PRELIMINARY FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS (FMECA) OF THE BRAYTON ISOTOPE POWER SYSTEM (BIPS) GROUND DEMONSTRATION SYSTEM

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Drawing No. 306960

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ABBREVIATIONS

ACS - Auxiliary Cooling System (for HSA)
AIRPHX - AiResearch-Phoenix
APS - Alarm and Protection System

BIPS - Brayton Isotype Power System
BRU - Brayton Rotating Unit

CCD - Configuration Control Document

DVM - Digital Volt Meter

EAB - Emergency Argon Backfill
ECS - Emergency Cooling System (for HSA)
EVCBS - Emergency Vacuum Chamber Backfill System

FIRS - Facility Instrumentation and Recording System
FMECA - Failure, Modes, Effects and Criticality Analysis
FS - Flight System

GDS - Ground Demonstration System
GE-VF - General Electric - Valley Forge
GFE - Government Furnished Equipment
GMS - Gas Management System
GMV - Gas Management Valve (Helium vent in HSA)
GSC - Gas Service Cart

HRHX - Heat Rejection Heat Exchanger
HS - Heat Source (see IHS)
HSA - Heat Source Assembly
HSHX - Heat Source Heat Exchanger (in HSA)
HSIS - Heat Source Insulation System
HVP - High Vacuum Pump
HVTC - High Vacuum Test Chamber

IHS - Isotope Heat Source

MBR - Mini-Brayton Recuperator
MHW - Multi-Hundred Watt
MJS - Mariner Jupiter Saturn

PICS - Post Impact Containment Shells
PSC - Power Supply Console

QA - Quality Assurance

ABBREVIATIONS (Contd)

RGA - Residual Gas Analyzer
RTG - Radioisotope Thermoelectric Generator

TSP - Titanium Sublimation Pump

W_e - Watts, electrical
WFMS - Working Fluid Management System
W_t - Watts, thermal

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PHOENIX, ARIZONA

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1. INTRODUCTION

A Failure Modes, Effects and Criticality Analysis (FMECA) has been made of the Brayton Isotope Power System Ground Demonstration System (BIPS-GDS). Details of the analysis are discussed in the following sections.

The BIPS Flight System was recently analyzed in an AIRPHX report.* Since the results of the Flight System FMECA are directly applicable to the BIPS to be tested in the GDS mode, the contents of the earlier FMECA have not been repeated in this current analysis. (The BIPS-FS FMECA has been reviewed and determined to be essentially current. The reader is referred to the latest edition of the BIPS Design Integrity Checklist** for an update of those Flight System failure modes that have been identified as being most critical.)

*AIRPHX Report 76-311709, "Preliminary Failure Modes, Effects and Criticality Analysis (FMECA) Brayton Isotope Power System Flight System," January 12, 1976.

**AIRPHX Report 76-311971, "BIPS Design Integrity Checklist," June, 1976.

2. BIPS-GDS CONFIGURATION

The BIPS is being developed by ERDA as a 500 to 2000 W_e, 7-year life, space power system utilizing a closed Brayton cycle gas turbine engine to convert thermal energy (from an isotope heat source) to electrical energy at a net efficiency exceeding 25 percent. During Phase I of the development program, the prime contractor, the AiResearch Manufacturing Company of Arizona (AIRPHX), will demonstrate the performance and endurance capabilities of the BIPS in a Ground Demonstration System (GDS). The BIPS to be demonstrated will be, insofar as economically and technically feasible, prototypical of the BIPS Flight System. The major differences will be in the heat rejection and heat source components. A simple Heat Rejection Heat Exchanger (HRHX) will simulate the space radiator, and Electrical Heat Sources (EHSs) will simulate the Isotope Heat Sources (IHSs). These and other minor differences between the BIPS GDS and BIPS FS are shown in Table I.

The BIPS will be tested in the GDS mode in a High Vacuum Test Chamber (HVTC) at AIRPHX during 1977-78. All components of the BIPS except the HRHX and the controls will be placed in the HVTC used to simulate the vacuum of space. AIRPHX Drawing No. 306960, "Preliminary BIPS GDS Piping and Instrumentation Diagram" (see Appendix), shows schematically the major elements comprising the BIPS GDS test facility set up as presently conceived.

The major components of the BIPS-GDS and its test facility support equipment are briefly described in the following paragraphs. For additional information, the reader is referred to the BIPS Configuration Control Document (CCD) (AIRPHX Report 75-311274B, dated March 15, 1976) which is revised periodically and to the BIPS Design Layout Summary (AIRPHX Report 76-311972, dated June 15, 1976).

The major components of the BIPS-GDS and its facility support equipment consist of the following:

TABLE I

SIMILARITIES AND DIFFERENCES

BETWEEN THE BIPS GDS AND THE BIPS FS

SUB-SYSTEM	CONFIGURATION	MATERIALS	PERFORMANCE	WEIGHT
MINI BRU	Identical except for instrumentation (Added for GDS tests)	Identical	Identical	Identical (38 pounds)
MBR	Similar except for instrumentation (Added for GDS tests) and size (MBR used in GDS tests is oversize since it has been optimized for three HSAs rather than two). The same basic design can be incorporated into a smaller version optimized for the 2 HSA flight system.	Identical	FS optimized for 2 capsule operation; GDS optimized for 3 capsules	Less for flight system (134/106 pounds)
HSA	Identical except for: 1) Instrumentation (added for GDS tests), 2) EHS power leads (for GDS), 3) Gas management valve (used only in HSA for FS for venting helium generated by isotope decay), and 4) Auxiliary cooling valve (used for venting cover gas from insulation - the GDS will utilize system which will permit reinjection of cover gas; FS ACV will be one-shot mechanism, probably actuated by radio command).	Identical except for external support housing and end domes (stainless steel for GDS; Beryllium for FS) and as noted under "configuration"	Identical	Similar; FS predicted to be somewhat lighter, primarily because Beryllium will replace stainless steel for housing.
RADIATOR	GDS will utilize a liquid to gas HRHX to simulate the space radiator of the FS	GDS HRHX - copper; FS - radiator - aluminum or Beryllium or Lockalloy	HRHX will simulate space radiator	(FS ~ 80 pounds) in Beryllium
CONTROLS	GDS: All circuits breadboarded; circuit boards to be plug-in type; no hybridizing; ease of accessibility and reliability prime considerations. Parasitic load and load drivers convection cooled. FS: All circuits hybridized; packaged for minimum volume, weight. All cooling by radiation	TBD	Identical	Flight System lighter due to hybridizing electronic components (FS ~ 10 pounds)
BELLOWS AND DUCTS	Identical except HRHX ducting for GDS different from radiator ducting of FS. FS has two more low temperature bimetallic joints. (HRHX inlet/outlet ducting). GDS has 15 more weld joints than FS.	Identical	Identical	Basic system without cooler and radiator identical. (FS ~27 pounds)
STRUCTURE	Identical except GDS uses vac tank support in place of radiator for FS. Radiator/ component support structure interface ring is identical to FS interface ring.	GDS uses all aluminum. FS uses Lockalloy and Beryllium	Identical	FS lighter structure (FS ~ 32 pounds)
INSULATION	Identical except for additional instrumentation penetrations	Identical	6 to 8% higher thermal loss in GDS (300 to 400 watts) due to instrumentation penetrations.	Identical (18 pounds)

NOTES:

(1) Although intended to be "identical" in many instances, lessons learned from GDS, performance and endurance tests may lead to changes in flight system components and/or configuration.

(2) For test purposes, GDS will incorporate a number of additional valves, gas supply systems, and protective devices.

(3) GDS loop will contain two turbine bypass shutoff valves and a pressure relief valve for development testing protection; FS will not.

(4) GDS loop will contain a one-way check valve in compressor inlet to eliminate the possibility of reverse flow during startup. Possibility of removing check valve from FS will be investigated during GDS testing.

(5) GDS loop will not be as well sealed as the FS because of extensive instrumentation and greater number of potential leak paths. For this reason, an He-Xe tank will be connected to GDS loop. A pressure regulator will control inlet pressure into closed loop and provide replenishment of working fluid to compensate for leakage. The FS will be sealed after initial charging.

(6) Flight monitoring system will be included in GDS to a limited degree. Transducers selected for flight, and some associated electronics, will be included in GDS test.

2.1 Mini-BRU

This machine contains a radial-flow turbine, a radial-flow compressor, and a radial-gap alternator. These components are mounted on a common shaft which rotates at 52,000 rpm and is supported on gas lubricated hydrodynamic journal and thrust bearings. The alternator is cooled by the compressor discharge; the foil bearings are cooled with compressor bleed cooling. The complete Mini-BRU assembly includes a flight-type housing, turbine and compressor inlet and exit ducting, and an output terminal block. Mounting pads are provided to permit the unit to be installed in the BIPS-FS. Power output is 1300 W_e with input of 4800 W_t (two MHW heat sources).

2.2 Heat Source Assembly (HSA)

The purpose of the HSA is to receive heat by radiation from the Isotope Heat Source (Electric Heat Source for GDS) and transfer it to the working fluid by forced convection within the Heat Source Heat Exchanger (HSHX). In addition to the HSHX, the HSA consists of a multifoil insulation blanket, an outer housing with mounting points and instrumentation leads, an auxiliary cooling system, and an emergency cooling system.

2.3 Mini-Brayton Recuperator (MBR)

The purpose of the MBR is to transfer thermal energy from the working fluid coming from the Mini-BRU turbine discharge to the compressor discharge working fluid prior to its return to the Heat Source Heat Exchanger of the HSA. This recovery of thermal energy serves to increase cycle efficiency by reducing the required heat source output for a given power level. The MBR is a counterflow heat exchanger fabricated entirely from Hastelloy X. The core assembly is brazed using a gold braze alloy applied in foil form.

2.4 Ducts and Bellows

The Mini-BRU, MBR, HSA, and radiator will be connected by means of a system of ducts and bellows. Multiple bellows will be required to absorb the relatively large thermal growths of the major components of the BIPS-FS. Ducts and bellows will be fabricated from Columbium (C-103 alloy) and from Hastelloy-X. Certain sections will require bimetallic joints or transition sections (C-103 to Hastelloy-X; Hastelloy-X to aluminum or beryllium).

2.5 Insulation System

The high operating temperatures of the BIPS, the relatively low output power, and the high cost and weight of the radioisotope require the use of a low loss insulation system in order to increase cycle efficiency and keep overall weight and cost within limits. Multiple layers of thin metallic foil (zirconia coated nickel and zirconia coated Columbium) have tentatively been selected to shroud the Mini-BRU, MBR, and the hot ducts and bellows of the BIPS.

2.6 Controls

The BIPS Control System provides for engine starting, load-following (control of output), system component protection, and engine shutdown. The present baseline design provides considerable latitude for improvements in functional characteristics to effect system optimization.

2.7 Heat Rejection Heat Exchanger (HRHX)

The HRHX will be used in the GDS to simulate the heat rejection capabilities of the Flight Systems space radiator. The purpose is to reject the waste heat of the Brayton cycle and thereby maintain the compressor inlet temperature at a low level. The HRHX is being developed by GE and will utilize a water-ethylene glycol mixture as a coolant.

2.8 Electrical Heat Source (EHS)

Two Electrical Heat Sources will be used in the GDS to simulate the thermal energy produced by the Isotope Heat Source. These are units previously used in the MHW/RTG program. The EHSs will be refurbished by GE-VF and furnished to AIRPHX as GFE by ERDA.

2.9 Power Supply Console (PSC)

The PSC consists of a power supply capable of furnishing power to the electrical heat source. Two PSCs will be used in the GDS, one for each EHS. Monitoring with appropriate switching provisions is provided to read input voltage and current to the EHS. An alarm input is provided to allow an out-of-limits condition signal to de-energize the EHS under certain prespecified conditions.

2.10 High Vacuum Test Chamber and Pumping System - HVTC/PS

The HVTC/PS will be used as the test chamber for testing the BIPS-GDS. The HVTC/PS consists of a test chamber and the associated vacuum pumps, valves, controls, and instrumentation. Included is all instrumentation required for pressure measurement and control of the vacuum pumping system. A conceptual schematic of a pumping system and associated components is contained in AIRPHX Drawing No. 306960. However, the final configuration is yet to be determined and will be determined once proposals of prospective vendors have been reviewed and a supplier selected.

2.11 HSA ACS Gas Management System (GMS)

The HSA Auxiliary Cooling System (ACS) utilizes helium gas to short circuit the insulation that surrounds the Heat Source Heat Exchanger in the HSA and thereby facilitate cooling when the GDS is not operating and the EHS is energized (IHS simulation). This helium is vented to space when the BIPS is set into operation, thereby permitting the insulation to function in its intended manner. The HSA ACS GMS will permit purging of the system, and refilling the system with helium, krypton, or argon. The emergency argon backfill system provides the capability of refilling the HSAs with argon in certain emergency conditions (yet to be determined) in order to facilitate cool down of the HSAs. A Gas Service Cart originally built for use in the MHW/RTG program will be provided by GE-VF and will become a part of the GMS. Preliminary design configuration of the GMS is shown on AIRPHX Drawing No. 306960.

2.12 Working Fluid Management System (WFMS)

The BIPS utilizes a mixture of helium and xenon of molecular weight 83.8 as a working fluid. The system demands a high purity gas for long term, reliable operation, and a high standard of purity has been established. The Working Fluid Management System is being designed to provide a means of recharging the working fluid loop with He/Xe as well as evacuating the loop and purging with argon. A Hot Titanium Gettering device is included for purifying the inert gases before being introduced to the working fluid loop. Provision is also made for sampling and analyzing the contents of the working loop.

2.13 Emergency Vacuum Chamber Backfill System (EVCBS)

Refractory metal (Columbium alloy C-103) in the BIPS is subject to damage if allowed to become contaminated at temperatures above 450°F. An emergency backfill system will flood the chamber with an inert gas (argon) in the event that certain predetermined conditions arise during operation of the BIPS-GDS thereby protecting the hot refractory metal. The EVCBS will be activated by a signal from the Alarm and Protection System.

2.14 GDS Alarm and Protection System (APS)

The GDS Alarm and Protection System will utilize inputs from designated sensors located within both the BIPS and HVTC. Certain predetermined conditions (i.e., overspeed, overtemperature, loss of vacuum in HVTC, etc.) will cause an audible alarm to be sounded and, in certain instances, emergency actions to be initiated. These emergency actions include slow down or shutdown of the BIPS, de-energizing of the EHSs, and backfilling of the HSAs and/or the HVTC. Tentative emergency shutdown provisions are shown on AIRPHX Drawing No. 306960. The APS has not yet been designed. It is primarily intended to give maximum protection to the BIPS-GDS during initial checkout and performance tests. Experience gained will hopefully permit a reduction in automatic shutdown modes to be employed during the follow-on endurance test.

2.15 GDS/Facility Instrumentation and Recording System (FIRS)

The GDS and test facility will incorporate instrumentation to monitor BIPS component performance as well as performance of the HVTC. Most of the data will be recorded on a data logger. All data will be available on a selective basis for real time display. Selected instrumentation outputs will be routed to the Alarm and Protection System to trigger alarm and possible emergency shutdown actions. For additional information on the GDS-FIRS, see AIRPHX Report No. 76-311740, "N-Building Facility Definition," dated June 1, 1976.

3. DISCUSSION

The collection, tabulation, and analysis of failure mode data followed traditionally accepted practices. Each major component and subsystem, except as noted below, were reviewed to determine possible modes or manner of failure, their probable cause, and the effect of the failure on the system. Means of minimizing the failure mode were also investigated. The data was recorded on worksheets, copies of which have been included in the Appendix to this report.

An attempt was then made to quantify the degree of criticality of each failure mode and its potential effect. Columns headed "A", "B", and "C" on the FMECA worksheets were used for this purpose. The likelihood of the failure mode actually occurring was ranked on a relative scale from 1 to 100 (with 100 being the most likely) and this number placed in Column "A". The effect of the failure on the overall system was then estimated on a scale of 1 to 100 (with 100 being the most severe) and this number placed in Column "B". Numbers in Columns A and B were then multiplied together to produce a criticality ranking or rating and this number was recorded in Column "C". Failure modes having the highest rating (most critical) were then tabulated in a separate summary listing (see Section 4, Table II).

The following scale was used in assigning the effect of the failure in Column "B":

Effects Impact	Failure Results In
100	Damage to BIPS-GDS
75	Possible damage to BIPS or loss in system efficiency
60	Premature (unnecessary) shutdown of BIPS-GDS
40	Delay in test
1	Negligible impact

For the reader who is accustomed to seeing hazards categorized in accordance with MIL-STD-882, a hazard category (HAZ CAT) column was included in the worksheets. Entries in this column denote the estimated severity of the effects of failure in accordance with the following categories:

I - Negligible - will not result in personnel injury or system damage

II - can be counteracted or controlled without injury to personnel or major system damage

III - Critical - will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival

IV - Catastrophic - will cause death or severe injury to personnel or system loss

While it may be seen that each hazard category equates to both system damage and personnel injury, the vast majority of the possible failures will not endanger personnel.

The contents of the FMECA worksheets and Table II (at the end of Section 4) will be periodically reviewed as the design of the BIPS-GDS progresses. Criticality ratings will undoubtedly change as the design evolves. It is also inevitable that there will exist disagreement with the ratings assigned. They are, after all, simply the concensus of a few and are, at best, educated guesses. Notwithstanding the recognized weaknesses, these ratings do provide a relative measure of the criticality of component failures and are therefore considered useful. Failure modes identified as being most critical will be given special emphasis for elimination or minimization during the system development effort. In addition, copies of this FMECA will be placed in the hands of all key BIPS program personnel.

AIRPHX Drawing No. 306960, "Preliminary BIPS-GDS Piping and Instrumentation Diagram" revised May 27, 1976 (see appendix) provided the basis for the analysis. However, it is important to note that this drawing must be considered as very tentative in many respects. The drawing underwent a number of changes during the preparation of this FMECA and will continue to be revised as the test facility equipment design is refined. The vacuum pumping system, in particular, is subject to change once prospective vendors have been given the opportunity to propose designs to satisfy the AIRPHX Procurement Specification* presently being readied for release. The GDS Alarm and Protection System is not presently defined in sufficient detail to permit a meaningful analysis to be conducted. It is intended to provide maximum protection during checkout and performance tests. Experience gained will hopefully permit a reduction in automatic shutdown modes. It is important that the endurance test which follows the checkout and performance tests be conducted with the minimum number of automatic shutdown protection circuits in order to preclude inadvertent shutdowns resulting from spurious signals, malfunctioning instrumentation, etc.

This preliminary FMECA likewise did not analyze the GDS/Facility Instrumentation and Recording System on the basis that it will follow accepted design practices for such data acquisition systems and 100 percent acquisition of data is not critical to the overall success of the BIPS-GDS. However, reliable design coupled with quality materials and assembly will be required in both the GDS APS and the GDS/FIRS in order to minimize false alarms and unnecessary shutdowns.

*AIRPHX Procurement Specification PSC-76-311738, "High Vacuum Test Chamber and Pumping System," dated 5-31-76.

4. SUMMARY

Worksheets listing failure modes considered most credible have been reproduced as an appendix to this report.

Failure modes and effects found to have the highest rating (most critical to system) have been listed in Table II which follows. There were eleven entries estimated to result in a criticality rating exceeding 100. These appear in Table II in descending order of criticality ranking.

Although many possible failure modes have been identified among the subsystems and components comprising the test facility portion of the BIPS-GDS, criticality ratings are relatively low. This primarily results from the fact that the likelihood of failure of these subsystems and components is very low. All subsystems will use proven technology. For example, the Power Supply Consoles used to power and to control the Electrical Heat Sources have been operated on the MHW/RTG program for several thousand hours without failure. Likewise, the Gas Service Cart, which will be used in the HSA ACS Gas Management System, has demonstrated reliable operation on the MHW/RTG program. The High Vacuum Test Chamber and Pumping System is to be designed and installed by a contractor who specializes in such installations. Proven components and designs must be utilized, and proposals received from prospective vendors will be evaluated for reliable operation.

Those subsystems that must operate automatically under certain emergency situations have been identified as being susceptible to failure. Solenoid actuated valves will be required to perform key tasks, and redundant valves have been proposed for certain critical operations to enhance reliability. The FMECA also leads one to the conclusion that the Alarm and Protection System (yet to be designed) will require reliable design backed up with an uninterruptible power supply in order to initiate emergency actions and also to preclude false alarms and shutdowns.

The reader is again reminded that the GDS Piping and Instrumentation Diagram (AIRPHX Drawing No. 306960), on which this FMECA is based, is considered to be preliminary and conceptual in a number of respects. System reliability will continue to be stressed as the GDS test facility evolves. A final FMECA on the BIPS-GDS is scheduled for publication in January 1977 and will cover the final design.

TABLE II

MOST CRITICAL FAILURE MODES AND EFFECTS - BIPS-GDS

Order No.	Subsystem	Criticality Ranking	Comments
1	Emergency Vacuum Chamber Backfill System (EVCBS) Solenoid Valves	200	Failure of solenoid valves SV 205A and SV 205B to open under certain emergency conditions would prevent the HVTC from filling with argon and would result in possible severe damage to the hot refractory components. A series/parallel arrangement of normally closed solenoid valves will essentially eliminate individual valve failure that would result in either a premature actuation of the EVCBS or a complete failure to actuate. However, the valves are dependent upon power being available during an emergency since they fail closed. This makes the incorporation of an uninterruptible power supply for the Alarm and Production System a mandatory item.
2	Overspeed and Shutdown Control	180	Solenoid valves (two normally opened in series) are required to open under certain emergency conditions. Opening of the valves will result in shutdown of the BIPS by isolating the Mini-BRU turbine from the working fluid flow. The valves quite properly fail open to protect the system; however, premature opening of both valves as result of erroneous signal generated by the Alarm and Protection System or a facility power failure would terminate the GDS test unnecessarily. The Alarm and Protection System (not yet designed) must obviously be designed so as to minimize false alarms and must be powered by an uninterruptible power supply.
3	HRHX Coolant Refrigeration System (Facility Coolant System)	150	This system refrigerates the liquid coolant used in the HRHX (radiator simulator). It is subject to failure resulting from such things as overheating or burn out of a compressor motor or the opening of circuit breaker as result of overload. Failure would result in an increase in working fluid temperature and consequent lowering of BIPS cycle efficiency. A high quality unit is planned; however, redundant units or injection of tap water into HRHX coolant loop should be considered.
4	HRHX Coolant Refrigeration System - Temperature Control Valve TCF-121	150	Should this valve stick closed or otherwise inhibit the flow of coolant to the HRHX, a situation similar to that described above would result. A high quality fail-open valve should be selected.

TABLE II (Contd)

Order No.	Subsystem	Criticality Ranking	Comments
5	HSA GMS Emergency Argon Backfill Solenoid Valve, SV-401	150	It may prove desirable to backfill the HSAs with argon under certain emergency shutdown conditions in order to accelerate cooldown of system and to prevent damage to the insulation and the refractory metal in the HSA. Failure of valve to open when energized would result in no backfilling of HSAs. A normally closed valve has tentatively been selected. Redundant valves in parallel should be considered. Normally open valves would preclude loss of backfill capability if power is lost.
6	HSA GMS Emergency Argon Backfill Solenoid Valve SV-401	150	The solenoid valve may also fail to open in an emergency situation if it fails to receive signal from the Alarm and Protection System. Most probable cause would be a loss of power. This again points to need for providing the entire Alarm and Protection System with an uninterruptible power supply.
7	High Vacuum Test Chamber (HVTC) Main Chamber Flange Seal (Dual Seal)	150	Leakage of air into HVTC would as a minimum result in a test delay and could result in damage to the refractory metals if leakage occurred at a time when system is hot. Most likely source of leakage will be the main chamber flange seal, primarily because of overall length. Steps will be taken to prevent damage to seals when the chamber is open and to assure that seals are properly secured to chamber flanges. Addition of a vacuum pump to scavenge air molecules from main chamber flange annulus before they could enter the chamber is presently planned.
8	HVTC Roughing Pump	80-150	Failure of the roughing (fore) pump to evacuate HVTC to 10^{-2} torr would prevent the high vacuum pumps from functioning since the HVPs are incapable of ejecting molecules to atmospheric pressure. A test delay would result with the possible added complication of contamination to the chamber and to the BIPS, if oil or other contaminants are allowed to backstream. A detailed review of the proposed vacuum system design will be conducted to prevent this condition.

TABLE II (Contd)

Order No.	Subsystem	Criticality Ranking	Comments
9	HVTC High Vacuum Pump (HVP)	80-150	The HVPs evacuate the chamber to pressure of <10^{-6} torr. Failure to perform as required will, as a minimum, result in test delay and, as with roughing pump failure, may introduce contaminants into the chamber. It is mandatory that HVTC system design precludes introduction of contaminants in event of pump failure.
10	Working Fluid Management System (WFMS) Vacuum Pump	80-150	This vacuum pump is used to evacuate the BIPS working fluid loop prior to purging and/or filling with Xe/He mixture. Failure to function will, as a minimum, result in test delay and may allow contaminants to enter loop. Failure is unlikely since the duty cycle is short; however, a high quality pump is considered important in view of possibly severe results of a pump failure. A means of catching possible backstreaming of oil is also required.
11	HVTC Sustaining Pump System	120	A Titanium Sublimation Pump (TSP) has been tentatively identified as the pump that will maintain the HVTC at a pressure of <10^{-6} torr. Inability to maintain the desired vacuum will result in initiation of an emergency shutdown of GDS and a delay in test. Pumping capability can be lost if the titanium element is allowed to become expended. This is a normal failure mode for this type of pump; however, it can be anticipated. Provision will be made for isolating the pump to allow for replacement of a titanium element. Pump capability is also dependent upon continuous power to heat the titanium element in pump. Incorporation of an uninterruptible power supply is tentatively planned.

APPENDIX

FMECA WORKSHEETS

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
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PHOENIX, ARIZONA

SYSTEM BIPS - GDS

SUBSYSTEM Heat Rejection Heat Exchanger (HRHX)

COMPLETED BY

DATE

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Coolant Manifold	Leakage at copper coil/manifold interface.	Defective braze.	Loss of coolant (H_2O/ethylene-glycol). Gross leak would result in rise in temperature of working fluid and consequent loss in BIPS cycle efficiency.	Quality brazes; 100% inspection of joints.	1	75	75	II	Temperature rise would be detected by thermocouples in HRHX.
Copper Coils (brazed to fin tubes).	Rupture of coil walls.	Defective tubing.	Loss of coolant (H_2O/ethylene-glycol). Gross leak would result in rise in temperature of working fluid and consequent loss in BIPS cycle efficiency.	Close acceptance control of tubing and lubrication.	1	75	75	II	Temperature rise would be detected by thermocouples in HRHX.
	Coil debonding from coil/fin tube interface.	Defective braze.	Degradation of HRHX cooling capacity.	Quality brazes; Close QC inspection. GE analysis shows that in event of complete debonding of 1 of 6 coolant tubes (extremely remote) required cooling can be maintained by increasing coolant flow rate and decreasing coolant temperature.	1	75	75	II	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ____________ COMPLETED BY ____________

SUBSYSTEM HRHX (contd) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Filter (in coolant supply line)	Clogged filter	Particulate matter in refrigeration system.	Insufficient coolant flow lowers efficiency of BIPS.	Coolant loop will incorporate two filters in parallel; valves will permit isolation of either filter for cleaning or replacement if necessary.	1	75	75	II	
Inlet/outlet manifolds (headers) and copper ducts	Leak at duct/manifold interface	Defective braze; assembly defect.	Loss of Xe/He working fluid; possible air contamination of working fluid.	Quality brazes; 100% inspection. Proof pressure test should detect.	1	75	75	II-III	
Coolant system - 1 1/2 ton refrigeration system (removes heat from coolants)	Unit ceases to function	Compressor motor overheats; overload opens circuit breaker.	Working fluid temperature increases, lowering BIPS cycle efficiency.	Select high quality unit. Consider redundant units. Consider injection of tap water into HRHX coolant loop during short periods required for repairs or servicing of coolant system.	2	75	150	II	
Refrigeration system temperature control valve TCV-121	Valve sticks closed or otherwise inhibits flow of coolant.	Defective assembly.	Working fluid temperature increases, lowering BIPS cycle efficiency.	Select high quality, fail-open valve.	2	75	150	II	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

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PHOENIX, ARIZONA

SYSTEM BIPS - GDS

SUBSYSTEM Power Supply Console (PSC)

COMPLETED BY

DATE

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
AC power Control Panel	Circuit Breakers inoperative.	Faulty circuit Breaker	Possible damage to PSC power supplies and digital voltage meters. Delay in testing while repairs are made.	Quality CBs make failures improbable.	1	40	40	II	
Power Supply, 150 vdc, 702. (Sorenson DCR 150-70A).	Excessive voltage/ current output.	Component failure within supply; operator error.	No effect on PSC (as soon as output reaches preset limits of voltage and current, output drops); In the remote instance that a series of multiple failures in PSC results in excessive output current, the effect would be to create high temperatures in HSHX. This would be sensed and the Alarm and Protection System would automatically remove power from the EHS supplying heat to that HSHX.	Unit has both overvoltage and overcurrent protection; circuitry has been thoroughly checked out in MHW RTG program.	1	60	60	I	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______ COMPLETED BY ______

SUBSYSTEM PSC (contd) DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Power Panel [contains +24 vdc supply for alarm and monitor panels and EHS power dropout relay (K1)].	+24 vdc power dropout.	Failure within power supply or short circuit on associated panel(s).	Alarm and input monitor panels inoperative; Relay K1 drops out (via relay dropout on Alarm and Protection System Console) thereby removing power from EHS.	Past experience has demonstrated high reliability.	1	60	60	I	
	K1 relay fails to open.	Internal short; mercury solidifies. (Impurities in H_2 gas can cause solidification of Hg, however this failure mode is extremely remote).	Failure to remove power from EHS in alarm condition. If console is unattended (as during endurance test) BIPS GDS damage will result.	Redundant voltage could be provided. However, the PSC developer has stated that the history of demonstrated high reliability obviates the requirement to incorporate redundancy. (Relay is normally open).	1	100	100	I-III	
Alarm Panel [contains visual and audio alarms and associated enable/disenable switch and relay. Also contains EHS power on/off and panel on/off switches (relays)]	Loss of alarm signals.	Failure within flasher assembly or sonalert, e.g., short of capacitor C5 in flahser will disable both alarms.	Alarm relay K1 will still be energized, resulting in removal of power from EHS. Results in shutdown of BIPS.	When PSC was used with MHW/RTG, alarms in MHW Readout Console were activated prior to PSC alarms. Similar logic should be adapted for BIPS GDS console.	1	60	60	I	

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

SYSTEM ____________ COMPLETED BY ____________

SUBSYSTEM PSC (contd) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Alarm Panel (contd)	Alarm relay, K1, fails to pick up.	Open coil or shorted protection diode; open pin ("B") on connector J2.	Loss of visual and audible alarms and failure to remove power from EHS power dropout relay, K1, in power panel results in failure to de-energize EHS. If unattended, damage to HSA could result.	Relay and protection diode are redundantly configured (parallel redundancy).	1	100	100	I-III	
	Alarm relay, K1, picks up but contacts remain shorted.	Contamination (foreign matter, solder, etc.) due to poor workmanship by relay vendor.			1	100	100	I-III	
	Panel enable relay K2 fails to pick up.	Open coil or shorted protection diode.	Failure to apply power to close relay K1 in power panel results in no application of power to EHS. Results in delay in testing.	Sufficient reliability has been demonstrated.	1	40	40	I	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______ COMPLETED BY ______

SUBSYSTEM PSC (contd) DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
EHS input monitor panel (contains digital voltmeters to display EHS voltage and current and to provide capability to route these parameters to the data acquisition system).	Voltmeter failure.	Faulty DVM; shocks, temperature, humidity.	Loss of measurements.		1	1	1	I	
Blower Assembly (for console cooling)	Loss of blower.	Motor failure; bearing failure; deterioration of lubricants with age.	Console heat increase resulting in possible arcing, piece part parameter drift or open circuits.		2	1	2	I	
Rear Connector Panel (contains all console interface connectors).	Connector failure.	Pin openings, dielectric breakdown causing arcing, shorting between adjacent pins.	Possible premature alarm activated and EHS power removed if pin "F" of Connector J-5 shorts to any other pin associated with alarm panel. Failure to activate alarms and remove power from EHS during alarm condition if pin "F" is open.	Excessive mating and demating highly aggravate connector failure rates. Keep to minimum.	1	40-100	40-100	I-III	

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______________________ COMPLETED BY ______________________

SUBSYSTEM HSA Gas Management System DATE ______________________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Emergency Argon Backfill (EAB) Pressure Control Valve (PCV-401) (provides proper inert gas pressure to backfill system).	Valve fails open.	Faulty valve	Supply pressure (>2800) placed on backfill system components. However, PCV-401 is a two-stage valve; both stages would have to fail. If this should occur, Pressure Relief Valve (PRV-401) will protect system.	Redundant valves (stages) provide reliable operation.	2	40	80	I	
EAB Pressure Relief Valve (PRV-401).	Valve fails open.	Broken spring.	Argon supply exhausted to atmosphere. Would require replacement of valve and Argon supply. Possibly critical if occurs during unattended operation.	Failure extremely remote.	1	75	75	II-III	
	Valve fails to function in overpressure condition.	Corrosion; foreign matter present.	Backfill system components would be subjected to overpressure. This would require failure at both stages of PCV-401 in addition to PRV-401 failure (triple failure).	Failure extremely remote.	1	75	75	II-III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
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PHOENIX, ARIZONA

SYSTEM ______ COMPLETED BY ______

SUBSYSTEM HSA GMS (contd) DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
EAB Backfill Solenoid Valve (SV-401) (permits flow of Argon to backfill HSAs when actuated by signal).	Fails to open when energized (fails normally closed).	Solenoid coil open.	Backfilling does not occur. (During attended operation, hand valve, HV-402, can be actuated to permit backfilling to occur)	Select high quality component. Consider redundant solenoid valves in parallel. Consider N/O valve(s) to preclude loss of backfill capability if power failure occurs.	2	75	150	II-III	
	Fails to open when emergency arises.	Loss of power to Alarm and Protection System.	Backfilling does not occur.	Incorporate uninterruptible power supply for Alarm and Protection System.	2	75	150	III	
EAB Relay Assembly (provides power to SV-401 when actuated by EAB activate signal provided "Auto/open" switch is in "auto" position.	Fails to close when energized (N/O).	Coil open; foreign matter prevents contact closure.	Backfilling does not occur. (During attended operation, hand valve, HV-402, can be actuated to permit backfilling to occur)	Select high quality component. Consider redundant relays in parallel or eliminate relay by providing voltage to energize SV-401 direct. At the same time, the "Auto/open" switch would be eliminated and HV-402 would be used for "non-auto" operation.	1	75	75	II-III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM

SUBSYSTEM HSA GMS (contd)

COMPLETED BY

DATE

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Vent Solenoid Valves - 1 per HSA (provide venting of HSA ACS to chamber to permit vacuum operation).	Valve will not close.	Foreign material prevents closure.	EAB system inoperative; However, HSA will fill with Argon introduced into chamber by the Emergency Vacuum Chamber Backfill System.	Failure mode unlikely since valve is N/C and system is relatively free of contaminants.	2	1	2	I	
	Valve will not open when energized (N/C) or does not remain open.	Coil open or burns out; foreign matter prevents valve opening.	HSA cannot be evacuated via vacuum chamber pumps. Results in test delay; valve must be changed. (Gas service cart vacuum pump is incapable of evacuating HSA.	Failure mode unlikely. Failed valve would be detected during system purge prior to evacuation of vacuum chamber. GE has recommended Nupro P.N. 47C313078G1 and recommends holding voltage be reduced to 5 vdc.	2	40	80	I	
Pressure Gages - 1 per HSA (provide means for measuring HSA pressure.	If Ion Gages: Glass envelope breaks.	Unknown.	Air contamination of HSA and vacuum chamber possible if manual shut off valve in series with gage is open.	Failure mode unlikely. Manual shut off valve.	1	75	75	III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ____________________ COMPLETED BY ____________________

SUBSYSTEM HSA GMS (contd) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
HSA Gas Management Valves - 1 per HSA. (provides containment of ACS inert gas during storage of HSA and during assembly of HSA into GDS).	Valve closed.	Operator error.	Results in test delay.	This is a manual valve with positive stem retraction. Operating procedures will require test operators to assure that valves are open prior to sealing chamber.	1	40	40	I	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

SYSTEM ______

SUBSYSTEM HSA GMS Gas Service Cart (GSC)

COMPLETED BY ______

DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
GSC Vacuum Pump (used in purging cycle of HSA GMS).	Pump motor fails.	Motor windings open or short.	Evacuation capability lost. Results in test delay. Check valve in pump assembly prevents air contaminating HSA. (Even if check valve fails - double failure - system is at ambient temperature. Thus, no damage would occur to C-103 in HSHX).	Pump operated continuously during MHW RTG testing; operation for GDS will be confined to intermittent periods only, prior to performance and endurance tests. Hence, pump failures are not anticipated.	2	40	80	I	
GSC Absolute Pressure Gage (M_1, M_3) (displays pressure in psi to provide course indication of line pressure).	Crack in case or glass.	Shock or strain defect in material.	None; meter design provides isolation of meter face from fluid of system monitored; hence, no air contamination will result from case rupture.	None required.	1	1	1	I	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______

SUBSYSTEM HSA GMS Gas Service Cart (GSC) (contd)

COMPLETED BY ______

DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
GSC Micron Gage (M_2) (displays pressure in microns for line pressure in vacuum conditions).	Sensor fails.	Random failure.	None; redundant sensors used.	None required.	1	1	1	I	
GSC Regulator Valves – $R_1/R_2 + R_3/R_4$ (provides pressure regulation of Argon and Helium supplies and indicates cylinder and delivery static pressures).	Valve sticks open.	Material defect; foreign material present.	None; redundant regulators prevent application of cylinder pressures on GDS components.	None required.	2	1	2	I	
GSC Adjustable Relief Valve (provides system pressure relief through pumpset to control at 30-35 psia).	Valve will not close.	Material defect: foreign material present.	GSC will continuously be evacuated by pump; evacuation by GSC to specified levels cannot be completed. Results in test delay.	Valve has demonstrated high reliability.	2	40	80	I	

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM

SUBSYSTEM HSA GMS GSC (contd)

COMPLETED BY

DATE

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
GSC Manual Valves - V_1, V_2, V_4, V_6, V_7, V_8, V_{10}, V_{11}, V_{12}, V_{13} (provides gas flow shut-off or by-pass) and GSC Metering Valve - V_9 (adjusts gas flow rate to HSA).	Valve will not open.	Unknown.	Depends upon which valve is involved. Results in some loss of GSC capability; delay in test operations when opening of valve is required.	All valves have positive stem retraction; therefore occurrence of this failure mode is extremely unlikely.	1	40	40	I	
	Valve will not fully close.	Foreign matter present.	Possible loss of monitoring capability. Because of redundancy, loss of one shut-off valve is not critical to removing a gas supply cylinder. May result in delay in test operations.	High line filtration is incorporated. Soft seat valves are used for long term reliability where repetitious shut-off operation is required.	1	40	40	I	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ____________ COMPLETED BY ____________

SUBSYSTEM HSA GMS GSC (contd) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
GSC Manual Valves (contd)	Valve leaks.		Some loss in pump down capability; remote possibility of air contamination of HSA but no damage would result since system is at ambient temperature when GSC is being utilized.	All valves incorporate a bellows seal between test environment and outside atmosphere. Likelihood of air leak is remote with this type of device in this application. The manual valves have a replaceable bellows and stem assembly. The metering valve is an all-welded hermetically sealed valve.	1	40	40	I	

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ____________________ COMPLETED BY ____________________

SUBSYSTEM High Vacuum Test Chamber (HVTC) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
HVTC	Main chamber flange leaks.	Damage to seal; seal does not fit properly.	Degradation of high vacuum; possible contamination of chamber and consequent damage to hot C-103. May require shutdown, resulting in test delay.	Use high quality viton o-ring seals; Exercise care to preclude striking or rubbing against seals when chamber is open. Assume that seals are properly secured to chamber flange to assure tight seal. As additional protection against contamination, add a vacuum pump to scavenge any air molecules from main chamber flange before they may enter chamber.	2	75	150	III	
	Leaks occur in view port(s), and/or flanged ports for high vacuum pump inlet(s), ion gages. Sustaining pump, residual gas analyzer, electric/pneumatic feedthroughs, HRHX penetrations, and sustaining pump roughing pump.	Seal does not fit properly.	Degradation of high vacuum; possible contamination of chamber and consequent damage to hot C-103. May require shutdown, resulting in test delay.	Use high quality seals and gasket flanges around ports; Do not use seal lubricants on any seal exposed at any time to the main chamber.	1	75	75	III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______________________ COMPLETED BY ______________________

SUBSYSTEM HVTC (contd) DATE ______________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
HVTC (contd)	Containment seam welds leak.	Defective weld technique.	Degradation of high vacuum; possible contamination of chamber and consequent damage to hot C-103. May require shutdown, resulting in test delay.	All containment seam welds should be vacuum side, full penetration, single-sided, groove-type welds using either metal inert gas or tungsten inert gas process; Inspect all welds using accepted procedures.	1	75	75	III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

SYSTEM ____________

SUBSYSTEM HVTC Pumping System

COMPLETED BY ____________

DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Roughing (fore) Pump (evacuates chamber down to 10^{-2} Torr).	Fails to evacuate chamber to designated pressure.	Mechanical failure or electrical failure (motor fails or interrupted).	High Vacuum Pumps (HVP) are unable to function since they are incapable of ejecting molecules to atmospheric pressure; Results in test delay. Possible contamination to chamber if oil or other contaminates are allowed to backstream. (BIPS, however, is cold at start up when roughing pump failure could be critical).	Select high quality roughing pump; Incorporate cold trap to catch possible back-streaming of oil; Incorporate sensor to detect pump failure and to automatically close gate valves SV200C and SV200E, and (by means of the Auto Pump Sequencer) to close the HVP gate valves SV200B and SV200D (and to shut down the HVPs, if operating).	2	40-75	80-150	I-III	
High Vacuum Pumps - HVP-201A and HVP-201B. (Evacuate HVTC to pressure $<10^{-6}$ Torr).	Failure to function as required. (Specific failure modes and causes depend upon type of pump selected, e.g., Turbo Molecular Pump, Diffusion Pump, or Sublimation Pump).	Electrical power interruption; Mechanical failure; Roughing (fore) pump has failed to evacuate chamber to 10^{-2} Torr, point at which HVP is effective.	Possible delay in test; however, HVPs are planned, either of which is capable of evacuating HVTC to desired level. Possible back-streaming and contamination of chamber.	Select high quality pumps; Provide for automatic closure of gate valve associated with failed pump to prevent contamination entering chamber.	2	40-75	80-150	I-III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ____________________ COMPLETED BY ____________________

SUBSYSTEM HVTC Sustaining Pump System (SPS) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Titanium Sublimation Pump (maintains HVTC at pressure of $<10^{-6}$ Torr).	Pumping capability degraded.	Loss of coolant.	Possible inability to maintain desired vacuum.	Water is used for coolant; failure is remote.	2	40	80	I	
	Pumping capability lost.	Titanium element expanded: Loss of power (to heat Titanium element in pump).	Inability to maintain desired vacuum, resulting in initiation of emergency shutdown sequence.	Normal for this type of pump; can be anticipated. Requires isolation of pump and replacement of titanium element. Incorporation of uninterruptible power supply is highly desirable so as to preclude unscheduled shutdowns from power outages.	2	60	120	I	

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______

COMPLETED BY ______

SUBSYSTEM Endurance Vacuum Chamber Backfill System (EVC/BS)

DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Solenoid Valves SV205A, SV205B, (when open, allow argon to enter chamber in an emergency situation in order to protect hot refractory components).	Valves fail to open when energized (fails normally closed).	Solenoid coil open.	Backfilling does not occur as desired; results in possibly severe damage to refractory components.	Select high quality components; series/parallel configuration will minimize failure probability.	1	100	100	III	
	Valves fail to open when emergency arises.	Loss of facility power.	Backfilling does not occur as desired; results in possibly severe damage to refractory components.	Incorporate uninterruptible power supply for Alarm and Protection System.	2	100	200	III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ____________________ COMPLETED BY ____________________

SUBSYSTEM Working Fluid Management System (WFMS) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Hot Titanium Getter (purifies Argon and Xe/He before being introduced into working fluid loop).	Heating element fails.	Open coil; loss of continuity; loss of power.	Possible introduction of contaminants into loop.	Failure remote; reliable units available.	1	75	75	III	
	Cooling jacket leakage; failure to cool.	Material defect; loss of coolant (water) supply.	Unknown; results in test delay while unit is replaced.	Failure extremely remote.	1	40	40	I	
	Degradation of getter alloy.	Normal with time and use.	Loss in gettering capability; alloy replaceable.	Degradation predictable; replacement can be programmed.	1	40	40	I	
Vacuum Pump (used to pump down working fluid loop prior to purging).	Fails to evacuate loop.	Mechanical failure or electrical failure (motor fails or power is interrupted).	Results in test delay; possible contamination of loop if oil or other contaminants are allowed to backstream. (BIPS is cold at time pump failure could be critical.	Failure unlikely since duty cycle is short; Cold trap can prevent contamination by catching possible backstreaming of oil.	2	40-75	80-150	I-III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

SYSTEM ____________ COMPLETED BY ____________

SUBSYSTEM Working Fluid Management System (contd) DATE ____________

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Residual Gas Analyzer (RGA) Head (use to analyze constituents remaining in system after pump down to $\sim 10^{-4}$ Torr).	Filament burns out.	Material defect; normal aging.	Loss of analysis capability; otherswise, no effect on test.	Failure remote; duty cycle is short.	1	1	1	I	
Pressure Control Valves - PCV 101A and PCV 101B (provides proper pressure of Xe/He and Argon for filling working fluid loop).	Valve fails open.	Faulty valve; mechanical failure.	Full pressure of gas supply tank placed on system; pressure relief valve, PRV-1, will prevent damage by venting gas to atmosphere.	Use quality valves; failure remote.	2	40	80	I	
Pressure Relief Valve PRV-1 (vents gas in event of over pressure condition).	Valve fails to function in overpressure condition.	Corrosion; foreign material present.	Working fluid management system (and possibly working fluid loop) would be subjected to overpressure. This would require failure of both the PRV and one of the pressure control valves.	Use quality valve; Double failure extremely remote.	1	40-100	40-100	I-III	

*A MODE LIKELIHOOD (1 TO 100) - *B EFFECTS IMPACT (1 TO 100) - *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET

SYSTEM ______

SUBSYSTEM Overspeed and Shutdown Control

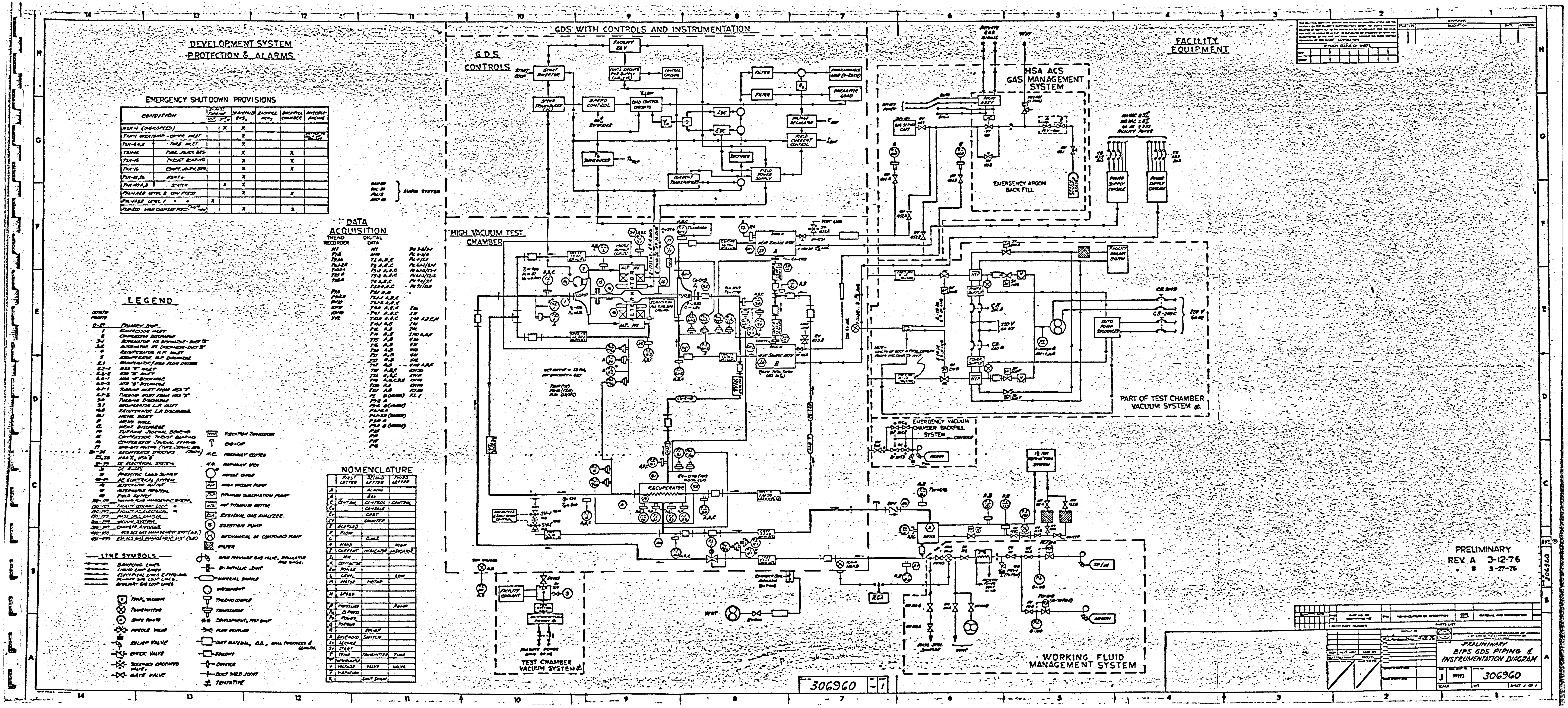
COMPLETED BY ______

DATE ______

COMPONENT	FAILURE MODE (S)	PROBABLE CAUSE	EFFECT OF FAILURE	FAILURE MODE MINIMIZATION	*A	*B	*C	HAZ CAT	SAFETY ACTION OR COMMENTS
Solenoid Valves, SV-1 (open upon receipt of proper signal from Alarm and Shutdown System, thereby shutting down BIPS by isolating turbine from working fluid flow).	Opens prematurely.	Open circuit, solenoid coil burns out, erroneous signal from Alarm and Shutdown System; Power failure.	Two normally open series valves are planned. Failure of one valve to open position would not have an immediate effect. However, if both valves open for any reason, BIPS GDS test would be prematurely terminated. No damage would result but test would be delayed.	Select high quality valves; Alarm and Protection System must be designed to minimize false alarms; must include uninterrupted power supply.	3	60	180	I	

*A MODE LIKELIHOOD (1 TO 100) – *B EFFECTS IMPACT (1 TO 100) – *C CRITICALITY (A x B)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS WORKSHEET



DEVELOPMENT SYSTEM PROTECTION & ALARMS
EMERGENCY SHUT DOWN PROVISIONS
DATA ACQUISITION
LEGEND
NOMENCLATURE
GDS WITH CONTROLS AND INSTRUMENTATION
GDS CONTROLS
HIGH VACUUM TEST CHAMBER
HSA ACS GAS MANAGEMENT SYSTEM
EMERGENCY ARGON BACK FILL
FACILITY EQUIPMENT
PART OF TEST CHAMBER VACUUM SYSTEM
EMERGENCY VACUUM CHAMBER BACKFILL SYSTEM
RECUPERATOR
TEST CHAMBER VACUUM SYSTEM
WORKING FLUID MANAGEMENT SYSTEM
PRELIMINARY
REV A 3-12-76
PRELIMINARY BIPS GDS PIPING & INSTRUMENTATION DIAGRAM
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