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HAZARD ANALYSIS REPORT

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**HERCULES AEROSPACE DIVISION
HERCULES INCORPORATED
ALLEGANY BALLISTICS LABORATORY
CUMBERLAND, MARYLAND**

**SAFETY ANALYSIS OF THE CSTR - 1
BENCH - SCALE COAL
LIQUEFACTION UNIT**

MAY 1981

D. A. HULBURT

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PREPARED FOR

**U. S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
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Conclusions presented in this hazards analysis report are based upon the hardware (or design), materials of construction, operating conditions, process materials and procedures as they existed at the time of the analysis (or as they were presented to Hercules for analysis). If changes in any of these parameters occur in the future, the conclusions of the current hazard analysis may be invalidated.

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I. SUMMARY

A. OBJECTIVE

The objective of the program reported herein was to provide a Safety Analysis of the CSTR-1 bench scale unit located in Building 167 at the Pittsburgh Energy Technology Center. This Safety Analysis conforms to DOE Order 5481.1⁽¹⁾ and was performed in accord with the "Management Implementation Plan for a Safety Analysis and Review System"⁽²⁾ developed as a separate task under the same contract, with one exception: an audit of the unit to demonstrate conformance with all guides, codes, and standards was excluded as being out of scope of the present contract.

B. CONCLUSIONS

It was apparent that considerable effort was expended in the design and construction of the unit, and in the development of operating procedures, with regard to safety. Exhaust ventilation, H₂ and H₂S monitoring, overpressure protection, overtemperature protection, and interlock systems have been provided. Present settings on the pressure and temperature safety systems are too high, however, to insure prevention of vessel deformation or damage in all cases. While the occurrence of catastrophic rupture of a system pressure vessel (e.g., reactor, high pressure separators) is unlikely, the potential consequences to personnel are severe. Feasibility of providing shielding for these components should be considered. A more probable mode of vessel failure in the event of overpressure or overtemperature and failure of the safety system is yielding of the closure bolts followed by high pressure flow across the mating surfaces. As a minimum, shielding should be designed to restrict travel of resultant spray. The requirements for personal protective equipment are presently stated in rather broad and general terms in the operating procedures. Safe practices and procedures would be more assured if specific requirements were stated and included for each operational step.

No specific Risk Criteria were provided by PETC for the conduct of this analysis. In the absence of specific Risk Criteria, the Implementation Plan⁽²⁾ specifies a set of Recommendation Guidelines as 'triggers' for making recommendations for individual hazards. Recommendations were developed for all hazards 'triggered' by the guidelines. The overall probability of incident, as a function of incident severity to personnel and facilities, was determined for the system as presently designed, and for the system with recommendations incorporated. These results are summarized in Table I. (The Recommendation Guidelines are reproduced in Table I-1 for the various incident severities to personnel and facilities.) Inclusion of the 'triggered' recommendations will reduce the probability of catastrophic incidents by a factor of over 2000, the probability of critical incidents by a factor of 4, and marginal incidents to personnel by a factor of 75.

C. RECOMMENDATIONS

The following recommendations are made for reducing the likelihood or severity of hazards 'triggered' by the guidelines, and are the basis upon which the calculations of overall incident probability were made. Additional recommendations for reducing the likelihood or severity of systems hazards are provided in Section III-B.

1. Change Set Point on Reactor Thermocouples to 550°C Maximum

Rupture of the reactor is categorized as a potential catastrophic hazard to personnel. Set points must be below the temperature at which reactor bolts may fail under pressure in order that probability of occurrence is within guidelines. Incorporation of this recommendation will reduce the probability from 3×10^{-4} to 6×10^{-9} .

2. Install Surge Check Valve on Suction Line to H₂ Compressor

This will mitigate rate of H₂ flow into compressor cabinet in the event of gross leak or rupture. Incorporation of this recommendation will reduce the probability of a critical incident from 5×10^{-6} to 1×10^{-10} and will reduce the severity of incidents with a likelihood of 5×10^{-6} from 'critical' to 'marginal.'

3. Use H₂ Instead of H₂S to Pressure Test H₂S System

This will eliminate possibility of H₂S exposure due to a leak from untested system, unless operator errs and uses H₂S by mistake. Probability of 'critical' exposure is reduced from 6.9×10^{-6} to 6.9×10^{-9} and probability of 'marginal' exposure is reduced from 2×10^{-3} to 7×10^{-6} .

4. Develop Procedures for Safe Handling of Plugs in the System

No procedures currently are included in the operating manual and therefore it was assumed (conservatively) that the operator could circumvent overpressure protection in attempting to free a plug. Inclusion of procedures for safely handling plugs reduces the overall probability of overpressurizing the slurry line from 9×10^{-4} to 5×10^{-6} (categorized as a 'marginal' hazard).

5. Transfer Compressed Gas Cylinders with Approved Cylinder Carts Only

Method of transferring cylinders is presently not specified and therefore it was assumed cylinders might be dropped at the general rate for an operator dropping an item. If cylinder carts are specified, the likelihood of dropping a cylinder is reduced by the probability the operator fails to follow established procedure.¹⁰ The probability of a catastrophic incident is reduced from 1×10^{-4} to 1×10^{-7} and the probability of a marginal incident is reduced from 1×10^{-4} to 1×10^{-7} .

TABLE I

OVERALL INCIDENT PROBABILITIES⁽¹⁾

	<u>Current System</u>	<u>System With Recommendations Incorporated</u>
Effects to Personnel		
Catastrophic	3×10^{-4}	1.3×10^{-7}
Critical	1.6×10^{-5}	4.2×10^{-6}
Marginal	3×10^{-3}	4×10^{-5}
Effects to Facilities		
Catastrophic	3×10^{-4}	1.1×10^{-7}
Critical	6.9×10^{-6}	1.9×10^{-6}
Marginal	3.4×10^{-5}	3.9×10^{-5}

(1) Based on 1 hour of operation.

TABLE I-1

RECOMMENDATION GUIDELINES⁽¹⁾

Descriptor	Incident Severity to Personnel	Guideline ⁽²⁾ Probability	Incident Severity to Facilities	Guideline ⁽²⁾ Probability
Catastrophic	Death or Permanent Total Disability	1×10^{-7}	Loss of large, expensive Operation or Building(s) or Off-site structure(s).	1×10^{-6}
Critical	Permanent Partial Disability	1×10^{-6}	Loss of major equipment item(s), some damage to ad- jacent units, loss of entire small Operation, significant production loss.	1×10^{-5}
Marginal	Temporary Dis- ability	1×10^{-5}	Moderate damage to major equipment item(s), but re- pairable, minor damage to adjacent units.	1×10^{-3}
Negligible	First Aid Case or None	1×10^{-3}	Minor damage to major equip- ment item(s), loss of minor equipment item or no damage.	1

(1) Taken from Reference (2).

(2) For one hour of operation.

II. INTRODUCTION

A. BACKGROUND

The CSTR-1 is a bench-scale continuous-flow coal liquefaction unit designed and constructed by the Catalysis Branch, Process Sciences Division, Pittsburgh Energy Technology Center. DOE Order 5481.1 requires that DOE Operations with hazards of a type or magnitude not routinely encountered and/or accepted by the public be analyzed to assure that potential hazards are systematically identified, potential impacts are analyzed, and that reasonable measures to eliminate, control, or mitigate the hazards have been taken. The Safety Analysis reported herein was conducted to meet these objectives. Work was carried out under Contract DE-AC22-80PC 30198. This report completes Task No. 1 of this contract.

B. SCOPE OF THE ANALYSIS

The scope of the analysis reported herein was the CSTR-1 process unit. The equipment modules which were within scope are identified in Table II. Bounds of the analysis with respect to slurry was the slurry feed tank. Slurry preparation, which is performed in another area, was not in scope. Bounds of analysis with respect to liquid products was draining of the product from the receivers. Testing of product and ultimate disposal was not in scope.

TABLE II

SCOPE OF CSTR-1 EQUIPMENT

Cylinder Rack Module
Gas Compressor Station Module
Gas Delivery Module
Slurry Feed Module
Reaction Module
Product Separation Module
Control and Interlock System

Similarly, the bounds of the analysis with respect to off-gases was the sampling of the gases. Handling, processing, or testing of samples was not in scope. Analysis of the facility building (Building 167) in which the unit is housed was not in scope. Interfacing of the unit with building systems such as ventilation and fire protection was considered, however.

The Safety Analysis reported herein conforms to DOE 5481.1 and the Implementation Plan⁽²⁾ developed under Task No. 4 of this contract with the one exception that an audit to demonstrate conformance to applicable guides, codes, and standards is not included. While this provision of DOE 5481.1 was noted, the vast number of applicable regulations was not evident until midway through the development of the Implementation Plan when the document specifying prescribed standards was identified and requested from PETC. The number of guides, codes, and standards which would have to be checked for applicability and then audited against is far beyond what anyone envisioned and is clearly beyond the scope of the present contract. A listing of prescribed standards is presented in Appendix D for reference. The Safety Analysis was conducted in accord with the Level 2 Safety Analysis requirements of the referenced Implementation Plan.

C. BASIS OF THE ANALYSIS

The Safety Analysis as reported herein was based on the process flow diagrams, material balance, equipment data, and operating procedures provided to Hercules or as represented to Hercules by the Pittsburgh Energy Technology Center. A detailed listing of the data and information package which was used as the basis of the analysis, is documented in Appendix A.

III. DISCUSSION

This section of the report contains a description of the CSTR-1 process and discussion of the safety analysis of the unit. The section consists of six subsections: A - Description of the Operation, B - Summary of Recommendations, C - Process Hazards Analysis, D - Workplace Health Analysis, E - Workplace Safety Analysis, and F - Environmental Analysis. A Level 2 safety analysis is reported herein. The Safety Analysis Level Determination⁽²⁾ which established this level of analysis is provided in Appendix E.

A. DESCRIPTION OF THE OPERATION

The CSTR-1 is a bench scale continuous-flow coal liquefaction unit designed to screen potential coal liquefaction catalysts (disposable and supported catalysts), to evaluate catalyst and process parameters, and to study catalyst aging mechanisms. Nominal operating conditions are ~2000 psig, ~430°C, and a coal slurry feed of ~800 gm/hr at ~25% coal. The unit consists of six process modules, a control system console, and ancillary equipment. A functional block diagram of the unit is shown in Figure III-1.

System gases (H₂ for liquefaction, N₂ for inerting/purging, H₂/H₂S if catalyst is to be pre-sulfided) are supplied to the unit in standard compressed gas cylinders at the cylinder rack. (Other gases such as synthesis gas may be used in place of H₂ at some future date). The nitrogen and hydrogen are compressed by respective compressors in the gas compression module and returned to high pressure (5000 psig) accumulators in the cylinder rack module. High pressure hydrogen, high pressure nitrogen, low pressure nitrogen and hydrogen/hydrogen sulfide are pressure and flow controlled in the gas delivery module which supplies the CSTR unit proper. Gas delivery module valving is designed to preclude the supply of high and low pressure gases simultaneously, or the supply of high pressure hydrogen and high pressure nitrogen simultaneously. The design is "fail-safe" in that high pressure purge nitrogen is supplied in the event of instrument air failure or power failure.

Pulverized coal is pre-slurried (SRC II heavy distillate carrier typical) and charged to a slurry feed tank in the slurry feed module. The tank is agitated and the slurry is recirculated to maintain a uniform suspension. The slurry is fed to the reaction module by one of two high pressure pumps. Flow rate is monitored by a load cell from which the slurry feed tank is supported.

The hydrogen-coal slurry is fed through a common line to a one-liter autoclave reaction vessel. The feed line first passes through a preheater. The preheater and the heater on the autoclave are used to control the temperature of the process. The reactor is agitated and, for supported catalysts runs, contains a bucket for the catalyst. Disposable catalysts are fed into the system with the coal slurry.

Figure III -1. CSTR -1 Functional Block Diagram

The reaction products flow from the reactor through a standpipe (which maintains level in the reactor) to the heavy oil separation section. This section consists of two high pressure heavy oil separators mounted in a vertical relationship. Associated piping and valving is designed so that the heavy oil is normally collected in the lower separator.

To depressurize and empty the lower separator, the system is first valved (solenoid operated valves) to isolate the lower separator and collect heavy oil in the upper separator. Once the lower separator has been emptied it is repressurized by system tail gas and the valving is reset to direct heavy oil to the lower separator. The heavy oil which was accumulating in the upper separator flows to the lower one by gravity. The heavy oil in the lower separator is let down through a valve to a heavy oil receiver which operates at ambient pressure. Flash gas from the depressurized heavy oil is directed through a meter to the system vent. The depressurization let-down cycle is performed on a time schedule basis which is designed to preclude overfilling of any of the heavy oil vessels.

Overheads from the heavy oil separators are directed to the light oil separation section. Water may be optionally injected into the vapor line, and a water cooled heat exchanger is also in the line to cool the feed stream to the light oil separation section. The operation of the light oil separation section is identical to that for the heavy oil separation section discussed above.

Tail gas from the light oil separators is directed through a flow meter to the system vent. System pressure is controlled by back-pressure regulators on the tail gas line. The system is provided with several high temperature shutdown switches, several high pressure shutdown switches and a number of pressure relief valves.

Potential process hazards of the CSTR-1 unit relate primarily to the high temperature-high pressure operating conditions and the flammability/explosivity characteristics of hydrogen and hydrogen sulfide. The extreme toxicity of hydrogen sulfide presents a health hazard to personnel especially in the event of an acute exposure. Coal derived liquids are suspected carcinogens and represent a potential long term health hazard. Personnel injury hazards relate primarily to handling of gas cylinders and to manual operating steps which may involve the use of a ladder, step stool or other similar device. The quantities and rates of flow of materials in the CSTR-1 process are so low that they do not represent any credible hazard or real concern to the environment.

The CSTR-1 unit is located in the high bay area of Building 167 at the Pittsburgh Energy Technology Center.

B. SUMMARY OF RECOMMENDATIONS

The recommendations discussed in subsequent sections are summarized below. These recommendations are offered as a means of reducing the likelihood or the severity of potential hazardous incidents in the operation of the CSTR-1 unit. Recommendations are presented in two categories: (1) those 'triggered' by the Implementation Plan Recommendation Guidelines (see Table I in Section I - Summary), and (2) those, which while not triggered by the guidelines are nonetheless offered as a means of maximizing the level of safety in the operation.

1. Recommendations 'Triggered' by Recommendation Guidelines

- a. Change set point on reactor thermocouples to 550°C maximum. Rupture of the reactor is categorized as a potential death or permanent disability incident. Set point must be below temperature at which reactor bolts may fail under pressure in order that probability of occurrence is within guidelines.
- b. Install surge check valve on suction line to H₂ compressor. This will mitigate potential H₂ flow into compressor cabinet in the event of gross leak or rupture.
- c. Use H₂ instead of H₂S to pressure test H₂S system. This will eliminate possibility of H₂S exposure due to leak from untested system.
- d. Develop procedures for handling plugs in the system to reduce possibility of overpressurizing system in attempting to free the plug.
- e. Transfer compressed gas cylinders with approved cylinder carts only, to reduce likelihood of personnel injury due to dropped cylinder.

2. Other Recommendations

Equipment

- a. Study feasibility of providing shields to protect operators from contents spray for reactor and high pressure separators.
- b. Install check valve in H₂ compressor discharge line to mitigate emptying accumulator in the event compressor ruptures rendering compressor discharge valve inoperable.

- c. Relocate PS-53 to between GC-51 and MV-58 and PS-54 to between GC-52 and MV-60. Pressure switches currently do not protect system if manual valves are closed between compressor and pressure switch.
- d. Relocate N₂ tie-in to high pressure H₂ line to upstream of CV-101 and CV-102. As presently configured, components upstream of check valves are not pressure tested since check valves prevent pressurization.
- e. Set points on PT-301, PT-302, and PT-401 be 4,000 psig maximum during operation.
- f. Provide warning/caution signs for H₂S and H₂ at cylinder rack and H₂ and high temperature, high pressure at CSTR-1 unit.

3. Procedures and Practices

- a. Devise procedures for testing all check valves for back leakage periodically. Present pressure tests are designed to detect external leaks only.
- b. Operating procedures should specify specific items of personal protective equipment required, and the operating steps for which they are required.
- c. Recommend that shutdown procedures include depressurization of accumulators (and purging of H₂ accumulator). Cylinder rack purge and test procedures seem to assume accumulators are empty, but no mention of so doing is made in current shutdown procedures.
- d. The order in which the various purge and pressure tests of the several modules are to be conducted should be stated up front, and the procedures should then be presented in that order.
- e. Recommend that H₂ lines be purged as well as vented before correcting leaks.
- f. Procedures for flush oil leak test of slurry feed module should state that MV-216 should be opened. This will allow for venting of pressure should operator fail to shutdown pump at 4,000 psig and relief valve operates.
- g. Procedures should include periodic inspection of accumulators for possible environmental (weather) damage such as corrosion; and testing in accordance with DOT regulations for compressed gas cylinders.

- h. Cleanliness and condition of rupture discs should be checked before each run.
- i. Closely monitor metallurgical condition of system pressure vessels and piping.
- j. Install protective covers on cylinder rack manifolds if cylinder is not installed at that spot.
- k. When pressure testing the compressor systems, abort the test if the pressure on the suction side is observed to be increasing. This indicates back leakage through the compressor and the suction side may become overpressurized.
- l. Procedures for draining receivers should state that less than 10 psig must be confirmed before opening valve, and should specify goggles, full face shield, and protective gloves and apron.
- m. Use only approved ladders or platforms for any work that can't be done safely from the floor surface.
- n. Check that all guards are in place before starting a run.
- o. Review Operating Manual for incorrect valve number designations. (Those identified in the course of analysis have been noted in the manual which will be returned to use as a guide.)

C. PROCESS HAZARDS ANALYSIS

The process hazards analysis is a constituent analysis of an overall safety analysis and considers the hazard consequences of fire/explosion, material release, and vessel failure due to component failure(s), operator error(s), process upset, procedural deficiency, or design characteristics. A discussion of the process hazards analysis of the CSTR-1 unit is presented in the paragraphs which follow. The discussion is accompanied by hazards analysis fact sheets which document the individual identified process hazards.

1. General

a. High Pressure and Temperature

The set points on the system pressure transducers and thermocouples are presently stated to be 4500 psig and 700°C, respectively. These values are in excess of the component ratings. It is recommended that the set points be changed to 4000 psig and 550°C, respectively. The basis of these values is as follows. The AE10V4071 valves in the system are rated at 11,500 psig at room temperature. This rating is based on the cold-worked properties of Type 316SS and is valid so long as operating temperature does not exceed 800°F. Once 800°F is exceeded a permanent metallurgical change occurs and the valve must be derated to 4600 psig at room temperature. Nominal process conditions for the CSTR-1 were stated at 430°C (806°F). Thus, it cannot be guaranteed that due to process upset or a planned run at higher temperature, that a valve or valves will not be exposed to a temperature above 800°F. Therefore the derated valves are judged to be the proper basis for the rating of the unit.

At higher temperatures, the pressure rating of the system vessels becomes limiting. The limiting factor in the design of the standard autoclave/pressure vessel is the SA193B16 cap screws. The allowable P-T envelope based on the derated valves and the pressure vessels is shown in Figure III-2. The allowable envelope is based on ASME pressure vessel code (62.5% of yield stress). The curve based on 90% of yield stress is also shown.

The guidelines used in establishing the set points were as follows: 1) maximum working pressure should not be exceeded at design temperature, 2) temperature should not exceed maximum working pressure envelope at design pressure, and 3) 90% yield stress envelope should not be exceeded in the event of both temperature and pressure excursions. Based on these considerations, the set points of 4000 psig and 550°C were selected. (Note that the first guideline is exceeded slightly).

b. Pressure Tests for Leaks

The operating procedures contain an extensive set of procedures for testing the system for external leaks. However component testing

Figure III-2. Pressure - Temperature Ratings

for internal leaks is only incidental to these procedures, and in particular system check valves are not tested for back leakage. To minimize possibility of backflows or cross contamination, it is recommended that procedures be established to test check valves for backflow periodically.

c. Operating Procedures

Substantial effort to provide a complete set of operating procedures is evidenced by the existing operating manual. To improve the clarity of the procedures with regard to the number of different purge and pressure test procedures, it is suggested that the prescribed order of the various procedures be stated at the outset and that the individual procedures then be presented in that order. For example, one would not want to H₂ pressure test the cylinder rack until the gas compressor station had first been pressure tested but this is not clearly evident by the order of the procedures in Section IV. Not until Section V is some mention made of the proper order for the various tests.

The operating procedures contain some general overall statements with regard to personal protective equipment. Specific personnel protective equipment requirements should be stated and the specific requirements should be included with the individual operating procedure. For example, the procedure for sampling tail gas should specify personal protective equipment, if different or in addition to that required in the general area.

The purge/pressure test procedures for the cylinder rack seem to presume the accumulators are depressurized at the outset. However, the shutdown procedures do not indicate any steps to depressurize the accumulators or to purge the H₂ accumulator on shutdown of the unit on the previous run. These steps should be included in the shutdown procedures to preclude presence of high pressure nitrogen or hydrogen in the accumulators when in a standby or shutdown mode. Purge/pressure test procedures should include a check of accumulator pressure gauges before proceeding.

Disconnected cylinder manifold lines should not be left exposed, but should be provided with a protective cover if disconnected for a period of time. Present procedures for "back-blowing" the lines should nevertheless be retained.

Statement on Page IV-6 relative to closing all valves should include gas compressor station and valves on supply lines to the units served.

The cylinder rack area, compressor cabinet, and unit proper should be provided with appropriate warning/caution signs for hydrogen and hydrogen sulfide.

A number of typographical errors/misnumbered component designations were discovered in the course of reviewing the procedures. These are marked in the copy of the operating manual used for conducting the analysis.

2. Documentation of Identified Process Hazards

Individual identified process hazards are tabulated and documented on "Process Hazards Analysis" fact sheets. The following discussion provides a description and interpretation of each of the column entries on the fact sheets. A blank fact sheet is presented in Figure III-3 for reference.

a. Potential Event and Causative Factors

A description of the potential hazardous event accompanied by a description of the failure(s) which must occur for the event to occur, is entered in the first column. A sequential Hazard Number is assigned to the Potential Events for use in referencing the Table entry in the text of the discussion.

b. Event Probability

The calculated probability of occurrence of the 'Potential Event' described, based on the failure logic as described by 'Causative Factors' is entered in the second column. The calculation procedure is described in Appendix B and the failure data used are documented in Appendix C.

c. Potential Effect and Consequences

A description of the potential effect of the identified event accompanied by a description of the consequences to personnel and/or equipment is entered in the third column. Effects may be such things as equipment rupture, fire/explosion, or release of toxic material. Consequences describe the extent of potential injury/illness to personnel or damage to equipment.

d. Effect Probability (Effect Prob.)

Probability that the stated 'Potential Effect' will occur, given occurrence of the Potential Event, based on engineering analysis and judgment, is entered in the fourth column.

e. Consequence Probability (Conseq. Prob.)

Probability that the stated 'Consequence' will occur, given occurrence of the Potential Event and Potential Effect, based on engineering

SYSTEM: _____ SUBSYSTEM: _____ EQUIPMENT: _____

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		

Figure III-3. Process Hazards Analysis Fact Sheet

analysis and judgment, is entered in the first subcolumn for 'Personnel' or 'Equipment' as appropriate.

f. Incident Probability (Inc. Prob.)

The Incident Probability is obtained by multiplying the 'Event', 'Effect', and 'Consequence' probabilities, and represents the overall probability that the stated consequence will occur due to the indicated hazard.

g. Hazard Category (Haz. Cat.)

Hazard Severity Categories as defined in Table III are entered.

h. Existing Control Measures

Existing measures and safeguards which control or mitigate the hazard are documented.

i. Comments and Recommendations

Recommendations for eliminating, controlling or mitigating the hazard, or comments are entered. Recommendations are mandatory for hazards which violate the Recommendation Guidelines (Table I, page I-2).

3. Cylinder Rack

Identified process hazards in the cylinder rack module relate to cross contamination of nitrogen supplies with H_2 or H_2/H_2S , external leaks of H_2 or H_2/H_2S , bursting of accumulators, or accidents in handling compressed gas cylinders. The cylinder rack analysis is documented in Table III-1. Hazards are referred to by the entry number (Hazard Number) in the first column of the table.

The likelihood of cross contamination is very low based on the number of valves normally closed and the system check valves which are designed to prevent backflow. Testing check valves periodically for backflow (as recommended in Paragraph 1 - General) will ensure that any failed components are discovered and that the likelihood remains low. Potential cross contamination hazards are documented as Hazards 1-6.

The likelihood of external leaks of H_2 or H_2/H_2S is governed by the number of potentially leaking components in each section of line. The system is pressure tested with N_2 prior to admitting H_2 or H_2/H_2S , which should eliminate gross leaks. Nonetheless, due to the molecular dimension of H_2 , hydrogen leaks in the absence of N_2 leaks are possible. During the H_2 test modes the leak probability is taken to be two orders of magnitude greater than calculated for the run mode (once system is "proofed"). The probability of a 'substantial' leak in the H_2 test mode is taken to be

TABLE III
HAZARD SEVERITY CATEGORIES

Hazard Category	Descriptor	Consequences to		
		People	Property	Environment
I	Catastrophic	Death or Permanent Total Disability	Loss of large, expensive Operation or Building(s) or Off-site structure(s).	<u>Large Scale Damage</u> Major cleanup costs or long-term water or soil contamination, potential enforcement action including civil suits or enforced shutdown.
II	Critical	Permanent Partial Disability	Loss of major equipment item(s), some damage to adjacent units, loss of entire small Operation, significant production loss.	<u>Moderate Scale Damage</u> Not sufficient to cause long-term problems, violations of regulations leading to potential enforcement action in the form of fines.
III	Marginal	Temporary Disability	Moderate damage to major equipment item(s), but repairable, minor damage to adjacent units.	<u>Some Damage</u> Incident noticable off-site, minor vegetation damage or fish kill.
IV	Negligible	First Aid Case or None	Minor damage to major equipment item(s), loss of minor equipment item or no damage.	<u>Little or No Damage</u>

smaller than the overall leak probability by a factor equivalent to operator error in conducting the prior N_2 pressure test. In the event leaks are discovered during the H_2 test, it is recommended that the line be purged as well as vented before correcting the leak. The likelihood of a fire due to leaking H_2 is marginal in terms of the recommendation guidelines. However, the assumption of an ignition probability of 1 is conservative in view of the out-of-doors location and likewise the assumption that personnel are present and injured is conservative.

For the case of the H_2S line (Hazard 9), operator exposure to H_2S must be presumed in the event of a leak during the pressure test mode. The consequences of this hazard are taken to be marginal (Hazard Category III - Temporary Disability) at worst. The recommendation criteria are violated by two orders of magnitude in likelihood. This hazard can be eliminated by using straight H_2 rather than H_2/H_2S to pressure test the system. The same is recommended. External leak hazards are documented in Table III-1 (Hazards 7-9).

Failure of either of the high pressure accumulators represents a potential Category I hazard to personnel and the unit. Failure may be due to overpressurization by the compressor or due to premature metal failure at design operating pressure. The energy associated with bursting of an accumulator at 5000 psig is equivalent to 1.5 lb TNT. The likelihood of either failure mode is sufficiently small that recommendation guidelines are not violated. Recommendations are made for the inspection and testing of the accumulators to ensure degradation is not occurring. This is especially important in view of the exposure of these accumulators to the elements. Accumulator hazards are documented in Table III-1 (Hazards 10 and 11).

Accidents involving full compressed gas cylinders which might result in breaking of the cylinder valve and a 'rocketing' cylinder also represent a Category I hazard. Recommendations regarding operator training and proper equipment and procedures for handling compressed gas cylinders are given in Table III-1 (Hazard 14).

Rupture of a hydrogen or hydrogen sulfide line also represents a Category I hazard due to the potential for rapid release of cylinder or accumulator contents with the possibility for acute H_2S exposure or fire/explosion. The likelihood of these events is very low, however, due to the safety factors between operating pressures and component ratings. These hazards are documented in Table III-1 (Hazards 15 and 16).

Miscellaneous Hazards (12 and 13) are also documented in Table III-1.

4. Gas Compressor Station

Identified hazards in the gas compressor module relate to overpressurization of the compressor(s) suction side, discharge side, or delivery lines to the gas delivery module, hydrogen leaks into the cabinet, or rupture of the compressors. The gas compressor station is located in an enclosed cabinet through which air is pulled and exhausted. An H₂ monitor is located in the cabinet, which is set to alarm at 20% LEL and to shut-down the compressor at 40% LEL.

Compressor suction piping can be overpressurized during pressure test modes if there is back leakage through the compressor check valves and the reliefs on the suction side forward pressure regulators are inoperable. At the full test pressure of 5000 psig the suction traps would suffer deformation and possible rupture. Existing control measures include testing at 2500 psig before conducting the test at 5000 psig. Back leakage can be observed as an increasing pressure on PG-51 or PG-52, respectively. The system should be vented if pressure is observed to be rising.

Overpressurization of suction piping can also occur if the forward pressure regulators are mis-set or fail. Maximum pressure in this scenario is the cylinder supply pressure (≤ 2490 psig) which should be within the design safety factor for the suction traps. These hazards are documented in Table III-2 (Hazard 1 for the N₂ section and Hazard 4 for H₂)

The discharge piping of the compressors can be overpressurized if the compressor transducer system fails and the compressor and accumulator relief valves fail. The likelihood of these simultaneous failures is remote ($\sim 3 \times 10^{-13}$). Tubing and components are rated at near the design pressure of the compressor. Also, as presently configured, the pressure transducer is rendered "nonfunctional" if the manual valve on the compressor discharge is closed, which at the same time deadheads the compressor. The pressure transducers on the two compressors should be relocated to be upstream of the first valve (MV-58 or MV-60) on the discharge line. These hazards are documented on Table III-2 (Hazards 2 and 6, respectively).

The lines to the gas delivery module can 'see' the 5000 psig accumulator pressure if the pressure regulators fail open and the reliefs also fail. Components, however, are rated for 9000 psig or higher. These potential hazards are documented in Table III-2 (Hazards 3 and 7, respectively).

Hydrogen may leak into the compressor cabinet due to a leaking component, faulty compressor seal, a leaking diaphragm, or failure of the compressor hydraulic system relief valve which could result in blowing the seal or diaphragm. The rate of H₂ leakage is dependent on the specific flow resistance of the particular leak path. Installation of a surge check valve in the suction line should be considered to limit the potential hydrogen flow. Compressor cabinet ventilation and the H₂ monitor should protect

against fire/explosion in most instances. Hydrogen leak hazards are documented in Table III-2 (Hazard 5).

In the event of rupture of the H₂ compressor accompanied by loss of discharge check valve (must be assumed probable) the contents of the hydrogen accumulator would rapidly discharge. While the probability of compressor rupture is low (1×10^{-8}) the consequences of discharging the accumulator contents into an already serious situation should be avoided if possible. Therefore it is recommended that a check valve be installed on the discharge tubing on the chance it would be operable whereas the compressor valve would not. This hazard is documented in Table III-2 (Hazard 8).

5. Gas Delivery Module

Identified process hazards in the gas delivery module relate to leaks, ruptures, or overpressurization of hydrogen or hydrogen sulfide lines/components, and overpressurization of the nitrogen line pressure gauge, which may result in fire, explosion and/or toxic exposure.

External hydrogen leak scenarios are similar to those discussed for previous modules. Existing control measures include pressure testing with nitrogen to detect gross leaks and minimize size of potential hydrogen leaks, location of the module under the unit exhaust hood, and hydrogen monitors to detect presence of leaks before flammable concentrations are reached. As presently configured, the N₂ tie-in to the high pressure hydrogen line is made downstream of check valves CV-101 and CV-102. This means the system upstream of the check valves cannot be pressurized with the N₂ to check for leaks. It is recommended that the N₂ tie-in be made upstream of the tee leading to MV-103 and MV-104. Previous general recommendations in regard to 1) testing check valves, and 2) purging lines before correcting leaks also apply. These hazards are documented in Table III-3 (Hazard 1 for high pressure H₂ and Hazard 6 for low pressure H₂).

In the unlikely event of rupture of a component or section of tubing in the hydrogen or hydrogen sulfide sections of the module, the flow should be stopped or severely restricted by the surge check valve at the compressor cabinet (Hazards 2, 5, and 8).

External leak scenarios for hydrogen/hydrogen sulfide are similar to those for hydrogen only, with the addition of potential exposure of personnel. It is recommended that straight hydrogen be used to pressure test the system to avoid possible exposures (Hazard 3).

The rotameters and pressure gages in the hydrogen sulfide, low pressure hydrogen and low pressure nitrogen lines are the only components rated below the pressures of the cylinders supplying the gas delivery module. Normally pressures are kept within the rated operating range by the respective forward pressure regulators. Operator error in setting the regulator or failure of the regulator valve and relief, or backflow from the high pressure side of the module could overpressure and rupture these components. The pressure gauges specified have relieving backs and the rotameters are supplied with shields, which mitigates against personnel injury. Surge checks are provided to shut down flow of H₂ or H₂/H₂S (Hazards 4, 7, and 9).

The probability of failure to supply N₂ purge on demand is also documented in Table III-4 (Hazard 10). This situation represents a potential hazard, but the event probability shown must be multiplied by the demand probability to determine the overall incident likelihood. Demand probabilities are identified under the discussion for the CSTR-1 unit proper (Reaction and Separation Module).

6. Slurry Feed Module

Process hazards identified in the slurry feed module relate to overpressurization of module components with resultant damage, rupture, and operator injury or exposure. Hazards are documented in Table III-4.

The Pyrex flush oil tank is rated at 70 psig (based on Corning data for 4" beaded pressure installation). Failure of the immediate pressure regulator would apply 100 psig to the tank (control set point of upstream regulator). This is considered within the range of design safety factor for the tank. Simultaneous failure of both regulators is remote. (Hazard 1)

Similar hazard scenarios exist for the slurry feed tank. Based on hoop stress calculations only, the tank itself should be capable of 350 psig. The nitrogen purge rotameter is rated for 200 psig. Thus, it is likely the rotameter would fail and relieve overpressure and the tank itself would not be ruptured in the event of pressure regulator failure(s). (Hazard 2)

The discharge lines of the module pumps are subject to overpressurization in the event of dead-heading the pump and failure of the pump pressure relief valve. All pumps are provided with a relief valve. It is unlikely the Moyno recirculation pump could develop enough dead-head to rupture the line, however, pump damage could result. The slurry feed pumps relief valves discharge thru a trap to the system vent. The valve in the vent line must be kept open to ensure a free discharge path. (Hazard 3)

7. Reaction and Separation Modules

The identified process hazards in the Reaction and Separation Modules relate primarily to rupture of components with resultant potential consequences for fire, operator injury and/or operator exposure. Rupture may arise due to overpressurization, loss of material strength due to over temperature, or metallurgical failure at design operating conditions. Overpressurization may result from plugs in the system, component failure(s), or operator error(s). The system is provided with overpressure protection in the form of high pressure shutdown interlocks and relief valves. Changes in pressure set points were recommended in Paragraph C.1.a. Overpressure hazard scenarios are quantified on the basis that rupture will not occur below the set points of the pressure transducers and relief valves.

Excessively high temperatures may result from heater component failure(s) or undefined reaction chemistry. The system is provided with high temperature shutdown interlocks. Change in temperature set points were recommended in Paragraph C.1.a. Scenarios are quantified on the basis that rupture will not occur below the set point of the temperature switches.

Identified hazards are documented in Table III-5 and discussed below.

a. Overpressurization (Hazards 1, 2, 3, 4, 6, 9, 12, 14)

Overpressurization scenarios in the main process flow piping are documented as Hazards 1-4. The event probabilities for each section of the system are dependent on the numbers of restrictive components (e.g. valve, regulator), the number of sections of line, and the number of relief/safety devices applicable to that section. All of these potential hazards are unlikely.

Overpressurization associated with letdown of the heavy oil and light oil separators is documented in Hazard 6 and Hazard 9 respectively. Note that overpressurization is not sufficient to rupture the receiver unless the operator has failed to drain the receiver from previous letdowns as stated by the procedures. Draining the receiver under pressure, however, is a hazard to the operator from splashing of material and flashing of gas.

The hazard of an unknown pressure generating reaction is documented as Hazard 12. The event probability is taken as the failure probability of all pressure safety systems; i.e., it is assumed (1) the reaction occurs, and (2) the relief system is adequate if it operates.

Overpressurization scenarios within the water injection system are documented as Hazard 14. The high pressure water pump is provided with a pressure relief valve. Pressure of water supply should be checked to determine if it exceeds rating of Pyrex tank.

b. Excessively High Temperature (Hazard 11)

High temperature may be a result of failures in the preheater or reactor heater control equipment or from some unknown exothermic reaction. In either case, the system is protected by high temperature shutdown switches. The probability of an unknown reaction is taken to be on the order of the general human failure rate (equivalent to failure to sufficiently characterize reaction chemistry) which is felt to be conservative.

c. Vessel Failure at Design Temperature and Pressure (Hazard 13)

Scenarios relating to vessel failure at normal operating temperatures and pressures are documented as Hazard 13. In one scenario, the generic random failure rate for pressure vessels is given. Failure may also arise due to metallurgical effects of the process service. Austenitic stainless steel are highly resistant to hydrogen attack, which would not be expected at the process temperature and pressure. However, H_2S stress corrosion effects and possible synergistic effects of H_2S or other constituent gases on hydrogen attack are not fully understood. The alloy steel cap screws used to close the autoclave vessels would be subject to hydrogen attack but are isolated from the vessel interior by the vessel gasket. Close monitoring and inspection of the metallurgical condition of the system vessels is advisable.

d. Miscellaneous Scenarios (Hazards 5, 7, 8, 10, 15)

The scenarios 5, 7, 8, and 10 are really operability problems rather than safety hazards. They relate to operator errors in performing the separator depressurization procedures and are included for reference as they were identified in the course of the safety analysis.

Hazard 15 related to the release of flammable (H_2 primarily) and/or toxic (H_2S) gas due to a leaking component. The system is protected by exhaust ventilation, H_2 monitors and H_2S monitors. Thus, operator exposure or formation of a flammable mixture is unlikely.

D. WORKPLACE HEALTH ANALYSIS

The Workplace Health Analysis is a constituent analysis of an overall safety analysis, which considers potential hazards to employee health as a result of working in the operation under design conditions. Included is an identification of potential health hazard materials present in the operation, and an evaluation of the potential for operator exposure to these materials.

Materials in use or which are produced in the CSTR-1 unit which represent potential health hazards are listed in Table III-6. As can be seen from the table, potential health hazards of the CSTR-1 operation relate to inhalation of irritant or toxic gases or dusts, or contact with recognized or suspected carcinogenic liquids. Potential for occupational exposure will be minimized by operator care in executing manual operations in the process and use of proper protective equipment. Potential exposure scenarios are discussed in the following paragraphs and documented in Table III-7. In as much as the unit has not been operated, no workplace monitoring data base exists. A monitoring program should be conducted to establish baseline concentrations of airborne contaminants once the unit is placed in operation.

TABLE III-6

POTENTIAL HEALTH HAZARD MATERIALS CSTR-1 PROCESS

<u>Material</u>	<u>Health Hazard</u>	<u>TLV</u>
Hydrogen Sulfide	Irritant and Asphyxiant	20 ppm ⁽¹⁾
Pulverized Coal	Silicosis	2 mg/m ³ ⁽²⁾
Flush Oil (Diesel/ Kerosene)	Recognized Carcinogens	-
Coal-Derived Liquids	Suspected Carcinogens	-
Off-gases	Irritant or Toxic S, N, or O Compounds	-
Synthesis Gas ⁽³⁾	Asphyxiant Due to CO Con- stituent	50 ppm ⁽⁴⁾

Notes: (1) Acceptable ceiling value for 8 hr. day.

(2) Respirable fraction less than 5% SiO₂.

(3) Indicated as possible future use.

(4) TLV for carbon monoxide.

1. Hook-Up of H₂/H₂S Cylinders

The potential for exposure to H₂S exists due to a leak at the cylinder rack. The system is pressure tested with nitrogen before H₂/H₂S is admitted to the system. Therefore a leak of H₂/H₂S is judged unlikely. In the unlikely event that the cylinder or cylinder valve itself is leaking, the operating procedures contain instructions for removing the cylinder to a 'safe' location and notifying the Safety Office.

2. Preparation of Coal Slurry

Coal slurry is prepared in an area other than the CSTR-1 unit proper and transferred to the unit for use. Although the slurry preparation area is not specific to the CSTR-1 unit the potential exposure hazards were nonetheless identified and documented as Hazard 2 in Table III-7. Personnel should add coal to the slurry mix tank in a manner which avoids or minimizes formation of a coal 'dust cloud'. Respiratory protection in accord with ANSI standards should be worn unless it can be demonstrated by monitoring that an exposure hazard does not exist. The same comments apply to handling and addition of disposable catalyst, if used.

Face shield and nonpermeable gloves and clothing should be worn to avoid contact with coal derived liquids when adding the liquid to the slurry tank.

3. Transfer Slurry to Slurry Feed Tank

The potential for personnel contact with coal-derived liquids in this step is similar to that in preparing the slurry. Contact may occur due to spilling or direct contact. Therefore protective equipment similar to that used in preparing the slurry should be used.

4. Fill Flush Oil Tank

Contact with flush oil due to spilling or splashing may occur when filling the flush oil tank. Face shield and skin protection should be worn to avoid contact.

5. Load Reactor Catalyst Basket

If a supported catalyst is used, the potential for operator contact exists in adding the catalyst to the reactor basket. Consequences, if any, depend on specific catalyst in use. Precautions for handling specific catalysts should be indicated on each run sheet.

6. Heavy Oil Depressurization and Sampling

Potential for exposure to flash gas or contact with hot coal-derived liquids exists in this manual operation, especially if receiver drain

valve is opened when receiver is under pressure. Procedures and operator training should stress importance of ensuring receiver is at or near ambient pressure before opening drain valve. Face shield and skin protection should be worn to avoid contact.

7. Light Oil Depressurization and Sampling

Potential exposures during light oil depressurization and sampling are similar to those for the same operations with heavy oil, and the same precautions should be taken.

8. Tail Gas Sampling

The tail gas sample is normally taken in a 'closed' system and exposure is therefore unlikely. If the alternate sampling system is used the potential for operator contact with the acidic solution exists. Therefore goggles or face shield and gloves appropriate for the acid solution being used are indicated personal protective equipment.

9. Flash Gas Sampling

Potential exposures are similar to those for tail gas sampling and the same precautions should be followed.

10. Monitoring the Process

The process normally operates as a 'closed' system with the only discharge being the process vent which exhausts to atmosphere outside the building. The entire unit is located under an exhaust hood which provides ventilation and withdrawal in the event of any external leaks. Exposure is therefore unlikely during routine monitoring of the operation.

11. Cleanup

Clean-up procedures are not documented in detail. As a minimum, precautions to avoid contact with coal-derived liquids should be taken. Other precautions may be advisable as a function of solvent(s) used in clean-up procedures.

E. WORKPLACE SAFETY ANALYSIS

The Workplace Safety Analysis is a constituent analysis of the overall safety analysis which addresses potential occupational injury hazards of the Operation under normal operational conditions.

Identified potential occupational injury hazards for the CSTR-1 unit relate to manual material handling operations, rotating equipment, electrical equipment, and high temperature surfaces. Identified hazards are documented in Table III-8 and discussed in the paragraphs which follow.

1. Handling of Compressed Gas Cylinders

Improper or careless handling of compressed gas cylinders may result in strained muscles or broken bones of hand or foot. Approved cylinder carts should be used to transport cylinders. Care must be taken in manually transferring cylinders to or from carts to ensure hands or fingers are not caught between cylinder and other equipment (e.g., cart, cylinder rack).

2. Installation of Reactor, Slurry Feed Tank or Filling of Flush Oil Tank

These items are located at such an elevation that a ladder or platform may be needed or desirable to accomplish the required activity. The items are of such a weight that if they are improperly lifted, held in an awkward or extended position, or dropped, bodily injury could result. Only approved ladders or platform should be used. Care must be taken in the manual activities to avoid operator injury.

3. Rotating Equipment

Rotating equipment in the CSTR-1 unit includes H₂ and N₂ compressors, slurry recirculation and feed pumps, and slurry feed tank and reaction agitators. Available equipment data indicated that machine guards were included. It is recommended that the pre-startup checklist include a check to insure all guards are in place.

4. High Temperature Surfaces

The preheater and reactor sections of the unit are designed to operate in the neighborhood of 400°C. These items and components downstream will therefore be at elevated temperature. Where it is undesirable for process reasons or otherwise impractical to provide insulation to protect against contact with hot (> 140°F) surfaces, warning signs clearly identifying hazardous lines and vessels should be posted.

5. Electrical Hazards

Electrical equipment in the CSTR-1 includes motor drives and associated wiring for such items as compressors and pumps, electrical heaters with associated power wiring, and control and instrument wiring. Motors generally meet Class I, Group D designations. Operators and maintenance personnel should be cognizant of the hazards associated with the types of equipment installed and should take proper precautions when maintenance, repair, or disassembly/assembly of equipment is required.

F. ENVIRONMENTAL ANALYSIS

The Environmental Analysis is a constituent analysis of an overall Safety Analysis which addresses the emissions, effluents, and wastes associated with an Operation under normal operational conditions.

The flow rates and quantities of materials involved in the CSTR-1 unit are on a very small scale and therefore do not represent any appreciable environmental hazard. Approximately 2 lb/day of gases and vapors will be discharged to the atmosphere when the unit is running at normal thru-puts. Constituents of the air emission are expected to be principally unreacted hydrogen, methane and low molecular weight homologs, and some compounds of S, N, or O such as H_2S , CS_2 , COS , NH_3 , H_2O , CO , and CO_2 . Rates of emission are just too low to be of any appreciable concern.

There will be no normal process effluents from the unit. Approximately five gallons/day of products in the form of heavy oil and light oil will be generated. Samples of product will be taken periodically and used for analysis and characterization. Disposal of residual product will be by shipment to approved out-of-state landfill.

In addition, small quantities of waste will be generated on a once per run basis via cleanup procedures. Purge gases, consisting primarily of the purge N_2 , and in some cases residual H_2 in the system will be emitted during pre-startup procedures. In the event of system upsets (pressure or temperature) which activate the depressurization system, the system will be depressurized to atmosphere. Total system holdup is on the order of six liters. All vent lines are provided with knockout pots for removal of entrained liquid. Environmental analysis is documented in Table III-9.

TABLE III-1. CYLINDER RACK PROCESS HAZARDS

SYSTEM: CSTR-1

SUBSYSTEM: Cylinder Rack

EQUIPMENT: All

PAGE 1 OF 9

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
1. Contamination of low pressure N_2 with high pressure H_2		Use of fuel containing gas in situations where inert gas is intended.	1							Procedures state that all valves should be closed at start of purge and pressure test sequences.	Pressure tests do not check MV-1 thru MV-13, or CV-1 thru CV-7 for internal leakage.
a) Leaking/open valves and leaking check valves between cylinder 12 and cylinder bank 3 and H_2 accumulator pressurized.		Potential fire		< 1			< 1			Pressure tests check MV-14 thru MV-26, AOV-2, AOV-3, RV-1, RV-2, MV-55, MV-59, and MV-62 for internal leakage.	Probabilities are based on assumption these components are functional at outset. Recommend these components be 'proofed' periodically to detect failures.
Purge Mode	3×10^{-21}				$< 3 \times 10^{-18}$	III		$< 3 \times 10^{-18}$	III		
N_2 Test Mode	3×10^{-21}									Check valves installed in interconnecting piping.	
H_2 Test Mode	3×10^{-18}										
Run Mode	1×10^{-18}										
2. Contamination of purge N_2 with high pressure H_2											
a) Leaking/open valves and/or leaking check valves between cylinder 12 and cylinder 1 and H_2 accumulator pressurized.		Same as for entry 1.	1							Same as for entry 1.	Same as for entry 1.
Purge	1×10^{-33}			< 1	$< 1 \times 10^{-30}$	III	< 1	$< 1 \times 10^{-30}$	III		
N_2 Test	1×10^{-30}										
H_2 Test	1×10^{-36}										
Run	1×10^{-33}										

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SUBSYSTEM: Cylinder Rack

EQUIPMENT: ALL

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[illegible]

TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1		SUBSYSTEM: Cylinder Rack		EQUIPMENT: All		PAGE 3 OF 9					
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
5. Contamination of low pressure N ₂ with H ₂ S		Use of contaminated gas in situations where pure inert gas is intended.	1								
a) Leaking/open valves and leaking check valve and H ₂ S pressure greater than N ₂ pressure		1. Potential fire		< 1	<1x10 ⁻¹³	III	< 1	<1x10 ⁻¹³	III	Same as for entry 1.	Same as for entry 1.
		2. Potential H ₂ S exposure		< 1	<1x10 ⁻¹³	III	0				
Purge	3x10 ⁻¹⁶										
N ₂ Test	3x10 ⁻¹⁶										
H ₂ Test	1x10 ⁻¹⁶										
Run	1x10 ⁻¹³										
6. Contamination of purge N ₂ with H ₂ S											
a) Leaking/open valves and leaking check valves and H ₂ S pressure greater than N ₂ pressure		Same as for entry 5.	1							Same as for entry 1.	Same as for entry 1.
		1. Potential fire		< 1	<1x10 ⁻²⁸	III	< 1	<1x10 ⁻²⁸	III		
		2. Potential H ₂ S exposure		< 1	<1x10 ⁻²⁸	III	0				
Purge	1x10 ⁻²⁸										
N ₂ Test	1x10 ⁻²⁸										
H ₂ Test	1x10 ⁻³¹										
Run	1x10 ⁻²⁸										

TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1		SUBSYSTEM: Cylinder Rack		EQUIPMENT: All		PAGE 4 OF 9					
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
7. External leak of high pressure H ₂ a) Leaking component in high pressure H ₂ line H ₂ test mode	3x10 ⁻³	Ignition of H ₂ by operator in attempt to fix leak - fire	1x10 ⁻³	1 1x10 ⁻³	3x10 ⁻⁶ 3x10 ⁻⁹	III II	1	3x10 ⁻⁶	III	System is pressure tested with N ₂ before admitting H ₂ .	Recommend procedures require purging as well as venting before correcting H ₂ leaks. Allow time for leak to dissipate before correcting. Use 'non-sparking' tools.
Run Mode	3x10 ⁻⁵	Ignition of leaking H ₂ - fire	.1	<1	<3x10 ⁻⁶	III	1	3x10 ⁻⁶	III	System tested before running. Components located outside. Maximum opportunity for dilution of H ₂ .	
8. External leak of low pressure H ₂ a) Leaking component in low pressure H ₂ line											
H ₂ Test Mode	6.6x10 ⁻³	Ignition of H ₂ by operator in attempt to fix leak - fire	1x10 ⁻³	1 1x10 ⁻³	6.6x10 ⁻⁶ <6.6x10 ⁻⁶	III II	1	6.6x10 ⁻⁶	III	Same as for entry 7 - H ₂ test mode	Same as for entry 7.
Run Mode	6.6x10 ⁻⁵	Ignition of leaking H ₂ - fire	.1	<1	6.6x10 ⁻⁶	III	1	<6.6x10 ⁻⁶	III	Same as for entry 7 - run mode	

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TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1		SUBSYSTEM: Cylinder Rack		EQUIPMENT: All		PAGE 5 OF 9					
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
9. External leak of H ₂ /H ₂ S											Same as for entry 7.
a) Leaking component in H ₂ S line											
H ₂ Test Mode	1.8x10 ⁻³	1. Ignition of H ₂ /H ₂ S by operator in attempt to fix leak.	1x10 ⁻³	1	1.8x10 ⁻⁶	III	1	1.8x10 ⁻⁶	III	Same as for entry 7 H ₂ test mode	Recommend that H ₂ rather than H ₂ /H ₂ S be used to pressure test. Eliminates H ₂ S exposure possibility.
		2. Exposure to H ₂ S	1	1x10 ⁻³	1.8x10 ⁻⁶	II					
				1	1.8x10 ⁻⁶	III	0				
				1x10 ⁻³	1.8x10 ⁻⁶	II					
Presulfiding Mode	1.8x10 ⁻⁵	1. Ignition of leaking H ₂ /H ₂ S	.1	< 1	<1.8x10 ⁻⁶	III	1	1.8x10 ⁻⁶	III		
		2. Exposure to H ₂ S	1x10 ⁻¹	1	1.8x10 ⁻⁶	III	0				
				1x10 ⁻³	1.8x10 ⁻⁹	II					

TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1		SUBSYSTEM: Cylinder Rack		EQUIPMENT: All		PAGE 6 OF 9					
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
10. Failure of H ₂ Accumulator Integrity		Rupture of accumulator and release of H ₂	1								
a) Failure at ≤5000 psig	5x10 ⁻⁹	1. Personnel injured by blast, fragments or vapor cloud explosion. 2. Equipment damage.		≤ 1	5x10 ⁻⁹	I				Accumulator constructed in accordance with ICC-3AA-6000.	Accumulator is located outside and is exposed to the elements. Recommend periodic inspection to check for corrosion, and re-testing in accord with DOT regulations for compressed gas cylinders.
b) Accumulator overpressurized by compressor	2.7x10 ⁻¹³	Same as for entry 10 a).	1	≤ 1	2.7x10 ⁻¹³	I	1	5x10 ⁻⁹	I	Compressor has pressure cutoff switch and internal pressure relief on hydraulic system. Relief valve on accumulator line.	
c) Loss of material strength due to H ₂ embrittlement	<5x10 ⁻⁹	Same as for entry 10 a).	<1	≤ 1	<5x10 ⁻⁹	I	1	<5x10 ⁻⁹	I		Comment - H ₂ embrittlement not expected at ambient temperature.

TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1		SUBSYSTEM: Cylinder Rack		EQUIPMENT: All						PAGE 7 OF 9	
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
11. Integrity failure of N ₂ accumulator											
a) Failure at ≤5000 psig	5x10 ⁻⁹	Rupture of vessel blast O/P and frag- ments	1							Same as for entry 10 a).	Same as for entry 10 a).
		1. Personnel injury.		≤1	≤5x10 ⁻⁹	I					
		2. Equipment damage					.1	5x10 ⁻⁹	I		
b) Accumulator overpressurized by compressor.	2.7x10 ⁻¹³	Same as for entry 11 a).	1	≤1	≤2.7x10 ⁻¹³	I	1	2.7x10 ⁻¹³	II	Same as for entry 10 b).	
12. Face of pressure gauge blows out											
a) Overpressuri- zation or leak in gauge and back fails to relieve.	1x10 ⁻⁹	Fragments and release of H ₂ or H ₂ S poten- tial	1							Pressure gauge have pressure relieving backs. Ratings of gauges are adequate for the service.	
		1. Fragments		≤1	<1x10 ⁻⁹	II					
		2. H ₂ S exposure		.57	5.7x10 ⁻¹⁰	II					
		3. Fire		.57	5.7x10 ⁻¹⁰	II	.57	5.7x10 ⁻¹⁰	II	Eye protection is re- quired in the area.	

TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM: Cylinder Rack

EQUIPMENT: All

PAGE 8 OF 9

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
13. Cylinder installed in wrong bank or spot. a) Personnel deliberately circumvent CGA fittings with an adaptor.	1×10^{-7}	Delivery of "wrong" gas.	1	≤ 1	$< 1 \times 10^{-7}$	III	≤ 1	$< 1 \times 10^{-7}$	III	CGA fittings.	No adaptors on premises.
14. Cylinder mis- handled in instal- lation. a) Personnel fail to follow standard good practice for handling com- pressed gas cylinders.	≤ 1	Cylinder dropped. 1. Valve breaks. 2. Strikes person- nel.	1×10^{-4}	1×10^{-3} 1	1×10^{-7} 1×10^{-4}	I III	1×10^{-3} 0	1×10^{-7}	I	All cylinder stations have safety chairs.	Require use of cylinder carts for moving cylinders Personnel training should include proper handling of cylinders.

TABLE III-1
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Cylinder Rack EQUIPMENT: All PAGE 9 OF 9

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
15. Rupture of H ₂ line. a) Failure of tubing, valve or other component.	2x10 ⁻⁷	Release of H ₂ and ignition. 1. Personnel injury due to F/E. 2. Equipment damage.	≤1	1 1x10 ⁻¹	2x10 ⁻⁷ 2x10 ⁻⁸	II I	1	2x10 ⁻⁷	II	System is pressure tested before commencing a run.	
16. Rupture of H ₂ /H ₂ S line. a) Failure of tubing, valve or other component.	4x10 ⁻⁸	Release of H ₂ /H ₂ S 1. Personnel exposure. Ignition of released H ₂ /H ₂ S 1. Personnel injury. 2. Equipment damage.	1 ≤1	1 1x10 ⁻¹ 1 1x10 ⁻¹	4x10 ⁻⁸ 4x10 ⁻⁹ 4x10 ⁻⁸ 4x10 ⁻⁹	II I II I	1	4x10 ⁻⁸	II	Same as entry 15.	

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TABLE III-2. GAS COMPRESSOR PROCESS HAZARDS

SYSTEM: CSTR-1			SUBSYSTEM: Gas Compressor Module			EQUIPMENT: N ₂ Compressor and Aux.			PAGE 1 OF 4		
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PRCB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
1. Overpressurize Suction Side of Compressor											
a. Compressor check valves leak and for- ward pressure regulator re- lief fails (PP = 5000) test mode.	3x10 ⁻¹⁷	Rupture of suction trap (MAWP = 1800)	1	≤1	≤3x10 ⁻¹⁷	II	1	3x10 ⁻¹⁷	II	System is tested at 2500 psig before it is tested at 5000 psig.	Procedures should in- struct personnel to abort pressure test and vent system if pressure on PG-51 is rising.
b. Pressure reg- ulator FPR-51 set for max. pressure or fails in the mode (PP = 2490)	2x10 ⁻⁴	Rupture of suction trap (MAWP = 1800)	3.3x10 ⁻³	≤1	<7x10 ⁻⁷	II	1	7x10 ⁻⁷	II	Maximum cylinder pressure insufficient to exceed trap yield strength, assuming SF ≥ 1.6 in trap de- sign.	
2. Overpressurize Discharge Side of Compressor											
a. Pressure switch and compressor relief valve and accum- lator relief valve fail (PP = 11000)	2.7x10 ⁻¹²	Rupture of piping, valves or instru- ments.	<1	≤1	<2.7x10 ⁻¹³	III	1	<2.7x10 ⁻¹³	III	Components rated for near design pressure of compressor.	
3. Overpressurize Line to Gas Delivery Module											
a. Pressure regu- lator fails 'open' and fails to relieve (PP = 5000)	6x10 ⁻⁹	Rupture of piping valves, or other components	<1x10 ⁻⁶	≤1	<6x10 ⁻¹⁵	II	1	<6x10 ⁻¹⁵	III	Components rated for 9000 psig or higher.	

TABLE III-2
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Gas Compressor Module EQUIPMENT: H₂ Compressor and Aux. PAGE 2 OF 4

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
4. Overpressurize Suction Side of H ₂ Compressor											
a. Compressor Check Valves Leak and For- ward Pressure Regulator Re- lief Fails (PP = 5000) N ₂ Test Mode	3x10 ⁻¹⁷	Rupture of suction trap	1	≤1	<3x10 ⁻¹⁷	II	1	3x10 ⁻¹⁷	II	System is tested at 2500 psig before it is tested at 5000 psig.	Procedures should in- struct personnel to abort pressure test and vent system if pressure on PG-51 is rising.
H ₂ Test Mode		Rupture of trap 1. Vessel burst	1	≤1	<3x10 ⁻¹⁷	II	1	3x10 ⁻¹⁷	II	System checked with N ₂ before H ₂ and at 2500 psig before 5000 psig.	
		2. Ignition of H ₂	1x10 ⁻³	1	3x10 ⁻²⁰	II	1	3x10 ⁻²⁰	II	Compressor cabinet is ventilated.	
b. Pressure regulator set at max pres- sure or fails in this mode (PP = 2200) Run Mode	2x10 ⁻⁴	Rupture of trap 1. Vessel burst	3.3x10 ⁻³ 1	≤1	7x10 ⁻⁷	II	1	7x10 ⁻⁷	II	System checked with N ₂ before H ₂ and at 2500 psig before 5000 psig.	
		2. Ignition of H ₂	1x10 ⁻³	≤1	7x10 ⁻¹⁰	II	1	7x10 ⁻¹⁰	II	Surge check valves will shut off flow of H ₂ . PS-52 will shut down compressor.	

TABLE III-2
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Gas Compressor module EQUIPMENT: H₂ Compressor and Aux. PAGE 3 OF 4

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
5. H ₂ Leak Into Compressor Cabinet										System is pressure tested with N ₂ before H ₂ . Compressor cabinet ventilated	Install surge check valve in H ₂ compressor suction line.
a. Leaking valve regulator gauge, or transducer											
H ₂ Test	4.8x10 ⁻³	Ignition of H ₂	1x10 ⁻³	≤1	<4.8x10 ⁻⁴	II	1	4.8x10 ⁻⁶	II	H ₂ monitor.	
Run	4.8x10 ⁻⁵	Ignition of H ₂	1x10 ⁻³	≤1	4.8x10 ⁻⁸	II	1	4.8x10 ⁻⁸	II		
b. Failure of compressor seals	2x10 ⁻⁷	Ignition of H ₂	1x10 ⁻³	≤1	<2x10 ⁻¹⁰	II	1	2x10 ⁻¹⁰	II	Compressor cabinet ventilated. Compressor has leak detection system. H ₂ monitor.	
c. Failure of compressor diaphragm	5x10 ⁻⁶	Ignition of H ₂	1x10 ⁻³	≤1	5x10 ⁻⁹	II	1	5x10 ⁻⁹	II	Compressor cabinet ventilated. Compressor has leak detection system. H ₂ monitor.	
d. Failure of compressor hydraulic relief valve	3x10 ⁻⁵	Overpressurize compressor, blow seals and release H ₂ which ignites	1x10 ⁻³	≤1	<3x10 ⁻⁸	II	1	3x10 ⁻⁸	II		
6. Overpressurize Discharge Side of Compressor											
a. Pressure switch and accumulator relief valve fail (PP = 11000)	2.7x10 ⁻¹³	Rupture of piping or valves or instrumentation	≤1	≤1	2.7x10 ⁻¹³	III	1	2.7x10 ⁻¹³	III	Components are rated for 9000 psig or higher	
		Ignition of H ₂ released due to rupture.	1	1	2.7x10 ⁻¹³	I	1	2.7x10 ⁻¹³	II		

TABLE III-2
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Gas Compressor Module EQUIPMENT: H₂ Compressor and Aux. PAGE 4 OF 4

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
7. Overpressurize Line to Gas De- livery Module											
a. Pressure reg- ulator fails 'open' and fails to re- lieve (PP = 5000)	6x10 ⁻⁹	Rupture of piping, valves or other components (MAP ≥ 9000)	<1x10 ⁻⁶	≤1	<6x10 ⁻¹⁵	III	1	<6x10 ⁻¹⁵	III	Components rated 9000 psig or greater	
		Ignition of H ₂ re- leased due to rup- ture	<1	≤1	<6x10 ⁻¹⁵	II	1	<6x10 ⁻¹⁵	II	Line has surge check valve	
8. Compressor Rup- ture	1x10 ⁻⁸	Ignition of H ₂ re- leased due to rup- ture	1	1	1x10 ⁻⁸	I	1	1x10 ⁻⁸	I		Install surge check valve in H ₂ compressor suction line. Install check valve in discharge line before first cross as backup to loss of compressor discharge check valve on rupture.

TABLE III-3. GAS DELIVERY PROCESS HAZARDS

PAGE 1 OF 7

SYSTEM: CSTR-1

SUBSYSTEM: Gas Delivery Module

EQUIPMENT: High Pressure Hydrogen

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
1. External H ₂ Leak											
a. Leaking component											
H ₂ Test Mode	7.8x10 ⁻³	Ignition of H ₂ by personnel in attempt to fix leak.	1x10 ⁻³	1 1x10 ⁻³	7.8x10 ⁻⁶ 7.8x10 ⁻⁹	III II	1	7.8x10 ⁻⁶	III	System pressure tested with N ₂ before H ₂ . Piping under hood. Procedures specify venting before correcting H ₂ leak.	Recommend N ₂ line be tied-into H ₂ line upstream of MV-103/-104. Presently CV-101 and CV-102 prevent N ₂ pressure testing of components upstream thereof.
Run Mode	7.8x10 ⁻⁵	Ignition of H ₂ F/E	1x10 ⁻³	≤ 1	7.8x10 ⁻⁸	II	1	7.8x10 ⁻⁸	III	Piping under hood H ₂ monitors System tested before running.	Recommend line be N ₂ purged before correcting H ₂ leaks.
2. Rupture of Line											
a. Tubing or component failure.	2.6x10 ⁻⁷	Ignition of escaping H ₂	≤ 1	≤ 1	2.6x10 ⁻⁷	II	1	2.6x10 ⁻⁷	II	Exhaust ventilation H ₂ monitor Surge check valves in H ₂ line.	

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TABLE III-3
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Gas Delivery Module EQUIPMENT: Hydrogen Sulfide Line

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
3. External H ₂ /H ₂ S Leak a. Leaking component Test Mode	5.1x10 ⁻³	1. Personnel ignite H ₂ /H ₂ S attempting to fix leak	1x10 ⁻³	1 1x10 ⁻³	5.1x10 ⁻⁶ 5.1x10 ⁻⁹	III II	1	5.1x10 ⁻⁶	III	System is pressure tested with N ₂ before H ₂ or H ₂ /H ₂ S Exhaust ventilation H ₂ and H ₂ S monitors.	Recommend use of H ₂ rather than H ₂ /H ₂ S to conduct pressure test - eliminates exposure possibility
		2. Personnel exposure to H ₂ S	1x10 ⁻³	1	5.1x10 ⁻⁶	II	0			Procedures require venting before correcting leaks.	
	5.1x10 ⁻⁵	1. Ignition of leaking gas F/E	1x10 ⁻³	1	5.1x10 ⁻⁸	III	1	5.1x10 ⁻⁸	III	Exhaust ventilation H ₂ and H ₂ S monitors	Recommend line be N ₂ purged before correcting H ₂ or H ₂ /H ₂ S leaks.
		2. Personnel exposure to H ₂ S	1x10 ⁻³	1	5.1x10 ⁻⁸	II	0			System tested before running.	
4. Overpressure Line a. Mis-set pressure regulator	1x10 ⁻⁴	Rupture pressure gauge or flow meter fragments	1	1x10 ⁻²	1x10 ⁻⁶	III	1	1x10 ⁻⁴	IV	Pressure gauges have relieving backs Flowmeter has shield Eye protection required	Consider 'stop' on pressure regulator.
		Surge check works when rupture occurs	~1								
		1. H ₂ S exposure 2. Fire/Explosion		1x10 ⁻³ 1x10 ⁻³	1x10 ⁻⁷ 1x10 ⁻⁷	III III	0 1x10 ⁻³	1x10 ⁻⁷	III	Exhaust ventilation H ₂ and H ₂ S monitors	
		Surge checks fail	3x10 ⁻⁵								
		1. H ₂ S exposure 2. Fire/explosion		1 1	3x10 ⁻⁹ 3x10 ⁻⁹	II II	0 1	3x10 ⁻⁹	II	Surge check valves	

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TABLE III-3
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM: Gas Delivery Module

EQUIPMENT: Hydrogen Sulfide

PAGE 3 OF 7

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
4. Overpressure Line (cont'd.)											
b. Pressure regulator failure and failure to relieve	6.6x10 ⁻⁸	Rupture pressure gauge or flowmeter - fragments	1	1x10 ⁻²	6.6x10 ⁻¹⁰	II	1	6.6x10 ⁻⁸	IV	Pressure gauges have relieving backs Flowmeter has shield Eye protection required	
		Surge checks work	~1								
		1. H ₂ S exposure		1x10 ⁻³	6.6x10 ⁻¹¹	III	0				
		2. Fire/explosion		1x10 ⁻³	6.6x10 ⁻¹¹	III	1	6.6x10 ⁻¹⁰	III		
		Surge checks fail	3x10 ⁻⁵								
		1. H ₂ S exposure		1	2x10 ⁻¹²	II	0				
		2. Fire/explosion		1	2x10 ⁻¹²	II	1	2x10 ⁻¹²	II		
c. Backflow of high pressure H ₂ or N ₂	2x10 ⁻¹⁴	Rupture pressure gauge or flowmeter	1	1x10 ⁻²	2x10 ⁻¹⁶	II	1	2x10 ⁻¹⁴	IV		
		Surge checks work	~1								
		1. H ₂ S exposure		1x10 ⁻³	2x10 ⁻¹⁷	II	0				
		2. Fire/explosion		1x10 ⁻³	2x10 ⁻¹⁷	II	1x10 ⁻³	2x10 ⁻¹⁷	III		
		Surge checks fail	3x10 ⁻⁵								
		1. H ₂ S exposure		1	6x10 ⁻¹⁹	II	0				
		2. Fire/explosion		1	6x10 ⁻¹⁹	II	1	6x10 ⁻¹⁹	II		

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TABLE III-3
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM: Gas Delivery Module

EQUIPMENT: Hydrogen Sulfide

PAGE 4 OF 7

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
5. Rupture of Line a. Component failure	1.7x10 ⁻⁷	Surge checks work	~1							Pressure gauges have relieving backs Flowmeter has shield Eye protection required.	
		1. H ₂ S exposure		1	1.7x10 ⁻⁷	III	0				
		2. Fire/explosion		1	1.7x10 ⁻⁷	III	1	1.7x10 ⁻⁷	III		
		Surge checks fail	3x10 ⁻⁵								
		1. H ₂ S		1	5.1x10 ⁻¹²	II	0				
		2. Fire/explosion		1	5.1x10 ⁻¹²	II	1	5.1x10 ⁻¹²	II		

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TABLE III-3
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Gas Delivery Module EQUIPMENT: Low Pressure Hydrogen PAGE 5 OF 7

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
6. External H ₂ Leak											
a. Leaking component	2.4x10 ⁻³	Personnel ignite H ₂ in attempt to fix leak	1x10 ⁻³	1 1x10 ⁻³	2.4x10 ⁻⁶ 2.4x10 ⁻⁹	III II	1	2.4x10 ⁻⁶	III	System is pressure tested with N ₂ before H ₂ Exhaust ventilation H ₂ monitor Procedures require venting line before correcting leaks.	Recommend line be N ₂ purged before correcting H ₂ leaks.
7. Overpressurize Line											
a. Mis-set pressure regulator	1x10 ⁻⁴	Rupture of pressure gauge or flowmeter	1	1x10 ⁻²	1x10 ⁻⁶	III	1	1x10 ⁻⁴	IV	Pressure gauge has relieving back	
		Surge check works F/E	~1	1x10 ⁻³	1x10 ⁻⁷	III	1x10 ⁻³	1x10 ⁻⁷	III	Flowmeter is shielded Eye protection is required	
		Surge check fails F/E	3x10 ⁻⁵	1	3x10 ⁻⁹	II	1	3x10 ⁻⁹	II	Exhaust ventilation H ₂ monitor Surge check valves	
b. Pressure regulator fails and failure to relieve	6.6x10 ⁻⁸	Rupture of pressure gauge or flowmeter	1	1x10 ⁻²	6.6x10 ⁻¹⁰	II	1	6.6x10 ⁻⁸	IV	Pressure gauge has relieving back	
		Surge check works F/E	~1	1x10 ⁻³	6.6x10 ⁻¹¹	III	1x10 ⁻³	6.6x10 ⁻¹¹	III	Flowmeter is shielded Eye protection is required	
		Surge check fails F/E	3x10 ⁻⁵	1	2x10 ⁻¹²	II	1	2x10 ⁻¹²	II	Exhaust ventilation H ₂ monitor Surge check valves	

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TABLE III-3
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Gas Delivery Module EQUIPMENT: Low Pressure Hydrogen PAGE 6 OF 7

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
7. Overpressurize Line (cont'd.)											
c. Backflow of high pressure H ₂ or N ₂	2x10 ⁻¹⁴	Rupture of pressure gauge or flowmeter	1	1x10 ⁻²	2x10 ⁻¹⁶	II	1	2x10 ⁻¹⁴	IV	Pressure gauge has relieving back	
		Surge checks work F/E	~1	1x10 ⁻³	2x10 ⁻¹⁷	III	1x10 ⁻³	2x10 ⁻¹⁷	III	Flowmeter is shielded Eye protection is required	
		Surge checks fail F/E	3x10 ⁻⁵	1	6x10 ⁻¹⁹	II	1	6x10 ⁻¹⁹	II	Exhaust ventilation H ₂ monitor Surge check valves	
8. Line Rupture											
a. Component failure	8x10 ⁻⁸	Release of H ₂	1				1	8x10 ⁻⁸	IV	Pressure gauge has relieving back	
		Surge check works F/E	~1	1x10 ⁻³	8x10 ⁻¹¹	III	1x10 ⁻³	8x10 ⁻¹¹	III	Flowmeter is shielded Eye protection is required	
		Surge check fails F/E	3x10 ⁻⁵	1	2.4x10 ⁻¹²	II	1	2.4x10 ⁻¹²	II	Exhaust ventilation H ₂ monitor Surge check valves	

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TABLE III-3
(CONTINUED)

SYSTEM: CSTR-1		SUBSYSTEM: Gas Delivery Module					EQUIPMENT: Nitrogen			PAGE 7 OF 7	
POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
9. Overpressurize Low Pressure N ₂ Line											
a. Mis-set pressure regulator	1x10 ⁻⁴	Rupture pressure gauge	1	1x10 ⁻²	1x10 ⁻⁶	III	1	1x10 ⁻⁴	IV	Pressure gauge has re- lieving back. Eye protection is required. Downstream components protected by addi- tional regulators.	
b. Failure of pressure regulator and failure to relieve.	6.6x10 ⁻⁸	Rupture pressure gauge.	1	1x10 ⁻²	6.6x10 ⁻¹⁰	III	1	6.6x10 ⁻⁸	IV	Pressure gauge has re- lieving back. Eye protection is required. Downstream components protected by addi- tional regulators.	
10. Failure to sup- ply N ₂ purge to CSTR-1 on demand											
a. Solenoid valve fails to operate or H ₂ valve fails to close or N ₂ valve fails to open.	5x10 ⁻³										

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TABLE III-4. SLURRY FEED PROCESS HAZARDS

SYSTEM: CSTR-1

SUBSYSTEM: Slurry Feed Module

EQUIPMENT: Flush Oil Tank

PAGE 1 OF 3

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
1. Overpressurize Flush Oil Tank											
a) Pressure regulator fails or is mis-set (pp 100 psig)	3×10^{-4}	Rupture of Pyrex tank (MR = $70 \times \frac{8}{5}$ psig) • Personnel injured by flying glass, contact with flush oil • Loss of tank	1.6×10^{-2}	≤ 1	4.8×10^{-6}	III	1	4.8×10^{-6}	III	Procedures require eye protection in area.	
b) As in a) plus upstream regulator fails or is mis-set (pp 3500 psig)	9×10^{-8}	Rupture of Pyrex tank • Personnel injured by flying glass, contact with flush oil • Loss of tank	1	≤ 1	9×10^{-8}	II	1	9×10^{-8}	III	Same as for entry 1 a)	

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TABLE III-4
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Slurry Feed Module EQUIPMENT: Slurry Feed Tank PAGE 2 OF 3

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
2. Overpressurize Slurry Feed Tank											
a) Pressure regu- lator fails or is mis-set (pp = 100 psig)	3×10^{-4}	1. Rupture rotameter (MAP = 200 psig) • Personnel injured by missile • Loss of meter	$< 10^{-15}$	1×10^{-3}	$< 3 \times 10^{-22}$	III	1	$< 3 \times 10^{-19}$	IV	Rotameter is shielded. Procedures require eye protection in area.	
		2. Rupture tank and release slurry • Personnel injury • Loss of tank	$< 10^{-15}$	1	$< 3 \times 10^{-19}$	II	1	$< 3 \times 10^{-19}$	III	Rotameter acts as relief valve for tank.	
b) As in a) plus upstream regu- lator fails or is mis-set (pp 3500 psig)	9×10^{-8}	1. Rupture rotameter • Personnel injury • Loss of meter	1	1×10^{-3}	9×10^{-11}	III	1	9×10^{-8}	IV	Same as for entry 2 a)	
		2. Rupture tank and release slurry • Personnel injury • Loss of tank	$< 10^{-15}$	1×10^{-3}	$< 9 \times 10^{-26}$	II	1	$< 9 \times 10^{-23}$	III		

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TABLE III-4
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Slurry Feed Module EQUIPMENT: Pumps and Piping PAGE 3 OF 3

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
3. Overpressurize Discharge Line											
a) Moyno pump deadhead and relief valve fails.	3.1×10^{-5}	Rupture line and release slurry.	<1	.1	$<3 \times 10^{-6}$	III	<1	$<3 \times 10^{-6}$	IV	Relief valve controls event probability.	Vent line should be open during pres- surization of line for pressure test.
b) Feed pump dead- headed and re- lief valve fails.	1.5×10^{-5}	Rupture line and release slurry.	1	.1	$<10^{-6}$	III	1	1.5×10^{-6}	IV	Same as for entry 3 a).	
c) Plug occurs and operator circum- vents relief system in attempt to break plug with pressure.	9×10^{-2}	Rupture line and release slurry.	1×10^{-2}	.1	$<9 \times 10^{-4}$	III	1	9×10^{-4}	IV	Procedures require eye protection in area.	Operators must be extremely careful in attempting to free plugs.

TABLE III-5. REACTION & SEPARATION PROCESS HAZARDS

PAGE 1 OF 10

SYSTEM: CSTR-1

SUBSYSTEM: Reaction and Separation

EQUIPMENT: Valves and Piping

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
1. Overpressurize Line Before Re- actor Inlet											
a) Plug in line and shutdown and relief systems fail.	1.4×10^{-11}	Line rupture - re- lease of H_2 and slurry.	1	≤ 1	1.4×10^{-11}	III	1	1.4×10^{-11}	III	High pressure shutdown and relief systems control event proba- bility.	Rupture disc should be inspected prior to run to insure no make-up with coal.
		F/E of released material.	≤ 1	≤ 1	1.4×10^{-11}	II	1	$< 1.4 \times 10^{-11}$	II	Exhaust ventilation H_2 monitor. Procedures require eye protection Procedures call for 'proving' safety systems prior to startup.	
2. Block in Line Be- tween Reactor In- let and PT-401											
a) Plug in line or valve or valve closed and shutdown and relief systems fail.	1.4×10^{-15}	Rupture of valve or vessel and release of hot reaction product.	1	≤ 1	1.4×10^{-15}	I	1	1.4×10^{-15}	I	Same as for entry 1 a).	

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TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Reaction and Separation Module EQUIPMENT: Piping and Valving PAGE 2 OF 10

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
3. Block in Line Between PT-401 and BPR-402											
a) Plug in line or valve, or valve failed closed and failure of shut-down/relief systems.	7.2×10^{-16}	Rupture of valve or vessel and release of hot reaction product.	1	≤ 1	7.2×10^{-16}	I	1	7.2×10^{-16}	II	Same as for entry 1 a).	
4. Block in Line Between BPR-402 and Vent.											
a) Plug in line or valve and failure of relief.	5.9×10^{-7}	Rupture of knock out drum V-410.	1	≤ 1	5.9×10^{-7}	II	1	5.9×10^{-7}	III	Same as for entry 1 a).	

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TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Reaction and Separation Module EQUIPMENT: H.O. Depressurization

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
5. Failure to Switch from V-401 to V-402	4.1x10 ⁻³	Overfill V-401									
6. Overpressurize Low Pressure Side of System											
a. Let down V-402 and CV-405 plugged or failed closed or MV-424 closed or blocked and relief valve fails	1x10 ⁻⁶	1. Rupture of H ₂ O receiver 2. H ₂ O pressurized. Operator splashed and exposed to gas when he drains receiver	1x10 ⁻³ 1	1 1	1x10 ⁻⁹ 1x10 ⁻⁶	I III	1 0	1x10 ⁻⁹	II		Procedures should include reading pressure gauge to insure <10 psig on receiver before draining. Face shield and rubber gloves minimum equipment.
b. Let down V-402 and flash gas line downstream of MV-424 block and relief valves fail	8.5x10 ⁻¹⁰	1. Rupture of H ₂ O receiver 2. H ₂ O pressurized. Operator splashed and exposed	1x10 ⁻³ 1	1 1	8.5x10 ⁻¹³ 8.5x10 ⁻¹⁰	I II	1 0	8.5x10 ⁻¹³	III		Procedures should include reading pressure gauge to insure <10 psig on receiver before draining. Face shield and rubber gloves minimum equipment.
c. Operator uses nitrogen to aid in draining H ₂ O receiver and exceeds 10 psig and relief valve fails	6.3x10 ⁻⁷	H ₂ O receiver pressurized - operator splashed with H ₂ O product	1	1	6.3x10 ⁻⁷	II					Procedures should include reading pressure gauge to insure <10 psig on receiver before draining. Face shield and rubber gloves minimum equipment.

TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM: Reaction and Separation Module

EQUIPMENT: NO Depressurization

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
7. Switch From Separator V-401 to Separator V-402 Without Re-pressurizing V-402.	1×10^{-3}	Damage trim in AOV-401	1	0			1	1×10^{-3}	IV		

TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM: Reaction and Separation Modules

EQUIPMENT: I.O. Depressurization

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
8. Filling V-405 When Use of V-406 is In- tended or In- dicated	4.1x10 ⁻³	Overfill V-405									
9. Overpressurize Low Pressure Side of System											
a. Let down V-406 and CV-407 or MV-424 plugged or closed and relief valve fails	5.3x10 ⁻⁷	1. Rupture of LO receiver 2. LO receiver pressurized - operator splashed and ex- posed to flash gas	1x10 ⁻³ 1	1 1	5.3x10 ⁻¹⁰ 5.3x10 ⁻⁷	I II	1 0	5.3x10 ⁻¹⁰	II		Procedures should in- clude reading pressure gauge to insure <10 psig on receiver be- fore draining. Face shield and rubber gloves minimum equip- ment.
b. Let down V-406 and flash gas line down- stream of MV-424 blocked and relief valves fail	4.5x10 ⁻¹⁰	1. Rupture of LO receiver or flash gas to pot 2. LO receiver pressurized	1x10 ⁻³ 1	1 1	4.5x10 ⁻¹⁰ 4.5x10 ⁻¹⁰	II II	1 0	4.5x10 ⁻¹⁰	II		Procedure should in- clude reading pressure gauge to insure <10 psig on receiver be- fore draining. Face shield and rubber gloves minimum equip- ment.
c. Operator uses N ₂ to aid in draining I.O. receiver and exceeds 10 psig and relief valve fails	3.3x10 ⁻⁷	LO receiver pres- surized	1	1	3.3x10 ⁻⁷	II	0				Procedure should in- clude reading pressure gauge to insure <10 psig on receiver be- fore draining. Face shield and rubber gloves minimum equip- ment.

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TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Reaction and Separation Modules EQUIPMENT: L.O. Depressurization PAGE 6 OF 10

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
10. Switch From Separator V-405 to Separator V-406 Without Repressurizing V-406.	1x10 ⁻³	Damage to trim in AOV-404	1	0			1	1x10 ⁻³	IV		

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TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Reaction and Separation Modules EQUIPMENT: Preheater and Reactor PAGE 7 OF 10

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
11. Excessively High Process Temperature											
a. Failure of preheater temperature control and failure of temperature shutdown system	2.4×10^{-9}	Rupture of reactor or downstream vessel due to loss of strength with temperature	≤ 1	≤ 1	2.4×10^{-9}	I	1	2.4×10^{-9}	I	High temperature interlocks	Change TSH set points to 550°C NOTE: Event probability assumes shutdown system can intervene before failure. Demand on shutdown is 1.7×10^{-4}
b. Failure of reactor temperature control and failure of temperature shutdown system	2.4×10^{-9}	Rupture of reactor	1	≤ 1	2.4×10^{-9}	I	1	2.4×10^{-9}	I	High temperature interlocks	Change TSH set points to 550°C NOTE: Event probability assumes shutdown system can intervene before failure. Demand on shutdown is 1.7×10^{-4}
c. Unknown exothermic reaction and shutdown system fails	$< 1 \times 10^{-9}$	Rupture of reactor	≤ 1	≤ 1	$< 1 \times 10^{-9}$	I	1	$< 1 \times 10^{-9}$	I	High temperature interlocks	Change TSH set points to 550°C NOTE: Event probability assumes shutdown system can intervene before failure.

TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1 SUBSYSTEM: Reaction and Separation Modules EQUIPMENT: Vessels PAGE 8 OF 10

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
12. Unknown Pressure Generating Reaction and Relief System Failure and Shutdown Failure	6.5×10^{-16}	Rupture of vessel	1	≤ 1	$< 7 \times 10^{-16}$	I	1	7×10^{-16}	I	High pressure interlocks and relief valves	
13. Loss of Vessel Integrity											
a. Random failure	3×10^{-8}	Rupture of vessel	1	≤ 1	$< 3 \times 10^{-8}$	I	1	$< 3 \times 10^{-8}$	I		
b. Failure due to chemical attack on metal	Unknown	Rupture of vessel	1			I			I		Austenitic stainless steels are highly resistant to classic H_2 attack. However stress corrosion effects of H_2S and possible synergistic effects of H_2S or other constituent gases on H_2 attack are not fully understood. Therefore, close monitoring of the metallurgical condition of system vessels is advisable.

TABLE III-5
(CONTINUED)

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SYSTEM: CSTR-1 SUBSYSTEM: Reaction and Separation Modules EQUIPMENT: Water System

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
14. Overpressure Water Injection System											
a. Pump dead- headed and relief valve fails	4.8×10^{-8}	Line rupture	1	≤ 1	$< 5 \times 10^{-8}$	III	1	5×10^{-8}	III	Relief valve	
b. Fill tank with vent valve closed	1×10^{-3}	Burst pyrex tank	?	≤ 1	$< 1 \times 10^{-3}$	IV	1		IV	Operator eye protec- tion required.	Check water supply pressure to determine if rupture of tank is credible.

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TABLE III-5
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM: Reaction and Separation Modules

EQUIPMENT: All

PAGE 10 OF 10

POTENTIAL EVENT CAUSATIVE FACTORS	EVENT PROB.	POTENTIAL EFFECT CONSEQUENCES	EFFECT PROB.	PERSONNEL			EQUIPMENT			EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
				CONSEQ. PROB.	INC. PROB.	HAZ. CAT.	CONSEQ. PROB.	INC. PROB.	HAZ. CAT.		
15. External Leak											
a. Leaking components	1×10^{-4}	Release of flammable or toxic material	1	1×10^{-3}	1×10^{-7}	III	1	1×10^{-4}	IV	H ₂ S monitor	
		Ignition of re-released H ₂	1×10^{-3}	≤ 1	1×10^{-7}	II	1	1×10^{-7}	II	Exhaust ventilation H ₂ monitor H ₂ S monitor	

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TABLE III-7. CSTR-1 WORKPLACE HEALTH HAZARDS

SYSTEM: CSTR-1

SUBSYSTEM: _____

EQUIPMENT: All

PAGE 1 OF 4

POTENTIAL HAZARD		CONSEQUENCES	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
EQUIPMENT ITEM OR PROCEDURAL STEP	RANKING			
1. Installation and Hook-Up of H ₂ /H ₂ S Cylinder				
a. Exposure to H ₂ S	Unlikely	Headaches, dizziness, irritation of eyes and mucous membranes at low concentrations. Paralysis of respiratory center and death at very high concentrations	Potential exposure requires leaking fitting and is limited by size of leak and dispersal/dilution effects of natural outside ventilation. Presence of H ₂ S in the atmosphere at low concentration is detectable by its offensive odor.	The nose should not be relied upon after initial detection of H ₂ S since the sense receptors can be 'overwhelmed' and rendered no longer reliable.
2. Preparation of Coal Slurry				
a. Inhalation of pulverized coal	May occur	Potential long term health hazard due to silica content.		Coal should be added to slurry mix tank in a manner which minimizes formation of coal dust cloud. Respiratory protection should be required unless it can be established by monitoring that an exposure hazard does not exist.
b. Contact with coal-derived liquid (solvent)	May occur	Contact dermatitis. Percutaneous absorption of constituents of coal-derived liquids which are suspected cancer-causing agents.	General OSH section of procedures speaks to need for wearing personal protective equipment, and for immediately washing any affected areas.	Recommend that specific personal protective equipment requirements be listed with specific operational procedures as well as in the general OSH section.
c. Inhalation or contact with catalyst	May occur	Dependent on specific catalyst in use.		Precautions for handling specific catalyst should be indicated on slurry preparation sheet for the particular run.

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TABLE III-7
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM:

EQUIPMENT: ALL

PAGE 2 OF 4

POTENTIAL HAZARD		CONSEQUENCES	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
EQUIPMENT ITEM OR PROCEDURAL STEP	RANKING			
3. Transfer Coal Slurry to Slurry Feed Tank				
a. Contact with coal/catalyst slurry	May occur	Contact dermatitis. Percutaneous absorption of constituents of coal-derived liquids which are suspected cancer-causing agents. Dependent on specific catalyst in use.		Recommend that specific personal protective equipment requirements be listed with specific operational procedures as well as in the general OSH section. Precautions for handling specific catalyst should be indicated on slurry preparation sheet for the particular run.
4. Fill Flush Oil Tank				
a. Contact with kerosene or diesel fuel, or inhalation of vapors.	May occur	Contact dermatitis possible. Moderate toxicity by inhalation. Potential carcinogenic hazard.		Use only with adequate ventilation. Wear face and skin protection.
5. Load Reactor Basket				
a. Contact with catalyst	May occur	Dependent on specific catalyst in use.		Precautions for handling specific catalyst should be listed on run sheet.
b. Contact with coal-derived liquids	May occur	Contact dermatitis. Absorption of coal-derived liquids which are suspected carcinogens. Possible burns from hot liquid.	General OSH section of procedures speaks to need for wearing personal protective equipment, and for immediately washing any affected areas.	Require protective gloves and full face shield.

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TABLE III-7
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM:

EQUIPMENT: All

PAGE 3 OF 4

POTENTIAL HAZARD		CONSEQUENCES	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
EQUIPMENT ITEM OR PROCEDURAL STEP	RANKING			
6. Heavy Oil Depressurization and Sampling	May occur	Irritation of respiratory tract, eyes, and/or nose.	General ventilation provided. Ability for local ventilation through use of elephant snout if needed.	Operator training should stress importance of ensuring heavy oil receiver is at near ambient pressure before opening drain valve, to minimize flashing at drain. Monitoring to establish exposure level, if any, should be included in facility OSH Plan.
a. Inhalation of toxic or irritating flash gas, or contact with the same.				
7. Light Oil Depressurization and Sampling	May occur	Dependent on specific catalyst in use.	General OSH section of procedures speaks to need for wearing personal protective equipment, and for immediately washing any affected areas.	Precautions for handling specific catalyst should be listed on run sheet. Require protective gloves and full face shield.
a. Inhalation of toxic or irritating flash gas, or contact with same.				
b. Contact with coal-derived liquids.	May occur	Contact dermatitis. Absorption of coal-derived liquids which are suspected carcinogens. Possible burns from hot liquid.		

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TABLE III-7
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM:

EQUIPMENT:

PAGE 4 OF 4

POTENTIAL HAZARD		CONSEQUENCES	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
EQUIPMENT ITEM OR PROCEDURAL STEP	RANKING			
8. Tail Gas Sampling				
a. Inhalation or contact or toxic or irritating tail gas constituents	Unlikely	Irritation of respiratory tract, eyes, and/or nose.	Sampling conducted in 'closed' system.	Require gloves and chemical goggles for handling acid solution and taking samples.
b. Contact with acidic solution (alternate procedure only)	May occur	Inflammation or burn of the skin.		
9. Flash Gas Sampling				
a. Inhalation of or contact with toxic or irritating flash gas constituents.	Unlikely	Irritation of respiratory tract,	Sampling conducted in 'closed' system.	Require gloves and chemical goggles for handling acid solution and taking samples.
b. Contact with acidic solution (alternate procedure only)	May occur	Inflammation or burn of skin.		
10. Exposure to Toxic or Irritant Material While Monitoring Process	Unlikely	Eye, skin, or respiratory tract irritation. Possible headache or nausea.	System checked for leaks prior to operation. Unit located under exhaust hood. Unit monitored for presence of H ₂ S with alarm and shut-down interlock.	Protective equipment to avoid contact with coal-derived liquids and solvents. Ventilation or respiratory protection may be indicated depending on solvents used.
11. Clean-Up	May occur	Contact with coal-derived liquids and solvents possible. Possible solvent inhalation hazard.	Procedures not specified in enough detail to ascertain.	

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TABLE III-8. CSTR-1 WORKPLACE SAFETY HAZARDS

SYSTEM: CSTR-1

SUBSYSTEM:

EQUIPMENT:

PAGE 4 OF 2

POTENTIAL HAZARD		CONSEQUENCES	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
EQUIPMENT ITEM OR PROCEDURAL STEP	RANKING			
1. Installation or Replacement of Compressed Gas Cylinders at Cylinder Rack	May occur	Strained muscles, broken bones in foot or hand.	Cylinder rack is provided with safety chains. Safety shoes are required by operating procedures.	Approved cylinder carts should be provided and used to transfer cylinders. Personnel should wear leather gloves. Area should be kept free of snow and ice in winter time.
a. Operator injury due to mis-handling, dropping cylinder, or catching fingers between cylinder and equipment.				
2. Installation of Reactor, Slurry Feed Tank, or Filling of Flush Oil Tank	May occur	These items are elevated such that a step stool, platform, or ladder may be needed or used. Potential for fall, especially if unapproved device is used. Items are of sufficient weight that if dropped, foot or ankle could be injured; or if held in extended or awkward position bodily strain could result.		Provide and use only approved devices or structures.
a. Operator injury due to fall, dropping item on body part or 'leverage' situation.				
3. Compressors, Pumps, Agitators	Unlikely	Operator injury if unguarded rotating element is contacted.	Equipment is enclosed or guarded.	Unit should be inspected prior to each start-up to ensure equipment is guarded and guards are in place.
a. Potential for unguarded rotating equipment				

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TABLE III-8
(CONTINUED)

SYSTEM: CSTR-1

SUBSYSTEM:

EQUIPMENT:

PAGE 2 OF 2

POTENTIAL HAZARD		CONSEQUENCES	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
EQUIPMENT ITEM OR PROCEDURAL STEP	RANKING			
4. Preheater, Reactor and Ancillaries				
a. High temperature metal surface	May occur	Burn to personnel or contact with hot metal surface.		Sections of unit which are not insulated, and cannot be for process reasons, and whose surface temperature exceeds 140°F should be clearly identified and labelled with appropriate warning signs.
5. Electrical Heaters and Connections to Motors				
a. Electric shock	Unlikely	Electrical burns, serious injury or possibly death.		Disconnect and lockout equipment before conducting maintenance, repair, or disassembly/assembly. Do not use water or other conductive extinguishing agents to fight fire involving electrical equipment.

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TABLE III-9. CSTR-1 ENVIRONMENTAL HAZARDS

SYSTEM: CSTR-1

SUBSYSTEM: All

EQUIPMENT: All

PAGE 1 OF 1

MATERIAL RELEASE IDENTIFICATION CONSTITUENTS	TYPE OF RELEASE	QUANTITY	EXISTING CONTROL MEASURES	COMMENTS AND RECOMMENDATIONS
1. Off-Gases On Volumetric Basis: Predominantly H ₂ With Some CH ₄ , H ₂ S, H ₂ O and Possible Other Low Molecular Weight Con- stituents	Emission vented to atmosphere	~2 lb/day		Capacity of unit is too small to represent a credi- ble emission problem.
2. Heavy Oil Product Coal-Derived Liquid	Liquid product collected for testing. Material is recycled or disposed of as follows: drummed in DOT approved drums and shipped to secured landfill.	~5 gal/day		
3. Light Oil Product Principally Condensed Water	Liquid collected for testing. Material is disposed of as fol- lows: drummed in DOT approved drum and shipped to secured land- fill.	~1/2 pint/day		
4. Purge Gases	Intermittent emission vented to atmosphere.			
5. System Depressurization Vent Relief Principally H ₂ With Some CH ₄ , H ₂ S, and Other Gases, Followed by Purge N ₂	Abnormal emission vented to at- mosphere in the event of system temperature or pressure upset only.	Maximum system holdup ~6 li @ 2000 psig, 420°C = 0.064 lb H ₂		

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3. WASH-1400, "Reactor Safety Study," Appendix III - Failure Data, U.S. Nuclear Regulatory Commission, October 1975.
4. Lees, F. P., et al, "Some Data on the Reliability of Instruments in the Chemical Plant Environment," The Chemical Engineer, London, 255, pp. 396-402, November 1971.
5. Bush, S. H., "Pressure Vessel Reliability," Journal of Pressure Vessel Technology, February 1975.

APPENDIX A

SYSTEM DOCUMENTATION

1. Engineering Drawings

<u>Drawing No.</u>	<u>Rev.</u>	<u>Date</u>	<u>Title</u>
D-7120	-	10-14-80	Flowsheet for CSTR-1
B-6278	-	10-14-80	Gas Compressor System Bldg. 167 High Bay
B-6279	-	10-14-80	Cylinder Rack, Bldg. 167 High Bay

2. Equipment and Procedures Data

CSTR-1 Operating Manual

3. Miscellaneous Data

Material Balance - no identifying date or number
Interlock Logic - no identifying dates or numbers

APPENDIX B

ANALYSIS METHODOLOGY

This appendix documents the general methodologies used to conduct the Safety Analysis. Discussion is presented for the four analysis components: process hazards, safety concerns, health concerns, and environmental concerns.

A. Process Hazards Analysis

The process hazards analysis was conducted in a four-step approach: (1) Hazards Identification, (2) Hazards Quantification, (3) Consequence Assessment, and (4) Design and Operating Criteria recommendations.

1. Hazards Identification

Hazards identification begins with system familiarization by the analyst to develop an intimate understanding of the process, of how it is intended to function, and of the important process variables. System familiarization consists of a review of process documentation, an on-site visit, and discussions with operations, engineering, and management personnel.

Potential hazards are identified by a systematic analysis of the system documentation; e.g., process flow diagrams, equipment drawings and data, material and energy balances, and operating procedures. Several techniques are used in the systematic analysis. The basic technique is usually identification by inspection, which is supplemented by the additional techniques of FMEA and logic modeling. This approach is preferred to rigid adherence to any single methodology. A straight FMEA is undesirable for the following reasons. First, each individual component may have numerous modes of failure, only several of which may represent potential hazards. Potential hazards are likely to get 'lost' or 'buried' among the many other line items in a FMEA. Second, the FMEA considers hazards arising from single failures only. Third, the logic of a FMEA is inductive rather than deductive. It thus becomes divergent rather than convergent in terms of thought processes and analysis 'bookkeeping.' A FMEA is useful for identifying hazards arising from single component failures, or for establishing cause and effect relationships in an equipment item, but is not preferred as a sole method or means of documenting an analysis.

Identification by inspection is the primary techniques used in the analysis. Potential hazards are identified from a detailed analysis which proceeds equipment item by equipment item, or by operational procedure. Causative factors (single or multiple component failures or operator errors) are determined by inspection of the system documentation. If equipment or control systems are particularly complex, logic-modeling techniques are used to develop the causative factor failure logic. Logic modeling is a rigorous and time-consuming technique, and therefore relatively expensive. Judicious application of logic modeling is therefore indicated to ensure it is cost-effective. Therefore, logic modeling is normally used as a supplementary technique, unless the size, complexity, or other considerations of the system indicate otherwise.

Identified hazards are documented on a 'fact sheet' and entered as a description of a potential hazardous event, accompanied by a description of the causative factors (failure logic) required for the event to occur. A description of the potential effect(s) of the event is also documented.

2. Hazards Quantification

Identified potential hazardous events are quantified by applying failure data to the causative factor failure logic. Use of failure data based on actual operating experience, and which takes into account the operating environment and severity of service is used wherever possible.

Mathematically, failure probabilities are based on exponential distributions (unless otherwise indicated) and are given by

$$P_f = 1 - e^{-\lambda t} \approx \lambda t$$

λ = failure rate

t = operating time

Certain failures may be time independent or data may be in terms of 'per demand' or 'per operation' and are handled accordingly.

Failure probabilities for multiple failures related by 'AND' Logic are determined by the product of the individual probabilities. For 'OR' Logic, the overall probability is approximated by the sum of the individual probabilities.

Effect probabilities for effects such as 'fire/explosion' or 'rupture' are determined from an engineering analysis which compares the potential of the process or event to the response required to produce the undesired effect in the same engineering terms (e.g., vessel pressure if potential event occurs versus pressure rating; or ignition source energy level versus minimum ignition energy of material). Quantification may be based on a probit analysis if probit data are available, or on a safety factor approach. If insufficient material data or design detail exists, and it is deemed not cost effective to develop the data, conservative effect probabilities are used. Should this result in an unacceptable hazard, then one alternative is to expend effort to develop data to determine the credibility of the effect.

Incident probabilities are calculated by multiplying the probabilities for occurrence of the event, the effect, and the specific consequences.

3. Consequence Assessment

The severity of the consequences of potential hazards are assessed, considering such factors as size and construction of equipment, quantity or flow rate of materials and their properties, location and layout of equipment, numbers and location(s) of personnel, and existing safeguards or mitigating factors. Hazard severity categories are assigned based on this assessment.

4. Design and Operating Criteria

Recommendations are provided for all identified incidents which violate specified risk criteria or recommendation guidelines. Recommendations are based on analyst knowledge of the causative factors, failure probabilities, process potentials and material response data. Recommendations may also be provided to further reduce the likelihood or severity of hazards, even though they meet the established criteria or guidelines. Recommendations may take the form of equipment substitution, design changes, procedural changes, or other engineering or administrative controls.

B. Safety Hazards

Workplace safety hazards are identified by inspection of documentation and on-site review, and is usually based upon and builds upon information and knowledge generated during the process hazards analysis.

Specific attention is given to operator-equipment interaction, manual process operations, and potential equipment hazards. The workplace safety analysis is intended to focus on process related hazards and is not intended to be or represent a complete OSHA compliance inspection or audit.

An assessment of likelihood and severity is made. Existing safeguards and controls are documented. Recommended control measures and comments are provided.

C. Health Hazards

Workplace health hazards are identified by inspection of documentation and on-site review, and is usually based on information and knowledge developed in the course of the process hazards analysis. Potentially hazardous materials in use or likely to be generated in the process are identified and documented. Potential sources and modes of operator exposure are identified by inspection and an assessment of likelihood and consequences is made based on system design or procedure, quantity or rate of material, existing control methods, and monitoring data, if available. Recommendations for additional engineering controls, personal protective equipment, or monitoring are made based on the hazard evaluation. The workplace health hazards are not intended to be a full-fledge occupational health, hygiene and monitoring program; but is intended to identify areas where attention should be focused and where controls, monitoring or personal protective equipment may be indicated.

D. Environmental Hazards

Environmental hazards are identified by inspection of documentation and monitoring data, where available, and is usually based on information and knowledge developed in the course of the process hazards analysis. Releases of material from the process are identified and characterized. Existing control measures are evaluated and documented. Recommendations for additional control measures or monitoring are developed as deemed advisable. The Environmental Analysis is not intended to represent a complete Environmental Impact Statement, but is intended as a check on the basis of the EIS, where applicable and data exist, as an aid to identifying areas where attention and monitoring should be focused to correct problems or determine if violations exist, or to document that violations, in fact do not exist.

APPENDIX C

FAILURE RATE DATA

The following failure rate data were used in quantifying hazards identified in the analysis.

<u>Item</u>	<u>Failure Rate⁽¹⁾</u>	<u>Source⁽²⁾</u>
Manual Valves		
Wrong Position	$1 \times 10^{-3}/D$	H
Plugged - clean ⁽³⁾	$3 \times 10^{-4}/D$	W
- dirty	$3 \times 10^{-3}/D$	E
- slurry	$3 \times 10^{-2}/D$	E
External leak - liquid	$3 \times 10^{-8}/H$	W
- gas	$3 \times 10^{-6}/H$	E
Internal leak - clean	$2 \times 10^{-5}/H$	GB
- dirty	$1 \times 10^{-4}/H$	E
- slurry	$1 \times 10^{-3}/H$	E
Check Valves		
Fail to open	$3 \times 10^{-4}/D$	W
Reverse leak - clean	$1 \times 10^{-6}/H$	W
- dirty	$1 \times 10^{-5}/H$	E
- slurry	$1 \times 10^{-4}/H$	E
External leak - liquid	$3 \times 10^{-8}/H$	W
- gas	$3 \times 10^{-6}/H$	E
Air-Operated Valves		
Fail to operate	$1 \times 10^{-3}/D$	W
Plugged - clean	$3 \times 10^{-4}/D$	W
- dirty	$3 \times 10^{-3}/D$	E
- slurry	$3 \times 10^{-2}/D$	E
External leak - liquid	$3 \times 10^{-8}/H$	W
- gas	$3 \times 10^{-6}/H$	E
Internal leak - clean	$2 \times 10^{-5}/H$	L
- dirty	$1 \times 10^{-4}/H$	L
- slurry	$1 \times 10^{-3}/H$	E
Solenoid Valves		
Fail to operate	$3 \times 10^{-3}/D$	W
Internal Leak - clean	$2 \times 10^{-5}/H$	L

APPENDIX C (CONT'D.)

<u>Item</u>	<u>Failure Rate⁽¹⁾</u>	<u>Source⁽²⁾</u>
Relief Valves		
Fail to open	$3 \times 10^{-5}/D$	W
Open prematurely	$3 \times 10^{-5}/H$	W
Leak	$2 \times 10^{-5}/H$	L
Pipe Rupture	$3 \times 10^{-9}/H$	W
Relays		
Fail to energize	$3 \times 10^{-4}/D$	W
N.O. contacts fail to close	$1 \times 10^{-6}/H$	W
Short across NO/NC contacts	$3 \times 10^{-8}/H$	W
Open NC contact	$3 \times 10^{-7}/H$	W
Pressure Switch		
Fail to operate	$3 \times 10^{-4}/D$	W
Pressure Vessel		
Catastrophic failure-noncorrosives	$5 \times 10^{-9}/H$	P
Rupture Disc	$5 \times 10^{-6}/H$	L
Pressure Regulator	$2 \times 10^{-4}/H$	
Temperature Measurement		
Thermocouple	$6 \times 10^{-5}/H$	L
Transducer	$1 \times 10^{-4}/H$	L
Solid State Relay	$2 \times 10^{-6}/H$	

(1) Failure Rates - Failures per demand or operation (D), or failures per operating hour (H).

(2) Sources - W --WASH 1400, Reference 3.
           E - Base failure rate adjusted for service environment.
           L - F. P. Lees, et al., Reference 4.
           P - Pressure vessel reliability, Reference 5.
           H - General operator error failure rate, Hercules Data Bank.

(3) Streams - Clean - cooling water, instrument air, N₂, H₂, etc.
           Dirty - process fluid
           Slurry - process slurry

APPENDIX D

PRESCRIBED STANDARDS

DOE has adopted certain operational environment, safety, and health standards. These are classified as either prescribed standards or recommended standards. Prescribed standards define minimum requirements with which DOE and its contractors must comply, while recommended standards are those which shall be considered for guidance. Prescribed standards are presented for different classifications or types of hazards. Those, which in our judgment, are likely to be applicable to coal conversion processes, as opposed to other types of operations or facilities in general, are identified below. Specific standards which appear to be specifically or directly applicable are further identified by an asterisk (*).

EMERGENCY PREPAREDNESS

- (1) Executive Order 11490, Assigning Emergency Preparedness Functions to Federal Departments and Agencies, and Amendments
- (2) Emergency Planning, Preparedness and Response Program, Chapter 0601 and Appendix 0601.
- (3) Damage Assessment, Chapter 0621 and Appendix 0621.
- (4) Facilities General Design Criteria, Chapter 6301 and Appendix 6301.
- (5) Telecommunications, Chapter 0270 and Appendix 0270, Part VIII.
- (6) DOE Response to Accidents Involving Nuclear Weapons in the Custody of the DOD, Chapter 0527 and Appendix 0527.
- (7) Prevention of Accidental or Unauthorized Nuclear Detonations, Chapter 0460.
- (8) Immediate Evacuation Signal for Use in Industrial Installations Where Radiation Exposure May Occur, ANSI N 2.3-1967 (ANSI).

ENVIRONMENTAL PROTECTION

- *(1) Prevention, Control, and Abatement of Air and Water Pollution, Chapter 0510 (DOE IAD 0510-1), Implementing Executive Order 11752, Prevention, Control, and Abatement of Environmental Pollution at Federal Facilities, and the Following Standards, Regulations, and Guidelines Promulgated Pursuant to Federal Environmental Legislation:

APPENDIX D (CONT'D.)

ENVIRONMENTAL PROTECTION (CONT'D.)

(1) (a) Air

- 1 New Source Performance Standards (40 CFR 60)
- *2 National Hazardous Air Pollutant Standards (40 CFR 61).
- 3 Regulations Designating Air Quality Control Regions (40 CFR 81).

(b) Water

- *1 Discharge of Oil (40 CFR 110)
- *2 Oil Pollution Prevention (40 CFR 112)
- *3 National Oil and Hazardous Substances Contingency Plan (40 CFR 1510)
- *4 Water Quality Standards Approved by the Federal Government (40 CFR 120)
- *5 Thermal Discharges (40 CFR 122)
- *6 Policies and Procedures for the National Pollutant Discharge Elimination System (40 CFR 125)
- *7 Pretreatment Standards (40 CFR 128)
- 8 Secondary Treatment Information (40 CFR 133)
- 9 Transportation for Dumping, and Dumping of Material Into Ocean Waters (40 CFR 220-226)
- 10 Best Technology Available for the Design, Construction, and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact (40 CFR 401 and 40 CFR 402)

(c) Drinking Water

- 1 Interim Primary Drinking Water Regulations (40 CFR 141)
- 2 Interim Primary Drinking Water Regulations Implementation (40 CFR 142)

(d) Solid Waste

- *1 Thermal Processing of Solid Wastes and Land Disposal of Solid Wastes (40 CFR 240 and 241)
- *2 Solid Waste Storage and Collection (40 CFR 243)

(e) Radiation

- 1 Standards and Requirements for Radiation Protection, DOE 0524
- 2 Performance Testing and Procedural Specifications for Thermoluminescence Dosimetry (Environmental Applications) ANSI N 545-1975 (ANSI)

APPENDIX D (CONT'D.)

ENVIRONMENTAL PROTECTION (CONT'D.)

(1) (f) Pesticides

- 1 Environmental Safeguards on Activities for Animal Damage Control on Federal Lands (Executive Order 11643)
  - 2 Regulations for Enforcement of the Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 162)
  - 3 Regulations for the Acceptance of Certain Pesticides and Recommended Procedures for the Disposal and Storage of Pesticides and Pesticides Containers (40 CFR 165)
  - 4 Exemption of Federal and State Agencies for Use of Pesticides Under Emergency Conditions (40 CFR 166)
  - 5 Worker Protection Standards for Agricultural Pesticides (40 CFR 170)
  - 6 Certification of Pesticide Applicators (40 CFR 171)
- *(2) Intrastate or Interstate Regulations of Environmental Protection Authorities.
- *(3) Effluent and Environmental Monitoring and Reporting, Chapter 0513.
- (4) Standards and Requirements for Radiation Protection, Chapter 0524.

FIRE PROTECTION

- *(1) Industrial Fire Protection, Chapter 0552
- *(2) General Design Criteria, Chapter 6301
- *(3) National Fire Codes (NFPA)
- (4) Standard for Fire Protection of AEC Electronic Computer Data Processing Systems. WASH 1245-1 (Compliance With this Standard Satisfies the Requirements for NFPA-75.)
- *(5) Lists of Inspected Appliances, Equipment, and Materials (UL)
- *(6) Factory Mutual Approval Guide (FM)
- (7) TP20-11 General Fire Fighting Guidance for Nuclear Weapons

APPENDIX D (CONT'D.)

HEALTH PROTECTION

a. Radiation Protection

- (1) Standards and Requirements for Radiation Protection, Chapter 0524
- (2) Occupational Radiation Exposure Information, Chapter 0525
- (3) Performance Specifications for Direct Reading and Indirect Reading Pocket Dosimeters for X and Gamma Radiation, ANSI N13.5-1972 (ANSI)
- (4) Radiation Symbol, ANSI N2.1-1969 (ANSI)
- (5) Radiological Safety in the Design and Operation of Particle Accelerators, ANSI N43.1-1969 (ANSI)
- (6) Specification and Performance of Onsite Instrumentation for Continuously Monitoring Radioactivity in Effluents, ANSI N13.10-1974
- (7) Personnel Neutron Dosimeters (Neutron Energies Less than 20 MeV), ANSI N319-1976
- (8) Implant Plutonium Monitoring for Personnel Protection, ANSI N317-1977
- (9) "Standards for the Unrestricted Release of Radioactively Contaminated Equipment and Facilities," ANSI N328
- (10) "Inspection and Test Specifications for Direct and Indirect Reading Quartz Fiber Pocket Dosimeters," ANSI N322-1977.

b. Occupational Medicine

- *(1) Occupational Medical Program, Chapter 0528
- *(2) DOE Employee Occupational Health Services Program, DOE 4161.

c. Industrial Hygiene

- *(1) Current Threshold Limit Values (ACHIH)
- *(2) Practices for Respiratory Protection, ANSI Z88.2-1969 (ANSI)

d. Public Health and Sanitation

Food

- (1) "Food Service Sanitation Manual," USPHS Publication No. 934 (1962)
- (2) "The Vending of Food and Beverages," USPHS Publication No. 546 (1965)

APPENDIX D (CONT'D.)

HEALTH PROTECTION (CONT'D.)

d. Public Health and Sanitation (Cont'd.)

Water

- (1) National Primary Drinking Water Regulations, 49 CFR 141, USEPA (1975)
- (2) "Manual for Evaluating Public Drinking Water Supplies," USEPA Publication No. 1820 (1971)
- (3) "Manual of Individual Water Supply Systems, USEPA Publication No. 430 9/73-003 (1975)
- (4) "Quality Standards for Bottled Water," USEPA (1973) 21 CFR 11
- (5) "A Sanitary Standard for Manufactured Ice," USPHS 1183 (1964)
- (6) GSA Handbooks on Performance Standards for Cleaning Public Buildings (General Services Administration).

OCCUPATIONAL SAFETY

a. General Safety

- *(1) General Design Criteria, Chapter 6301
- (2) Forest Service Safety Standards (USDA)
- *(3) Boiler and Pressure Vessel Code; Sections I-XI (ASME)

b. Construction Safety

- (1) Construction Safety Program, Chapter 0505
- (2) Pipeline Safety Standards Title 49 CFR Part 192

c. Crane Safety

- *(1) ANSI Series B 30.2 Through B 30.9 (ANSI)
- *(2) Crane Manufacturers Association of America, Specification No. 70 (CMAA)

d. Drilling Safety

- (1) Petroleum Safety Orders, Administrative Code, Title 8, Chapter 4, Subchapter 14, State of California (Except the Requirements of Paragraph (b) Section 6640, of Article 41 of the 1959 Orders is Permanently Waived-API RP 98 Applies)
- (2) Applicable Division of Production Specifications and Recommended Practices on Oil Field Equipment (API)
- (3) Safe Practices in Drilling Operations, Third Edition, 1967 RP 2010 (API)

APPENDIX D (CONT'D.)

e. Electrical Safety

- *(1) National Electrical Code, NFPA 70 (ANSI-C1)
- *(2) National Electrical Safety Code (ANSI-C2)

f. Explosives Safety

- (1) Safety Manual, AMCR 385-100, U. S. Army Materiel Development and Readiness Command
- (2) DOD Ammunition and Explosives Safety Standards, DOD 4145.27M (DOD)
- (3) Blaster's Handbook (DuPont)

g. Firearm Safety

- (1) Physical Protection Handbook (GSA-)
- (2) Pistols and Revolvers, FM 23-35, 7-60 (AMC)
- (3) Safety With Firearms Handbook (NRA)
- (4) Firearms Handling Handbook (NRA)

h. Mine and Tunnel Safety

- (1) Federal Metal and Nonmetallic Mine Safety Act, Public Law 89-5771, Standards, 30 CFR 55, 56, 57
- (2) Tunnel Safety Orders, Administrative Code, Title 8, Chapter 4, Subchapter 20, State of California
- (3) Mine Safety Orders, Administrative Code, Title 8, Chapter 4, Subchapter 12, State of California

APPENDIX E

SAFETY ANALYSIS REQUIREMENT DETERMINATION

For illustrative purposes, the technical sections of the Safety Analysis Requirement Determination have been completed and are included in the following pages.

SAFETY ANALYSIS REQUIREMENT DETERMINATION

SUMMARY AND SIGNATURES

OPERATION: CSTR-1Sub-Operation (if any): NA

1. SAR not required (Check as applicable)

- ☐ Solely construction activity
☐ Nuclear safety of weapon designs
☐ Contract, PETC/DOE will not assume ES&H responsibility

If any checked, proceed to Step 6.

2. SAR may be Required (Check as applicable)

- ☐ Contract, PETC/DOE will assume ES&H responsibility
☒ In-House operation

3. Complete Sheet 2 and attach

- ☐ SA not required. Go to Step 6.
☒ SA is required. Go to Step 4.

4. Complete Sheet 3 and attach.

Level 2 SA required

5. Complete Sheet 4 and attach

Cost estimate \$ _____

- ☒ New operation (SAR must be complete before operation commences)
☐ Pre-existing facilities. Should SAR be completed before facility put to next use?
☐ YES ☐ NO

6. _____
Signature of preparer Title Date

7. ☐ Concur ☐ Do not concur

_____
Signature of reviewer_____
Title_____
Date

Reasons and Comments:

SAFETY ANALYSIS REQUIREMENT DETERMINATION

HAZARDS GENERALLY ENCOUNTERED/ACCEPTED

OPERATION: CSTR-1Sub-Operation (if any) NA

1. Answer the following for the operation

YES NO

- Any operating temperatures above 120°F or below -20°F? ☒ YES ☐ NO
- Any operating pressures above 15 psig or below ambient? ☒ YES ☐ NO
- Any equipment rotating above 4000 rpm? ☐ YES ☒ NO
- Any materials with NFPA Health Hazard Rating of 2 or above? ☒ YES ☐ NO
- Any materials with NFPA Flammability Rating of 2 or above? ☒ YES ☐ NO
- Any materials with NFPA Reactivity Rating of 2 or above? ☐ YES ☒ NO
- Any tools and/or equipment not typically found in the home or office? ☒ YES ☐ NO
- Any sources of ionizing radiation other than instrumentation? ☐ YES ☒ NO
- Any other factor(s) which indicate(s) a SA is needed ☐ YES ☐ NO
- ☐ All of the above checked NO. SA is not required
- ☒ Some of the above checked YES. Proceed to Step 2

2. Certain DOE operations may involve equipment and/or materials which result in an answer of YES in Step 1, but which represent only hazards of a type or magnitude which are routinely encountered and/or accepted by the public. Check as applicable:

- ☐ Motor vehicle operation, maintenance (types of vehicles used by the general public)
- ☒ Small quantities (≤ 5 gallons) of commercial fuels and lubricants used solely in operation of machinery and vehicles
- ☐ Kitchen and domestic appliances
- ☐ Office equipment
- ☐ Portable power tools
- ☐ Domestic water systems
- ☐ Machine shop equipment
- ☐ Domestic hot water systems
- ☐ Portable electric heaters
- ☐ Utility boilers which meet the following conditions:
Built, instrumented, inspected, and tested to ASME Code
Capacity: $\leq 250,000$ lb/hr at ≤ 250 psig
- ☐ Other - Identify:

3. Considering the exclusions of Step 2, are there any items in Step 1 which are still answered YES?

☒ YES SA is required☐ NO SA is not required

4.

Signature of preparer

Date

SAFETY ANALYSIS REQUIREMENT DETERMINATION

LEVEL OF ANALYSIS

OPERATION: CSTR-1Sub-Operation (if any) NA

1. Short description: <u>Bench-scale continuous-flow coal liquefaction unit designed to screen potential catalysts, evaluate catalyst and process parameters, and study catalyst aging mechanisms</u> ☐ State-of-the-Art ☒ Advanced Technology		
2. Type of operation ☐ Non-chemical ☐ Laboratory ☒ Bench-scale ☐ PDU ☐ Pilot plant ☐ Demonstration ☐ Commercial	3. Materials in use ☒ Explosive ☒ Flammable ☒ Toxic ☐ Corrosive ☒ Erosive ☐ None of the above	4. Personnel exposure ☐ Remote operation ☐ Occasionally exposed ☒ Frequently exposed ☐ Normally exposed
5. Operating parameters: Other considerations: <u>Unit is rack mounted under exhaust hood. No shielding or barriers. Gases supplied and accumulated in compressed gas cylinders.</u> Thruput or batch size <u>~ 400 gml/hr</u> Operating temperature range <u>~ 800 °F</u> Operating pressure range <u>~ 2000 psig</u>		
6. Considering the type of operation, process, materials, personnel and siting factors, assign a Level of SA based on consequences of potential incidents as follows: Non-chemical or laboratory unit: Level 1 Bench-scale unit: Level 1 or 2 using criteria below Process development unit: Level 1, 2 or 3 using criteria below Pilot plant: Level 2 or 3 using criteria below Demonstration or Commercial Units: Level 3		
CRITERIA Level 3 - Potential for major off-site impacts Level 2 - Potential for permanent disability or death, or significant equipment/facility loss on-site Level 1 - Negligible potential for serious injury, and loss of equipment not a major concern		
Based on the above, a Level 2 SA is assigned. (Highest level which applies)		
7. _____ Signature of preparer _____ Date		

BUDGETARY COST ESTIMATE

Sub-Operation (if any) 24

- 1. Complete this Step for backfit operations only, otherwise go to Step 2.**

Years _____

Use _____

4

☐ None applicable☐ Qualitative

Quantitative

☐ No significant accident

☐ **Disabling injury**

☐ Facility damage

Fatality

D. Considering the factors above, should the Safety Analysis be completed prior to the operation being put to next use? ☒ YES ☐ NO

2. The following Budgetary Cost Estimate Guidelines are based on a percentage of EITHER the construction cost of the operation OR the design engineering manpower cost. Use the upper end of the ranges for a complete Safety Analysis, the lower end of the ranges for a complete Process Hazards Analysis only. Better estimates can be made as SA experience is accumulated.

<u>SA Level</u>	<u>Percent of Construction Cost Basis</u>	<u>Percent of Design Engineering Basis</u>
1	0.1 - 0.3	2 - 4
2	1 - 2	5 - 10
3	2 - 4	5 - 10

For backfit operations consider the extent and applicability of existing analyses when determining budget allocation.

Level of SA (from Sheet 3): 2

Cost estimate _____ % of \$ _____ = \$ _____

Basis and reasoning:

3. Signature of Preparer

Date _____

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