be used are still subject to further investigation and presently consists of choosing among the following methods: subsurface thermocouples, electrical resistivity methods, passive seismic monitoring, subsidence measurements, active seismic techniques, and a helium tracer method. Subsurface thermocouples will undoubtedly be used, since this method has proved to be the most successful. Most of the methods listed above are presently being used in current UCG field tests, and the choice will depend to some extent on their success in these operations.

2.2.4.3 Process Control Instrumentation

Process control instrumentation will consist of off-the-shelf equipment and should not pose any problems. The parameters to be monitored by the process control instrumentation are listed below with the expected range of each parameter.

Injection air:

flow:	8.5 to 100 sm^3/min (300 to 3500 SCFM)
pressure:	800 to 1500 kPa (100 to 150 psig)

Linking air:

flow:	2.8 to 5 sm^3/min (100 to 175 SCFM)
pressure:	1500 to 4300 kPa (200 to 600 psig)

Production gas:

flow:	70 to 250 sm^3/min (2500 to 9000 SCFM)
pressure:	385 to 655 kPa (40 to 80 psig)
temperature:	315 to 340°C (600 to 1000°F)

Figure 2-24. PRELIMINARY P&ID OF THE SDB INSTRUMENTATION SYSTEM

Process water:

flow: 0-60 kg/min (0 to 15 GPM)

For Burn No. 3, instrumentation will be added to monitor twice the amount of injection and production gases stated above.

2.2.4.4 Product Analysis

2.2.4.4.1 Gas Chromatographic Analyses

The chemical components of the product gases requiring analysis by GC are: H_2 , CH_4 , CO , N_2 , CO_2 , Ar , H_2S , ethylene, ethane, propylene, propane and butanes. The heating value of the gases also must be determined. Accuracies of ± 2 to 3 percent are sufficient.

Product gases are obtained for analysis from two sources: the product gas stream at the production wellhead and from "sniffer" tubes in each instrumentation well. The sniffer tubes consist of canisters located within the coal seam, with tubes to the surface from which gas samples can be drawn periodically. These tubes allow measurement of gas composition in situ and determination of gas composition distribution and variation with time within the reactor zone. As a by-product, pressure transducers on the sniffer tubes allow in situ pressure determination and pressure distribution and variation with time within the reactor zone. Sandia developed a standard sniffer tube assembly for use at Hanna and this assembly is used in this program. The assembly consists of three plastic-sheathed canisters within the coal seam, with a copper multi-tube connection to the surface.

The analyzer is a gas chromatograph that is available off-the-shelf from several suppliers. The Hewlett-Packard Model 5840A is being used at Hanna and is adequate for this program. Two chromatographs, a primary and a backup, are required. After drying, the product gas stream is sent directly to the GC via a sample tube; sniffer tube gases are collected in sample bombs and transported manually to the analyzers.

2.2.4.4.2 Continuous Calorimeter Analysis

Part of the dried product gas slipstream mentioned above is sent through a continuous calorimeter which has a direct hookup to the computer. The calorimeter is essentially a specially designed burner capable of burning gases within a given range of heating value. Calorific value is determined by combusting the gas and measuring the temperature rise in the dynamic air mass above the burner (flue gas). The calorific value obtained in this way should correspond to that calculated from GC analysis.

2.2.4.4.3 Determination of Tar and Water Content

A slip stream from the product gas line passes through a cold trap to condense out water and tars. The cold trap drains to a vessel of known volume equipped with a sensor to detect the tar-water interface and a "dump" sensor. When the vessel fills, its contents are automatically weighed. Knowing the rate of flow in the slipstream and the weight of water and tars collected during a certain time period allows the weight percent of water and tars present in the product gas to be calculated.

The water content of the unaltered product slipstream is also monitored by a continuous hygrometer. Given the importance of water content in the gasification process, redundant water analyses are necessary.

Both analyses mentioned above are completely automated.

2.2.4.4.4 Particulate Concentration Analysis

Analysis for particulate concentration in the product gas will be done manually using a cascade impactor to collect particles in the production line. Particulate size and elemental analysis data will be obtained in addition to concentration data.

2.2.4.5 Reactor Definition Methods

2.2.4.5.1 Thermal Instrumentation

In previous UCG experiments, one of the most valuable reactor definition methods has been subsurface thermocouples. Figure 2-25 (Burn No. 3) illustrates the well layout used to determine reactor shape and volume. There are a total of 16 instrumentation wells each containing 14 thermocouples, one meter apart, some being above, in, and below the coal seam. Using the temperature data and a thermal conduction model, reactor shape can be estimated. Sandia laboratories, in LERC's Hanna II operation, determined the size 0.76-1.1 m (2.5-3.5 feet) of the reverse combustion linkage path by use of this method. Although not specifically stated, the resolution obtained in defining the reactor zone shape during gasification appears to be 1.2-1.8 m (+4-6 feet). This was accomplished with 15 wells each containing 10-12 thermocouples.

The main problems associated with subsurface thermocouples are the following:

- Short lifetime. Most thermocouples last only a few hours to a few days at 538-650°C (1000 to 1200°F).
- Short detection range of 2.1-3.0 m (7-10 feet).
- Requires wells into the coal seam. These wells can disturb flow patterns, are costly, and can aggravate the underground subsidence problem especially in steeply dipping beds which could be highly fractured. Subsidence can also cause complete destruction of the instrument wells.

Figure 2-25. PLAN VIEW OF THE INSTRUMENTATION WELL PATTERN WHICH MAY BE USED IN BURN NO. 3

- Probable decrease in resolution due to limits on the number of vertical instrumentation wells which can be fielded. Projecting a 18.2 m (60 feet) length of coal seam dipping at 60° onto a roughly horizontal plane (the ground surface) yields an area on which to field instrument wells only half that afforded in horizontal beds. Figure 2-25 illustrates the "shrinkage" which occurs. It is not yet clear whether the desired number of instrument wells (16) can be placed on this limited area without major disruptions occurring between them.
- Placement of wells. The short detection range and relatively high cost of the wells makes well placement extremely important. DOE has used its predictive model for reactor growth patterns to aid in instrument well placement. This permits maximum benefit from a minimum number of wells. As previously stated, the horizontal models will not provide the same degree of reliability in the SDB geology. This increases the uncertainty in the probable value of the wells. With the constraint in the number of wells, accurate placement of those wells is more important. This imposes an additional level of difficulty in the drilling of the wells which is reflected in increased drilling costs.

A possibility which will be explored is that of slant instrumentation wells drilled entirely in the coal seam, which are spaced between the two production wells on Burn No. 3 or around the production well 1.5-9.1 m (5-30 feet) in Burn No. 2. The increased cost of drilling the slant wells could be offset by the fewer number required since these slant wells, being coaxial to the reaction zone and the coal seam, can hold a much greater number of thermocouples in the zone of major interest. Slant instrumentation wells also diminish the subsidence problem and can greatly improve resolution.

2.2.4.5.2 Electrical Methods

The basis for using electrical methods to delineate the reaction zone lies in the coal changing resistivity as it dries and becomes heated. The table below shows this relationship.

<u>Condition of Coal</u>	<u>Approximate Resistivity (Ω-m)</u>
Water saturated virgin coal	200
Dry unaltered coal	1×10^9
Coal at 400°C (750°F)	1×10^5
Coal at 705°C (1300°F)	1

There were two methods used during the Hanna II operation: the modified Schlumberger (MS) technique and the Direct Excitation Electrical Potential (DEEP) technique. Both methods use the same array of surface potential probes on a 5 m (15 feet) spacing placed over the area of interest. These probes, which are buried 1.2-1.8 m (4-6 feet) are used to measure the local electrical potentials set up by current injection electrodes. The major physical difference between the MS and DEEP techniques is the location of their current injection probes. The MS technique uses outlying current probes and might inject currents up to 10-20 amps. The DEEP technique uses one of the production wells as a current probe and one outlying current probe. Injection currents are about 1 amp.

Both methods rely on the modification of current paths through the earth, due to the changing resistance of the coal during linking and gasification. This change in current paths is sensed by the surface potential probes which are automatically "read" by the computer and expressed in the form of electrical potential contour or resistivity contour plots.

The main advantages of these methods is their remoteness to the coal seam and their relatively low cost. Unlike the costly subsurface

thermocouple technique, there is no need to disturb the coal with wells or other apparatus which might alter the air flow or subsidence properties of the seam.

Unfortunately, however, these methods may not give adequate resolution for our purposes. The experience to date indicates that only a qualitative picture of initial reactor growth can be obtained. The data obtained well into the gasification phase are highly interpretive. Sandia Laboratories is presently conducting these tests on Hanna IV and hopefully will yield more definitive results. Steeply dipping beds add even more uncertainty to these techniques for a variety of reasons.

Firstly, the slanted seams essentially compress (see subsurface thermocouple section) the surface potential contours from which reactor shape characteristics are obtained. This compression may lead to an even greater loss in resolution. Secondly, the effect of the dipping strata and the use of a slant current probe (production well) on the ability to extract useful information from these techniques is still uncertain. Lastly, holes would have to be drilled in the surface rock strata to house many of the potential probes, since approximately 40% of the site has no soil in which to bury the probes.

Based on the discussion above, the use of these techniques on the SDB project is still questionable. The current performance of these methods at Hanna IV will, of course, also be considered.

2.2.4.5.3 Passive Seismic Methods

This method essentially involves placing geophones in the instrumentation wells to monitor the noise associated with gasification, namely thermal cracking and subsidence events. By sophisticated computer treatment of the geophone pulses, the approximate location of the seismic sources can be determined. Subsidence noises are generally the only ones amenable to interpretation.

The exclusive use of this method to delineate reactor boundaries is not feasible, however, due to non-uniform subsidence of the strata above the coal seam. As with the resistivity techniques this method is still being evaluated for use in SDB.

2.2.4.5.4 Subsurface Subsidence Measurements

Subsurface subsidence has been monitored on the Hanna burns by using a modified slifer technique and/or passive seismic methods. The slifer technique is relatively simple, but expensive if used in dedicated instrumentation wells. It involves using dedicated wells into which cables weakened at 0.3 m (1 foot) intervals are grouted in place. The length of this cable is continuously monitored by computer using a method known as time domain reflectometry. As subsidence occurs, this cable breaks off giving real time occurrence and the amount of subsidence occurring in that localized zone. A technique similar to this might be applied fairly easily and inexpensively to SDB UCG if slant instrumentation wells are used. In this case, weakened cables placed in the instrumentation wells which house the thermocouples may indicate the growth of the reaction chamber up the coal seam by breaking off or melting as the reaction chamber grows toward the production well. Melting can be distinguished from cable breakage by the rate of cable length change as well as correlation with temperature data. Cable melting should therefore define the combustion front whereas cable breakage would monitor subsidence events. This would serve as a backup for subsurface thermocouples which experience a high failure incidence at elevated temperature. This technique is still being evaluated for use in UCG.

2.2.4.5.5 Borehole to Borehole Active Seismic Method

This technique involves drilling seismic source and receiver boreholes on both sides of the expected reactor zone and transmitting seismic signals through the as yet ungasified coal. As gasification proceeds, the burn out zone grows and part of the signal is transmitted

through the burn out zone and part is reflected off the zone boundary. The modified transmitted and reflected signals are collected and are subjected to computer analysis to yield reactor definition estimates. The first and only attempt of this method, which was conducted by Sandia on Hanna II, could sense gross boundary movements of 3 m (10 feet). This technique requires more developmental work to make it an effective reactor definition method.

Lawrence Livermore is presently trying a borehole-borehole reactor definition method at its Hoe Creek UCG operation, but instead of seismic sources it is using radio waves. This technique is still being developed. Based on projected cost and the present state of the art, these techniques will probably not be used on this project.

2.2.4.5.6 Aboveground Active Seismic Technique

A recent paper extracted from USBM Technical Progress Report 101 of October 1976 (Zepper, C. M. and Ruskey, F.), describes a shallow seismic reflection method for the mapping of faults, sand channels, etc., in coal seams. It is, in essence, a modified seismic technique which has been used in the petroleum industry for years. An array of geophones placed 0-1 m (0-3 feet) below the surface is first established over the area to be studied (coverage at depth is one-half the surface geophone spread distance). These geophones detect seismic signals from a 1.5-3 m (5-10 feet) deep shot hole. Seismic waves travel from the shot well to the various strata surfaces to the surface where they are detected by the geophones. Computer treatment of the data can yield a two-dimensional structure diagram.

Recent developments in instrumentation, field procedures, higher recorded frequencies, and data processing show that, with care, resolution of ± 1 m (± 3 feet) is now attainable, at least in two dimensions. It is anticipated that with the continued improvement being made in instrumentation and data collection systems, application of higher frequency energy sources and detectors, refined field procedures, and better data processing and presentation, the coal seam thickness and homogeneity can be

ascertained by this method. It would then be better suited to UCG reactor definition. However, because of the needed development, this technique is not planned in this project.

2.2.4.5.7 Using Carbon, Oxygen, and Hydrogen Mass Balance to Calculate Reactor Void

Reactor void volume will be estimated by using a carbon, oxygen, and hydrogen mass balance to determine the amount of coal gasified. This calculation relies on the sum total of the products produced to date, as well as an ultimate and proximate analysis of the coal and its resultant char upon heating. By using these data, both the amount and volume of the coal gasified and the amount of the coal devolatilized can be calculated.

2.2.4.5.8 Helium Tracer Studies to Determine Reactor Void Volume

This method will inject a measured "pulse" of helium into the injection air and monitor the production gases with a leak detector in order to determine its mean residence time and mean velocity in the subsurface reactor. From the integration of the helium peak eluting from the production well (the helium detector is connected to a strip chart recorder) and the total quantity of helium injected, the mean flow rate will be calculated. Reactor volume will then be calculated from the mean flow rate and mean velocity.

2.2.4.6 Data Acquisition and Reduction System

The data acquisition and reduction system which will be completely automated must serve four main functions:

- data collection
- real time data manipulation

- display and storage of process operational data such as injection/production gas flow rate and pressures and water injection rate; computer control of these variables may also be included depending on a cost study.
- to a large extent, checking the reliability of the data it collects.

The data collection and manipulation functions will involve cyclic computer collection, manipulation, and sorting of the data obtained from all remote sensors, including instruments with continuous monitoring capabilities. For example, the computer will be programmed to "read" and temporarily store signals from all the pressure transducers, thermocouples, pitot tubes, calorimeter, etc., every five (5) minutes, and convert the signals to their desired forms. At the end of each hour, it will calculate average hourly pressure, temperatures, etc., for that time period, print it on a line printer, and permanently store these averages on a disc or tape. In addition, the computer will manipulate and store data from instruments operating on an intermittent basis such as gas chromatographs, gravimetric balances, etc. All of this information (hourly averages or most recent 5-minute collection cycle) will be available to the user at any time through computer printouts and a cathode ray tube (CRT) display. A computer controlled X-Y plotter will also yield plots of any collected data upon command.

The cyclic computer collection of all the operating data makes it ideally suited to control the operating parameters via remotely controlled valves or other control devices. This will be accomplished by computer feedback loops which constantly compare the output of sensors to a desired set of operating conditions and adjusts the remotely controlled devices accordingly. Incorporation of this function into this project devices will depend on cost considerations.

The computer will also be programmed to check to some extent the reliability of the data it is collecting and warn the operator when inconsistencies due to sensor failure or other malfunctions occur. For

example, it will compare the output from redundant sensors or instruments or check on the condition of its thermocouples by measuring their resistances prior to taking a reading. Furthermore, many "off the shelf" items allow an internal check of its operation. These internal checks will be carried out and monitored by computer.

2.2.5 FACILITIES

2.2.5.1 Design Requirements

The test facility was designed for the North Knobs site to satisfy the requirements of test plans and to provide a basis for cost estimation. It will consist of the following:

- Well systems including injection, production, and instrumentation wells, manifolds and gas recovery piping systems.
- Injection gas systems including a "linking" air compressor and process air compressors.
- Support systems including fuel oil, propane, process water supply, electrical supply, and fire protection.
- Buildings or vans including those required for instrumentation and monitoring, process control and shop use.
- Interconnecting and access roads, security fencing, area lighting and other general site systems.

The design of the facilities will also consider and be compatible with the following features and requirements:

- Provide a site layout which can be constructed incrementally to support each phase of the test program as that phase becomes a requirement, in such a way that construction modifications necessary for the next test do not interfere with the ongoing test.
- Provide a flexible test facility that will accommodate growth of the total facility as well as any individual system.
- Provide a self-sufficient facility where economically and functionally feasible.

- Provide a facility with a 3-5 year life projection.
- Provide adequate foundations for the loads imposed by equipment fastenings.
- Orient and locate all equipment and facilities to protect them from the effects of subsidence in the vicinity of the reactor voids.
- Select materials and methods of construction that take into account the weather extremes.
- Provide a site layout which considers the usual occurrences of blowing and drifting snow in winter and hot/dry conditions in summer, and the prevailing wind.
- Provide systems which can, within reason, be disassembled and transported to other locations within the site or to other sites.
- Provide a facility which will allow the site to be restored reasonably comparable to its original pre-operational condition when the test program has been completed.

2.2.5.2 Facility Design Update

The purpose of the Phase I facility design activity was to:

- Provide a conceptual design reflecting the latest requirements in sufficient detail to permit preparation of final construction plans, specifications, and procurement documentation to commence immediately upon starting Phase II.
- Provide sufficient design detail to develop realistic design, construction, and procurement schedules compatible with the program milestones.

- Provide sufficient design detail to develop realistic construction and procurement cost estimates.
- Provide sufficient design detail to identify the equipment and services which must be procured in advance of the normal procurement cycle and be compatible with the schedule, and to determine the time required to procure these "long-lead items."

The design will be completed in Phase II. The conceptual layout which best satisfies the above considerations is shown in the Plot Plan, Figure 2-26. This layout shows the configuration of the test facilities to support the scaled-up test program, with all equipment and wells required. The facility constructed for the first burn will be only a part of that shown.

2.2.5.3 Site Facility Description

The entire test site, including four well modules (three burns) of the γ configuration, instrumentation wells, linking, and injection compressors, water reservoir, support buildings, and access and interconnecting roads, can be located on an area of approximately 300 m by 300 m (1000 feet by 1000 feet) as shown in Figure 2-26. The major elements of the test site lie between the "I" bed and the "G" bed as shown and parallel with the beds. Subsidence, if any, will occur downdip of the "G" bed outcropping and should have no effect on any aboveground facility. The entire 6 ha (15-acre) plot will be cleared, graded, and shaped as required for construction activities.

Access from the state road and within the site is provided by a newly constructed 7 m (22-foot) wide gravel road using borrow material for the sub-base and base courses of the required thicknesses. These roads also are slightly elevated to facilitate self-clearing of snow by the wind.

Figure 2-26. PLOT PLAN

The site layout is governed by the well depths, well configuration, and drilling angle for the injection wells. The wells for the shallowest burn module are the closest-spaced at the surface and dictate location of the compressors, flare stack, and pipe racks. The support buildings, instrument vans, fuel oil tanks, and vehicle parking, as well as the compressors, are grouped around this module. Subsequent construction and extension of piping and racks for Burn No. 2 and No. 3 can then be accomplished without interfering with the Burn No. 1 operation. This layout can also accommodate a change in the location of Burn No. 2 or No. 3 without seriously affecting other site components. The injection gas system, which consists of the linking gas compressor and up to six production compressors, is located to keep the high cost piping runs as short as possible. A minimum (30 m) (100-foot) separation between the heavy compressors and the product wells is specified to keep any subsidence in the burn cavern or within the "G" bed coal seam from affecting the compressors, piping, or structures. The instrument well areas for each burn are located above each burn cavern and are accessible.

Supporting systems, such as the diesel generator, electrical substation, diesel oil storage, water reservoir, and buildings, are located on the periphery of the gas systems since their interface is with the gas systems and roadways and not the wells themselves.

The maintenance building is a 450 m^2 (4800-square foot), prefabricated, insulated, heated metal building on a concrete slab that will house maintenance and administrative functions, including a carpenter shop, instrument shop, welding shop, electrical/mechanical shop, grounds maintenance area, and maintenance office. Mobile or transportable shelters are used for the multiplexer, gas chromatograph equipment, data acquisition, process control, and office shelters. The multiplexer shelter is required for Burn No. 2 and No. 3 and, consequently, is located in close proximity to the instrument wells for those burns. The gas chromatograph (GC) shelter is located close to the product well being used to keep the sample lines short and to eliminate the need for tracing to prevent condensation.

These shelters can be moved to new locations as new production well modules are developed. The data acquisition and instrumentation shelter and the process control and office shelter are both 3 m by 12 m (10 feet by 40 feet), and are interconnected with enclosed vestibules and walkways for protection against inclement weather. They are located adjacent to the maintenance building. These shelters are heated and air-conditioned to provide a satisfactory environment for the electronic equipment. The use of mobile or transportable shelters permits installation, outfitting, checkout, and test of this sophisticated equipment at a location remote from the site that provides better working conditions for these sensitive operations. In addition, this work could be performed during the winter months or during construction activities when working conditions on the site are poor.

A diesel oil storage tank of 57 m³ (15 000-gallon) capacity provides fuel for operation of the diesel engines. It is surrounded by an earthen dike 1 m (3 feet) high to contain spills. The tank provides for 20 days of diesel operation at the normal Burn No. 1 rate of fuel oil usage or 5 days at the maximum Burn No. 3 rate prior to requiring replenishment.

The water reservoir is an earthen bermed plastic-lined reservoir of approximately 225 m³ (8000 cubic feet) capacity. This allows two hours of continuous flow from a 2 m²/min (500 gpm) gasoline-driven fire pump supplying two hydrants simultaneously. Hydrants and fire hoses protect the fuel oil storage area, the equipment area, the buildings, and the well area. The water reservoir also supplies process water, water for domestic plumbing, and water for gasification chamber quench by means of a deep well turbine pump.

All interconnecting piping between the gas systems and the wells is run on aboveground pipe supports or sleepers located parallel to the equipment and the seams with suitable connections between equipment, injection wells, and product wells.

The piping and its supports are installed only as far as the well being tested at that time. As new wells are developed, the piping is extended. Special provisions, such as flexible joints and adjustable

supports are used where needed to prevent undue stress on the piping and appurtenances in the event of subsidence. Electric heaters and insulation blankets are installed on injection and linking air piping to prevent freezing during extreme winter weather.

The entire 6 ha (15-acre) area is fenced to prevent vandalism or injury to unauthorized persons and range animals. Area lights around the equipment buildings, and shelter areas provide lighting for the continuous operations required for the test programs.

2.2.5.4 Electric vs. Diesel Compressors

A preliminary tradeoff analysis was performed to determine the economics of installing Pacific Power and Light electrical service at the site to provide power for all activities, versus providing diesel engine-driven compressors and a diesel engine-driven generator for lights, air-conditioning, controls, and general utility service.

There are several disadvantages of electric power that must be considered:

- Approximately 12 months is required to obtain an easement from the Bureau of Land Management to run a power line over their land to serve the site. The total time from commitment to Pacific Power and Light to first power delivery is approximately 18 months.
- Electric power line outages due to such weather extremes as high winds and ice can shut down the entire facility. Backup diesel generators can be provided for some critical activities. Provision of a totally redundant power source (diesel generators) would be quite expensive and difficult to justify. If the compressors and other major equipment items are diesel-powered, and a diesel generator provides power to the smaller pumps, instrumentation, lights, etc., failure of one of the engines would cause only a minimal impact on test operations.

- Diesel engine-driven compressors of the size required for this project are widely used for oil field and construction work and are available for lease. Electric motor-driven compressors are available for purchase; however, the lead time becomes a pacing item, and further salvage value or "buy back" value is low because the demand is low.

It is for these reasons that the conceptual design update and the related cost estimate includes the use of diesel engine-driven compressors and diesel engine-driven generators as a baseline instead of an all-electric site. Joint studies with Pacific Power and Light Company are continuing to definitize and formalize these tradeoffs.

A more detailed study will be performed at the onset of the Phase II design activities, when the electrical loads and costs have been better defined.

2.2.6 ENVIRONMENTAL ACTIVITIES

A project constraint is "to minimize the impact on the environment. A project objective is "to determine the impact of the process on the environment. The environmental activities to date have dealt with these separately. An environmental analysis of the concept has defined possible areas of detrimental effects. The test plan, geology, and facility design will utilize that information to minimize environmental impact. An environmental monitoring plan has been developed that will provide data that will permit determination of the environmental impact.

2.2.6.1 Environmental Analysis of Conceptual Design

2.2.6.1.1 Introduction

This analysis considers parameters for gasification of steeply dipping coal beds that may potentially impact the environment. Specifically, the study relates to the ability to comply with regulations dealing with air, water, and land quality in the Rawlins, Wyoming, area.

Activities considered in the analysis include (a) impacts of process design and subsequent project implementation, (b) preliminary estimate of emissions or effluents, (c) health and safety and area socioeconomic impacts, (d) federal and state regulations, (e) site-specific problems, and (f) abatement measures and control systems.

Details are contained in Appendix B, "Environmental Analysis of Concept Design."

2.2.6.1.2 Conclusions

Potential environmental and health and safety impacts related to the design are:

Phase I. Minuscule impacts are expected. On-site activities are limited to occasional visits for survey and data gathering.

Phase II. Site preparation, access road construction, and construction equipment emissions are expected. The primary problem in Phase II is judged to be particulates (dust) from road construction and abatement measures may be necessary to assure compliance.

Phase III. Activities represent the underground gasification (burning). Primary attention will be directed to criteria pollutant emission from the flare which burns the product gas. Although there are no criteria on polynuclear aromatics, per se, the possibility exists that ambient air standards will be issued on these materials by the fall of 1979. During the worst of meteorological conditions, SO_2 , NO_x , and particulate pollutants could conceivably exceed standards during Burn No. 3. The proposed monitoring program will detect any such conditions so that appropriate protective or abatement measures may be taken. Any impacts on air quality will, of course, be limited to the burning periods with the emission source being the flared product gas. Other emission sources may be diesel exhausts, and abatement measures may be required. Any condensible fluids collected will be disposed of using environmentally acceptable techniques. Water quality will be monitored periodically and pumpout procedures employed, if required, to maintain the quality. Ground subsidence, if any, during this experimental project will be assessed during the project to allow planning of adequate safeguards.

Post-burn activities will have minimal impact except possibly for limited duration as a direct aftermath of Phase III.

Socioeconomic impacts throughout all phases will be almost non-existent. Regulatory constraints will involve the Clean Air Act, Federal Water Pollution Control Act, OSHA, the Safe Drinking Water Act and possibly the Toxic Substances Control Act (TOSCA), as well as various Wyoming regulations. Details are discussed in the report.

2.2.6.2 Environmental Planning for Monitoring (WBS 1.1.2)

2.2.6.2.1 General

Numerous federal and Wyoming environmental requirements impact the UCG/SDB field test program. Non-compliance with these requirements could result in severe schedule and economic disruptions to the program. Consequently, the purpose of this activity is to define those methods and procedures which will be used during the field test program to assure compliance with federal, state, and local environmental regulations.

The following support activities were performed during Phase I in development of the Environmental Plan for Monitoring:

- Appropriate Wyoming agencies and the Environmental Protection Agency Region VIII office in Denver, CO, were contacted to determine their environmental monitoring requirements for UCG.
- Identification was made of specific air and water pollutants to be monitored, types of monitoring equipment, sample analyses, and frequency of sampling.
- Determination was made of the availability of air pollution monitoring equipment. Estimates also were made of the lead time required to prepare the equipment for field use.
- On-site power requirements necessary for monitoring activities were determined, and the feasibility and cost of using portable generators was evaluated.
- Several reports on underground coal gasification were reviewed to determine environmental monitoring requirements at other UCG sites. Conversations were held with personnel from Laramie Energy Research Center and Lawrence Livermore Laboratory.
- A draft of the Environmental Monitoring Plan was prepared. This plan presents a detailed description of Phases II and III environmental activities, including post-burn activities. The plan's environmental parameters include ambient air quality, ground and surface water quality, and ground subsidence.

2.2.6.2.2 Environmental Monitoring Plan Approach

The plan details activities that will be implemented before, during, and after the burns to satisfy environmental requirements including federal and Wyoming state monitoring requirements.

The objectives of the plan's environmental monitoring activities are:

- To determine existing levels of environmental quality in the vicinity of the North Knobs, Wyoming, test site (i.e., establish baseline environmental quality).
- To monitor for changes in environmental quality during and after the test burns.
- To produce data usable in preparation of an Environmental Impact Assessment (EIA).
- To provide assurance to appropriate regulatory agencies and local citizens that preservation of environmental quality is an integral part of the field test program.

Phase II activities provide baseline environmental information. This effort involves characterization of the existing air and water quality at the test site. The data will provide useful input to the Environmental Impact Assessment (EIA), and furnish a basis for comparison with the environmental data collected during and after the test burns.

The environmental monitoring activities during the test burn period of Phase III will aid in detecting any significant changes in environmental conditions or the release of contaminants directly attributable to the test burn activities. These data will be compared against baseline environmental quality data to make this assessment and to ensure that adequate environmental safeguards are initiated.

Following the three test burns, the environmental monitoring activities will provide data for determining the nature and magnitude of any changes in environmental conditions from baseline conditions at the site. In addition, it is possible that some pollution of subsurface waters near the site may result from underground gasification tests, depending on movement of these groundwaters through the burn area. Post-burn environmental activities will provide adequate monitoring of these groundwater resources and permit evaluation of the appropriateness of the safeguards taken.

The major areas of activity covered by the plan include:

- Monitoring equipment installation
- Meteorological monitoring
- Monitoring of atmospheric concentrations of criteria pollutants
- Measurement of process-specific air pollutants
- Groundwater quality monitoring
- Subsidence monitoring

2.2.6.2.3 Environmental Monitoring Plan Description

Phase II Environmental Activities. During this phase, baseline environmental quality data are collected at the test site near North Knobs, Wyoming, for a one-year period. The effort consists of preparing the monitoring equipment, and collecting data for meteorological parameters, criteria air pollutants, trace elements, process specific air pollutants, and water quality parameters.

The five activity areas during Phase II are:

- Mobilize Monitoring Equipment - All environmental monitoring equipment is prepared for use at the UCG test site. The preparation of the equipment includes a thorough checkout of all circuitry, calibration using reference gases, and operation for a 48-hour period to assure equipment is functioning properly.
- Monitor Meteorological Parameters - On-site wind speed and direction is monitored with a portable meteorological tower so that during the test burns, air monitoring instruments can be located to detect pollutants released by the tests. The data will assist in properly locating the instruments upwind from the portable diesel generator to minimize the effects of hydrocarbon emissions or to allow adjustments where shifting winds cause the diesel emissions to be directed toward the air monitoring instruments.
- Monitor Atmospheric Concentrations of Criteria Pollutants - Ambient air monitoring of five criteria air pollutants is conducted at the UCG test site during the baseline monitoring program. These include the methane hydrocarbons, ozone, and total suspended particulates. National Ambient Air Quality Standards (NAAQS) have been established for these five pollutants plus carbon monoxide. Periodic monitoring for carbon monoxide is conducted to verify that no ambient concentrations other than background levels are being produced at the test site.

The monitoring equipment used at the test site has been specified. All equipment meets requirements of the EPA reference methods specified in the Federal Register, December 1, 1976. All four gaseous pollutants are monitored continuously, while total suspended particulates are monitored on a six-day sampling period in accordance with the National Air Sampling Network (NASN) schedule.

- Measure Process-Specific Pollutants - Samples of ambient air are analyzed for hydrogen sulfide and carbonyl sulfide. These pollutants may be emitted during the UCG test burns; therefore, baseline data are required for comparison with during-burn concentrations. The ambient air is sampled by taking grab samples in evacuated Mylar bags to be analyzed by a gas chromatograph. These samples are taken at least twice during the baseline period; and if any measurable concentrations are found, additional samples will be taken.

In addition, the air is monitored for ambient concentrations of trace elements. This is performed by analyzing the total suspended particulate filter samples by atomic absorption spectrophotometry. The following trace elements are analyzed: antimony, arsenic, beryllium, cadmium, lead, mercury, selenium, and zinc. This analysis is conducted four times during the baseline test period.

- Monitor Water Quality Parameters - The baseline water quality monitoring program determines the concentrations of selected parameters in the coal seam and in adjacent underlying and overlying aquifers before starting the gasification test experiments. The data are compared with that obtained from subsequent phases to determine changes in the selected parameters.

Analyses of sampled wells include the following water quality parameters:

- Temperature, conductivity, and pH.
- Inorganic laboratory analyses for: total dissolved solids (TDS), total suspended solids (TSS), carbonates, sulfide, cyanide, chloride, fluoride, and total nitrogen derived from separately reported analysis of ammonia (NH_3), nitrates (NO_3) and nitrites (NO_2), and organic nitrogen.

- Trace element analyses for: mercury (Hg), arsenic (As), and approximately 20 others determined by emission spectroscopy.
- Organic laboratory analyses for: chemical oxygen demand (COD), total organic carbon (TOC), oils and tars, characterization of specific organics.
- Radioactivity: gross alpha and beta activity of filtrate.

Several sets of samples is collected from each monitoring well in the coal seam and from one underlying and one overlying aquifer during baseline monitoring.

2.2.6.2.4 Phase III Environmental Activities

During Phase III of the program, environmental quality data are collected during and after the three test burns. Due to the absence of flaring after the burns, the post-burn period will involve groundwater and subsidence monitoring. The activities necessary during this phase include: preparing the monitoring equipment and collecting data for meteorological parameters (criteria air pollutants, trace elements, process specific air pollutants and water quality parameters). Monitoring for ground subsidence is also conducted during this phase.

The six activity areas during this phase are:

- Mobilize Monitoring Equipment - All environmental monitoring equipment demobilized from the site at the end of the baseline environmental monitoring is prepared for use at the test site during Phase III. Preparation of the equipment includes the activities described previously in Phase II, Section 2.2.6.2.3.
- Monitor Meteorological Parameters. Monitoring of wind speed and direction continues during this phase so that data can be accurately compared to baseline information, enabling necessary adjustments for shifts in speed or direction to be made.

- Monitor Atmospheric Concentrations of Criteria Pollutants - Ambient air monitoring of five criteria air pollutants continues during the burn period of Phase III. Monitoring for ambient air concentrations of carbon monoxide is again conducted in conjunction with site safety operations.
- Measure Process-Specific Pollutants - During the three test burn periods, ambient air samples are analyzed for hydrogen sulfide and carbonyl sulfide. Additional air monitoring is also conducted during this period for ambient concentrations of trace elements.
- Monitor Water Quality Parameters - The during- and post-burn water quality monitoring program determines if any significant changes in groundwater quality are occurring. Data on concentrations of selected parameters are obtained from the SDB aquifer and from underlying and overlying aquifers and compared with data obtained during pre-burn monitoring. Since the first two burns are nine months ahead of the third burn, additional information on post-burn groundwater quality can be obtained from the first two burns. Table 2-IV lists the post-burn water quality parameters to be monitored.

In regard to the underlying and overlying aquifers, neither the frequency of sampling nor the number of parameters monitored need to be as great as the SDB aquifer. Therefore, samples from underlying and overlying aquifers are collected on a quarterly basis and analyzed only for the following parameters:

- Total dissolved solids
- Total organic carbon
- Nitrate
- Sulfides
- Cyanides
- Ammonia

Table 2-IV

POST-BURN GROUNDWATER QUALITY PARAMETERS TO BE MONITORED

SDB Aquifer

Temperature	Cyanide
pH	Chloride
Conductivity	Fluoride
Total Dissolved Solids (TDS)	Radioactivity
Total Suspended Solids (TSS)	Characterization of Specific Organics
Total Organic Carbon (TOC)	
Carbonates	Miscellaneous Analysis
Sulfides	
Chemical Oxygen Demand (COD)	<u>Underlying/Overlying Aquifers</u>
Total Nitrogen	Total Dissolved Solids
Ammonia	Total Organic Carbon
Nitrate-Nitrite Nitrogen	Nitrate
Organic Nitrogen	Sulfides
Trace Elements	Cyanides
Mercury	Ammonia
Arsenic	

- Monitor Subsidence - This effort determines the extent of ground subsidence resulting from the underground gasification tests. Before the start of Burn No. 1, locations of the subsidence monuments are determined. Monuments are placed in pre-determined locations by survey. During and after the test burns the monuments are surveyed at a specified frequency. Preliminary estimates are that surveys must be conducted at six-month intervals, beginning in November, 1980, and ending in November, 1983.

2.2.7 QUENCH MODE ANALYSIS

Provisions to control and terminate the underground process has been called out in the original RFP. DOE field tests in horizontal beds have made no other provision than to shut off the air and to let groundwater seep into the reactor. The inclined bed geology increases a possibility for problems. A quench mode analysis of the process has been performed to define possible problem areas and compare various options available.

2.2.7.1 Background

The question of process control and process termination in UCG was raised in the original RFP, and the problem of a runaway fire has been examined in this study.

Historically, fighting fires in active or abandoned coal mines as well as attempting to control naturally occurring fires in coal outcrops has been a story of repeated efforts, oftentimes over decades. The situation in a field UCG test is much different from these type of fires.

These fires, old and new, have one element in common, access to oxygen! For example, the Pittsburgh bed in southwestern Pennsylvania (one of the areas with many persistent abandoned mine fires) is above the water table in hilly terrain where it frequently outcrops. Fires in these kinds of situations have been most successfully fought by digging wide cutoff trenches where insulating backfill provides a barrier between the burning coal and the remainder of the seam, providing earthen seals over outcropping areas of burning coal or combinations of these methods. All situations demanded constant maintenance over a period of years.

Recent UCG burns have been quenched at Hoe Creek and Hanna. Both operations were conducted below the water table and quenched by the natural inflow of groundwater over time. Hoe Creek quenched in "about" a week and Hanna in "about" 8-10 months.

The Hoe Creek burn was conducted in the Felix II seam. The seam is 7.5 m (25 feet) thick and 38 m (125 feet) below the surface. It is an

aquifer. The burn gasified 117 tonnes (130 tons) (approximately 80 m³) of coal. The aquifer flow rates at this site were in the range of 19-38 dm³/day (5-10 gal/day).

The Hanna experiments were conducted in a coal seam some 9 m (30 feet) thick ranging from 97 m to 120 m (325 to 400 feet) deep. The seam is an aquifer. The burns are several months in duration and consumed 2700-3600 tonnes (3000-4000 tons) of coal.

The process control elements of the desired reaction only govern in the immediate area of the process and that the geological factors inherent to the particular site become more and more dominant as a function of the distance from the reaction. Among the geological factors of importance are: strength and insulating characteristics of the surrounding rock, permeability and hydrologic characteristics of the area, and a detailed knowledge of local faulting. In short, the ability to control or predict control of an underground burn is very dependent upon knowledge of these factors so that the gasification modules can be placed where they are indeed controllable.

In order to address these considerations in detail, a determination must be made as to the applicability of each quenching mode to the geologic situation at hand. Some of the considerations involved are:

- Groundwater availability - presence, flow rate, total reservoir, recharge rate, direction of flow
- Fracture permeability of the coal seam and host rocks to liquid and gas flows
- Likelihood of collapse and subsidence linkage to the surface
- Option costs

2.2.7.2 Special Factors in Steeply Dipping Beds

Gasification of steeply dipping coal beds presents problems which are different from those encountered when dealing with horizontal seams. Among these are:

- (a) The possibility that the dipping seam means that there will not be a well-defined horizontal water table above the seam.
- (b) Fracturing and faulting are much more likely.
- (c) There is the possibility of the burn progressing not only up and down dip, but also horizontally.

One method of defining requirements for an SDB quench system in these steeply dipping beds is to consider the ways in which control of in situ reaction propagation can be lost under the conditions listed above. This general technique is called failure mode analysis. It consists of envisioning the ways in which an unwanted event can occur and then considering the possibilities of these modes of failure in order to quantitatively or qualitatively assess the likelihood of failure. In this case because of the lack of detailed data, the analyses must be qualitative. From the failure analysis, one can step to the ways in which such occurrences can be detected and thence to methods of control.

Two basic geological situations must be considered in a quench mode analysis of in situ coal gasification. First, the case where the operations take place below the water table, and second, the case in which quenching becomes necessary above the water table or in a dry seam. In the west where aquifer flow rates are very low, the difference between these two cases may not be significant from a quenching standpoint. The major failure modes identified at this point in time for operations below the water table and in a dry seam are shown in Figure 2-27 and described below.

- (a) Fault Channeling - The operation of a module across a fault/fracture zone, displaced or not, can provide a channel for heat transmission updip within the seam or across other strata to other coal seams if a series of coal beds are present. The initial supply of oxygen is provided by the process air and an open fault could provide a route of access for surface air

Figure 2-27. FAILURE MODE ANALYSIS

once the fire is above the water table, even if the process air supply is removed.

- (b) Piping - The penetration of the necessary process and instrumentation piping into the gasification retort module will provide for the possibility of hot process gases escaping into other areas. The instrumentation piping, even if it is improperly grouted at the lower end, will not normally present a problem, since the system is closed off at the upper end. This closure will not allow any major convection heating of the pipe, so that all heat transfer through the instrumentation system must occur by conduction through the pipe. With the earth's heat sink surrounding the upper sections of casing, it is unlikely that any major amount of heat can be transmitted into upper coal beds, should they exist. The likelihood of the grouting around the casing cracking and providing a gas flow passage around the casing and thus to the surface is also small in the case of pilot scale modules. Discharge process piping updip through the coal bed presents the most distinct possibility for transmitting both heat and process gases out of the gasification module area to sections of the seam above the water table where the coal is not readily extinguishable. The fracture pattern of the coal bed, the shrinkage or swelling characteristics of the coal, the heat resistance of the grout, and the temperature of the discharge gases must all be considered for the site selected.
- (c) Overpressurization - The overpressurization of the reactor module during gasification presents another distinct failure possibility. Overpressurization could, of course, open up channels around piping, fractures to fault areas, or a finger pathway updip for heat and process gases to escape toward the surface. This could occur either in a dry seam where the channel passageways would more easily become available to the gas

flows, or by forcing back the water table from areas above the module. It could be caused by a pressurization controller mechanical malfunction or by the pinching off of the discharge piping by a roof fall in that immediate area.

The possibility of fault/fracture channeling being a very large problem in dry seams cannot be ignored. Their "limits" must be explored. Limits do appear to exist, as evidenced by inferred references in the literature to situations where the fire dies out without outside oxygen; i.e., far back in an outcrop burn when the fire becomes surrounded by solid coal, etc.

Some of the physical data needed to make the above determinations are listed below:

- Strike and Dip
- Bed Thickness
- Water Table Elevation
- Fault Locations and Intercepts, Possible Surface Connections
- Fracture Patterns, Including Face and Butt Cleat Orientation
- Pump Down Test Results
- Permeability Data
- Compressive, Tensile and Triaxial Strength of the Rock Strata
- Proximate and Ultimate Analysis of the Coal

2.2.7.3 Comparison of Quench Options

There are two ways to fight any fire, remove the oxygen supply or cool the material below its ignition temperature. In the following sections, a variety of modes for quenching a UCG fire is briefly explained, the advantages and disadvantages are compared, and the information necessary for a more detailed analysis is described.

- Option No. 1 - O₂ Cutoff

The simplest method of quenching is to cut off the supply of oxygen by:

- Throttling inlet air supply
- Shut down compressors
- Close air supply valve before air receiver is depleted in order to prevent product gas from backflowing into supply line.

- Option No. 2 - Flooding

In this option the air supply is cut off as in Option No. 1, and then copious quantities of water are poured into the cavity in order to cool the interior below ignition temperature.

- Option No. 3 - Inerting

Another method of quenching involves the injection of inert fluids/foams/gases into the cavity as in the following example:

- Remove air supply
- Start inert gas/foam/fluid flow from process input side
- After filling the cavity, close off the product gas line
- Pressurize the system below fracturing pressures
- Hold pressure for predetermined time.

Table 2-V briefly outlines the advantages and disadvantages of the quenching options. The following sections describe these same advantages and disadvantages in some detail.

- Oxygen Deprivation

Depriving the fire of oxygen by cutting off the supply of input air and leaving the discharge side open to atmosphere waiting till the

Table 2-V
COMPARISON OF QUENCH OPTIONS

Quench Mode	Advantages	Disadvantages	Cost	Recommendations
Option No. 1 - Cutoff, Oxygen deprivation	<ul style="list-style-type: none"> • A simple procedure using existing data base of experience in quenching below the water table • Gas seal below the water table • Minimal environmental impact 	<ul style="list-style-type: none"> • No information on natural O₂ deprivation die-out with depth • Runaway burn provides maximum environmental impact 	<ul style="list-style-type: none"> • Minimal 	<ul style="list-style-type: none"> • Mode of choice below the water table
Option No. 2 - Flooding, Material Cooling	<ul style="list-style-type: none"> • Quenches rapidly • Lack of cavity growth minimizes resource losses 	<ul style="list-style-type: none"> • Requires large external water supply • Produces much steam contaminated with light oils and coal tars • Above the water table the contaminated water outflow could be very high 	<ul style="list-style-type: none"> • Medium to high because of water and transportation costs 	<ul style="list-style-type: none"> • Not recommended - water not readily available in test site region
Option No. 3 - Inerting, Oxygen deprivation and Cooling	<ul style="list-style-type: none"> • High fracture penetration capability • Uses standard oil field fracing • Speed of quench • Minimal environmental impact 	<ul style="list-style-type: none"> • Shutdown equipment would not be immediately available for use in an emergency • Extensive subsidence could make it impossible to hold pressure 	<ul style="list-style-type: none"> • Medium - equivalent to oil field fracing operation 	<ul style="list-style-type: none"> • Recommended for further analysis and field test - may be very useful above the water table
Quenching Aids - Air Ejector	<ul style="list-style-type: none"> • Aids inflow of groundwater • Quenches rapidly • Uses existing equipment • Moderate environmental impact 	<ul style="list-style-type: none"> • May aid the influx of outside air through fractures when above the water table 	<ul style="list-style-type: none"> • Moderate - requires addition of air ejector and piping to supply 	<ul style="list-style-type: none"> • Use with burn below the water table • Do not use above the water table
Recycling	<ul style="list-style-type: none"> • Conserves water when flooding 	<ul style="list-style-type: none"> • Expensive • May provide extensive environmental impact with inefficient cleanup 	<ul style="list-style-type: none"> • Expensive - requires cleanup equipment + condensor + cooling tower 	<ul style="list-style-type: none"> • Do not use - cleaning of contaminated steam to the degree required may be impossible

pressure drops on the output side and then valving off the product gas stream is also a possibility. In both the Hanna and Hoe Creek tests, this method was followed successfully when operating below the water table. This method cools the burn region slowly from the outside in and provides a gas-tight seal. As water flows into the cavity from the surrounding area, any contaminants flow toward the cavity and the steam formed is ejected at a very low pressure with a minimum entrainment of coal tars, particulates, etc.

Unfortunately, with our present state of knowledge of both subsidence fracturing and natural fracture pattern of the coal and the surrounding rock, there is no way of knowing, after operations in a dry seam, that oxygen has not found another pathway to the combustion zone. We do know that natural fires started in outcropping seams do eventually die out at a depth, but we do not know in geologic time when that may have occurred. In the case of tests occurring below the water table, closing off the product gas discharge line can only increase the back-pressure and slow the inflow of water. Though initially inexpensive, this method has much higher risks at this time if operations above the water are proposed.

- Flooding

The classic method of fighting fire is to flow water on the burning surface in order to cool it below ignition temperature. An available quenching option is one where the air supply is cut off and large quantities of water are poured into the cavity. If a cavity dimension of 6 m x 9 m x 18 m (20 feet x 30 feet x 60 feet) is assumed, some 1020 m³ (270 000 gallons) of water are required to fill the cavity once. Bureau of Mines experiments in quenching coal refuse piles indicate much larger quantities are required to cool such a burn. As cooling water flashes to steam, large quantities would be rapidly ejected from the cavity into the atmosphere entraining coal tars, particulates, etc., and providing a large environmental impact.

- Foam

The Bureau of Mines has conducted various programs utilizing standard firefighting foams in simulated underground mine situations. They have also conducted an experiment on injecting these foams through a bore-hole into a tunnel. These experiments provided some information of interest in that:

- As expected, water usage was very low.
- The foam was not stiff, and channeling of air flows at the top of the foam was evident.
- The drifts could not reasonably be completely filled from a small 15 cm (6 inch) diameter hole in the center of the drift.

Though these experiments are not directly applicable, they do lead to the conclusion that the viscosities of these foams would be somewhat low for UCG purposes. It also leads to the possibility that a higher viscosity inert gas (LN_2/GN_2) foam as used in oil well fracturing might be most usable.

Using cavity dimensions of 6 m x 9 m x 18 m (20 feet x 30 feet x 60 feet) as the basic requirement, some 954-113 m³ (6-7000 bbl) of foam are required for the initial fill, far below the capacity of available oil field fracturing equipment.

Foam fracturing is a process whereby nitrogen, water and an emulsifying agent are combined and used as the fracturing fluid. One advantage of this system is the inhibition of leak-off in a permeable formation due to the strength of the gas bubbles and their ability to block off pores and reorient the force along the plane of weakest stress. It is conceivable that this method could also work in a dry seam. The environmental impact would probably not be greater than that of a normal fracturing job.

2.2.7.4 Quenching Aids

There are two aids to the major modes of quenching. The air ejector is used to draw a partial vacuum on the cavity. Recycling the steam from a flooding operation could aid in conserving water supplies where this is important.

- Air Ejector

The air ejector, or evactor, presently planned for the site is envisioned as an aid to quenching in many of the possible modes of operation. It will be able to draw a small partial vacuum on the total system while removing steam and combustion products, thus aiding the inflow of water or other quenching agents. In the unlikely event that it were capable of pulling a perfect vacuum, it would only add 2-3% to the lithostatic head, so the possibility of increasing the caving potential is small. It will, however, represent a large percentage air pressure differential; and thus, it is not recommended for use in dry seams because of the possibility of aiding the flow of oxygen from the surface.

- Recycling

It has been proposed that quench water injected into the cavity be recycled by condensing the resultant steam and returning it to the cavity to provide further cooling. It is analogous to condensing the steam from a coke cooling operation and reusing the water.

In order for such a system to work, the steam from the product gas line must first be sent through a very efficient oil/solids separator. This is required so that the water is acceptable to the condenser. Condensers fed oil/tar contaminated water lose their heat transfer capability within a matter of a few hours.

Secondly, large quantities of cooling water must be provided to the condenser shell. Since these quantities are probably not available as groundwater, it would be necessary to provide a cooling tower and an ancillary water treatment plant. Finally, it would be necessary to frequently sample and analyze the reinjected water to assure the environmental authorities that no potential carcinogens are being reinjected. Because of its expense and potentially large environmental impact, the use of this quenching aid will not be considered further.

2.2.7.5 Failure Indications

Due to the remote nature of the gasification operation, it is important to specify parameter changes which might indicate the necessity of quenching. These indicators need a much more detailed treatment as part of the Quench Plan once the site has been characterized and the site facility is designed. Some burn failure indicators are listed below.

- A sudden rise in the inlet pressure or a slow rise in the inlet pressure followed by a sudden drop could indicate a choking of the discharge piping and a subsequent breakout by one of the previously described failure modes. This inlet pressure indication would be accompanied by a corresponding drop in the pressure on the discharge side of the system.
- Failure could be coupled with initial drops in the flow rates on both the inlet and outlet sides of the piping system. After breakout, the flow rate on the inlet side would return to a level consistent with the size of the developed channel and the discharge flow would remain low.
- The process gas discharge temperature could serve as an indicator of channeling problems. Sudden increase in temperature along the discharge or injection pipes could indicate problems.

Part of the preliminary process gas facility layout is shown in Figure 2-28 together with gas monitoring instrumentation. With modest augmentation, this instrumentation should be sufficient to determine the existence of a failure situation. The use of the presently planned instrumentation and the supplemental methods are described below.

2.2.7.6 Failure Measurement

Possible burn failures may be detected by the monitoring steps listed below.

- Monitor inlet and outlet pressures on a continuous basis.
- Monitor inlet and outlet flow rates on a continuous basis.
- Monitor gas inlet and discharge temperatures continuously.
- Emplace a string of thermocouples up the discharge pipe and appropriate instrumentation piping in order to define "hot spot."
- Subtle indications of process gases escaping the gasification module could be obtained by introducing measured quantities of a tracer gas (He or SF₆) on the inlet side of the process and measuring the quantity of the same gas on the discharge side of the operation. Also, the introduction of a tracer gas measurable by portable field "sniffers" is required as a safety monitoring function and thus also usable as a quench requirement indicator.

LEGEND

- GLOBE VALVE
- GATE VALVE
- FLOW INDICATING CONTROLLER
- PRESSURE INDICATOR
- TEMPERATURE INDICATOR
- TRANSMITTER
- FLOW CONTROL VALVE
- FLOW ORIFICE
- PRESSURE REDUCING REGULATOR
- TEMPERATURE INDICATING CONTROLLER

Figure 2-28. WELLHEAD PROCESS PIPING

2.2.7.7 Quench Mode Recommendations

This recommended quench mode is:

- Operate all gasification reactor modules below the water table.
- At start of quench, remove the oxygen supply.
- Operate the air ejector to aid the inflow of groundwater as needed.

The preliminary design of the site facilities has been based upon this operating mode. The layout is shown in Figure 2-28. This conservative mode of operation follows the thread of previous UCG efforts with the addition of the air ejector to speed quenching and, thus, minimize any cavity growth.

The general shutdown procedures we would plan to use at North Knobs are:

- Normal Mode
 - Below the Water Table
 - Close off inlet pipe flow.
 - Shut down the system.
- Emergency Shutdown
 - Below the Water Table
 - Close off inlet air flow.
 - Dump process water in the inlet at a rate which will not allow an excessive pressure build up in the reactor module--operate aspiration system at X% of maximum to aid pressure control.

- After all available process water is dumped,
aspirate the module until the water table in
the reactor area has returned to normal.
- Shut down the system.

2.2.8 Parametric Cost Analysis

2.2.8.1 Introduction

An analysis of the UCG process parameters has been obtained with the Gulf Economic Model for UCG. Although the model was developed for horizontal beds, the significance of parameters studied should be similar.

The underground coal gasification process embodies many variables which affect not only the process operating characteristics but also the process economics. In general, these variables can be grouped into physical properties of the coal seam, independent operational variables and dependent production variables. It is important to know the effect of each of these variables on economics in order to indicate where experimental work will be most fruitful.

An evaluation of process economics requires that cost studies be made on a system which would be representative of a commercial installation. Gulf Research & Development Company developed such a conceptual design for horizontal coal seams, and, in order to facilitate the lengthy economic calculations, also developed a computerized mathematical model. This proprietary model and its use for parametric studies related to our DOE contract are discussed at length in Appendix C of this report.

It must be emphasized that the conceptual design and computer program were developed for horizontal coal seams. Because seam characteristics, drilling costs, well layout, and field piping will differ between horizontal and steeply dipping beds, GR&DC intends to develop at their own cost a modified proprietary model for the SDB configuration. GR&DC expects that the absolute value of the economics will be different for a steeply dipping bed plant; however, for many or most of the variables, the effect of changes in their values will be similar, regardless of seam orientation.

The studies which are reported in Appendix C are for a plant producing 152×10^3 GJ/d (144×10^9 Btu/day) of low-heating-value gas from a horizontal seam of subbituminous coal located in the western United

States. The gasifying medium was air. This size plant furnishes sufficient gas to generate approximately 600 MW of electric power.

2.2.8.2 Parameters Studies

Sixteen different cases were run in which individual parameters were varied and four cases were run in which two or more parameters were varied together. The base values of the parameters which were held constant as they were varied one by one are shown in Table 2-VI and the ranges through which they were varied are shown in Table 2-VII. Table 2-VII also contains the calculated price for LHV gas with equity financing over the range of the various parameters.

From Table 2-VII it may be seen that many parameters were varied over a range of 100% or more; and to reduce the results to a more comparable basis, the effects were calculated for a 50% increase in parameter value at its mid-range. The effect of this increase on the price of LHV gas is shown in Table 2-VIII.

Table 2-VIII shows that the most effective way to reduce the cost of gas from UCG is to increase its heating value. This decreases the plant size, number of wells, fuel requirements, and coal consumption. For the heating value effect, all of the combustible gases were assumed to increase together in the same proportion. Runs were also made in which methane only and hydrogen only were increased. When either of these alone increased by 50%, the product gas heating value increased by about 15%. Gas prices decreased, but to a lesser extent than when heating value increased 50%.

The next most effective ways to reduce gas cost are to increase product gas recovery and air utilization, i.e., to minimize leakage. To express the numbers from Table 2-VIII in another way, each 2% decrease in

Table 2-VI

BASE PARAMETER VALUES FOR PARAMETRIC COST ANALYSIS

<u>Parameter</u>	<u>Base Value</u>
<u>Coal Data</u>	
Seam depth, m (ft)	183 (600)
Seam thickness, m (ft)	9.1 (30)
Density, t/ha-m (T/acre-ft)	13 970 (1900)
Heat content, kJ/kg (Btu/lb)	18 600 (8000)
<u>Operational</u>	
Well spacing, ha (acres)	0.81 (2)
Aspect ratio ^(a)	1
Production rate/well, m ³ /d (10 ⁶ scf/d)	141 580 (5)
Injection air rate, m ³ /t coal (scf/T)	1605 (51 430)
Injection air pressure, kPa (psig)	790 (100)
Production wellhead pressure, kPa (psig)	445 (50)
Sales gas delivery pressure, kPa (psig)	1310 (175)
Water/O ₂ consumption ratio, weight	1.5
<u>Production</u>	
Gas production rate, m ³ /t coal (scf/T)	2620 (84 000)
Gas composition, mol % H ₂	18.0
CO	18.0
CH ₄	5.0
C ₂ H ₆	0.5
CO ₂	10.0
H ₂ S	0.1
N ₂ + Ar	48.4
Gas heating value, kJ/m ³ (Btu/scf)	6560 (176)
Sweep efficiency, %	100
Air utilization, %	100
Gas recovery, %	100

(a) Aspect ratio - distance between production rows divided by distance between wells in row.

Table 2-VII

SUMMARY OF PARAMETER VARIATIONS AND THEIR EFFECT ON UCG ECONOMICS

PARAMETER STUDIED	Range of Parameter		Sales Gas Price, \$/GJ(\$/10 ⁶ Btu)	
	Low	High	At Low Range	At High Range
<u>COAL SEAM</u>				
Depth, m (ft)	91 (300)	233 (764)	1.70 (1.79)	1.80 (1.90)
Seam thickness, m (ft)	1.5 (5)	10.4 (34)	2.30 (2.43)	1.74 (1.84)
Coal density, t/ha-m (T/acre-ft)	13 970 (1900)	27 480 (3737)	1.76 (1.86)	1.71 (1.80)
<u>OPERATIONAL</u>				
Well spacing, ha (acres)	0.28 (0.7)	1.58 (3.9)	1.72 (1.82)	1.90 (2.00)
Aspect ratio (Note a)	0.2	8.9	2.45 (2.59)	1.53 (1.61)
Production rate/well, m ³ /d (10 ⁶ scf/d)	65 103 (2.3)	274 670 (9.7)	2.80 (2.95)	1.53 (1.61)
Air rate, m ³ /t coal (scf/T coal)	1055 (33 810)	1915 (61 430)	1.50 (1.58)	2.04 (2.15)
Air pressure, kPa (psig)	480 (55)	1480 (200)	1.65 (1.74)	1.91 (2.02)
Production wellhead pressure kPa (psig)	240 (20)	745 (93)	2.78 (2.93)	1.35 (1.42)
<u>PRODUCTION</u>				
Gas rate, m ³ /t coal (scf/T coal)	1875 (60 000)	3230 (103 500)	2.27 (2.39)	1.56 (1.65)
CH ₄ in product gas, mol %	2.1	7.0	2.55 (2.69)	1.46 (1.54)
H ₂ in product gas, mol %	12.6	21.3	2.14 (2.26)	1.59 (1.68)
Gas heating value, kJ/m ³ (Btu/scf)	4580 (123)	8380 (225)	4.10 (4.33)	1.18 (1.25)
Sweep efficiency (coal usage), %	25	97	2.20 (2.32)	1.76 (1.86)
Air utilization, %	40	98	3.86 (4.07)	1.78 (1.88)
Gas recovery, %	40	98	4.42 (4.66)	1.78 (1.85)
<u>COMBINED PARAMETERS</u>				
Air rate, m ³ /t coal (scf/T coal)	1070 (34 290)	1850 (59 140)	{ 1.85 (1.95)	1.73 (1.83)
Gas rate, m ³ /t coal (scf/T coal)	1870 (60 000)	3230 (103 500)		
Air pressure, kPa (psig)	410 (45)	1010 (132)	{ 2.50 (2.64)	1.30 (1.37)
Production pressure, kPa (psig)	240 (20)	840 (107)		
Depth, m (ft)	76 (250)	182 (598)	{ 2.92 (3.08)	1.15 (1.21)
Air pressure, kPa (psig)	370 (39)	1310 (175)		
Production pressure, kPa (psig)	200 (14)	1135 (150)		
Depth, m (ft)	76 (250)	182 (598)	{ 3.12 (3.29)	2.20 (2.32)
Air Pressure, kPa (psig)	370 (39)	1310 (175)		
Production pressure, kPa (psig)	200 (14)	1135 (150)		
Air leakage, %	5	30		
Gas leakage, %	5	30		

Note a: Aspect ratio = distance between production rows divided by distance between wells in row.

Table 2-VIII

EFFECT OF 50% INCREASE IN PARAMETER
VALUE ON LHV GAS SALES PRICE

<u>Parameter</u>	<u>Change in Sales Gas Price, %</u>
Product gas heating value	-54.0
Product gas recovery	-30.4
Air utilization	-26.8
Gas production/t coal	-24.2
Injection air/t coal	+23.5
Methane content of gas	-20.7
Hydrogen content of gas	-20.6
Production wellhead pressure	-16.9
Production rate/well	-9.5
Sweep efficiency	-4.9
Aspect ratio	-4.7
Well spacing	+3.8
Injection air pressure	+3.8
Coal seam thickness	-3.5
Coal seam depth	+2.1
Coal concentration/unit surface area	-1.6

either air or gas leakage (or 1% in both) reduces sales gas price by 1%. Decreased leakage reduces cost because of reduced plant size, number of wells, fuel requirements, and coal consumption.

Gas production per ton of coal and air injection per ton of coal have opposite effects on gas price as they are increased. Since they will probably increase together rather than individually, the net effect of increased air injection and gas production is likely to be small.

Increased production wellhead pressure has a beneficial effect on gas price because the conceptual plant design requires that the production gas be compressed to 1135 kPa (150 psig) before it goes to the main plant, and the high costs of field compressors and their operation can be reduced at high wellhead pressure. Increasing wellhead pressure by increasing air injection pressure is cheaper than the cost of compressing production gas, because the air volume is only about 57% as great as the volume of product gas.

Increased production rate per well reduces the number of wells and the amount of field piping required. The total plant investment and the sales gas price are thereby reduced.

The remaining parameters have only moderate effects on gas price in this study. This arises because their effects are largely related to well costs and field piping, and these constitute a minor portion of the plant investment and operating costs in the conceptual plant.

In addition to the relationship of gas production and air injection mentioned above, other parameters are related in various fashions. Outlet and inlet pressure, well depth and pressure, and depth, pressure, and leakage are three sets of variables which have been

examined together in this study. In the first two of these three, the effect of outlet pressure dominates the combined effects so that the effect of wellhead pressure alone accounts for most of the change in gas price. When gas leakage increases with increasing pressure, the effect of pressure dominates at low pressures and low leakage rates, whereas the effect of leakage dominates at high pressures and high leakage rates. For the magnitude of the relationships chosen for this study, an optimum pressure was obtained.

2.2.8.3 Discussion

The effects calculated in this study were determined by the values assigned to all the variables, and the interactions which could be investigated are almost limitless. One parameter which has not been varied is the pressure at which the sales gas is delivered. If this pressure could be lessened, it is possible that the other pressure parameters will be less important.

This study does not take into account relations between operational and product parameters. The development of process models which is contemplated in the DOE contract should help correct this deficiency. The ease of using the economics model will enable the process models to be tested as the experimental investigations proceed.

One definite limitation in this study is that it applies only to horizontal coal seams. In order to apply such a study to steeply dipping beds, it will be necessary to develop a conceptual plant and mathematical model for that configuration. Many of the parameters would be expected to have similar effects for either horizontal or steeply dipping beds. However, because well costs are greater in steeply dipping beds and because field piping may involve greater costs as the wells are spaced in a single row along the seam, some of the parameters may have

increased effects in the SDB process. Some parameters which should be particularly examined in the steeply dipping bed model are well depth, seam thickness (as it affects drilling costs), well spacing, production rate per well, and sweep efficiency. The whole concept of optimizing the positioning of wells, field piping, and gas handling plants must be carefully considered as this new model is developed.

2.2.9 PERMIT PLANNING

The existing DOE field projects have experience in most activities related to installation and operation of a UCG test facility. The fact that the SDB project is being performed by industry makes permitting of much greater importance. Permitting requirements in the state of Wyoming by local, state, and federal agencies were surveyed, and a preliminary list of permits was formulated. This list must be resurveyed and will be subject to revision.

The permits required for the construction and operation of the North Knobs site fall into two categories:

- Permits required for 1978 geological/hydrological testing
- Permits required for facility construction and operation.

Permits falling in the first category will be needed in April, 1978, while the permits in the second category will be needed in the spring of 1979.

2.2.9.1 Permits for Geological/Hydrological Testing

These permits will allow site access and on-site geologic and hydrologic activities to proceed. The following permits are required:

- License to explore for minerals by coring--Wyoming DEQ (includes \$20 000 reclamation bond)
- Permit to appropriate ground water--Wyoming State Engineer (one permit for each drill hole)
- Temporary tram road--BLM

The first two are presently being submitted. Obtaining state approvals does not appear to pose any problems. The BLM Temporary Tram Road Permit may cause a minor delay in the startup of 1978 site activities. It requires a route for the access road; an archeological study of the route; and at least 30 days for the BLM to review and approve the application. Neither the route determination nor the archeological survey can be conducted until most of the present snow cover has melted. Mid-March appears to be the earliest date that these activities can be conducted with permit approval then expected in mid-April, 1978.

2.2.9.2 Permits Required for Facility Construction and Operation

The permits outlined below will be required before any site construction activities can be started. Since these permits will require from four to six months of agency review time, they must be submitted by October 1, 1978 to preclude project delays.

The following list outlines the permits that have been identified to date and briefly describes the data requirements for each permit. There may be additional permits and additional data requirements.

- Permit to Mine

Supporting documents are as follows:

- Surface owner's consent
- Surface and mineral ownership map
- Legal description of permit area
- Proof of publication of newspaper notices
- Proof of filing notice with Carbon County
- Proof of notification of adjacent surface and mineral owners
- Land use
- History
- Archeological survey
- Topography
- Geology
- Hydrology
- Soils survey
- Vegetation inventory
- Wildlife
- Mine plan
- Mine facilities: design criteria, construction method, and schedule
- Mining method and schedule

- Waste disposal plan
 - Reclamation plan including aquifer restoration plan
 - Reclamation cost estimate and bond
-
- Water Quality Permit--WY DEQ
 - Air Quality Permit --WY DEQ
 - Permit to Appropriate Groundwater--WY State Engineer
 - Permit to Construct a Water Well--WY State Engineer
 - Permit to Construct a Reservoir--WY State Engineer
 - Right of Way Permit--BLM
 - Carbon County Building Permits
 - Construction Permit--WY DEQ

A consultant experienced in Wyoming permitting operations will be retained to assist in determining all the required permits, their data requirements, and in submittal of the permit applications. Each of the agencies shown in Table 2-IX may require permits for the SDB project. Needed permits for the SDB project will be determined and data requirements of those permits will be defined. Data collection planned for the SDB project will be reviewed and provisions to obtain missing data will be made. The consultant will then provide assistance in assembling the data into the formats required by the permits, and formulating responses to the regulatory reviewer's questions.

Table 2-IX

POTENTIAL AGENCIES INVOLVED IN PERMITTING THE UCG-SDB PROJECT

Federal

Bureau of Land Management
Environmental Protection Agency

State

Wyoming Department of Environmental Quality
 Air Quality Division
 Land Quality Division
 Water Quality Division
 Solid Waste Management Division
Wyoming State Engineer
Wyoming State Archeologist
Wyoming Public Lands Department
Wyoming Game and Fish Department
Wyoming State Mine Inspector
Wyoming Occupational Health and Safety Department
Wyoming Recreation Department
Wyoming Agriculture Department
Wyoming Industrial Siting Council
Wyoming Land Use Commission

Local

Carbon County Commissioners
Carbon County Land Use Planners
Other Carbon County Agencies

2.2.10 Safety Planning

Site safety activities will provide for personnel health and safety, fire protection, safety training, and support to the test operations. The site safety plan and safety procedures will be revised and updated as necessary to reflect new or modified test site requirements in Phase III. Construction activities and start of testing will influence safety considerations.

Safety procedures will be developed and reviewed and revised as necessary. These procedures will address site safety practices during all phases of the project and will include a site safety training plan. All site personnel will receive site safety and first aid training under this plan. Content of the training program and the frequency of training will be reviewed periodically and modified as necessary. Visitors will be briefed on safety practices before being permitted on site.

The identified hazards of UCG operations consist mainly of toxic gases occurring from the process operations, high pressures present in the compressed air and the product gas systems, and high product gas temperature.

Carbon monoxide, hydrogen sulfide, respirable dusts possibly contaminated with polynuclear aromatic hydrocarbons, and coal tar condensates present the most significant process-related health hazards. The test site and personnel areas will be monitored for CO and H₂S. The PNA content in the dust, if any, will be determined and appropriate health measures taken. The downwind concentration of dust is expected to be below the OSHA limits, but any leakage of gas upstream from the flare stack must be quickly stopped. The coal tar liquids will be handled and disposed of according to regulations covering cancer-suspect agents.

Subsidence is the only known geologic hazard. Sudden precipitous surface deformations are highly unlikely, but fissures could open through which toxic gases could escape. This leakage can be reduced by filling the hole with clay.

Dangers associated with the high pressure compressed air injection system and the product gas system are similar to ones from industrial experience. These systems will be designed with proper safeguards and the personnel will be trained.

Other hazards associated with the UCG site include drilling operations, and severe weather conditions at North Knobs. Personnel without experience in drill rig safety procedures will be kept away from the drilling area. It will be necessary that all site personnel be properly clothed and equipped during the winter, and that the test site and project vehicles be equipped to sustain life for two or three days in case of heavy snow.

During construction, testing, and between tests, safety personnel will monitor the various activities to determine whether or not there is adequate compliance with the safety regulations. Managers and supervisors will be notified of discrepancies. Safety personnel will also be responsible for procuring and maintaining safety equipment.

2.2.11 SITE SUPPORT PLANNING - PHASE I (WBS 3:2.1)

2.2.11.1 General

The complexity of the UCG/SDB project dictates the need for major planning and coordinating efforts in Phases II and III to assure that the test site is designed, constructed and operated in conformity with established project milestones. The objectives of the Phase I Site Support Planning support this goal. The task objectives were:

- Coordinate Phase I site-related planning activities.
- Define Phase II and III site support planning activities and estimate associated costs.
- Integrate the planning for Phases II, III, and IV project activities.

2.2.11.2 Phase I Site Planning

Several site-related tasks were interactive in Phase I. These included: Conceptual Design Update; Permit Support; Environmental Plan for Monitoring; Site Selection (TRW/Gulf joint effort) and Site Support Planning. It was vital that these tasks interact correctly, since collectively they formed the baseline for developing the Phases II, III, and IV Project Plan. These tasks elements were coordinated through frequent technical interchange meetings where task interactions were identified and accommodated in terms of real time.

2.2.11.3 Task Integration

The Work Breakdown Structure (WBS) identified the tasks necessary to implement the project objectives. However, it did not interrelate the tasks nor did it identify interfaces or interdependencies. To accomplish this an effort was initiated to develop an activity network of all WBS level 4 elements which would identify task performance, duration, start

and completion dates, interdependencies and constraints. A first iteration of the network was completed and it is envisioned that it will be refined early in Phase II to provide a mechanism for conducting schedule impact analysis when unforeseen events occur.

2.2.11.4 Phases II and III Site Planning

A major objective of Phase I was to identify Phases II and III site support activities in detail. To accomplish this with the least uncertainty, LERC's UCG experience at Hanna, Wyoming, was used as a baseline. Technical interchanges with LERC and Sandia personnel during site visits provided valuable information on site layout, equipment requirements, data acquisition and reduction, instrumentation utilized (LERC vs Sandia), facilities, site support, site operations (pre-test and post-test), test operations and personnel requirements. Problems and solutions were discussed at length to benefit from the real-world experience gained through three completed tests (Hanna I, II, and III). While the Hanna experience cannot be extrapolated directly, it was valuable in planning SDB site support activities. Specifically, the staffing approach utilized at Hanna was used to guide a site staffing study for this project. While performing this study, the following ground rules were used: (1) year-round site operation; (2) around-the-clock test operations; (3) manual process operations and automated data acquisition; (4) minimal staff size utilizing cross-trained personnel. Table 2-X describes the study results for site staff size.

Table 2-X
ON-SITE STAFF

TITLE	FUNCTION	SHIFT				TOTAL NO.
		DAY	2	3	4	
Test Director	Directs Site Support Director as to test execution. Makes final decision regarding test configuration, process variable values, quench methods and test schedules.	1	--	--	--	1
Site Support Director	Responsible for operation of all site systems. Reports to Test Director during test periods. Responsible for on-site staff, site safety and security, site operation.	1	--	--	--	1
Shift Engineer*	Maintains process equipment in operating mode. Directs technicians and helpers. Responsible for physical operation of the burn. Also responsible for site safety and emergency medical procedures.	1	1	1	1	4
Data Analyst	Collects and analyzes test data relating to process variables and products, interprets data and recommends necessary activities to Test Director.	2	--	--	--	2
Purchasing/Control	Purchases low cost items for use on site, tracks large orders initiated by Gulf (Harmarville), controls government property, sees that fiscal procedures are compatible with Gulf requirements, prepares monthly reports for project manager.	1	--	--	--	1
Secretary/Typist	Provides typing and secretarial support, answers telephone, maintains books, supports professional staff.	1	--	--	--	1
Technician	Maintains, calibrates and repairs electronics systems, works with data analyst to record and reduce test data, supports the lead engineer. Collects environmental data, maintains and repairs environmental equipment.	2	1	1	1	5
Helper*	Supports lead engineer, provides site maintenance, provides backup for the technicians, picks up necessary supplies in town.	1	1	1	1	4
TOTAL		10	3	3	3	19

*On duty 21 shifts/wk day and night schedule.

2.2.12 Cost Review

During Phase I, a complete cost review of subsequent activities was performed. The review reaffirms that the original total project budget can be maintained. However, the existing spending profile developed during contract negotiations to fit the expected DOE budged curve cannot be maintained.

Phase II costs, FY-1979 and 1979, have increased by approximately \$300 000, with a corresponding decrease during Phase III, FY 1980, 1981, and 1982. The current cost profile approximates the originally proposed cost and activity schedule. These schedule modifications and related costs are made necessary to provide proper chronological sequence of events considering contract requirement, local government requirements, and weather.

The schedule and cost modifications are detailed on the manpower, cost, major milestone schedule, and cost sharing forms to be found in Section 3.5, Standard Forms.

2.2.13 ADVISORY COMMITTEE ACTIVITY

The first Manager Advisory Committee meeting was held January 25, 1978; the first Technical Advisory Committee meeting was held January 26 and 27, 1978. Both meetings were at GR&DC facility in Harmarville, Pennsylvania.

2.2.13.1 Management Advisory Committee (MAC)

The members of this committee are:

Dr. U. Merten, Vice President of GR&DC and Committee Chairman
Mr. R. H. Graham, Manager, Mineral Technology for GR&DC
Dr. R. Shatz, Vice President of TRW
Dr. R. Robertson, Manager, Fossil Energy Operations, TRW

All members attended the meeting with the following project management personnel:

Mr. J. H. Daniel, Project Manager
Mr. B. E. Davis, Project Technical Coordinator
Mr. R. A. Bebout, Project Control Manager and Secretary for MAC
Dr. P. Alexander, TRW Project Manager

The significant results of the meeting are:

- The committee agreed with project personnel to process each subcontract modification to completion without introducing additional scope after GR&DC had prepared a formal (written) modification document.
- More intercompany exchange of information is required to resolve the slant drilling problem.
- At least two secondary sites should be acquired and evaluated. The project personnel were directed to prepare a proposal for DOE funding of the effort.

- Project management personnel are to meet monthly to consider overall project status.
- Communication between project personnel at all levels must be encouraged by company managements.
- Covers for all reports to DOE will bear logo's of both GR&DC and TRW.
- The committee expressed their approval of the project status and plans.

2.2.13.2 Technical Advisory Committee (TAC)

The members of this committee are:

Mr. R. H. Graham, Chairman
 Dr. J. O. Cowles, TRW
 Dr. A. M. Garon, GR&DC
 Mr. W. C. Goins, Jr. (absent), Drilling Consultant, GOC
 Dr. D. P. Gold (absent), Penn State University
 Prof. J. Jennings, Texas A&M
 Dr. R. R. Oder, GR&DC, Secretary
 Dr. P. Raimondi, GR&DC
 Mr. J. J. Selters (absent), GMRC
 Dr. H. C. Juvkam-Wold
 Mr. R. L. Robertson, TRW

The format for TAC meeting is for project personnel to discuss the technical approach being used to resolve problems and associated unresolved areas. The committee, in turn, offers advice regarding the approach, the unresolved areas, and areas that the project team should consider in future work.

The significant results of this meeting were:

- Slant Drilling - The discussions between project personnel and drilling experts raise sufficient concerns to warrant bringing a development drilling effort into the project in 1978.
- Process Modeling - Process modeling at least sufficient to assist in interpretation of feed/product data will be an important part of the technical program. The extent of modeling required should be determined and a technical rationale should be developed to justify application for additional funds to support such model development.
- Quenching - The committee concurs that the specific recommendation of operation below the water is a desirable approach for the test program. A technical rationale for additional investigations in quenching operations should be developed, which treats both abortive and normal quenching requirements.
- Length of Test Burns - The committee felt the length of the test burns should be reviewed to consider the ability to fully meet the project objectives. The major concern was the ability to determine the maximum desired reactor volume.
- Volume - The project manager asked the committee to consider expanding committee expertise in the environmental area to review the project environmental effort.

3.0.0. PLANS FOR PHASES II, III AND IV

3.0 PLAN FOR PHASES II, III, AND IV

The major part of the UCG/SDB project objectives will be implemented in the remaining three phases. Discrete plans for major activities will be developed in Phase II and subsequently refined in Phase III. First order project planning, task integration, and scheduling for the implementation of Phases II, III, and IV are discussed herein.

3.1.1 Overview

Figure 3-1 identifies the major milestones for the remaining project phases. All tasks will be scheduled consistent with those milestones. Close review of this schedule reveals that it is success oriented and highly interrelated at the task level. Close task management and control will be provided to assure milestones are met in a cost effective way. Factors to be considered are:

- High degree of task interdependence

Many functional areas contain critical task sequences. This is obvious in the data acquisition and reduction area where DOE software may not fit project requirements. Should additional development of software be required, a high degree of interaction between participants (DOE, GR&DC, TRW) will be required with relatively quick response.

- Extensive data flow between tasks

This aspect is most apparent in the area of site-related tasks. Site characterization data are vital to shaping the final test design which in turn impacts the facility design and subsequent construction/installation activities.

- Complexity resulting from major participants (DOE, GR&DC, TRW) sharing some tasks

This factor is most obvious in design, procuring, and construction activities. Drawings, specifications, etc., prepared by

Figure 3-1

TRW will be provided through GR&DC to DOE for approval prior to commitment of funds. Upon approval by DOE, these data will be used by GR&DC as a basis for contracting with a supplier who will provide hardware/services to TRW.

- Success-oriented schedule

The major milestones established for the project were set during the initial planning stage, prior to detailed schedule preparation. Subsequent planning indicated that the time available for critical task sequences is marginally sufficient and does not allow built-in contingency time that could be required with complex situations as described above.

Constant consideration of these factors will be maintained throughout Phases II, III, and IV implementation.

Figure 3-2 provides an overview of major activities planned for Phases II and III (detailed networks for each project phase are included as the final pages of this volume). Figure 3-2 is a simplified planning network that graphically portrays major activities as a function of time and identifies task interrelationships, constraining activities, significant interdependencies, and a sequence for task accomplishment. While the network logic is not explicitly shown (i.e., feedback loops and iterative functions are omitted), it may be inferred from the nature of the tasks. The following paragraphs discuss briefly the major activities shown in Figure 3-2.

3.1.2 Phase II

All Phases II, III, and IV planning is based on the feasibility study performed in Phase I. Those efforts, including site selection, concept design update, and preliminary test design provide the basis for finalizing the technical approach and program planning contained herein.

Phase II major activities comprise:

Figure 3-2. UCG/SDB PROGRAM PLANNING NETWORK (SIMPLIFIED)

- Site Characterization
- Final Test Design
- Facility Design
- Facility Construction and Equipment Installation (partial)
- Permeability Testing
- Environmental Monitoring
- Phase II Final Report Preparation

All Phase II tasks are site-specific and, as indicated in Figure 3-1, significant interdependencies exist between all tasks except environmental monitoring which is a parallel activity that does not impact other site-related tasks. A brief description of major Phase II tasks follows below.

3.1.2.1 Site Characterization

Since site-specific data are required to finalize the test design and are consistent with the facility design, a site characterization effort will begin early in Phase II. Permits will be acquired from the appropriate agencies. Exploratory wells will be drilled to permit hydrological evaluation. Cores will be taken and surface samples will be acquired to support geological analyses. The results of the characterization work will be utilized to finalize test design for permeability testing and subsequent burns.

3.1.2.2 Final Test Design

A preliminary test design was developed during Phase I without the benefit of site specific data. This design will be finalized in Phase II using data provided by the characterization tasks, coal studies, and process models. It is anticipated that DOE will provide models that can be modified for application to steeply dipping beds. The final test design will provide detailed specifications for permeability testing and the test burns. In addition, it will provide detailed requirements to guide site facility, equipment, and well design efforts.

3.1.2.3 Facility Design

The test site conceptual design was updated during the Phase I feasibility study utilizing preliminary information. During Phase II a detailed facility design will be prepared based on site specific characterization data, finalized test design requirements, and site support requirements. Supporting analyses and trade studies will be conducted as required to optimize cost-effective compliance with project milestone and test requirements.

3.1.2.4 Facility Construction & Equipment Installation (Partial)

Facility construction and equipment installation will be accomplished in two parts consistent with the Facility Design effort described above. This approach is due to the fact that permeability testing is scheduled a year prior to the first test burn and a small part of the overall facilities, equipment, well drilling, etc., are required for this activity.

3.1.2.5 Permeability Test

Final site evaluation cannot be completed until the permeability of the coal seam has been determined sufficient for linking. The final test design task will provide the detailed requirements for permeability testing. Data acquired must confirm the design parameters selected for linking operations prior to test burns.

3.1.2.6 Environmental Monitoring

The environmental monitoring on the test site will begin in April, 1978, to obtain four season baseline data prior to test operations. The parameters to be monitored were defined from an environmental analysis of the concept design conducted during Phase I. As indicated in Figure 3-1, monitoring will continue following test operations for another set of four-season data.

3.1.2.7 Preparation of Phase II Report

At the conclusion of the Phase II tasks, a final report will be prepared similar to the Phase I final report. Additional study, updated plans, and detailed design specifications will permit refined cost estimates for Phases III and IV.

3.1.3 PHASE III

Phase III major activities comprise:

- Facility Construction and Equipment Installation (Final)
- Test Burns Nos. 1, 2, and 3
- Phase III Final Report
- Site Restoration
- Environmental Monitoring

3.1.3.1 Facilities Construction and Equipment Installation (Final)

As indicated in Figure 3-1, those facilities and equipment required for three test burns and not completed in Phase II will be constructed and installed early in Phase III. Major buildings, road improvements, instrumentation and equipment installation, and module preparation for all three burns will be included. Acceptance tests will be conducted on all systems prior to use in test.

3.1.3.2 Test Burns

Three major burns will be conducted in Phase III. Burns No. 1 and No. 2 will be the summer-fall of 1980. Burn No. 3 will follow in the summer of 1981. Test data reduction and analysis will be conducted as indicated following each test and may impact successive tests. All tests will be in accordance with detailed procedures such that rerun/restarts will provide repeatable results. Environmental monitoring will begin prior to each test burn and will continue after each test.

3.1.3.3 Final Report

At the conclusion of the Phase III tasks, a final report will be prepared describing all work performed, conclusions, and recommendations.

3.1.3.4 Site Restoration

Site restoration activity will begin following the conclusion of test Burn No. 3 in Phase III. It is recognized that this work will be constrained throughout the winter months and will continue well into Phase IV. All building, equipment, piping, footings, power poles, etc., added to the site will be removed. Well casings will be removed to a depth 10 feet below ground level and all wells will be capped. Ground surfaces will be graded to approximate original contours and seeded.

3.1.3.5 Environmental Monitoring

Post-test environmental monitoring begins in Phase III and will continue into Phase IV in order to obtain data after testing.

3.1.4 PHASE IV ACTIVITIES

Phase IV major activities are not addressed in Figure 3-2. Significant activity planned for Phase IV is the preparation of a pilot plant cost estimate and a final project report.

3.1.5 WORK BREAKDOWN STRUCTURE (WBS)

Figure 3-3 illustrates the project Work Breakdown Structure utilized from the outset with slight modifications. Specifically, the Engineering Design area (1.4) has been redefined to more closely describe the real-world approach that will be followed: Equipment and Facilities Acquisition (3.1) has been expanded to include a Test and Acceptance task; and Field Test Operation (2.1) has been expanded to include a Field Operations task.

*Phase I Tasks.

3.2.0 PLANS FOR PHASE II

The implementation plan for Phase II is described in the following sections in terms of:

- Objectives
- Statement of Work
- Description of Activities
- Work Breakdown Structure Elements
- Deliverables

3.2.1 PHASE II OBJECTIVES

There are several objectives to be accomplished by the Phase II activities. They are presented below with a brief description of each.

- Measure the Relevant Geological and Hydrological Properties of the North Knobs Site

The major prerequisite for a site-specific test program is knowledge of the coal seam surface, seam heterogeneity, physical and chemical properties of the coal, and groundwater flow characteristics in and around the seam. There are two candidate seams at the North Knobs site for the gasification tests.

- Define the Pretest Quality of Air and Groundwater at the North Knobs Test Site

It is essential to obtain this information as a baseline to permit evaluation of potential impact of the test activity on the environment.

- Establish a Site-Specific Test Program for Gasification of the Steeply Dipping Coal Resource at North Knobs Site

The test planning to date has been based upon state-of-the-art data. A site-specific test program must be established that utilizes the geological and hydrological information obtained early in this phase.

- Complete Test Site Design and Begin Site Construction

A detailed design of the complete test facility will be prepared. Essentially all of the major suppliers and subcontractors will be chosen subject to DOE approval. Procurement packages containing drawings and specifications will be assembled and put out for bids from qualified contractors. Awards will be made and site construction will begin in Phase II.

- Demonstrate Slant Drilling Capabilities

Slant drilling is essential to the success of this project. The ability to slant drill is within the state-of-the-art of well drilling; however, experience in drilling holes to project specifications is limited and the initial drilling activities could be time-consuming. The capability for this type of drilling should be demonstrated early in the project.

- Install a Representative Process Module

In addition to the well drilling, well completion techniques for installing subsurface piping should be demonstrated.

- Measure the Air Permeability of the Coal Seam

Permeability of the coal seam is important for backward burn linking of wells. The objective is to determine whether the test site coal seams are sufficiently permeable to permit the use of this technique.

- Coordinate Activities with other DOE Gasification Projects

There is much to be gained by a continued exchange of information and expertise between the participants in the various DOE gasification projects.

3.2.2 PHASE II STATEMENT OF WORK

There are several specific tasks identified in the contract statement of work (SOW) that are scheduled to be completed in Phase II. An abstract of these is presented here for reference.

- Characterize the selected site both geologically and hydrologically.
- Gather environmental data related to air and water quality for baseline analysis and prepare an EIA.
- Define critical process parameters for the selected site design concept.
- Estimate the scaling factors for the design concept with particular emphasis on resource utilization.
- Formulate systems requirements using the experimental approach group supported by the test operations and site support groups. Assess these requirements and develop hardware implementation options.
- Design process control instrumentation and product gas monitoring systems.

It is understood that the Government (DOE) will supply GR&DC with the design drawings and specifications for the reactor definition instrumentation packages in such a form that they can be given, with no modifications, to a commercial subcontractor for fabrication (i.e., "off-the-shelf" status).

3.2.3 DETAILED DESCRIPTIONS OF PHASE II ACTIVITIES

The network activity chart described in Section 3.1.0 of this report indicates the interrelationships of the various project activities in Phase II. The activities were briefly described to permit the reader to understand the tasks involved. This section contains a more detailed description of Phase II activities and includes significant technical data that were produced during Phase I. These detailed descriptions are arranged sequentially and are identified by the appropriate WBS number that appears on the network activity chart (see last page of this volume).

3.2.3.1 ENVIRONMENTAL IMPACT ASSESSMENT (WBS 1.1.3)

An Environmental Impact Assessment (EIA) will be prepared for the selected site in accordance with DOE "Guidelines for Environmental Review" (39 FR 5020, as amended by 42 FR 711). It will evaluate the expected environmental impacts of the proposed project on the site based on the environmental analysis of the process conceptual design and available baseline monitoring data. The EIA is necessary for DOE environmental review. In accordance with DOE guidelines, the following information will be included in the EIA:

- A description of the proposed project
- A description of the existing environment that will be affected by the proposed project, incorporating available baseline environmental data from the pre-burn monitoring activities. Sufficient data will be provided to characterize the existing environment and allow a meaningful assessment of potential environmental consequences of the project on existing conditions.
- Potential environmental impacts and risks of the proposed project including: (a) adverse impacts which cannot be avoided if the project is implemented; (b) cumulative long-term environmental effects; and (c) beneficial environmental

effects. Potential environmental impacts will be assessed for site preparation, construction, operation, and site restoration activities of the proposed project.

- Potential conflicts of the proposed project with federal, state, regional, and local plans and policies and a plan of action to resolve these conflicts.
- A brief description of reasonably available alternatives to the proposed project including mitigative actions or measures for minimizing potential adverse environmental impacts.

The approach to preparing the EIA will consist of the following activities:

- Data Acquisition and Evaluation
 - Compile a data base for characterization of the existing environment at the proposed site and the surrounding area.
- Characterization of Existing Site Environment
 - Characterize the existing physical, environmental, and socioeconomic conditions at the proposed site.
- Assessment of Potential Environmental Impacts
 - Determine the environmental consequences likely to result from the project design and activities.
 - Assess the expected impacts on the existing environmental conditions at the site.

- Determine cumulative and/or long-term environmental impacts of the proposed project.
- Determine irreversible or irretrievable commitment of resources for the proposed project.
- Description of Alternatives to the Proposed Project
 - Briefly describe reasonably available alternatives to the proposed project.

3.2.3.2 INITIAL DATA COLLECTION (WBS 1.2.1)

Activities performed in this element will include collection of data from available sources and dissemination of the results of the Phase II Geology activities. These activities will also include preparation of procurement packages, negotiations with subcontractors, and support activities as they relate to the subject of geology.

The Phase I data package will include four groups of site-specific information. The first group is data obtained by consultants. An example of this is a report on UCG target selection in the North Knobs area. The second group is data obtained from previous work by other companies. This includes chemical analyses of coal seams in Section 11, and analyses of water samples from a well in Section 11. The third group is data obtained from government publications. Examples of this include reconnaissance soil surveys and climatologic data. The fourth group is data obtained by Gulf during Phase I activities. This group includes geophysical logs of hydrologic testing wells and aerial photography.

The Phase II 1.2 Geology WBS will include descriptions of level 3, 4, 5, and 6 activities. These descriptions will delineate preactivity needs, deliverables, contractors, and time schedules.

3.2.3.3 SURFACE MAPPING (WBS 1.2.2)

The purpose of activities performed under this section is to obtain aerial photographs and topographic maps for the UCG site and facility. This work will be done by subcontractors to meet criteria set up by Gulf.

Initial activities will involve a field surveying program to establish horizontal and vertical control at the UCG site. This program will establish the surface location and elevation of: (a) the corners of Section 11, (b) the Energy Development Company and Gulf drill holes, and (c) the "G" coal seam outcrop. In addition, stakes will be located at 300-foot intervals as follows: (a) on the north and east section lines of Section 11, (b) on the "G" coal seam outcrop, and (c) on the west and south section lines of Section 11 where they cross access roads.

Black and white aerial photography will provide stereographic coverage meeting standard U.S. Geological Survey specifications. The acquisition scale will be adequate to produce topographic maps with contour intervals of both 5 feet and 2 feet. The area covered will include the UCG site outcrop belt. This effort will provide 9 inches x 9 inches contact prints at a scale of approximately 1 inch = 500 feet, and enlarged black and white photographs of the UCG facility.

Topographic maps will be prepared using horizontal and vertical control data and aerial photographs. A map of the UCG site outcrop belt will cover an area of 3000 feet x 7000 feet with a scale of 1 inch = 100 feet and a contour interval of 5 feet. A map of the UCG facility will cover an area of 1500 feet x 1500 feet with a scale of 1 inch = 20 feet and a contour interval of 2 feet.

Topographic/photographic profiles across the UCG facility will be constructed for illustration and correlation of the surface and sub-surface geology. These will be used in the design of the drilling operations and in determining the reactor shape after gasification.

3.2.3.4 SITE EVALUATION (WBS 1.2.3)

The purpose of activities under this section is to obtain surface and subsurface geologic data to aid in determining the location of the UCG facility and the drilling techniques to be used. These activities consist of a surface geologic mapping program and a core drilling program.

During the surface geologic mapping program, regional and site specific geologic data will be collected in order to construct geologic maps, cross sections, and interpretive models. The geologic data will be collected by: (1) field observations of outcrops; (2) trenching operations to expose coal seams; and (3) description and mapping of fracture traces.

The field geologic mapping will be done on both large- and small-scale topographic maps and aerial photographs. A detailed surface geologic map, geologic cross sections, and stratigraphic column of the UCG facility will be produced. These items will also be produced at a smaller scale for Section 11 and the surrounding sections.

Several trenches will be dug across the three coal seam outcrops to expose the coal seams and the lithology immediately above and below the coal. The trenches will be of sufficient depth to remove soil cover and expose relatively fresh material. Lithology in the trenches will be thoroughly described to include type, thickness, bedding attitude and character, structure, and coal cleat orientation and character. Large-scale geologic columns will be produced along with correlation diagrams for the coal seams.

A surface fracture trace map will be produced incorporating field observations and analysis of aerial photographs. A geologic interpretation of the density and orientation of fracture traces will also be made.

The core drilling program will produce subsurface cores to be analyzed for lithologic, stratigraphic, hydrologic and structural data. Core from the coal seams will be available for physical and chemical analyses. The program will also provide holes which can be converted to use in the hydrologic testing and environmental monitoring programs.

The core holes will be located in close proximity to the proposed reactor modules. Cores will be taken throughout the interval from the surface to the rock unit below the coal seam to be gasified. These cores will be examined and logged prior to shipment to testing laboratories. A report on the core drilling program including descriptions and correlation diagrams will be produced.

All drilled holes will have geophysical logs run in them. These will be used to determine in situ subsurface properties and for interpretation and correlation of subsurface geology. The log suite will include gamma ray, gamma-gamma density, resistivity, drift, temperature, and caliper logs.

A report will be prepared incorporating all data acquired during the site evaluation. This report will include interpretations and recommendations for further activities.

3.2.3.5 GEOLOGIC DATA ANALYSIS (WBS 1.2.4)

The activities performed in this section will provide topical Geology reports to the necessary Gulf, TRW, DOE, and other personnel, and contribute to the final Phase II report. The activities include collection, reproduction, and dissemination of the required reports. These reports will include, for example, surface geologic mapping of the UCG site outcrop belt, and aerial photography analysis of fracture patterns. These reports will comprise a package of information acquired at the UCG site during the Phase II Geology activities.

The final Phase II report will include all of the important elements of the topical Geology reports, as well as recommendations for further activities.

3.2.3.6 HYDROLOGIC TESTING PROGRAM (WBS 1.2.5)

The activities performed in this section will determine the subsurface hydrologic characteristics of the UCG site. These activities will include extensive drilling and field testing programs.

Prior to any field work, a knowledge of existing hydrologic conditions will be gained by review of available, pertinent data such as geophysical logs, geologic maps, and aerial photographs. Additional data can be obtained from existing piezometers installed at the site for water level measurements.

This information will aid in the design of the hydrologic field testing program. Items that will be considered in this design include: (a) duration of pumping for drawdown tests; (b) specifications for pump for drawdown tests; and (c) data acquisition system.

A total of 14 hydrologic testing wells will be drilled. These include some previously drilled holes which will be utilized for hydrologic testing. The wells will be located in close proximity to the proposed reactor modules with the surface elevation identified for each location. Drill cuttings from each hole will be sampled at 10-foot intervals and descriptive data will be recorded for each sample.

Geophysical logs will be run in each hole. The logging program specifications will be the same as those outlined in the Site Evaluation section (WBS 1.2.3).

The testing wells will be either pumped wells or observation wells. Pumped wells will be cased from the surface to the aquifer immediately below the coal seam. Observation wells will be cased and

perforated to permit monitoring the aquifers both above and below the coal seam as well as the coal seam aquifer. These wells will also be used to obtain baseline water samples as part of the environmental monitoring program.

Well drawdown and recovery testing will proceed in three phases. These phases will involve pumping from: (1) the aquifer underlying the coal; (2) the coal seam aquifer; and (3) the aquifer overlying the coal. Water level changes will be monitored in the observation wells during each phase.

At the completion of testing the data will be evaluated and a hydrologic interpretation will be made. This information will be utilized to determine the amount and flow rate of water available to the reactor module during gasification. The data will also aid in determining the water available for quenching after gasification is completed. A final report will be prepared with recommendations for further activities.

3.2.3.7 CORE ANALYSIS - PREBURN (WBS 1.2.6)

Three-inch cores from four wells drilled during Phase II will be analyzed for chemical and physical properties. Coal samples taken at one-foot intervals will be tested for the following items:

- Proximate Analysis
- Ultimate Analysis
- Heating Value
- Ash Fusion
- Mineral Inclusions

The boundary strata will be analyzed for:

- Tensile Strength
- Petrographics
- Triaxial Compression

Data collected from these analyses will be summarized in a report showing the ash distribution in each core hole and the chemical composition of the coal versus the ash fusion values. This information will be incorporated into the modeling effort, the test burns, and the test burn reports.

3.2.3.8 PERMEABILITY TESTING (WBS 1.2.7)

Air permeability testing will be carried out on the completed wells drilled for Burn No. 1. This activity involves renting a compressor and the appropriate hardware (flow meters, piping, etc) to conduct the permeability test. The actual testing will consist of pumping air down the injection wells, through the coal seam, and out the production wells. The flow of air will be measured and the permeability will be calculated. The results of this test will determine the feasibility of backward burn linking in Test No. 1. Possible long lead times in obtaining this compressor will be considered.

3.2.3.9 TEST DESIGN (WBS 1.3.3)

Phase II test design activities will consist of three major aspects: 1) reviewing of the latest published and field test data on UCG and aboveground coal gasification, 2) predicting product gas composition at the proposed experimental conditions through mathematical simulation and bulk coal studies, and 3) designing experimental strategies for Burn Nos. 1, 2, and 3 which will be coordinated with test procedure definitions and data acquisition. Throughout test design, the unique properties of steeply dipping coal bed gasification will be considered. Due to the subsidence-prone nature of SDB, the reaction model postulated for horizontal beds may not hold. That is, subsidence will undoubtedly occur; and the manner in which it occurs may grossly change the gasification process. Much of Phase II Test Design Planning will be spent in evaluating the system in terms of what may happen, how to detect it, its effects, and how to deal with them in order to maintain high-quality gas production. The literature describing the most recent

work in UCG and aboveground gasification will be reviewed for possible application to this project. A study of the process parameter effects in the boundary range established in Phase I will be undertaken. Inputs to this activity include core analysis and bulk coal studies in which the gasification behavior of the coal will be determined. Using these inputs, a mathematical model will be developed to predict product composition through the ranges proposed.

After reviewing the SDB characteristics of the proposed site and the results of the above activities, possible gasification modes unique to SDB will be made and incorporated into the Burn Nos. 1, 2, and 3 schedules. During this activity, boundary values for parameters will become frozen.

3.2.3.10 SITE SELECTION CRITERIA (WBS 1.3.4)

During Phase II, the prospective site will continue to be evaluated in terms of the site criteria established during Phase I. These site criteria were developed based on DOE requirements, quench mode requirements, environmental constraints, and geological factors. Other factors such as compatibility with the test plan and reasonable process and facilities designs were also considered.

3.2.3.11 DESCRIPTION OF BULK COAL STUDIES (WBS 1.3.5)

Laboratory bulk coal studies will be performed on three to four corings from the site to obtain gasification characteristics, carbonization (pyrolysis) behavior, compositional make-up and ultimate and proximate analyses. The pyrolysis and combustion experiments will be carried out in an isothermal tube reactor which is arranged to receive various combinations of air, carbon dioxide, oxygen, and water.

The reactor will not be used to obtain gasification or pyrolysis kinetics, since these measurements cannot be realistically applied to coal in situ. It will be used, however, to determine the composition

and relative amounts of products obtained from the site under certain conditions. These results will then be compared with the products and their relative concentrations calculated from thermodynamic principles. These data will serve as input to a computer modeling effort as well as the test burns themselves. The reactor may also be used to study the carbonization behavior of the site coal, since accurate analysis of both the char and the volatile matter are required for the C, H, and O mass balance calculations. These calculations will be used throughout the field test.

As a first step in designing an experimental schedule, one can envision the reactions occurring in UCG and systematically study these. This involves the study of various reactants under differing conditions of temperature, pressure, and concentrations as indicated below:

- Coal + Air + H₂O
- Pyrolyzed Coal (Char) + Air + H₂O
- Coal + CO + CO₂ + H₂ + H₂O
- Char + CO + CO₂ + H₂ + H₂O
- Volatile Matter + Heat

This involves a tremendous number of experiments and may require that this experimental program be coupled with thermodynamic considerations and field limitations to decrease the number.

3.2.3.12 PHASE II REPORT (WBS 1.3.6)

The Phase II final report will involve significant technical coordination effort to permit preparation of a comprehensive report which summarizes Phase II activities. The report will also contain the revised plans for Phases III and IV as a result of these activities.

The geological activities associated with site characterization will be described in this report and will include a discussion of surface and subsurface geology, exploratory coring wells, hydrology,

and other activities. Baseline air and water monitoring activities and the results will also be included. This will be used to prepare an EIA. It will also aid in determining the effect of the Phase III burns on the environment.

The revised test design plan with its associated test procedure definition will also be described. The document will detail the conduct and operation of the burns in Phase III. The physical facilities and process design will also be discussed.

This report will include all of the Phase II deliverables which are:

- A detailed characterization of the site follows:
 - Depth of seam
 - Seam thickness
 - Lithology
 - Structure
 - Cleat orientation
 - Anomalous conditions
 - Dip
 - Porosity and permeability of the enclosing rock formations
- An Environmental Impact Assessment of the tests on the selected site including a compendium of baseline environmental baseline data specific to the site
- Definition of the critical process parameters
- An estimation of the scaling factors for the design concept
- Definition of process systems requirements including, as necessary, design drawings and statements of work for subcontractors
- Definition of the process control systems and product gas monitoring systems

It is understood that the Government (DOE) will supply the design drawings and specifications for the reactor definition instrumentation packages

in such a form that they may be given, with no modifications, to a commercial subcontractor for fabrication (i.e., "off-the-shelf" status).

3.2.3.13 FACILITIES AND EQUIPMENT INSTALLATION DESIGN (WBS 1.4.2)

The designs for these elements will be based on the conceptual design update that was performed during Phase I for the test facilities at the North Knobs site. The designs will satisfy the requirements of test plans developed under other tasks and will include the following:

- Well systems including injection, production and instrumentation wells, manifolds and gas recovery piping systems.
- Injection gas systems including a "linking" air compressor and process air compressors.
- Support systems including fuel oil, propane, process water supply, electrical supply and fire protection.
- Buildings or vans including those required for instrumentation and monitoring, process control, and shop use.
- Interconnecting and access roads, security fencing, area lighting and other general site systems.

The designs will also consider and be compatible with the following features and requirements:

- Provide a site layout which can be constructed incrementally to support each phase of the test program as that phase becomes a requirement, in such a way that construction modifications necessary for the next test do not interfere with the ongoing test.
- Provide a flexible test facility that will accommodate growth of the total facility as well as any individual system.

- Provide a self-sufficient facility where economically and functionally feasible.
- Provide a facility with a 3-5 year life projection.
- Provide adequate foundations for the loads imposed by equipment fastenings.
- Orient and locate all equipment and facilities to protect them from the effects of subsidence in the vicinity of the production chambers. Where it is impossible to avoid these areas, the design must be such as to prevent damage to equipment or injury to personnel in the event of subsidence.
- Select materials and methods of construction that take into account the weather extremes where the site is located.
- Provide a site layout which considers the usual occurrences of blowing and drifting snow in winter and hot/dry conditions in summer, and a prevailing northwest wind.
- Provide systems which can, within reason, be disassembled and transported to other locations within the site or to other sites.
- Provide a facility which will allow the site to be restored reasonably comparable to its original pre-operational condition when the test program has been completed.

The entire test site, including four well modules (three burns) of the γ configuration, instrumentation wells, linking and injection compressors, water reservoir, support buildings and access and inter-connecting roads will be located on an area of approximately 300 m by 300 m (1000 feet by 1000 feet). The major elements of the test site will lie between the "I" bed and the "G" bed and parallel with the beds. Subsidence,

if any, will occur downdip of the "G" bed outcropping and should have no effect on any aboveground facility. The entire 6 ha (15-acre) plot will be cleared, graded and shaped as required to provide easy access for exploratory drill rigs as well as the follow-up production drill rigs and construction activities.

The existing access road will be bladed and elevated with local borrow material to facilitate "self-clearing" of snow by the high prevailing winds in the area. Access from the state road and within the site will be provided by a new gravel road using local borrow material for the sub-base and base courses of the required thicknesses. These roads will also be slightly elevated to facilitate self-clearing of snow by the wind. Local construction contractors say that nearby borrow material is suitable for all road construction and fill material. Local contractors also confirm that the existing road is adequate for use as an all-weather road and is capable of supporting the loads imposed by flatbed trailers used for delivering the 25-ton compressors.

The site layout will be determined by the well depths, well configuration and drilling angle for the injection wells. The wells for the shallowest burn module will be the closest-spaced at the surface and will dictate the location of the compressors, flare stack and pipe racks. The support buildings, instrument vans, fuel oil tanks, and vehicle parking, as well as the compressors, will be grouped around this module. Subsequent construction and extension of piping and racks for Burn Nos. 2 and 3 can then be accomplished without interfering with the Burn No. 1 operation. This layout could also accommodate a change in the location of Burn Nos. 2 and 3 without seriously affecting other site components. The injection gas system, which consists of the linking gas compressor and up to six production compressors, will be located to keep the high cost piping runs as short as possible. A minimum 30 m (100-foot) separation between the heavy compressors and the product wells will be included to keep any subsidence in the burn cavern or within the "G" bed coal seam from affecting the compressors, piping or structures. The instrument well areas for each burn will be located above each burn cavern.

Supporting systems, such as the diesel generator, electrical substation, diesel oil storage, water reservoir and buildings, will be located on the periphery of the gas systems since their interface is with the gas systems and roadways and not the wells themselves.

The maintenance building and related shelters will be located "upwind" or "crosswind" from the objectionable gas flare and the compressor noise to minimize their impact. A 450 m² (4800-square feet), prefabricated, insulated, heated metal building on a concrete slab will house maintenance and administrative functions, including a carpenter shop, instrument shop, welding shop, electrical/mechanical shop, grounds maintenance area, maintenance office, and lunch room. Mobile or transportable shelters will be used for the multiplexer, gas chromatograph equipment, data acquisition, process control and office shelters. The multiplexer shelter, about 3 m by 6 m (10 feet by 20 feet), will be required for Burns Nos. 2 and 3 and, consequently, will be located in close proximity to the instrument wells for those burns. The gas chromatograph (GC) shelter will be about 3 m by 6 m (10 feet by 20 feet) and will be located close to the product well being used to keep the sample lines short and eliminate the need for tracing to prevent condensation. These shelters will be capable of being moved to new locations as new production well modules are developed. The data acquisition and instrumentation shelter and the process control and office shelter will be about 3 m by 12 m (10 feet by 40 feet) and will be interconnected with enclosed vestibules and walkways for protection against inclement weather. They will be located adjacent to the maintenance building. These shelters will be heated and air conditioned to provide a satisfactory environment for the electronic equipment. The use of mobile or transportable shelters will permit installation, outfitting, checkout and test of this sophisticated equipment at a location remote from the site to provide better working conditions for these sensitive operations. In addition, this work will be performed during the winter months or during construction activities when working conditions on the site are poor.

A diesel oil storage tank of 57 m³ (15 000-gallon) capacity will provide fuel for operation of the diesel engines. It will be

surrounded by an earthen dike to contain spills. The tank will provide approximately 20 days of diesel operation at the normal Burn No. 1 rate of fuel oil usage or 5 days at the maximum Burn No. 3 rate prior to requiring replenishment.

The water reservoir will be earthen bermed plastic lined reservoir of approximately 225 m^3 (8000 cubic feet) capacity. This will allow two hours of continuous flow from a $2 \text{ m}^2/\text{min}$ (500 gpm) gasoline engine driven fire pump supplying two hydrants simultaneously. Hydrants and fire hoses will protect the fuel oil storage area, the equipment area, the buildings and the well area. The water reservoir will also supply process water, water for domestic plumbing, and water for gasification chamber quench by means of a deep well turbine pump.

All interconnecting piping between the gas systems and the wells will be run on aboveground pipe supports or sleepers located parallel to the equipment and the seams with suitable connections between equipment, injection wells and product wells.

The piping and its supports will be installed only as far as the well being tested at that time. As new wells are developed, the piping will be extended. Special provisions, such as flexible joints and adjustable supports will be used where needed to prevent undue stress on the piping and appurtenances in the event of subsidence. Electric heaters and insulation blankets will be installed on injection and linking air piping to prevent freezing during extreme winter weather.

The entire 6 ha (15-acre) area will be fenced to prevent vandalism or injury to unauthorized persons and range animals. Area lights around the equipment, buildings and shelter areas will provide lighting for the three shift operations required for the test programs.

During the Phase I activity concerned with updating the concept design, a number of design studies and engineering investigations were performed. The results of these are summarized in the following sections in detail. The preliminary designs and the initial evaluation of equipment,

pipings and valves will be optimized during the Phase II detail design efforts and will be based on design approaches and considerations developed during the experimental analysis, field test operation, site installation, and site operation planning activities.

Air Injection System

The "linking" air injection system will consist of a low flow $5.7 \text{ sm}^3/\text{min}$ (200 CFM) high pressure 4200 kPa (600 psi) compressed air system which will provide air from a reciprocating compressor through an accumulator, a pressure control station and thence to the injection well. The linking compressor will be required on-site in the spring of 1979 to provide air for the permeability test program, and therefore must be a separate system from the production air system which will not be required until the spring of 1980. The linking air manifold will also allow linking air to be used in the product well to support combustion when charcoal is used to initiate burning.

The compressed air supply for the coal gasification production will be provided by diesel-driven centrifugal or screw compressors. Four production compressors with a combined capacity of 5.5 MM SCFD (2 @ 2 MM each; 1 @ 1 MM; 1 @ .5 MM) will be installed initially. Since Burn No. 1 (requiring a constant 2 MM SCFD) and Burn No. 2 (requiring a maximum of 5 MM SCFD) are planned to run sequentially during the summer of 1980, the four compressors will be installed at the same time. Two additional 2 MM SCFD compressors will be installed prior to Burn No. 3 in 1981, increasing the capacity in .5 MM SCFD increments to 9 MM SCFD. The pressure and flow into the injection wells will be controlled by the pressure reducing station. The flow will be recorded by the flow orifice recorder in the pressure reducing station. Blind flanges will allow extension of the production gas piping manifold in the future to serve the Burn No. 2 module and the Burn No. 3 modules. One pressure reducing, or control, station will control the production gas to both of the modules of Burn No. 3. If different flow rates should be required, remotely operated flow control valves will be used to balance out the flows as required.

Linking and production gas compressors will be started and stopped manually. Flows and pressures for both linking and production air will be remotely controlled by manual operation from the control trailer. Shutdown of air to the wells can also be accomplished from the control trailer. "Dumping" of air from the wells will be done locally. All instrument spools will be provided with manually controlled redundant bypass flow control capability.

Water Systems

The water systems will be supplied from the earthen diked water reservoir. Preliminary investigations indicate that adequate groundwater exists on the site. The water is highly alkaline but suitable for any use other than human consumption. The water will be supplied to the reservoir from a well with a submersible pump controlled by a float switch which will maintain a constant level above the float switch and will shut off the pump outlet line to provide backup and prevent overfilling in the event of the float switch failure.

Process water to enhance the coal gasification process will be required at the rate of $17.5 \text{ m}^3/\text{day}$ (615 cubic feet per day) per module or approximately $25 \text{ dm}^3/\text{min}$ (6-1/2 gallons per minute) maximum for Burn No. 3. Water will be supplied from the previously described reservoir by a centrifugal pump with a throttled bypass. The pump will run continuously at its rated capacity and the amount and times of water injection into the production air system will be controlled by a manual throttling valve, using an orifice to regulate flow. As additional well modules are added, the process water header will be extended to serve them using the same pump.

Fire protection requirements of the site will determine the size of the gasoline-driven fire pump and the reservoir. The fire/quench system will be an automatic wet-pipe system kept filled and pressurized at all times. To prevent cycling of the large fire pump due to minor leaks in the piping, a small "jockey" pump will be installed in parallel with the fire pump. It will be controlled by a pressure switch. When a

hydrant or injection well quench valve is opened, the jockey pump cannot satisfy the higher flow demand, and the main fire pump will automatically start and come on-line because of appropriately set pressure switches that detect the drop in pressure.

Supplying water to the burn cavities for quenching will be accomplished manually by opening the shutoff valve. To conduct the heat away from the burn cavity, the steam will be allowed to go out the production well line and return to the water reservoir where it will be cooled and condensed.

Water will be supplied to the buildings and shelters for wash-down and toilet flushing by means of a domestic-type pump and a hydro-pneumatic tank. Potable water and laboratory water will be brought onto the site in bottles.

Fuel Oil System

The fuel oil system will be a closed loop continuously circulating pressurized system utilizing a pump. Each engine will have its own day tank supplied through a float valve which will maintain constant level in the tank.

Instrumentation System Design

The revised test plan discussed in Section 2.2.3 has established process instrumentation requirements for this project. These include process control, product analysis, and reactor definition instrumentation as well as a data acquisition and reduction system which is discussed later.

Process control instrumentation will consist of "off-the-shelf" equipment and should not pose any problems. The parameters to be monitored are injection/production gas flow rates and injection water flow rates.

Product gases will be obtained for analysis from two sources: The product gas stream at the production wellhead and from "sniffer" tubes in each instrumentation well. The sniffer tubes will consist of canisters located within the coal seam, with tubes to the surface from which gas samples can be drawn periodically. These tubes will allow measurement of gas composition in situ and determination of gas composition distribution and variation with time within the reaction zone. The chemical components of the product gases requiring determination are: H_2 ; CH_4 ; C_2H_6 ; CO ; N_2 ; CO_2 ; Ar ; H_2S ; and H_2O . The heating value of the gases also must be determined. Accuracies of ± 2 to 3 percent are sufficient. As a by-product, pressure transducers on the sniffer tubes will allow in situ pressure determination and pressure distribution and variation with time within the reaction zone. Sandia developed a standard sniffer tube assembly for use at Hanna and this assembly will be used on this project. The assembly consists of three plastic-sheathed canisters within the coal seam, with a copper multi-tube connection to the surface.

The chemical analyzer will be a gas chromatograph of the type that is available off-the-shelf from several suppliers. The Hewlett-Packard Model 5840A is being used at Hanna and is adequate for this program. Two chromatographs, a primary and a backup, will be required. Water analysis will be done by standard off-the-shelf equipment. Given the importance of water content in the gasification process, redundant water analyses will be necessary. The experience of Hanna IV will be heavily utilized. Heat content will be determined by a continuous calorimeter.

The product gas stream is connected directly to the analyzer via a sample tube; sniffer tube gases are collected in sample bombs and transported manually to the analyzers.

The reactor definition instrumentation discussed below is still subject to change. It was established for two reasons: to obtain a rough cost estimate and to serve as a basis for evaluation. As a result of the first iteration of the test design, the use of some methods

is questionable and will be subject to further evaluation (see Section 2.2.4 for the results of this first iteration).

The most practical reactor definition instrumentation for commercial use is the remote type being used by Sandia in the Hanna experiments. The electrical resistivity portion of this instrumentation is relatively inexpensive to install and operate and, if useful data can be obtained from near-surface geophones, the passive seismic portion will also be relatively inexpensive.

Each of 24 instrumentation wells (8 in Burn No. 2 and 16 in Burn No. 3) will be equipped with 14 thermocouples spaced 0.9 m (3 feet) apart as measured from the bottom of the seam. The 0.9 m (3 foot) spacing is equivalent to a 0.5 m (1.5-foot) spacing across the true 4.5 m (15-foot) thickness of the seam, dipping at 60 degrees. This will be less than the thermocouple spacing used at Hanna; however, since the native permeability of a steeply dipping seam promises to be greater than that of a flat-lying seam, the probability of the combustion process "fingering" through the seam will be greater, and a closer thermocouple spacing is warranted.

The thermocouples above the seam are there primarily for subsidence monitoring. If these thermocouples indicate a temperature increase more rapid than would be expected from heat conduction through the overburden, fractures may have opened in the overburden, allowing hot gases to reach the vicinity of the thermocouples. The opening of these fractures will probably be related to subsidence. Further, cessation of signal from these thermocouples could indicate roof collapse with consequent breaking of leads.

The standardized multipoint modular thermocouple assembly developed by Sandia and described by Northrop, et al., will be used. These assemblies use K-type, armored thermocouples connected in leg-branched circuits. The assemblies are available as commercial items from several sources.

Both Burn No. 2 and No. 3 will be instrumented with a grid of potential electrodes located immediately over the expected burn area. The grid will cover an area of approximately four times the expected burn area and, following the Sandia experience at Hanna, electrode spacing within the grid will be 4.5 m (15 feet). The process modeling at Hanna indicated an expected burn pattern approximately oval in shape and with a ratio of width-to-length of about 0.60. Utilizing this pattern in the program and assuming an expected burn length along the seam of 60 m (200 feet), the burn area projected to a horizontal surface will be 560 m (6000 square feet) in Burn No. 2 and 1100 m² (12 000 square feet) in Burn No. 3. Accordingly, Burn No. 2 will utilize a grid of 13 x 9 electrodes, or a total of 117, and Burn No. 3 will utilize a grid of 19 x 11 electrodes, or a total of 209.

The electrodes will be stainless steel rods buried beneath the frost line (approximately 1.5 m), as used in Hanna IV. Present planning includes applying current by both the modified Schlumberger and Deep Excitation Electrical Potential techniques described by Northrop, et al., although Hanna IV results and the design phase of this program may modify this. The current source has a maximum output of perhaps 20 amperes and has a reversing rate of once per second.

Four geophones will be installed in each instrumentation well as passive seismic instrumentation. Three will be located in the seam overburden and separated by intervals of 6 m (20 feet). The fourth will be located at a depth below the surface of perhaps 3 m (10 feet). If passive seismic instrumentation is to be of practical use in commercial gasification operations, useful data must be obtained from geophones buried at shallow depth; therefore, the fourth geophone will be included to investigate this possibility. The geophones are inexpensive models comparable to the Geospace Model 20D vertical type presently in use at Hanna.

Well Design

The well design effort has three main objectives: finalize design criteria, develop a detailed well installation plan, and prepare

all bid packages for contractual work and equipment to install all process and instrumentation wells. Recent discussions with drilling experts revealed the need to develop a well design as early as possible in Phase II in order to decide on an acceptable drilling method. The first effort involves reviewing the well design criteria provided in Phase I, along with any modifications to these criteria which may have occurred between then and the start of this task. Established requirements will be confirmed and new ones developed such that all requirements on which the drilling (or well installation) plan design, scheduling and costing depend are determined by the time development of the plan begins. Examples of criteria are well size, configuration and layout; casing type and size; cement and grout characteristics; and well bottoming location. Design options and the effects of their selection on costs and scheduling must be clearly comprehended and considered in producing the final design.

Once a design has been established, full-scale well installation plan development can proceed, the final product of which will be bid packages containing all specifications, schedules, drawings, and supporting documentation needed by contractors to bid for and perform the work or provide equipment for the project.

There is an extensive array of alternative techniques that can be utilized to achieve the design objectives. They will be evaluated and trade-off studies performed to determine the best methods from a cost and technical standpoint. For example, a directional control method must be selected which will enable bottoming the well accurately at a predetermined location but which is not prohibitively expensive. Major project elements will then be arranged into a detailed schedule that will identify parallel and interdependent operations. These operations will be reviewed, evaluated, and modified where feasible to minimize expensive standby time and generally expedite all work.

3.2.3.14 SOFTWARE DEVELOPMENT (WBS 1.4.3)

Since an identical Sandia data acquisition and analysis system as used at Hanna IV will be used on this project, it is assumed that the Sandia software used with this system will also be used. Furthermore, it is assumed that DOE will provide Gulf/TRW with this software. It is understood that the software collects and routes thermal and electrical potential and passive seismic data to a variety of storage and output devices. The software also performs several analytical functions, including display of parameter variation with time, display of thermal and electrical potential contour maps within and above the reactor zone and display of seismic hypocenter locations. The software also allows some quantitative investigation of reactor performance through interpretation of the geophysical data.

The basic software will require some modifications for use in this program, in that a different number of data channels are involved and sampling rates may change from Hanna experience. The means of generating and displaying contour maps may require modification because of the steeply dipping seam geometry. The geophysical data interpretation will certainly require modification because of the dip of the seam.

The software will also require modification to accept and analyze process control and product analysis data peculiar to the North Knobs site. Certain analytical operations, such as computation of mass and energy balances will also be required. Software used by the LERC system is capable of doing this (the balance computations are available as subroutine identified as MATBL) and, since both software sets are written in the FORTRAN language, integrating this portion of the LERC software into the Sandia routines does not appear to offer formidable problems.

3.2.3.15 PROCUREMENT PACKAGE PREPARATION (WBS 1.4.4)

The general process of procurement for this project will be arranged into four activities:

- Package preparation
- Bidding or pricing of package
- Evaluation of bidding
- DOE approval

Provision will be made for small procurements (i.e., less than \$10 000) without the full four-step cycle.

Step one, the preparation of the package, is particularly crucial, in that the work necessary to define what item or items will be procured and the evaluation and the selection of sources from which they will be procured. The definition will likely include the following: analysts, engineering design, trade-off studies, and consideration of the best method of committing funds for acquisition of equipment or services.

Step two, wherein pricing will be obtained, will vary somewhat from procurement to procurement. Some procurements will be conducted as open competitive bidding, whereas, in the case of items available only from one source or where very long lead times are involved, the process may be one negotiation.

Step three will consist of evaluating the various prices and relevant factors and preparing a recommended course of action to forward to DOE.

Step four, approval, is envisioned as requiring one month from inception to receipt of go-ahead. A typical four-step procurement cycle will require from 2-1/2 to 3-1/2 months.

The principal technical problem in this task lies in the lead time necessary to accomplish the full cycle. This will be particularly bothersome in the case of procurements for mapping and exploratory drilling, occurring as they do immediately at the start of Phase II.

Only a limited amount of progress in well design can be made without the output from these operations. It is estimated the procurement in each case will require at least ten weeks. The time required to initiate these procurements will be minimized as much as possible.

It should be noted that the majority of the procurement activity will occur during Phase II. For preliminary information purposes, a list of anticipated procurements is provided:

- Mapping
- Exploratory drilling
- Linking Compressors
- Process Compressors
- Diesel Generator and Switchgear
- Vans
 - Instrumentation
 - Data Collection and Monitoring
 - Controls
- Instrumentation Equipment
- Data Acquisition Equipment
- Injection Wells
- Production Wells
- Instrumentation Wells
- Piping
- Valves

3.2.3.16 ECONOMIC ANALYSIS FOR EXPERIMENTAL DESIGN (WBS 1.6.2)

This task will define critical process parameters for the design concept at the selected site. This will be accomplished by utilizing the economic model and studying both independent and dependent variables over a range of values to determine how the system can be optimized in an economic sense.

The present economic model was completed about two years ago and is applicable to horizontal coal seams. The model will be revised to bring it up to date cost-wise and to make it applicable to steeply dipping coal beds. This work will require about four to six months to complete.

Some of the most important inputs to the economic model are not independent variables but rather are dependent variables whose relationship to the independent variables is not presently known. Among these dependent variables are gas yields, gas analyses (and related heating values), and resource utilization. Insofar as possible, process models will be used to furnish data to the economic model, but final development of the process model must await the outcome of the experimental studies.

3.2.3.17 TECHNOLOGY TRANSFER (WBS 1.7.0)

The technology transfer effort will be aimed at promoting rapid, wide dissemination of the information developed in this project to those groups most likely to utilize the information for further research and development or for commercialization. This task will include attending inter-DOE coordination meetings, preparing technical papers, and attending UCG conferences such as the DOE annual meetings. This effort continues in Phase III.

3.2.3.18 GR&DC FIELD OPERATIONS (WBS 2.1.3)

The activities here include the efforts of the GR&DC field crew and field supervision to implement the Phase II site characterization plan, site monitoring, maintenance, and restoration. During construction, the test director will work closely with the Site Support Manager to assure the acceptability of site facilities.

3.2.3.19 FACILITIES ACQUISITION (WBS 3.1.1)

During the period of performance of the on-site work, there will be a site crew. The makeup of this crew will vary according to the type and volume of work under way. Thus the proper inspection skills will be available when needed to handle the diversity of work which construction of the project involves.

It will be necessary at intervals to have personnel possessing special expertise present at the site for construction inspection and consultation. These time intervals will be comparatively short; and in view of short-term uncertainties in scheduling, it will be more practical to handle such contingencies on an "as-required" basis.

A major portion of the work in this task will involve dealing with earth-fill and excavation construction operations, placing form-work, and reinforcing steel and concrete. The inspection personnel during this period will be generally oriented toward the Civil Engineering discipline.

This activity continues in Phase III.

3.2.3.20 EQUIPMENT INSTALLATION AND CHECKOUT (WBS 3.1.2)

The 5 sm³/min, 4200 kPa (175 SCFM, 600 psig) linking air compressor will be the only major mechanical equipment installed in Phase II. The system is required for coal bed permeability tests. The compressor will be installed on a concrete pad in the compressor area. Above grade piping will interconnect the compressor, accumulator, and the valving-instrumentation manifold. Distribution piping will be routed on pipe supports to the test well and connected to the manifold. The entire piping system will be cleaned and pressure tested. The instrumentation and valving will be calibrated and adjusted for a pre-

test checkout. The compressor will be checked out, started, and brought on-stream per manufacturer's procedures. Final adjustments will continue until the entire system is operating satisfactorily.

This activity continues in Phase III.

3.2.3.21 INSTRUMENTATION INSTALLATION AND CHECKOUT (WBS 3.1.3)

The instrumentation installation and checkout schedule requires that procurement activities, particularly with regard to the data acquisition and analysis system, must take place in the final two months of Phase II. These activities will include preparation of a procurement package based on the performance specification, compiling a qualified bidder's list, issuing bids and selecting a supplier. Equipment purchase, delivery, and installation will occur in Phase III.

3.2.3.22 WELL INSTALLATION (WBS 3.1.4)

The Phase II well installation program is based on test plan criteria. A total of 11 process and 24 instrumentation wells will be drilled. Each production and instrumentation well will have a nominal 30 cm (12-inch) diameter, with a nominal 20 cm (8-inch) casing ID, which will be compatible with surface piping and the expected flow volumes and also capable of accepting the instrumentation wire bundles and sniffer tubes. All injection wells will have a 10 cm (4-inch) casing ID, which can accommodate the projected flow while permitting substantial cost savings by reducing casing costs. All wells will be logged, cased and cemented, and slotted liner hung from the casing above the thermocouple assembly in each instrumentation well. The purpose of the liner is to prevent hole collapse and clogging while permitting gas to enter freely. Since the liner must be purchased separately and perforated for the project, an optimal perforation pattern can and should be specified. (Oil companies most often use a 32 row by 60 mesh liner, yielding an open area of nominally 3% per lineal foot of liner.) High-temperature cement is presently planned for process wells only.

Well specifications, established in Phase II well design activities will necessitate the use of directional control in drilling. Drilling industry personnel and previous experience with water exploration well drilling at the North Knobs site have confirmed that maintaining a desired hole orientation, even to the relatively shallow depths required, will be a significant technical challenge demanding special care in directional control, particularly if a 30 cm (12-inch) diameter hole is needed. Furthermore, several drillers stated that to their knowledge, very few 30 cm (12-inch-) diameter vertical and virtually no 30 cm (12-inch) directional holes have ever been drilled in western coal seams. Vertical wells will also present problems, controllable through loading and correction. One technique being considered is to drill a pilot hole initially with a nominal 7.5 cm (3-inch) diameter (surveyed at 6 m [20-foot] intervals) for directional control of the slant wells and 15 cm (6-inch) diameter pilot hole (surveyed at 15 m [50-foot] intervals) for vertical wells and then reamed out to the necessary diameter. This procedure may ultimately keep costs down and could considerably enhance chances for success in bottoming the wells accurately.

A number of directional control techniques are currently available. The two most common are known as the whipstock/wedge and the high-torque drill/"bent sub" assembly known as the Dyna-Drill (manufactured by a division of Smith International).

The following logs will be run in all holes prior to casing:

- Electric (resistivity)
- Gamma (lithologic)
- Neutron (porosity)
- Gamma-gamma (density)
- 3-D velocity
- Caliper

The logging operation is expected to be straightforward and conventional, with the provision that the sonde be lowered on the drill-stem in all process wells. Following logging, a multi-shot directional survey will be run in each well to record its final configuration.

Drilling schedules will be designed to minimize standby and on-site time, avoid adverse weather conditions, and maintain a reasonable penetration rate. Logging will be scheduled to avoid caving problems. Lead time for scheduling a rig will be 3 to 6 months. There appear to be drilling contractors with equipment and competence to perform this work. However, rig availability may pose a problem. Casing and liners should be ordered at least three months in advance to ensure timely delivery.

3.2.3.23 FIELD INSTALLATION TEST AND ACCEPTANCE (WBS 3.1.5)

This task is directed toward assuring the quality, continuity, timely completion and adherence to construction documents of the construction and installation work performed at the project site. This work will be carried out by a site crew for the purpose of daily supervision and direction of the work in progress, and for formulation of test plans, acceptance criteria and interim and final reports.

The composition and size of this crew will be varied from time to time to assure that the proper skills will be available for inspection and consultation. They will work in conjunction with the activities defined under WBS 1.4.5, Field Engineering.

Since certain items of work, notably grading, earth fill and equipment footing construction, will be accomplished before the end of Phase II, the activities in this task begin well before the beginning of construction work.

It is anticipated that the work under this task will be outlined in detail for the entire period of the project by April 1, 1979. In addition, the final test and acceptance procedures for work through the end of Phase II should be complete at that time. Specific detailing of successive test plans and acceptance criteria will then be undertaken and completed. Although it is necessary that this work be completed in increments which satisfy schedule deadlines, it will necessarily be an ongoing task since much of the content cannot be finalized until other tasks have been completed. This is particularly applicable to the case of inputs from the various design tasks.

3.2.3.24 PERMIT SUPPORT (WBS 3.2.2)

All permits necessary for Phase II and Phase II site activities will be acquired under this WBS. The Phase II permits needed for 1978 site exploratory drilling and hydrologic drilling have been applied for. Bond will also be posted to cover these activities. The BLM temporary tram road permit, required before any site access road improvements can be made on BLM sections, will be applied for subsequent to BLM site inspection and review of the archaeological report in mid-March, 1978.

All Phase III permits will be applied for in adequate time for agency review and comment so that the permit applications can be approved by April 1, 1979. These permits include mining, air quality, water quality, construction, local zoning, and access road alignment. A complete list of required permits and required data for each permit is presently being prepared. Site construction activities cannot begin until these permits have been obtained. Site and aquifer reclamation bonds will also be posted with the permit applications. Because of the developmental nature of this project, it is anticipated that regulatory agencies will require a continuous input of data in their respective permitting areas over the life of the project.

At the conclusion of site operations in early 1982, site restoration releases will be acquired under this WBS.

3.2.3.25 SITE SUPPORT PLANNING (WBS 3.2.3)

Site Support Planning in Phase II includes those efforts required to plan, coordinate and integrate Phase II site activities and to provide appropriate documentation for each. It also includes detailed planning for Phase III site support activities. Sub-elements are defined as: Scheduling, Site Acceptance and Transfer, Site Operations Planning. These subtask elements are described below. Site support planning activities will continue during Phase III as necessary revisions to the construction and operating plans become apparent.

- Scheduling

Phase II emphasizes site-related activities. Many WBS task elements dormant in Phase I will be activated for the first time and will contribute to site preparations. Most of these tasks are interactive and some have second and third order interdependencies. In order to assure that task interfaces are addressed and sequenced properly, it is vital that mechanisms be established to analyze task requirements, define task interdependencies, and develop integrated schedules. In recognition of the importance of this effort, some preliminary work was initiated in Phase I to lay out the approach that will be utilized. An Activity Network was prepared using the limited data base available, and an integrated project schedule was developed. Phase II work will involve successive interaction of the network to surface third and fourth order interdependencies which will then be scheduled. After the initial scheduling is completed, the network will be used to input a Mini-PERT computer program that will perform Critical Path Analysis of the schedule. The final project schedule provided from this effort will be used for management visibility and control of project activities.

- Site Acceptance and Transfer

Time and funding constraints coupled with winter weather conditions suggest that site preparation will be evolutionary. Three segments of preparation are identified: 1) preparation required to support permeability tests; 2) preparation required to support Burn Nos. 1 and 2; and 3) preparation required to support Burn No. 3. Thus, site acceptance and transfer will occur in three parts immediately preceding each test activity. The importance of each test activity and the consequences of lost time suggest the need for a formal, preplanned event for demonstrating site readiness to support each test activity. Criteria will be developed and procedures prepared to demonstrate readiness of the required systems, facilities, equipment, etc. Formal transfer of these items will occur upon successful demonstration. As noted previously, the process will be repeated for the three preparation segments such that complete site acceptances occur prior to Burn No. 3.

- Site Operations Planning

Site preparation and subsequent site operation will involve many different participants performing diverse tasks, some simultaneously and others independently, over a long time period. Yet all activities must mesh appropriately to achieve the test objectives. The required coordination will be accomplished by providing an Operations Plan, mutually acceptable to all participants, that defines, describes, and schedules all site activities. Roles and responsibilities of all participants will be included, and interactions will be defined. The plan will be structured to cover Phases II, III, and IV and will be revised and reissued when dictated by events. While the primary purpose of the plan is to achieve coordinated on-site activities, it will serve the additional purpose of indoctrinating those unfamiliar with project details. A specific application in this area is the near-term need for the site restoration portion of the plan to support a land-use permit application.

3.2.3.26 BASELINE ENVIRONMENTAL MONITORING (WBS 3.3.1)

Environmental monitoring for the purpose of establishing baseline environmental quality at the UCG test site will be conducted. The monitoring program will consist of sampling and analyzing ambient air quality and ground and surface water quality. There are five sub-elements to this activity. They are described below.

- Mobilize Monitoring Equipment

The Environmental Engineering Division of TRW in Vienna, Virginia, will prepare all of the sampling equipment for field use. This preparation consists of cleaning the equipment, checkout of all electronic circuitry, and operation in the TRW laboratory. This work will begin in March, 1978, and the equipment will be transported to the North Knobs site in mid-April, 1978.

- Monitoring of Meteorological Parameters

This task provides for measurement of wind speed and direction at the test site so that air quality data can be correlated with wind parameters. During those periods when the wind is from a direction that causes emissions from the electric generator to be directed toward the air monitoring instruments, the data collected during that period will not be included as part of the data base.

- Monitoring Atmospheric Concentrations of Criteria Pollutants

Ambient air monitoring of criteria pollutants for which the National Ambient Air Quality Standards (NAAQS) have been established by EPA, will be conducted at the test site. Pollutants which will be monitored are sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, non-methane hydrocarbons, and total suspended particulates (TSP).

surrounded by an earthen dike to contain spills. The tank will provide approximately 20 days of diesel operation at the normal Burn No. 1 rate of fuel oil usage or 5 days at the maximum Burn No. 3 rate prior to requiring replenishment.

The water reservoir will be earthen bermed plastic lined reservoir of approximately 225 m^3 (8000 cubic feet) capacity. This will allow two hours of continuous flow from a $2 \text{ m}^2/\text{min}$ (500 gpm) gasoline engine driven fire pump supplying two hydrants simultaneously. Hydrants and fire hoses will protect the fuel oil storage area, the equipment area, the buildings and the well area. The water reservoir will also supply process water, water for domestic plumbing, and water for gasification chamber quench by means of a deep well turbine pump.

All interconnecting piping between the gas systems and the wells will be run on aboveground pipe supports or sleepers located parallel to the equipment and the seams with suitable connections between equipment, injection wells and product wells.

The piping and its supports will be installed only as far as the well being tested at that time. As new wells are developed, the piping will be extended. Special provisions, such as flexible joints and adjustable supports will be used where needed to prevent undue stress on the piping and appurtenances in the event of subsidence. Electric heaters and insulation blankets will be installed on injection and linking air piping to prevent freezing during extreme winter weather.

The entire 6 ha (15-acre) area will be fenced to prevent vandalism or injury to unauthorized persons and range animals. Area lights around the equipment, buildings and shelter areas will provide lighting for the three shift operations required for the test programs.

During the Phase I activity concerned with updating the concept design, a number of design studies and engineering investigations were performed. The results of these are summarized in the following sections in detail. The preliminary designs and the initial evaluation of equipment,

pipng and valves will be optimized during the Phase II detail design efforts and will be based on design approaches and considerations developed during the experimental analysis, field test operation, site installation, and site operation planning activities.

Air Injection System

The "linking" air injection system will consist of a low flow $5.7 \text{ sm}^3/\text{min}$ (200 CFM) high pressure 4200 kPa (600 psi) compressed air system which will provide air from a reciprocating compressor through an accumulator, a pressure control station and thence to the injection well. The linking compressor will be required on-site in the spring of 1979 to provide air for the permeability test program, and therefore must be a separate system from the production air system which will not be required until the spring of 1980. The linking air manifold will also allow linking air to be used in the product well to support combustion when charcoal is used to initiate burning.

The compressed air supply for the coal gasification production will be provided by diesel-driven centrifugal or screw compressors. Four production compressors with a combined capacity of 5.5 MM SCFD (2 @ 2 MM each; 1 @ 1 MM; 1 @ .5 MM) will be installed initially. Since Burn No. 1 (requiring a constant 2 MM SCFD) and Burn No. 2 (requiring a maximum of 5 MM SCFD) are planned to run sequentially during the summer of 1980, the four compressors will be installed at the same time. Two additional 2 MM SCFD compressors will be installed prior to Burn No. 3 in 1981, increasing the capacity in .5 MM SCFD increments to 9 MM SCFD. The pressure and flow into the injection wells will be controlled by the pressure reducing station. The flow will be recorded by the flow orifice recorder in the pressure reducing station. Blind flanges will allow extension of the production gas piping manifold in the future to serve the Burn No. 2 module and the Burn No. 3 modules. One pressure reducing, or control, station will control the production gas to both of the modules of Burn No. 3. If different flow rates should be required, remotely operated flow control valves will be used to balance out the flows as required.

Linking and production gas compressors will be started and stopped manually. Flows and pressures for both linking and production air will be remotely controlled by manual operation from the control trailer. Shutdown of air to the wells can also be accomplished from the control trailer. "Dumping" of air from the wells will be done locally. All instrument spools will be provided with manually controlled redundant bypass flow control capability.

Water Systems

The water systems will be supplied from the earthen diked water reservoir. Preliminary investigations indicate that adequate groundwater exists on the site. The water is highly alkaline but suitable for any use other than human consumption. The water will be supplied to the reservoir from a well with a submersible pump controlled by a float switch which will maintain a constant level above the float switch and will shut off the pump outlet line to provide backup and prevent overfilling in the event of the float switch failure.

Process water to enhance the coal gasification process will be required at the rate of $17.5 \text{ m}^3/\text{day}$ (615 cubic feet per day) per module or approximately $25 \text{ dm}^3/\text{min}$ (6-1/2 gallons per minute) maximum for Burn No. 3. Water will be supplied from the previously described reservoir by a centrifugal pump with a throttled bypass. The pump will run continuously at its rated capacity and the amount and times of water injection into the production air system will be controlled by a manual throttling valve, using an orifice to regulate flow. As additional well modules are added, the process water header will be extended to serve them using the same pump.

Fire protection requirements of the site will determine the size of the gasoline-driven fire pump and the reservoir. The fire/quench system will be an automatic wet-pipe system kept filled and pressurized at all times. To prevent cycling of the large fire pump due to minor leaks in the piping, a small "jockey" pump will be installed in parallel with the fire pump. It will be controlled by a pressure switch. When a

hydrant or injection well quench valve is opened, the jockey pump cannot satisfy the higher flow demand, and the main fire pump will automatically start and come on-line because of appropriately set pressure switches that detect the drop in pressure.

Supplying water to the burn cavities for quenching will be accomplished manually by opening the shutoff valve. To conduct the heat away from the burn cavity, the steam will be allowed to go out the production well line and return to the water reservoir where it will be cooled and condensed.

Water will be supplied to the buildings and shelters for wash-down and toilet flushing by means of a domestic-type pump and a hydro-pneumatic tank. Potable water and laboratory water will be brought onto the site in bottles.

Fuel Oil System

The fuel oil system will be a closed loop continuously circulating pressurized system utilizing a pump. Each engine will have its own day tank supplied through a float valve which will maintain constant level in the tank.

Instrumentation System Design

The revised test plan discussed in Section 2.2.3 has established process instrumentation requirements for this project. These include process control, product analysis, and reactor definition instrumentation as well as a data acquisition and reduction system which is discussed later.

Process control instrumentation will consist of "off-the-shelf" equipment and should not pose any problems. The parameters to be monitored are injection/production gas flow rates and injection water flow rates.

Product gases will be obtained for analysis from two sources: The product gas stream at the production wellhead and from "sniffer" tubes in each instrumentation well. The sniffer tubes will consist of canisters located within the coal seam, with tubes to the surface from which gas samples can be drawn periodically. These tubes will allow measurement of gas composition in situ and determination of gas composition distribution and variation with time within the reaction zone. The chemical components of the product gases requiring determination are: H_2 ; CH_4 ; C_2H_6 ; CO ; N_2 ; CO_2 ; Ar ; H_2S ; and H_2O . The heating value of the gases also must be determined. Accuracies of ± 2 to 3 percent are sufficient. As a by-product, pressure transducers on the sniffer tubes will allow in situ pressure determination and pressure distribution and variation with time within the reaction zone. Sandia developed a standard sniffer tube assembly for use at Hanna and this assembly will be used on this project. The assembly consists of three plastic-sheathed canisters within the coal seam, with a copper multi-tube connection to the surface.

The chemical analyzer will be a gas chromatograph of the type that is available off-the-shelf from several suppliers. The Hewlett-Packard Model 5840A is being used at Hanna and is adequate for this program. Two chromatographs, a primary and a backup, will be required. Water analysis will be done by standard off-the-shelf equipment. Given the importance of water content in the gasification process, redundant water analyses will be necessary. The experience of Hanna IV will be heavily utilized. Heat content will be determined by a continuous calorimeter.

The product gas stream is connected directly to the analyzer via a sample tube; sniffer tube gases are collected in sample bombs and transported manually to the analyzers.

The reactor definition instrumentation discussed below is still subject to change. It was established for two reasons: to obtain a rough cost estimate and to serve as a basis for evaluation. As a result of the first iteration of the test design, the use of some methods

is questionable and will be subject to further evaluation (see Section 2.2.4 for the results of this first iteration).

The most practical reactor definition instrumentation for commercial use is the remote type being used by Sandia in the Hanna experiments. The electrical resistivity portion of this instrumentation is relatively inexpensive to install and operate and, if useful data can be obtained from near-surface geophones, the passive seismic portion will also be relatively inexpensive.

Each of 24 instrumentation wells (8 in Burn No. 2 and 16 in Burn No. 3) will be equipped with 14 thermocouples spaced 0.9 m (3 feet) apart as measured from the bottom of the seam. The 0.9 m (3 foot) spacing is equivalent to a 0.5 m (1.5-foot) spacing across the true 4.5 m (15-foot) thickness of the seam, dipping at 60 degrees. This will be less than the thermocouple spacing used at Hanna; however, since the native permeability of a steeply dipping seam promises to be greater than that of a flat-lying seam, the probability of the combustion process "fingering" through the seam will be greater, and a closer thermocouple spacing is warranted.

The thermocouples above the seam are there primarily for subsidence monitoring. If these thermocouples indicate a temperature increase more rapid than would be expected from heat conduction through the overburden, fractures may have opened in the overburden, allowing hot gases to reach the vicinity of the thermocouples. The opening of these fractures will probably be related to subsidence. Further, cessation of signal from these thermocouples could indicate roof collapse with consequent breaking of leads.

The standardized multipoint modular thermocouple assembly developed by Sandia and described by Northrop, et al., will be used. These assemblies use K-type, armored thermocouples connected in leg-branched circuits. The assemblies are available as commercial items from several sources.

Both Burn No. 2 and No. 3 will be instrumented with a grid of potential electrodes located immediately over the expected burn area. The grid will cover an area of approximately four times the expected burn area and, following the Sandia experience at Hanna, electrode spacing within the grid will be 4.5 m (15 feet). The process modeling at Hanna indicated an expected burn pattern approximately oval in shape and with a ratio of width-to-length of about 0.60. Utilizing this pattern in the program and assuming an expected burn length along the seam of 60 m (200 feet), the burn area projected to a horizontal surface will be 560 m (6000 square feet) in Burn No. 2 and 1100 m² (12 000 square feet) in Burn No. 3. Accordingly, Burn No. 2 will utilize a grid of 13 x 9 electrodes, or a total of 117, and Burn No. 3 will utilize a grid of 19 x 11 electrodes, or a total of 209.

The electrodes will be stainless steel rods buried beneath the frost line (approximately 1.5 m), as used in Hanna IV. Present planning includes applying current by both the modified Schlumberger and Deep Excitation Electrical Potential techniques described by Northrop, et al., although Hanna IV results and the design phase of this program may modify this. The current source has a maximum output of perhaps 20 amperes and has a reversing rate of once per second.

Four geophones will be installed in each instrumentation well as passive seismic instrumentation. Three will be located in the seam overburden and separated by intervals of 6 m (20 feet). The fourth will be located at a depth below the surface of perhaps 3 m (10 feet). If passive seismic instrumentation is to be of practical use in commercial gasification operations, useful data must be obtained from geophones buried at shallow depth; therefore, the fourth geophone will be included to investigate this possibility. The geophones are inexpensive models comparable to the Geospace Model 20D vertical type presently in use at Hanna.

Well Design

The well design effort has three main objectives: finalize design criteria, develop a detailed well installation plan, and prepare

all bid packages for contractual work and equipment to install all process and instrumentation wells. Recent discussions with drilling experts revealed the need to develop a well design as early as possible in Phase II in order to decide on an acceptable drilling method. The first effort involves reviewing the well design criteria provided in Phase I, along with any modifications to these criteria which may have occurred between then and the start of this task. Established requirements will be confirmed and new ones developed such that all requirements on which the drilling (or well installation) plan design, scheduling and costing depend are determined by the time development of the plan begins. Examples of criteria are well size, configuration and layout; casing type and size; cement and grout characteristics; and well bottoming location. Design options and the effects of their selection on costs and scheduling must be clearly comprehended and considered in producing the final design.

Once a design has been established, full-scale well installation plan development can proceed, the final product of which will be bid packages containing all specifications, schedules, drawings, and supporting documentation needed by contractors to bid for and perform the work or provide equipment for the project.

There is an extensive array of alternative techniques that can be utilized to achieve the design objectives. They will be evaluated and trade-off studies performed to determine the best methods from a cost and technical standpoint. For example, a directional control method must be selected which will enable bottoming the well accurately at a predetermined location but which is not prohibitively expensive. Major project elements will then be arranged into a detailed schedule that will identify parallel and interdependent operations. These operations will be reviewed, evaluated, and modified where feasible to minimize expensive standby time and generally expedite all work.

3.2.3.14 SOFTWARE DEVELOPMENT (WBS 1.4.3)

Since an identical Sandia data acquisition and analysis system as used at Hanna IV will be used on this project, it is assumed that the Sandia software used with this system will also be used. Furthermore, it is assumed that DOE will provide Gulf/TRW with this software. It is understood that the software collects and routes thermal and electrical potential and passive seismic data to a variety of storage and output devices. The software also performs several analytical functions, including display of parameter variation with time, display of thermal and electrical potential contour maps within and above the reactor zone and display of seismic hypocenter locations. The software also allows some quantitative investigation of reactor performance through interpretation of the geophysical data.

The basic software will require some modifications for use in this program, in that a different number of data channels are involved and sampling rates may change from Hanna experience. The means of generating and displaying contour maps may require modification because of the steeply dipping seam geometry. The geophysical data interpretation will certainly require modification because of the dip of the seam.

The software will also require modification to accept and analyze process control and product analysis data peculiar to the North Knobs site. Certain analytical operations, such as computation of mass and energy balances will also be required. Software used by the LERC system is capable of doing this (the balance computations are available as subroutine identified as MATBL) and, since both software sets are written in the FORTRAN language, integrating this portion of the LERC software into the Sandia routines does not appear to offer formidable problems.

3.2.3.15 PROCUREMENT PACKAGE PREPARATION (WBS 1.4.4)

The general process of procurement for this project will be arranged into four activities:

- Package preparation
- Bidding or pricing of package
- Evaluation of bidding
- DOE approval

Provision will be made for small procurements (i.e., less than \$10 000) without the full four-step cycle.

Step one, the preparation of the package, is particularly crucial, in that the work necessary to define what item or items will be procured and the evaluation and the selection of sources from which they will be procured. The definition will likely include the following: analysts, engineering design, trade-off studies, and consideration of the best method of committing funds for acquisition of equipment or services.

Step two, wherein pricing will be obtained, will vary somewhat from procurement to procurement. Some procurements will be conducted as open competitive bidding, whereas, in the case of items available only from one source or where very long lead times are involved, the process may be one negotiation.

Step three will consist of evaluating the various prices and relevant factors and preparing a recommended course of action to forward to DOE.

Step four, approval, is envisioned as requiring one month from inception to receipt of go-ahead. A typical four-step procurement cycle will require from 2-1/2 to 3-1/2 months.

The principal technical problem in this task lies in the lead time necessary to accomplish the full cycle. This will be particularly bothersome in the case of procurements for mapping and exploratory drilling, occurring as they do immediately at the start of Phase II.

Only a limited amount of progress in well design can be made without the output from these operations. It is estimated the procurement in each case will require at least ten weeks. The time required to initiate these procurements will be minimized as much as possible.

It should be noted that the majority of the procurement activity will occur during Phase II. For preliminary information purposes, a list of anticipated procurements is provided:

- Mapping
- Exploratory drilling
- Linking Compressors
- Process Compressors
- Diesel Generator and Switchgear
- Vans
 - Instrumentation
 - Data Collection and Monitoring
 - Controls
- Instrumentation Equipment
- Data Acquisition Equipment
- Injection Wells
- Production Wells
- Instrumentation Wells
- Piping
- Valves

3.2.3.16 ECONOMIC ANALYSIS FOR EXPERIMENTAL DESIGN (WBS 1.6.2)

This task will define critical process parameters for the design concept at the selected site. This will be accomplished by utilizing the economic model and studying both independent and dependent variables over a range of values to determine how the system can be optimized in an economic sense.

The present economic model was completed about two years ago and is applicable to horizontal coal seams. The model will be revised to bring it up to date cost-wise and to make it applicable to steeply dipping coal beds. This work will require about four to six months to complete.

Some of the most important inputs to the economic model are not independent variables but rather are dependent variables whose relationship to the independent variables is not presently known. Among these dependent variables are gas yields, gas analyses (and related heating values), and resource utilization. Insofar as possible, process models will be used to furnish data to the economic model, but final development of the process model must await the outcome of the experimental studies.

3.2.3.17 TECHNOLOGY TRANSFER (WBS 1.7.0)

The technology transfer effort will be aimed at promoting rapid, wide dissemination of the information developed in this project to those groups most likely to utilize the information for further research and development or for commercialization. This task will include attending inter-DOE coordination meetings, preparing technical papers, and attending UCG conferences such as the DOE annual meetings. This effort continues in Phase III.

3.2.3.18 GR&DC FIELD OPERATIONS (WBS 2.1.3)

The activities here include the efforts of the GR&DC field crew and field supervision to implement the Phase II site characterization plan, site monitoring, maintenance, and restoration. During construction, the test director will work closely with the Site Support Manager to assure the acceptability of site facilities.

3.2.3.19 FACILITIES ACQUISITION (WBS 3.1.1)

During the period of performance of the on-site work, there will be a site crew. The makeup of this crew will vary according to the type and volume of work under way. Thus the proper inspection skills will be available when needed to handle the diversity of work which construction of the project involves.

It will be necessary at intervals to have personnel possessing special expertise present at the site for construction inspection and consultation. These time intervals will be comparatively short; and in view of short-term uncertainties in scheduling, it will be more practical to handle such contingencies on an "as-required" basis.

A major portion of the work in this task will involve dealing with earth-fill and excavation construction operations, placing form-work, and reinforcing steel and concrete. The inspection personnel during this period will be generally oriented toward the Civil Engineering discipline.

This activity continues in Phase III.

3.2.3.20 EQUIPMENT INSTALLATION AND CHECKOUT (WBS 3.1.2)

The 5 sm³/min, 4200 kPa (175 SCFM, 600 psig) linking air compressor will be the only major mechanical equipment installed in Phase II. The system is required for coal bed permeability tests. The compressor will be installed on a concrete pad in the compressor area. Above grade piping will interconnect the compressor, accumulator, and the valving-instrumentation manifold. Distribution piping will be routed on pipe supports to the test well and connected to the manifold. The entire piping system will be cleaned and pressure tested. The instrumentation and valving will be calibrated and adjusted for a pre-

test checkout. The compressor will be checked out, started, and brought on-stream per manufacturer's procedures. Final adjustments will continue until the entire system is operating satisfactorily.

This activity continues in Phase III.

3.2.3.21 INSTRUMENTATION INSTALLATION AND CHECKOUT (WBS 3.1.3)

The instrumentation installation and checkout schedule requires that procurement activities, particularly with regard to the data acquisition and analysis system, must take place in the final two months of Phase II. These activities will include preparation of a procurement package based on the performance specification, compiling a qualified bidder's list, issuing bids and selecting a supplier. Equipment purchase, delivery, and installation will occur in Phase III.

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Well specifications, established in Phase II well design activities will necessitate the use of directional control in drilling. Drilling industry personnel and previous experience with water exploration well drilling at the North Knobs site have confirmed that maintaining a desired hole orientation, even to the relatively shallow depths required, will be a significant technical challenge demanding special care in directional control, particularly if a 30 cm (12-inch) diameter hole is needed. Furthermore, several drillers stated that to their knowledge, very few 30 cm (12-inch-) diameter vertical and virtually no 30 cm (12-inch) directional holes have ever been drilled in western coal seams. Vertical wells will also present problems, controllable through loading and correction. One technique being considered is to drill a pilot hole initially with a nominal 7.5 cm (3-inch) diameter (surveyed at 6 m [20-foot] intervals) for directional control of the slant wells and 15 cm (6-inch) diameter pilot hole (surveyed at 15 m [50-foot] intervals) for vertical wells and then reamed out to the necessary diameter. This procedure may ultimately keep costs down and could considerably enhance chances for success in bottoming the wells accurately.

A number of directional control techniques are currently available. The two most common are known as the whipstock/wedge and the high-torque drill/"bent sub" assembly known as the Dyna-Drill (manufactured by a division of Smith International).

The following logs will be run in all holes prior to casing:

- Electric (resistivity)
- Gamma (lithologic)
- Neutron (porosity)
- Gamma-gamma (density)
- 3-D velocity
- Caliper

The logging operation is expected to be straightforward and conventional, with the provision that the sonde be lowered on the drill-stem in all process wells. Following logging, a multi-shot directional survey will be run in each well to record its final configuration.

Drilling schedules will be designed to minimize standby and on-site time, avoid adverse weather conditions, and maintain a reasonable penetration rate. Logging will be scheduled to avoid caving problems. Lead time for scheduling a rig will be 3 to 6 months. There appear to be drilling contractors with equipment and competence to perform this work. However, rig availability may pose a problem. Casing and liners should be ordered at least three months in advance to ensure timely delivery.

3.2.3.23 FIELD INSTALLATION TEST AND ACCEPTANCE (WBS 3.1.5)

This task is directed toward assuring the quality, continuity, timely completion and adherence to construction documents of the construction and installation work performed at the project site. This work will be carried out by a site crew for the purpose of daily supervision and direction of the work in progress, and for formulation of test plans, acceptance criteria and interim and final reports.

The composition and size of this crew will be varied from time to time to assure that the proper skills will be available for inspection and consultation. They will work in conjunction with the activities defined under WBS 1.4.5, Field Engineering.

Since certain items of work, notably grading, earth fill and equipment footing construction, will be accomplished before the end of Phase II, the activities in this task begin well before the beginning of construction work.

It is anticipated that the work under this task will be outlined in detail for the entire period of the project by April 1, 1979. In addition, the final test and acceptance procedures for work through the end of Phase II should be complete at that time. Specific detailing of successive test plans and acceptance criteria will then be undertaken and completed. Although it is necessary that this work be completed in increments which satisfy schedule deadlines, it will necessarily be an ongoing task since much of the content cannot be finalized until other tasks have been completed. This is particularly applicable to the case of inputs from the various design tasks.

3.2.3.24 PERMIT SUPPORT (WBS 3.2.2)

All permits necessary for Phase II and Phase II site activities will be acquired under this WBS. The Phase II permits needed for 1978 site exploratory drilling and hydrologic drilling have been applied for. Bond will also be posted to cover these activities. The BLM temporary tram road permit, required before any site access road improvements can be made on BLM sections, will be applied for subsequent to BLM site inspection and review of the archaeological report in mid-March, 1978.

All Phase III permits will be applied for in adequate time for agency review and comment so that the permit applications can be approved by April 1, 1979. These permits include mining, air quality, water quality, construction, local zoning, and access road alignment. A complete list of required permits and required data for each permit is presently being prepared. Site construction activities cannot begin until these permits have been obtained. Site and aquifer reclamation bonds will also be posted with the permit applications. Because of the developmental nature of this project, it is anticipated that regulatory agencies will require a continuous input of data in their respective permitting areas over the life of the project.

At the conclusion of site operations in early 1982, site restoration releases will be acquired under this WBS.

3.2.3.25 SITE SUPPORT PLANNING (WBS 3.2.3)

Site Support Planning in Phase II includes those efforts required to plan, coordinate and integrate Phase II site activities and to provide appropriate documentation for each. It also includes detailed planning for Phase III site support activities. Sub-elements are defined as: Scheduling, Site Acceptance and Transfer, Site Operations Planning. These subtask elements are described below. Site support planning activities will continue during Phase III as necessary revisions to the construction and operating plans become apparent.

- Scheduling

Phase II emphasizes site-related activities. Many WBS task elements dormant in Phase I will be activated for the first time and will contribute to site preparations. Most of these tasks are interactive and some have second and third order interdependencies. In order to assure that task interfaces are addressed and sequenced properly, it is vital that mechanisms be established to analyze task requirements, define task interdependencies, and develop integrated schedules. In recognition of the importance of this effort, some preliminary work was initiated in Phase I to lay out the approach that will be utilized. An Activity Network was prepared using the limited data base available, and an integrated project schedule was developed. Phase II work will involve successive interaction of the network to surface third and fourth order interdependencies which will then be scheduled. After the initial scheduling is completed, the network will be used to input a Mini-PERT computer program that will perform Critical Path Analysis of the schedule. The final project schedule provided from this effort will be used for management visibility and control of project activities.

- Site Acceptance and Transfer

Time and funding constraints coupled with winter weather conditions suggest that site preparation will be evolutionary. Three segments of preparation are identified: 1) preparation required to support permeability tests; 2) preparation required to support Burn Nos. 1 and 2; and 3) preparation required to support Burn No. 3. Thus, site acceptance and transfer will occur in three parts immediately preceding each test activity. The importance of each test activity and the consequences of lost time suggest the need for a formal, preplanned event for demonstrating site readiness to support each test activity. Criteria will be developed and procedures prepared to demonstrate readiness of the required systems, facilities, equipment, etc. Formal transfer of these items will occur upon successful demonstration. As noted previously, the process will be repeated for the three preparation segments such that complete site acceptances occur prior to Burn No. 3.

- Site Operations Planning

Site preparation and subsequent site operation will involve many different participants performing diverse tasks, some simultaneously and others independently, over a long time period. Yet all activities must mesh appropriately to achieve the test objectives. The required coordination will be accomplished by providing an Operations Plan, mutually acceptable to all participants, that defines, describes, and schedules all site activities. Roles and responsibilities of all participants will be included, and interactions will be defined. The plan will be structured to cover Phases II, III, and IV and will be revised and reissued when dictated by events. While the primary purpose of the plan is to achieve coordinated on-site activities, it will serve the additional purpose of indoctrinating those unfamiliar with project details. A specific application in this area is the near-term need for the site restoration portion of the plan to support a land-use permit application.

3.2.3.26 BASELINE ENVIRONMENTAL MONITORING (WBS 3.3.1)

Environmental monitoring for the purpose of establishing baseline environmental quality at the UCG test site will be conducted. The monitoring program will consist of sampling and analyzing ambient air quality and ground and surface water quality. There are five sub-elements to this activity. They are described below.

- Mobilize Monitoring Equipment

The Environmental Engineering Division of TRW in Vienna, Virginia, will prepare all of the sampling equipment for field use. This preparation consists of cleaning the equipment, checkout of all electronic circuitry, and operation in the TRW laboratory. This work will begin in March, 1978, and the equipment will be transported to the North Knobs site in mid-April, 1978.

- Monitoring of Meteorological Parameters

This task provides for measurement of wind speed and direction at the test site so that air quality data can be correlated with wind parameters. During those periods when the wind is from a direction that causes emissions from the electric generator to be directed toward the air monitoring instruments, the data collected during that period will not be included as part of the data base.

- Monitoring Atmospheric Concentrations of Criteria Pollutants

Ambient air monitoring of criteria pollutants for which the National Ambient Air Quality Standards (NAAQS) have been established by EPA, will be conducted at the test site. Pollutants which will be monitored are sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, non-methane hydrocarbons, and total suspended particulates (TSP).

Ambient monitoring will be conducted for a one-year period at the test site. All of the pollutants will be monitored continuously, with the exception of TSP, which will be monitored on a six-day frequency.

- Measurement of Process Specific Air Pollutants

Ambient air samples will be collected and analyzed for those pollutants which are specific to underground coal gasification. It is anticipated that an analysis will be conducted for 23 trace elements. In addition, analyses will be conducted for hydrogen sulfide and carbonyl sulfide.

- Baseline Water Quality Monitoring

The baseline water quality monitoring program will determine the concentrations of selected parameters in the coal seam and in adjacent underlying and overlying aquifers before the UCG tests. The data obtained from baseline monitoring will be compared with data obtained from subsequent phases to determine the nature of possible changes in the selected parameters. Water samples will be shipped to the GR&DC laboratory for analysis in accordance with EPA recommended procedures.

3.2.3.27 ENVIRONMENTAL LAB SUPPORT (WBS 3.3.3)

Environmental lab support involves conducting all of the water analyses during this phase in accordance with recommended EPA procedures. Water samples will be taken in accordance with the environmental monitoring plan included in Appendix BB. Water samples will be analyzed for the following:

Bicarbonate	Chemical oxygen demand
Carbonate	Cyanide
Conductivity	Phenol
pH	Organic carbon
Total solids	Inorganic carbon

Nitrogen as ammonia	Total radioactivity
Nitrate	Approximately 25 trace
Nitrite	metals such as lead,
Sulfate	selenium, arsenic, iron,
Sulfide	etc.

3.2.3.28 SAFETY PLANNING (WBS 3.4.1)

A comprehensive safety plan will be prepared in Phase II that will identify all safety requirements for the test site including process operations, fire protection, fire fighting, personnel health/safety, and provide a basis for developing a safety training program. The facility and process designs will be reviewed for compliance with federal, state, and corporate safety requirements. Safety equipment required at the test site will also be identified and procurement packages prepared for equipment purchase. Safety procedures independent of test operations will be prepared for implementation where appropriate. A more detailed description of the planned activities and documents is presented below.

- Safety Plan

A safety plan that addresses all activities and site peculiar hazards at the test site which is applicable to all personnel, permanent or visitors, on the site will be developed. The plan will identify the safety requirements that are applicable and must be considered during all site operations from the actual test operations to the maintenance and servicing activities.

- Design Reviews

A safety review of all facility, process and equipment designs will be performed to verify compliance with appropriate federal, state, and corporate (TRW and GR&DC) safety requirements. The designs will also be evaluated to determine their suitability to control site peculiar hazards.

- Safety Equipment

Numerous items of safety equipment will be required at the test site. These include such items as hard hats for permanent personnel and visitors, fire extinguishers in buildings, and equipment shelters and first aid equipment. Storage cabinets conveniently located for storage, control and maintenance of the safety equipment will also be required.

- Safety Training Plan

On-site operational personnel as well as transient operating personnel and visitors must be made aware of test site safety regulations, test and process operating hazards, and constraints. A Training Plan will be developed for this purpose. Some personnel, identified for additional tasks such as fire fighting, will receive additional training.

- Safety Procedures

Generally, test operations procedures will contain the necessary safety procedures and requirements related to the specific operation covered. Safety procedures, separate from the operating procedures, will be required for such things as an emergency evacuation of the test site or severe injury(ies) to personnel.

3.2.4 PHASE II WBS ELEMENT HEADINGS

This section is provided to permit the reader to scan the Work Breakdown Structure (WBS) element titles and quickly correlate the corresponding element numbers. The Phase II WBS elements are as follows:

- 0.1 Project Management
 - 1.1.3 Prepare EIA
 - 1.2.1 Initial Data Collection
 - 1.2.2 Mapping
 - 1.2.3 Site Evaluation
 - 1.2.4 Geological Data Analysis
 - 1.2.5 Hydrological Testing
 - 1.2.6 Core Analysis
 - 1.2.7 Permeability Testing
 - 1.3.3 Test Design
 - 1.3.4 Site Selection Criteria Design
 - 1.3.5 Bulk Coal Studies
 - 1.3.6 Technical Coordination - Phase II Report
 - 1.4.2 Facilities and Equipment Installation Design
 - 1.4.3 Software Development
 - 1.4.4 Procurement Package Preparation
 - 1.4.5 Field Engineering
 - 1.6.2 Economic Analysis for Experimental Design
 - 1.7.0 Technology Transfer
- 3.1.1 Facilities Acquisition
- 3.1.2 Equipment Installation and Checkout
- 3.1.3 Instrumentation Installation and Checkout
- 3.1.4 Well Installation
- 3.1.5 Field Installation Test and Acceptance
- 3.2.2 Permit Support
- 3.2.3 Site Support Planning - Phase II
- 3.3.1 Baseline Monitoring
- 3.3.3 Environmental Lab Support
- 3.4.1 Safety Planning
- 4.0 Program Control/Procurement Control

3.2.5 PHASE II DELIVERABLES

The major Phase II deliverables will be a report containing the following:

- A detailed characterization of the selected site as to
 - Depth of seam
 - Seam thickness
 - Lithology
 - Structure
 - Cleat orientation
 - Anomalous conditions
 - Dip
 - Porosity and permeability of the enclosing rock formations
- An Environmental Impact Assessment of the tests on the selected site including a compendium of baseline environmental baseline data specific to the site.
- A definition of the critical process parameters.
- An estimation of the scaling factors for the design concept.
- A definition of process systems requirements including, as necessary, design drawings and statements of work for sub-contractors.
- A definition of the process control systems and product gas monitoring systems.

3.3.0 PLANS FOR PHASE III

3.3.1 OBJECTIVES OF PHASE III

There are several objectives to be accomplished during performance of the Phase III activities. They are listed below with a brief description of each.

- Install the UCG Test Facility - The field test facility will be installed in a technically efficient manner to minimize effects on the environment and to assure safe operation of the site. This test facility will be designed for a three-burn test program.
- Demonstrate the ability to link, ignite, sustain, and terminate a UCG Process Module (Burn No. 1) - The process module installed in Phase II will be operated in an up-dip burn for a short period of time to gain experience in the various operational steps required for a UCG test. Input-output data (mass flow and composition) will be obtained during the test to allow revision of subsequent tests.
- Operate a process evaluation burn to study the relationships between process parameters (Burn No. 2) - The process module will be equipped with instrumentation wells to obtain information on reactor shape and growth patterns. An extensive experimental test schedule will be followed to study the variation of process parameters such as injection air flow rate, reactor pressure, water content, and reactor volume. Results will be analyzed and compared with field test data available from other projects. Plans for the third burn may be modified based upon the results of this test.
- Operate a parallel module experiment providing information on resource utilization (Burn No. 3) - The parallel linked module will enable us to estimate the feasibility of the linked module

operation option for a large-scale operation. The results of this test will provide valuable input into economic projections of the process and Phase IV pilot plant design activities.

- Monitor Water and Air Quality During and After the Test Program to Estimate the Effects of UCG on the Environment - Measurement of the environmental effects of the process are required both by regulatory agencies and as a part of the UCG-SDB project goals.
- Provide Improved Economic Projections of Commercial UCG of SDB - The Gulf economic model will be utilized to provide second-generation economic projections to commercial UCG of SDB.

3.3.2 PHASE III STATEMENT OF WORK

There are several specific tasks identified in the contract statement of work (SOW) that are scheduled to be completed in Phase III. An abstract of these is presented here for reference.

- Install a field site suitable for the UCG test program. Most of the site installation will be done in Phase III.
- Perform an initial burn in the module installed for permeability testings in Phase II.
- Install and operate a process module to evaluate and define process parameters.
- Install a two-module configuration (4 injection, 2 production wells) with subsurface instrumentation for evaluation of scaling factors.
- During site operations monitor air, water, and surface subsidence effects. Continue monitoring after termination of the test.

It is expected that several significant items will be provided by DOE during Phase III. These are:

- Instrumentation consultation.
- Site installation and startup consultation support (Test No. 1).
- Process model support for evaluation of test data.
- Subsidence consultation.

3.3.3 DETAILED DESCRIPTIONS OF PHASE III ACTIVITIES

The network activity chart described in Section 3.1.0 of this report indicates the inter-relationships of the various project activities in Phase III. The activities were briefly described to permit the reader to understand the tasks involved. This section contains a more detailed description of Phase III activities and includes significant technical data that was produced during Phase I. These detailed descriptions are arranged sequentially and are identified by the appropriate WBS number that appears in the network activity chart (see last page of this volume).

3.3.3.1 SURFACE MAPPING (WBS 1.2.2)

The Phase III portion of the surface mapping task will comprise installation and monitoring of subsidence nets for all three burns. While this is not strictly a mapping activity, it will be part of the ground surveying effort for the project which was defined as part of the surface mapping task.

As presently envisioned, surface subsidence monitoring will be carried out periodically through a series of first-order surveys conducted at the surface immediately above each actual or projected burn zone. An array of thirty monuments will be placed at each burn site and surveyed to determine relative vertical and horizontal position prior to burn ignition. A scheduling constraint will be imposed on this operation by well and instrumentation installation. The area slated for emplacement of subsidence monuments must be clear of surface traffic and materiel before the subsidence net can be permanently established. It will remain in place for the duration of the project. Consequently, establishment of the subsidence net and primary surveying are some of the last activities to occur before ignition.

Present planning calls for three surveys to be conducted of all monuments at each burn site: one after installation but prior to ignition; one shortly after burn completion; and the third, approximately one to one-and-one-half years following the burn. The last survey is performed to expose relatively long-term results of the experiment. As with various other field activities, subsidence monitoring may be affected by adverse weather and must be scheduled accordingly. It must be coordinated with other related environmental monitoring activities.

3.3.3.2 BURN NO. 1 DATA ANALYSIS

The data collected during Burn No. 1 will allow the following useful interpretations and relationships to be made.

- Total product composition - calculated from the amounts of particulates, tars, water, and product gases produced.
- Rate of dry gas production - calculated from the rate of wet gas production (measured), the rate of slipstream dry gas flow, and nitrogen balance.

- Leakage to seam - calculated from a nitrogen mass balance, i.e., nitrogen injected versus nitrogen produced.
- Production gas to injection gas ratio.
- Calorific value of dry product gas - calculated from the GC compositional analysis of the dry gas and possibly particulates and tars if they are present in appreciable amounts.
- Amount of coal affected - obtained from mass balances for carbon, hydrogen, and oxygen and lab studies made on the compositional make-up of the coal itself and its volatile matter and char after pyrolysis.
- Individual component concentration versus time -
 - heating value versus time
 - heating value versus pressure
 - heating value versus water content
 - heating value versus rate of air injection
- Rate of burn front movement - calculated from a crudely estimated shape of the reaction zone and the amount of coal affected.
- Thermal efficiency - calculated from the amount of coal affected versus the sum total of usable energy produced by the process.

3.3.3.3 BURN NO. 2 DATA ANALYSIS (WBS 1.3.8)

The data analysis activities in Burn No. 2 will be similar to those of Burn No. 1 but will involve a much larger volume of data since the main goal of Burn No. 2 is to conduct a systematic study relating process performance to the controllable variables. Furthermore, much greater emphasis will be placed on reactor shape definition activities. The second burn will be heavily instrumented with reactor definition packages. Therefore, in addition to the data analysis activities in Burn No. 1, the following results will be expected from Burn No. 2 activities.

- Volume of in situ reactor - calculated from helium tracer studies and mass balance calculations.
- Shape of in situ reactor - determined from subsurface thermocouples, seismic studies, subsurface pressure and gas compositional measurements (sniffer tubes), subsidence measurements, and electrical monitoring techniques. Application of a rock mechanics model, if available, would aid in this endeavor.
- Energy Return Ratio - ratio of total usable energy produced to total energy consumed operating the process.
- Overall process efficiency - ratio of total usable energy produced to total energy input to the process (i.e., operating energy plus coal utilized).
- Application of experimental data to a mathematical model.

3.3.3.4 BURN NO. 3 DATA ANALYSIS (WBS 1.3.9)

The data analysis activities in Burn No. 3 will be very similar to those of Burn No. 2 with even more emphasis on reactor shape definition activities. The principal goal of Burn No. 3, which will use the optimum conditions for flow rate, pressure, and water injection rate found from Burn No. 2, will be to determine the ability to control the areal sweep characteristics of the reactor between two well modules (injection-production well pairs).

Data analysis, therefore, will involve relating process variables, especially the gas flow distribution pattern among the various wells, to the progressing shape of the reactor. It will also involve using the flow distribution pattern data to provide a simplified model of the gas flow characteristics in the reactor to provide guidance in modifying the gas flow distribution pattern.

3.3.3.5 TECHNICAL DIRECTION (WBS 1.3.11)

During Phase III, technical activities will occur at the site and at off-site facilities. This activity will deal with:

- Coordination of data evaluation
- Process technical problems
- Coordination of economic evaluation activities
- Coordination of technology transfer activities between the project and DOE, industry and local governments (permits)
- Process model work
- Subsidence evaluation
- Coordination of activities between facilities

3.3.3.6 FIELD ENGINEERING (WBS 1.4.5)

This task began in Phase II and is a continuation of that activity. It will continue until completion of the project. As construction work and subsystems are completed and performance-tested, acceptance procedures will be performed. When a major milestone, such as a facilities transfer date is reached, it will be necessary for this task to have completed its activities in regard to the particular hardware involved by that date.

3.3.3.7 FIELD DATA ECONOMIC ANALYSIS (WBS 1.6.3)

Economic analyses will be made following each test burn using the economic model modified to accommodate the steeply dipping bed configuration. The independent operating variables and dependent process variables will be measured in each test and used as input to the model. The application of the model will follow each test burn as expeditiously as possible so that the results of the economic analyses can be used in guiding succeeding tests.

The data which are particularly important from the test burn are those which seem to have the greatest effect on economic results. These are:

- Product composition
- Leakage and outlet pressures
- Inlet and outlet pressures
- Air injection rate
- Gas production rate
- Resource utilization

Product composition is of particular importance because it determines the heating value of the gas. Since the conceptualized commercial model operates at some pre-selected total energy output, the heating value of the gas affects the number of wells required and all equipment capacities. Assuming that some operational parameters (e.g., pressure, water injection rate, air injection rate) can affect product composition, the optimum method should be that which produces the lowest cost product consistent with feasibility of operation.

As pointed out in Appendix C, increased outlet pressure has a beneficial effect on product cost when using the conceptualized plant model. On the other hand, leakage has a detrimental effect. Since leakage will probably be directly proportional to pressure in the reaction zone, it becomes particularly important to know the magnitude of this relationship to evaluate the test results. If leakage is excessive, it may be possible to modify succeeding tests to alleviate the problem.

The model will contain up-to-date well costs by the time it is used for these studies. At present, there are no definite costs for slant wells. The rest of the model will also contain updated costs as well as being specifically appropriate for SDB application. The model is easy to use and produces economic data in very short time so that it can

be applied as fast as test results become available. In this way the most critical parameters should be determinable from one test burn and such information should be of value in designing succeeding operations.

3.3.3.8 TECHNOLOGY TRANSFER (WBS 1.7.0)

This is a continuation of activity that began in Phase II.

The technology transfer effort will be aimed at promoting rapid, wide dissemination of the information developed in this project to those groups most likely to utilize the information for further research and development or for commercialization. This task will include attending inter-DOE coordination meetings, preparing technical papers, and attending UCG conferences such as the DOE annual meetings.

3.3.3.9 TEST DIRECTION (WBS 2.1.2)

This Phase III activity encompasses management of the test facility and testing crew during test operations. The purpose is to implement the test procedures defined under the Phase II activity, Test Procedure Definition. The constructed facility will be transferred to the test director at the beginning of linking operations for Burn No. 1. He is responsible for on-site activities during test operations and for the implementation of the test program which will include:

- Supervision of site personnel
- Direction of link operations
- On-site data evaluations
- Authorization for deviation from the test plan
- Quench operations as required
- Preparation of a report covering site activities during the tests

3.3.3.10 GR&DC FIELD OPERATIONS (WBS 2.1.3)

This is a continuation of activity that began in Phase II.

Phase III activities include inspection and surveillance during site construction, equipment installation, and systems checkout prior to acceptance of the site. Site maintenance and construction between tests and during winter shutdowns will be monitored. At the conclusion of the last test, this effort will include inspection and surveillance of site dismantling, aquifer monitoring, and aquifer and surface restoration.

3.3.3.11 FACILITIES ACQUISITION (WBS 3.1.1)

This is a continuation of activity that began in Phase II and, although largely consisting of different types of work, the Phase III portion of this task will utilize the same personnel make-up as described for Phase II.

Beginning in October, Phase III will experience freezing weather. If this should occur before the green concrete is fully hydrated, it will be necessary to heat it to prevent freezing. Weather records do not indicate the degree of likelihood of a freeze before October 21, but the scheduled period of curing is as early as seems practicable under the circumstances. In the event of an imminent freeze, the footings will be kept warm with rubber blankets containing electrical resistance heaters.

Following backfilling operations, fabrication of pipe racks and miscellaneous items of hardware will be performed. These portable items can be shop fabricated and transported to the site for later installation.

The necessity for meeting the scheduled facility transfer dates for Burn 1 and Burn 2, June 15 and August 1, 1980, respectively, means that piping installation and equipment placement and installation must

begin on January 15, 1980. Unless the winter weather is unusually mild (1975-76 and 1976-77 were) this could constitute a problem of some magnitude, resulting in increased costs and probable slippage of schedules.

As work on each subsystem is completed, testing will be conducted and necessary corrective work will be carried out. The period from May 15 to June 1, 1980, will be scheduled for equipment testing of the complete installation, exclusive of instrumentation. The period from June 1 to June 15, 1980, will be allocated for all-up testing of the entire installation.

3.3.3.12 EQUIPMENT INSTALLATION AND CHECKOUT (WBS 3.1.2)

This is a continuation of activity that began in Phase II. The four injection air system 900 kPa (125 psig) compressors will be placed on concrete pads and arranged opposite the existing linking air compressor which was installed in Phase II. All four compressors will be connected to the system accumulator and the valving-instrumentation manifold. From this manifold distribution, piping will be run aboveground on pipe supports to the wells for Burn Nos. 1 and 2 and connected to the individual well valving manifolds.

The product gas system valving-instrumentation manifold and flare stack will be installed and aboveground piping on pipe supports is routed and connected to the production wells for Burn Nos. 1 and 2. The flare stack will be assembled and supported per the manufacturers instructions and connected to a pilot ignition propane gas supply.

The aboveground diesel engine fuel supply storage tank will be set on concrete supports in the fuel system area. A circulating pump will be connected to the tank and the discharge piping supported and routed aboveground to the diesel-driven compressors and diesel generator and connected to the individual day tanks. A fuel return piping loop is provided back to the storage tank.

The water pump in the process water system will be installed adjacent to the water reservoir. The pump discharge will be routed underground and connected to the injection air supply header of the Burn Nos. 1 and 2 injection wells.

The fire/quench water system primary and secondary water pumps will be installed and connected to the water reservoir. The water discharge will be piped to the fire hose locations making up a fire water protection grid and to the Burn Nos. 1 and 2 injection wells for connection to the well manifolds for fire quench.

For the non-potable water system, a hydro-pneumatic unit will be installed and connected adjacent to the water reservoir. The unit discharge will be piped underground as a nonpotable water supply to hose spigots in the work areas and to the trailer toilets.

All piping systems will be cleaned and pressure tested per pre-established specifications. All instrumentation and valving will be individually tested and adjusted during prestart checkouts. When each system is ready, the equipment will be prepared, started, and brought on-stream according to the manufacturers instructions. All components will be monitored and tested for satisfactory operation in preparation for final acceptance.

3.3.3.13 INSTRUMENTATION INSTALLATION (WBS 3.1.3)

This is a continuation of activity that began in Phase II. Instrumentation installation procedures in this program again rely heavily upon the Sandia/LERC experience in Hanna. Downhole instrumentation will be assembled with a messenger cable and measuring tape. Assembly is done at the wellhead as the instrumentation is lowered into the hole. Some preplanning will be necessary as the depth of the instrumentation wells vary throughout the reactor zone. The hole will be filled with grout of the formulation used by Sandia by means of a small plastic hose and pump.

Potential electrodes will be buried at a depth of approximately 1.5 m (five feet). Cables from the electrodes are buried in trenches at a depth of approximately 0.3 m (one foot). Cables from the instrumentation wells are run to the data acquisition system using overhead cableways.

The instrumentation that will be used on this project will generate a large volume of data. This, plus the desirability of having the data available in usable form on an essentially real time basis, will dictate that an automated data acquisition and analysis system be used. Such systems are presently in use at Hanna and Hoe Creek.

Sandia and LERC presently utilize separate independent systems at Hanna. The LERC system uses Hewlett-Packard equipment and accepts downhole thermocouple, process control and product analysis data. Sandia uses a system supplied by Modular Computer (ModComp) Systems that accepts thermocouple, electrical resistivity, and passive seismic data. ModComp equipment is assumed for this project. This is assumed because developing the interface between the system and the process control and product analysis instrumentation will be a relatively straightforward procedure. Developing the interface between the remote reactor definition instrumentation and the Hewlett-Packard unit would be less straightforward. Further, the passive seismic output will be processed through a special microprocessor being developed by Sandia for use in Hanna IV. This microprocessor will automatically detect seismic events, correlate these among the receiving geophones and compute hypocenters. The problems of developing a new interface between this special-purpose processor and Hewlett-Packard equipment are unknown, but could be formidable.

3.3.3.14 WELL INSTALLATION (WBS 3.1.4)

An extensive discussion of this subject was presented in the Phase II descriptions. This task in Phase III is a continuation of that activity.

3.3.3.15 FIELD INSTALLATION TEST AND ACCEPTANCE (WBS 3.1.5)

During the last three months of 1979, test plans and acceptance criteria for equipment installation and system start-up will be finalized. With the arrival of equipment on site, which begins in January, 1980, and the installation of the various systems get under way, the task of component, subsystem and system testing will start. This effort will reach the first task milestone with facilities transfer in June, 1980.

Burn No. 2 follows Burn No. 1 very closely. The date of facility transfer for Burn No. 2 occurs during the scheduled operations of Burn No. 1. This indicates that the construction for Burn No. 2 will continue until near the end of Burn No. 1. Furthermore, it indicates that most of the construction work for both burns will be done in parallel. Considerable coordination and planning will be necessary to assure minimum conflict between the two construction activities. Additional site activity will take place during the drilling and construction for Burn No. 3 and, still later, when site restoration is under way.

3.3.3.16 PERMIT SUPPORT (WBS 3.2.2)

This is a continuation of the Phase II activities. The final activity under this WBS will be to obtain releases from site and aquifer restoration permits and bonds.

3.3.3.17 SITE SUPPORT PLANNING (WBS 3.2.3)

Site support planning in Phase III will basically be a continuation of the scheduling, site acceptance, and site operations planning activities performed during Phase II as necessary revisions to the construction and operating plans become apparent. Revisions to the plan will undoubtedly occur during Phase III since most of the construction and all of the tests will be carried out in this period.

3.3.3.18 DATA ACQUISITION AND REDUCTION (WBS 3.2.4)

Data acquisition and reduction basically involve computer collection and manipulation of the data which will be obtained from remote sensors, such as pressure transducers, thermocouples, gas chromatographs, gravimetric balances, conductivity probes, etc. Some of these data may be used by the computer to actually control the process variables (e.g., injection pressure, injection rate) while the remainder will be changed to a desirable form. Besides storing in memory, the computer will print out all the data it receives at certain regular intervals.

There will be certain data acquisition and reduction functions that, because of cost or other reasons, will be manually carried out. For example, gas samples from tubes placed in the coal seam (sniffer tubes) will be manually obtained and injected into a GC interfaced with a computer for automated readout. Helium tracer tests, due to their infrequent use (once or twice a day) will be manually performed. Some instrumentation calibration will also be performed manually.

This task principally involves supplying the personnel to assure the proper operation of the data acquisition and reduction system on a round-the-clock basis during the three burns. Some of the personnel associated with this task will be at the professional level, while others will be at the technical level. The professionals will be responsible for assuring that the overall goals of the acquisition and reduction system are being met. This involves interfacing the data acquisition activities with the field operations activities, assuring the responsibility for proper systems operation, and confirming that the manually operated tests are properly carried out. The technicians' responsibilities will include routine checking and calibration of instrumentation, routine analysis of gas samples from sniffer tubes, conduction of the helium tracer tests, and other activities as seen fit.

3.3.3.19 TEST SUPPORT OPERATIONS (WBS 3.2.5)

This activity will take place during Phase III test operations which are scheduled to occur between May and November, 1980, and March and November, 1981. Included in this function is the GR&DC site crew and shift supervision during test operations. Test operations will include crew training in facility operation and test procedures, startup, linking, burning, and quenching. The purpose of this activity is to implement the test plan developed in Phases I and II using the test procedures and the site facility as designed and constructed. Overall GR&DC site supervision during testing will be provided. The site crews during testing will be staffed to provide four rotating work shifts so that round-the-clock, seven-day-week operations can be conducted.

3.3.3.20 SITE RESTORATION (WBS 3.2.6)

This activity will include all efforts associated with removal of facilities and equipment installed to support and perform the test objectives of this project. It will include plugging and capping all of the wells that were installed and returning the surface of the test site to the appropriate contours that existed prior to test site construction. Unforeseen requirements that could result from regulatory requirements at the time of restoration have not been included here but will be considered at an appropriate time prior to finalizing the planning for site restoration.

3.3.3.21 PROCESS OPERATIONS (WBS 3.2.7)

This activity will provide the necessary coverage for the operation of the process equipment, such as the diesel-driven air compressors, valves, regulators, water pumps, flare stack, and other equipment required for satisfactory operation of the process system. Performance of this effort will require detailed coordination with several other activities, including site operations, data acquisition and

reduction, test operations, and site safety. Support for the site management and technical personnel on site will be defined during performance of this task.

3.3.3.22 SITE SERVICE OPERATIONS (WBS 3.2.8)

The UCG/SDB test site will include a wide variety of mechanical, electrical, and electronic equipment uniquely configured to support test operations. It will also include support facilities, roads, parking lots, area lighting, water systems, fuel systems, etc. Both equipment and facilities must be maintained during pretest, testing, and post-test periods. The Site Service Operations task will provide:

- Equipment Maintenance Services
- Facilities Maintenance
- Initial Provisioning and Resupply
- Clerical/Secretarial Services

3.3.3.23 TEST MONITORING (WBS 3.3.2)

This activity is a continuation of the environmental monitoring task begun in Phase II.

Under this task, environmental quality data will be collected during the three burns of the project. The task consists of preparing the monitoring equipment for field use, collecting and analyzing data for meteorological parameters, criteria air pollutants, trace elements, process specific air pollutants, and water quality parameters.

3.3.3.24 ENVIRONMENTAL LAB SUPPORT (WBS 3.3.3)

This is a continuation of environmental lab support that began in Phase II. It involves conducting all the water analyses done during this phase in accordance with recommended EPA procedures. Water samples will be taken in accordance with the environmental monitoring plan included in Appendix BB.

3.3.3.25 SITE SAFETY OPERATIONS (WBS 3.4.2)

Site safety activities will continue in Phase III providing for personnel health and safety, fire protection, safety training, and support to the site operations. The site safety plan and safety procedures will be revised and updated as necessary to reflect new or modified test site requirements in Phase III. Construction activities and start of testing will influence safety considerations.

3.3.4 PHASE III ELEMENT HEADINGS

This section is provided to permit the reader to scan the Work Breakdown Structure (WBS) element titles and quickly correlate the corresponding element numbers. The Phase III WBS elements are as follows:

- 0.1 Project Management
- 1.2.2 Surface Mapping
- 1.3.7 Test 1 Data Analysis
- 1.3.8 Test 2 Data Analysis
- 1.3.9 Test 3 Data Analysis
- 1.3.10 Phase III Final Report
- 1.3.11 Technical Direction
- 1.4.5 Field Engineering
- 1.6.3 Field Data Economic Analysis
- 1.7.0 Technology Transfer
- 2.1.2 Test Direction
- 2.1.3 Field Operations
- 3.1.1 Facilities Acquisition
- 3.1.2 Equipment Installation and Checkout
- 3.1.3 Instrumentation Installation and Checkout
- 3.1.4 Well Installation
- 3.1.5 Field Installation Test and Acceptance
- 3.2.2 Permit Support
- 3.2.3 Site Support Planning
- 3.2.4 Data Acquisition
- 3.2.5 Test Support Operations
- 3.2.6 Site Restoration
- 3.2.7 Process Operations
- 3.2.8 Site Service Operations
- 3.3.2 Test Monitoring
- 3.3.3 Environmental Lab Support
- 3.4.2 Site Safety Operations
- 4.0.0 Project/Procurement Control

3.3.5 PHASE III DELIVERABLES

The Phase III deliverables are as follows:

- Report of Test #1 activities
- Report of Test #2 activities
- Report of Test #3 activities
- Final report of Phase III including summary of test results, economic analysis, and environmental data.

3.4.0 PLANS FOR PHASE IV

The implementation of Phase IV tasks is described in the following sections in terms of:

- Objectives
- Statement of Work
- Description of Activities
- Work Breakdown Structure Elements
- Deliverables

3.4.1 OBJECTIVES OF PHASE IV

During Phase IV, a conceptual design and preliminary cost estimate for a pilot plant of sufficient size to fully demonstrate the feasibility of underground gasification of steeply dipping coal beds will be developed. The design and cost estimate will be of sufficient detail to aid the DOE in deciding which step to take next in the search for methods to commercialize underground gasification of steeply dipping coal beds.

Objectives of the pilot plant are as follows:

- To develop procedures for handling problems and operations which can only be investigated on a pilot plant scale such as,
 - Subsidence
 - Multi-module operation
 - Continuous operation, sequencing from one module to the next in the burn pattern.
- To confirm on a larger scale all the engineering and operational data collected in the smaller scale tests.
- To demonstrate that a salable product can be manufactured by the gasification of steeply dipping coal beds.
- To demonstrate the reliability of the process to produce a gas of consistent quality over a long period of time.

3.4.2 PHASE IV STATEMENT OF WORK

There are several specific tasks identified in the contract statement of work (SOW) that are scheduled to be completed in Phase IV. An abstract of these is presented below for reference (Figure 3-4).

- Define the scope of a pilot plant for commercializing the underground gasification of steeply dipping coal beds. The pilot plant design will use the results of the field experiments from Phase III, but will be based on a non-site specific coal.
- Design a field facility for the pilot plant which will include equipment and operation requirements for drilling the wells, gasification of the coal, initial clean up of the produced gas and transportation of the gas to a surface facility which will be located off the active gasification zone.
- Design a surface facility for upgrading the produced gas to a marketable product. Both the field and surface facility designs will be detailed to the extent required for cost estimation. Detailed descriptions and diagrams of plot plans, equipment, piping, instrumentation, etc., will not be included.
- Outline a subsidence plan.
- Develop a budget-grade estimate of the cost of the pilot plant based on the design produced.

Figure 3-4. TASKS REQUIRED FOR PHASE IV, CONCEPTUAL PILOT PLANT DESIGN AND COST ESTIMATE

3.4.3 DETAILED DESCRIPTION OF PHASE IV ACTIVITIES

The network activity chart described in Section 3.1 of this report indicates interrelationships of the various project activities in Phase IV. The activities were briefly described to permit the reader to understand the tasks involved. This section contains a more detailed description of the Phase IV activities.

3.4.3.1 PILOT PLANT ESTIMATE (WBS 1.5)

The pilot plant design will be based on a western coal with properties similar to the coal gasified in the Phase III tests. Assumptions will be made as to the availability of water and other environmental conditions. The design will also be based on injecting air as the oxidant in the gasifying fluid, unless current experimental work by other programs has shown the feasibility and desirability of using oxygen as the oxidant. Using air injection causes nitrogen to be present in the produced gas at about a 50% ratio. The gas will be scrubbed to remove particulates and liquids, then desulfurized using any of several processes such as hot carbonate absorption, amine scrubbing, etc. The gas has a low heating value of 3730 to 7460 kJ/m³ (100 to 200 Btu/SCF) and will be used as fuel for a gas turbine which drives an electric generator.

If oxygen injection is used, the surface facilities could be designed to manufacture a number of products such as substitute natural gas, medium heating value fuel gas, and chemicals such as methanol and ammonia. If medium heating value fuel gas 11 200 to 14 900 kJ/m³ (300 to 400 Btu/SCF) is chosen, upgrading the crude gas will be similar to that described above for the low heating value gas. This gas could also be used as fuel for a gas turbine. For the substitute natural gas 33 600 kJ/m³ (>900 Btu/SCF) option, the medium heating value gas will be further upgraded by: (1) shifting to adjust the H₂/CO ratio for methanation; (2) carbon dioxide removal; and (3) methanation. The design and cost estimate of the shifting, CO₂ removal, and methanation units will be kept separate from the design and cost estimate of the remainder of the pilot plant.

The conceptual design will provide for the treatment and disposal of wastes in an environmentally acceptable manner. Water availability and quality will be based on an assumed western location and the water system, including water treatment and the cooling water system, will be designed on this basis. Other supporting facilities included in the design will be steam generators for providing utility steam for the gas upgrading plant and steam power for some of the compressors.

As shown in Figure 3-5, the conceptual pilot plant design will be divided into two basic areas: the field facility located at the active gasification zone and a surface facility. The field includes the injection and production wells, piping, and a transportable production field station. Equipment on the transportable field station will include field compressors for transmitting the gas to the surface facility, linking compressors, tar separation equipment, boilers (if steam is injected), and other equipment required near the gasification zone. The surface facility will include air compressors or an oxygen plant, depending upon which oxidation method is selected, the gas upgrading facilities, utilities, and miscellaneous off-site equipment. A diagram of the pilot plant layout is shown in Figure 3-5.

Most aspects of the field facility will depend on the results of the Phase III experimental program such as the best well configurations, well spacing, and well completion techniques for gasifying steeply dipping coal beds. Certain aspects, however, such as the number of wells, rate of gasification, well depth, and gas composition will also depend on the particular coal seam and properties chosen for the pilot plant. Costs pertinent to these aspects may vary for other coals.

The conceptual design for the pilot plant will include material balances, flowsheets, information on the injection and production wells, information on field piping, and descriptions and sizes of major items of equipment. The design will be detailed to the extent required for the cost estimation. Detailed descriptions and diagrams of plot plans, minor equipment, piping, instrumentation, etc., will not be included.

Budget grade cost estimates for major equipment items such as compressors, desulfurization units, etc., will be obtained from equipment suppliers and licensors. Other costs will be based on historical information.

Figure 3-5. PLAN VIEW OF SURFACE FACILITIES

3.4.4 PHASE IV DELIVERABLES

A final report will be prepared which will contain the conceptual design and cost estimate for the pilot plant and further pertinent comments on the concept of underground gasification of steeply dipping coal beds not included in the Phase III report.

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORTFORM APPROVED
DATE 10/30/77

1. Contract Identification Underground Coal Gasification for Steeply Dipping Coal Beds		2. Reporting Period 1/1/78 through: 1/31/78		3. Contract Number EF-77-C-03-1472																				
4. Contractor (name, address) GULF RESEARCH & DEVELOPMENT COMPANY P. O. Drawer 2038 Pittsburgh, PA 15230		5. Contract Start Date 9/30/77		6. Contract Completion Date 9/30/82																				
7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months																		10. Percent Complete				
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1.1.1	Env. Anal. of Concept Design																							
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1.1.3	Prepare EIA																							
1.2	GEOLOGY																							
1.2.1	Initial Data Collection																							
1.2.2	Mapping																							
1.2.3	Site Evaluation																							
1.2.4	Geological Data Analysis																							
1.2.5	Hydrological Testing																							
1.2.6	Core Analysis																							
11. Remarks See Page 7 for major milestone definitions.																								
12. Signature of Contractor's Project Manager and Date												13. Signature of Government Technical Representative and Date												

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORT

Form approved
OMB NO. 2501-0047

1. Contract Identification Underground Coal Gasification of Steeply Dipping Coal Beds		2. Reporting Period 1/1/78 through 1/31/78		3. Contract Number EF-77-C-03-1472																									
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1.3.6	Ø II Technical Direction and Ø II Report																												
1.3.7	Test # 1 Data Analysis																												
1.3.8	Test # 2 Data Analysis																												
1.3.9	Test # 3 Data Analysis																												
1.3.10	Ø III Final Report																												
1.3.11	Ø III Technical Direction																												
11. Remarks																													
12. Signature of Contractor's Project Manager and Date													13. Signature of Government Technical Representative and Date																

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U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORT

FORM APPROVED
OCT 10 1976

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1.4.3	Checkout Software																								
1.4.4	Procurement Package Preparation																								
1.4.5	Field Engineering																								
1.5	PILOT PLANT COST ESTIMATE																								
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1.6.1	Parametric Cost Estimate																								
1.6.2	Econ. Anal. for Eng. Design																								
1.6.3	Field Data Economic Analysis																								
1.7	TECHNOLOGY TRANSFER																								
1.7.1	Inter-ERDA Coordination																								
11. Remarks																									
12. Signature of Contractor's Project Manager and Date													13. Signature of Government Technical Representative and Date												

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U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORT

FORM APPROVED
DATE 10/28/77

1. Contract Identification Underground Coal Gasification for Steeply Dipping Coal Beds		2. Reporting Period 1/1/78 through 1/31/78		3. Contract Number EF-77-C-03-1472																																																																		
4. Contractor (name, address) Gulf Research & Development Company P. O. Drawer 2038 Pittsburgh, PA 15238		5. Contract Start Date 9/30/77		6. Contract Completion Date 9/30/82																																																																		
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U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
MILESTONE PLAN AND MANAGEMENT REPORTFORM APPROVED
OAS 10-300

1. Contract Identification Underground Coal Gasification for Steeply Dipping Coal Beds		2. Reporting Period 1/1/78 through 1/31/78		3. Contract Number EF-77-C-03-1472																																																						
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MAJOR MILESTONES

1. 1 Oct 78: Permit Application Submittal; Preliminary Site Restoration Plan Complete
2. 2 Jan 79: Site Characterization Complete
3. 1 April 79: Start Construction, Phase A
4. 1 July 79: Phase A Facilities Transfer
5. 15 July 79: Permeability Test
6. 1 Aug 79: Start Construction, Phase B
7. 15 Jan 80: Equipment Delivery and Installation
8. 1 April 80: Drilling for Burn #2
9. 15 June 80: Burn #1 Facilities Transfer
10. 15 July 80: Burn #1 Ignition
11. 1 Aug 80: Burn #2 Facilities Transfer
12. 15 Sept 80: Burn #2 Ignition
13. 1 April 81: Start Construction, Phase C
14. 1 July 81: Start Construction, Phase C
15. 1 Sept 81: Burn #3 Ignition
16. 15 Nov 81: Start Post Burn Environmental Monitoring
17. 13 Sept 82: Project End

1. Contract Identification Underground Coal Gasification for Steeply Dipping Coal Beds																	2. Contract Number EF-77-C-03-1472							
3. Contractor (Name, address) GULF RESEARCH & DEVELOPMENT COMPANY P. O. Drawer 2038 Pittsburgh, PA 15230																	4. Contract Start Date 9/30/77							
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0.1	Project Management																879	880	881	882	8			
1.1	Env. Planning & Analysis																1288	958	958	468				
1.2	Geology																357							
1.3	Experimental Approach Anal.																2795	10	10					
1.4	Engineering Design																3320	91	91	291				
1.5	Pilot Plant Estimate																6199	894	224					
1.6	Economic Analysis																							
1.7	Technology Transfer																276	672	672	512				
2.1	Field Test Operations																1800							
3.1	Equip. & Facilities Acquis.																2237	8147	2598	267				
3.2	Site Operation																3660	18007	21915	8608				
3.3	Environmental Operation																2760	2685	2862	2052				
3.4	Site Safety																1373	2280	2281	1140				
4.0	Program Control																8667	8112	8112	4512				
14. Total																	46271	30576	48343	14130				
15. Remarks																	16. Manpower Expressed In: Hours				17. Manpower Plan Date 2/20/78			
18. Signature of Contractor's Project Manager and Date																	19. Signature of Government Technical Representative and Date							

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

ENERGY RD&D WORK IN PROGRESS

1. DESCRIPTIVE TITLE OF WORK

Underground Gasification for Steeply Dipping Coal Beds

2. PERFORMING ORGANIZATION CONTROL NUMBER

PDN-77-128 (Proposal Number 600CH101)

3. CONTRACT OR GRANT NUMBER

EF-77-C-03-1472

4. CONTRACTOR'S PRINCIPAL INVESTIGATOR/PROJECT MANAGER AND ADDRESS WHERE WORK IS PERFORMED

A. NAME (LAST, FIRST, MI) Daniel, Jerry H. PHONE 303 988-8140

B. BUSINESS ADDRESS: STREET Suite 610, 134 Union Blvd.
CITY Lakewood STATE CO ZIP 80228

5. A. NAME OF PERFORMING ORGANIZATION

Gulf Research & Development Company Corporate Research & Chemicals
(Organization) (Department)

B. MAILING ADDRESS (IF DIFFERENT FROM 4B)

P. O. Drawer 2038, Pittsburgh, PA 15230

C. TYPE OF ORGANIZATION PERFORMING THE WORK (Enter applicable code from instructions)

☒ NIP ☐

6. SUPPORTING ORGANIZATION

A. ERDA PROGRAM DIVISION OR OFFICE (FULL NAME) Fossil Fuels Division

B. TECHNICAL MONITOR (LAST, FIRST, MI) Hagen, Amelia PHONE 303 234-5791

C. ADDRESS (If Different from ERDA Hqs) DOE-Denver Project Office, 10755, Yukon, Denver, CO

D. ADMINISTRATIVE MONITOR (LAST, FIRST, MI) Reardon, D. E., San Francisco Operations Office

7. PROJECT SCHEDULE

A. START DATE October 1977 B. EXPECTED COMPLETION DATE September 1982
(Month) (Year) (Month) (Year)

8. A. FUNDING OPERATING AND CAPITAL EQUIPMENT OBLIGATION IN THOUSANDS OF DOLLARS

FUNDING ORGANIZATION(S)		CUMULATIVE PRIOR FISCAL YEARS	CURRENT FY	NEXT FY	ESTIMATED FUNDING SUBSEQUENT FISCAL YEARS TO COMPLETE
1. ERDA	OPERATING	372.1	1548.2	2755.0	\$8074.5
	CAPITAL				
2. GR&DC	OPERATING	21.9	90.5	162.2	475.4
	CAPITAL				
3.	OPERATING				
	CAPITAL				

B. ERDA BUDGETING AND REPORTING CLASSIFICATION CODE BL-02-04

9. DIRECT SCIENTIFIC AND TECHNICAL MANPOWER

	PROFESSIONAL	GRAD. STUDENTS	OTHER	TOTAL
NUMBER	10	-	5	15
EQUIVALENT MANYEARS	6.3	-	3.2	9.5

10. SUMMARY OF WORK (Limit to 200 words or less — include a description, objective, approach, and a final product expected).

Objective: Develop and demonstrate the technology for in situ gasification of steeply dipping coal beds; to verify economic feasibility and provide a preliminary design and cost estimate for a pilot scale project.

Approach: Appropriate geological, hydrological and coal seam permeability evaluation will be performed prior to actual in situ combustion testing. The first burn will utilize a single set of vertical wells, backward burn linking and air injection. Subsequent tests will evaluate down dip production wells, Russian technology, with a single extended module (1 production, 2 injection wells) and the final burn will be a 2-module configuration (2 production, 4 injection wells). This burn will evaluate air/water injection and could last up to 80 days. Linking will be attempted using backward burn techniques and a sweep of the seam through simultaneous module operation. Economic process parameters, product gas composition and environmental effects will be monitored throughout the field test program.

Expected Product: Preliminary design and cost estimate for a pilot scale project.

11. PROGRESS SINCE LAST REPORT (Limit to 100 words)

Preliminary geologic and hydrologic studies were completed and the North Knob, WY site selected for the first UCG/SDB test site.

A detailed report covering the environmental analysis of concept design, environmental monitoring program, parametric cost estimation, preliminary facility design, geologic studies and detailed technical approach was completed and submitted for review.

Detailed plans, costs and schedules were prepared for phases II and III field activities and Phase IV pilot plant design activities and submitted for review.

12. List publications in the last year that are available to the public which have resulted from the product. (Please give a complete bibliographic citation. Use additional sheets if necessary).

None

13. GENERAL TECHNOLOGY CATEGORIES (Enter applicable code or codes from instructions)

☒ A ☒ 3 ☒ A ☒ 1 ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

14. PHASE OF RD&D (Enter Project Percentage in Applicable Boxes)

1. ☐ Basic Research
2. ☒ Applied Research
3. ☒ Technology Development
4. ☐ Engineering Development
5. ☐ Demonstration

15. KEYWORDS: (Minimum of 5)

Gasification
Coal Gasification
Energy Conversion
Fossil Fuels
In Situ
Natural Gas
Steeply Dipping Coal Beds

16. A. RESPONDENT'S NAME & ADDRESS

B. PHONE NO.

C. DATE

R. A. Bebout
Gulf Research & Development Company
Pittsburgh, PA 15230

412-362-1600

February 17, 1978

4.0 CONCLUSIONS

4.1 General

The most significant conclusion emanating from the Phase I work is that the present program is the minimum effort that has any chance of meeting the primary project objective. However, the knowledge gained by performing the program can be greatly improved and expanded by increasing the tools available to evaluate the data obtained. Additionally, the chances of successfully completing the program will be improved by expanding the areas of highest technical risks (second site, slant drilling, process modeling). The significance of maximizing the use of LLL, LERC, and Sandia experience increased as a result of comparing the work scope with the budgetary restraints.

The Phase I work emphasized the need for a site, overall technical approach, test plan, instrumentation, and facility to maximum use of LLL, LERC, and Sandia experience. The utilization of that experience must include review of published literature, direct contact between technical personnel, on-site consultation during the actual tests, and independent review of the test results.

Areas where the LLL, LERC, and Sandia experience is not sufficient are in slant drilling, permit acquisition, understanding of the coal movement due to dip during the reaction, quenching, subsidence, and costing. Because of the lack of experience in these areas, the risks are larger.

The project plan can be implemented in the remaining 54 months if all milestones are met as presently scheduled. However, the schedule analysis effort accomplished in Phase I revealed that the current plan is highly success-oriented and contingency plans are required to reduce the attendant risks.

Phase I work enhances Gulf's original proposal idea that this program should provide a major step toward commercializing the UCG process. The government objective of transferring the LLL, LERC, MERC, Sandia experience to the industrial-commercial sector would best be implemented by:

- investigating the use of pure oxygen as the injection gas
- characterization of the UCG resource
- developing instrument systems usable in a commercial operation versus a development operation

The conclusions reached about the more detailed portions of the program including proposed contingency plans are presented in the following sections:

Site: The North Knobs site is the best site for conducting the first tests to gasify steeply dipping coal beds. This conclusion was reached from a review of the U.S. steeply dipping bed resource that began with a broad investigation of the total resource and became more detailed as the number of potential sites was progressively reduced. The most detailed investigation was performed at the North Knobs site. The two Colorado sites that were considered candidates at contract award were eliminated because of technical and legal problems.

The reasons for selecting the North Knobs site are:

- It maximizes the ability to transfer existing UCG knowledge into the SDB program.
- Two coal seams on the site that are of an acceptable thickness and dip for the project,
- Subbituminous coal,
- Water table at 35 meters,
- Non-potable ground water,

- No evidence of major faults in the geology,
- Relatively simple geology as compared to other sites,
- Easy access to test area,
- Little surface vegetation, and
- Relatively flat terrain.
- It minimizes the risks associated with developing slant drilling capability.

However, the possibility remains that detailed geotechnical site investigation will necessitate reconsidering another site. Therefore, a secondary site will be selected and a preliminary geotechnical evaluation performed.

Overall Technical Approach: To maximize the chances of successfully installing, linking, igniting, sustaining, and extinguishing an SDB test, the untried areas must be minimized. The untried areas must be investigated as thoroughly and early as possible. Slant drilling must be tried in 1978 to assure that the first module can be successfully installed in time for the first burn. Process modeling capability must be available to properly predict instrumentation placement and evaluate the final test plan.

After final management review of the overall technical approach and test plan, it is concluded that understanding of the coal and roof collapse process in the reactor and its effect upon the process would be enhanced by putting some reactor definition instrumentation in the first test. Burn No. 1 and No. 2 would then provide two points on the curve.

The ability to optimize the process variables, establish the effects of subsurface subsidence on the process, determine resource utilization, and determine the impact of the process upon the environment introduces additional program expansion needs. In these areas, the process model is again needed to develop the test plan and to optimize instrumentation placement. In addition, the length of Burn No. 2 (80 days) is insufficient to determine optimum module life. Extension of the

length of Burn No. 2 from 80 to 120 days is necessary for determination of the optimum process module life for economic projections for the commercial process. Off-the-shelf instrumentation must be reviewed again in more detail during Phase II considering the data collection criteria established by the test plan. To maximize the benefits of the tests, other instrumentation options should be included.

Available instrumentation systems will probably be adaptable to obtain the required information, but their applicability to a commercial operation needs a great deal of improvement.

Understanding of the coal and roof collapse process would also be enhanced by having a rock mechanics model. A water table above the reactor will provide sufficient quenching capability and minimize leakage from the cavity; however, the inherent complexity of geology associated with steeply dipping beds and the concomitant risk dictates that an effort must be introduced in Phase II to investigate all techniques that might be available for quenching. (This conclusion was reached at the end of Phase I and, therefore, is not reflected in other portions of this report.)

Facility: The facility design, construction, scheduling, and costing are a relatively straightforward adaptation of the existing experience. Slant drilling developments and permit acquisition are the undeveloped areas that will perturbate the adaptation process.

Environmental

Environmental analysis of the concept design concludes that the project's impact upon the environment will be minimal and within government regulation. Hydrology impact will be the most significant. Information required by the permitting process and the project objectives should be analyzed using a hydrology model. The use of a model should be included in the program. There may be an existing model that could be used. The complexity of steeply dipping strata may be beyond the capability of existing models resulting in the need for developing a new subroutine or a complete new model.

Permit acquisition will require predictions of the environmental effect of the flare gases and leakage gases. Such predictions will require the use of environmental air movement models. The use of existing models would have to be included in the scope of the program.

4.2 Deliverables from DOE

The following software used by Sandia, Lawrence Livermore, and the Laramie Energy Research Center for the operation and interpretation of their UCG tests is required:

- (a) Program names
- (b) User's manuals where available
- (c) Other relevant documentation
- (d) Program listings

This should include programs for the following:

(1) Computer control of the operational variables such as air injection rate and pressure, water injection rate (if available), pressure on production wellhead and others if available.

(2) Computer control of analytical devices such as chromatograph operation, gas cleanup system operation, and others if available.

(3) Cyclic computer collection, storage, and display of operational and analytical data.

(4) Data reliability checkout systems such as automatic data comparison from redundant systems, and computer determination of equipment malfunction.

(5) The performance and interpretation of reactor definition tests, such as subsurface temperature, in seam gas sampling and pressure, subsidence measurements, electrical monitoring tests, and passive and induced seismic monitoring. These tests were made by Sandia Labs at Hanna II. Lawrence Livermore's helium tracer and radio frequency techniques and programs for determining reactor volume and shape are also requested.

(6) Real time data analysis programs such as "RDFIL," "UPLOT," "PNOW," "PLASS," "SANDY," "MATBL," and "CHANG" and others if available.

This information is required early in Phase II to allow our personnel to become familiar with and possibly add to it prior to acquisition of the hardware.

5.0 RECOMMENDATION

The conclusions result in several recommendations for improving the success probability of the project and the amount of knowledge to emanate from this effort.

In summarized format, the recommendations are:

- Alternate site selection
- Accelerate slant drilling R&D
- Increase predictive and analytical capability
 - Process model
 - Rock mechanics model
 - Environmental modeling
- Resource characterization
- O₂ test
- Instrumentation
- Length of Burn No. 2

Details regarding each of these recommendations, where available, are provided in the following sections.

5.1 Alternate Site Selection

This program is to define and characterize two additional sites for gasification of steeply dipping coal beds. These sites will be used if either: (1) the North Knobs site is found to be geotechnically unacceptable, or (2) the program is later expanded to multiple sites.

The proposed project will select three sites in June and subsequently have some geological and hydrological drilling completed.

Activities within this program will include:

- Reviewing the available literature on coal deposits in the western United States and selecting two potential UCG sites within each state that has an SDB resource (New Mexico, Washington, Montana, Utah, and Colorado, as a minimum).
- Visit the prime sites in each state with geotechnical personnel and observe their topographic, geologic, botanic, and cultural setting; and select the five best UCG-SDB locations.
- Visit the five best UCG-SDB locations with a Gulf/TRW technical team and reduce the list to three UCG-SDB sites.
- Obtain leases for the three UCG-SDB sites.
- Define the local topographic, geologic, and hydrologic characteristics of the three UCG-SDB sites through a surface geologic mapping and exploratory drilling program; and identify the permit requirements to operate at those three sites.
- Select one or two of the three sites for retention as alternate sites.

The cost for selecting and evaluating the three sites is estimated to be \$290 000.

5.2 Slant Well Drilling

This program will retain a drilling consultant to: design a well and well completion based on the criteria established in the test plan.

- Review existing drilling rigs regarding their usability to complete the well, including availability.
- Design modifications as required for the selected drilling.
- Modify the rig.
- Move the rig to the site.
- Drill the test well.
- Inspect the well and compare the results with the criteria and design.
- Decide whether the drilling capability is sufficient or another iteration is required.

5.3 Process Modeling

The plan to develop an appropriate mathematical model for the underground gasification of steeply dipping coal contains five tasks. These tasks are:

- Identify concept for representing the unique (falling coal face, fixed pit) aspect of the process.
- Code and test the concept's ability to handle mass transfer by solids transport.
- Transfer relevant process concepts from existing process models (thermochemical features within the reaction face, as well as gaseous mass transport to and from the reaction face).

- Add thermochemical and gas transport features to the fixed pit part of the model.
- When experimental data become available, evaluate strengths and shortcomings of the model for predicting experimental observations.

5.4 Rock Mechanics Modeling

The rock mechanics modeling effort would include:

- Review of available models.
- Selection of a suitable model.
- Make revisions as needed.
- Input site data for prediction of subsidence.
- Core post burn reactor zone.
- Evaluate prediction with post burn data.
- Revise model.

5.5 Environmental Modeling

The environmental modeling effort will attempt to utilize air dispersion and hydrology models available within the corporation. If those models are available, the effort will concern itself with needed revisions and applications of the models to project data. If suitable models are not available, the effort will include acquisition of the models in addition to revision and utilization.

5.6 UCG-SDB Resource Characterization

The site evaluation work to date has shown that there is no one SDB field that typifies the national SDB resources. The addition of dip to the usual variables for UCG resources introduces additional degrees of uniqueness. TRW has compiled an estimate of the nature of the national SDB resource. The work needs to be carried to the next level of detail; i.e., characterization of each resource with regard to additional process problems that require resolution prior to commercialization of said resource.

Each SDB field presents some problems (or combination of problems) to commercialization that are site specific. A few of the variations are:

- Rank of coal
- Angle of dip
- Thickness of coal
- Amount of fracturing of coal and overburden
- Overburden composition
- Drilling problems
- Terrain
- Hydrology
- Number of seams

Each site will present surface operations problems that include:

- Ability to operate on the terrain
- Availability of required technical capability in the local area
- Availability of services, supplies, and manpower.

The potential for commercialization will vary from site to site. Phase IV of the present SDB project will produce a pilot plant project cost estimate, ostensibly for a subsequent project leading to commercialization of the process for SDB gasification. An element that should be addressed is the location of that project in an area with the greatest potential. The present project will demonstrate UCG in a steeply dipping bed. It will have a high degree of site specificity. Inherent in the cost estimate are site specific parameters. Characterization of the national resource would provide basic information relating to site specific parameters for subsequent projects.

GR&DC plans to submit a proposal for program modification to characterize the national SDB resource to a higher level of detail than now exists. The tasks would include evaluation of available data on the resource, some exploratory drilling to validate geological/hydrological data, estimations of technical problems related to site parameters, and estimation of commercial potential.

5.7 Oxygen Test

An oxygen test would involve:

- Development of test design.
- Modification of existing facilities to handle oxygen.
- Performance of the test.
- Analysis of the test data.
- Inputting test data to the economic model.
- Evaluation of technical and operating problems of oxygen usage for a commercial operation.

5.8 Instrumentation

The instrumentation recommendations are twofold, increased utilization of reactor definition instrumentation in the present program and an additional program to develop instrumentation for the commercial UCG installation.

Expansion of reactor definition instrumentation would:

- Install instrument wells in Burn No. 1.
- Increase instrumentation quantity in Burn Nos. 2 and 3.
- Investigate alternate types such as high resolution seismic.

An instrumentation development program would:

- Establish criteria for instrumentation of a commercial operation.
- Review available instrumentation with that criteria.
- Define areas where capability is lacking.
- Formulate a development effort to provide those capabilities.
- Propose an additional program to develop the required instrumentation.

5.9 Increased Length of Burn No. 2

The length of time that a module can be operated to produce gas of acceptable quality is an essential factor for commercialization. During Phase II the test plan will establish a duration for Burn No. 2 that will be long enough to obtain the desired information. A proposal for a contract modification to accommodate the longer burn will be prepared and submitted to DOE.

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