MK 14 CCSDS

FAILURE MODES & EFFECTS ANALYSIS

FINAL REPORT

SEPTEMBER 1980

CONTENTS

CONTENTS (Continued)

LIST OF FIGURES

SECTION 1

INTRODUCTION

This analysis of Failure Modes and Effects for the MK 14 Closed Circuit Diving System was prepared in two stages. The initial effort entailed a systematic examination of all system components to determine the effects of failure on the system using the "Fault Tree" analysis technique. The fault tree presents an account of all possible events leading to a failure from the complete system down through subsystems and components. This process resulted in the generation of a reliability model and established the relationship for functional events at each hardware level for faults being analyzed.

The second stage of the analysis was devoted to a detailed investigation into the causes, effects, frequency, and severity of the faults uncovered in the previous stage. The results of this investigation have been documented and are intended to be useful, where applicable, in system design decisions, establishment of reliability estimates and maintenance task definition and analysis.

MIL-STD-1629, Procedures for Performing a Failure Modes and Effects Analysis for Shipboard Equipment, provided guidelines used in completing this analysis. This Failure Modes and Effects Analysis (FMEA) is a compilation and integration of two separate FMEAs; "MK 14 Failure Modes and Effects Analysis," dated February 1980, prepared by Northrop Services Inc.; and "MK 14 Diving System Pump Module Failure Modes and Effects Analysis," dated April 1980, prepared by Westinghouse Electric Corp.

SECTION 2

MK 14 SYSTEM FUNCTIONAL DESCRIPTION

The MK 14 Closed Circuit Saturation Diving System (CCSDS) is designed for diving operations at continental shelf depths down to 1100 fsw. The system utilizes many assets available from the Deep Dive System (DDS), yet provides diver flexibility and mobility by the elimination of the associated cumbersome equipment required in other closed circuit breathing systems. The divers operate out of a Personnel Transfer Capsule (PTC), and are continuously supplied with the PTC helium/oxygen atmosphere. A two-pump system is used: one for pushing the breathing gas to the diver through the supply hose, and the other for pulling the exhaled gas back to the PTC via the return hose (hence the term push/pull system). CO_2 in the exhaled gas will be removed by a CO_2 scrubber located in the PTC at the discharge of the suction pumps. This cycle is repeated continuously (with negligible loss of helium) and allows 4 hours of diver bottom time when working from the PTC. The system also includes conventional two-way communications, and diver thermal protection by means of a conventional hot water suit and breathing gas heat exchanger.

For the purpose of Failure Modes and Effects Analysis, the MK 14 system consists of six subsystems: the breathing gas supply and return, the umbilical, the diver-worn equipment, the PTC control station, the hot water, and the communications. Figure 2-1 presents a block flow diagram of the system.

2.1 GAS SUPPLY AND RETURN

The pump/motor unit used by the MK 14 system is the Westinghouse MK 14 CCSDS Advanced Development Pump Package. This unit consists of a supply pump, a return pump, and the drive motor. Each pump/motor unit is designed to support one MK 14 diver. Both the supply and return pumps are identical, except for the direction of rotation of the cooling fan. Each pump has four pairs of opposed cylinders operating in sequence to provide minimum fluctuations in the output pressure. The prime mover for the assembly is a Westinghouse 7-1/2 hp, 1800 RPM, 440 V, 60 Hz, 3-phase induction motor with standard double extended shaft.

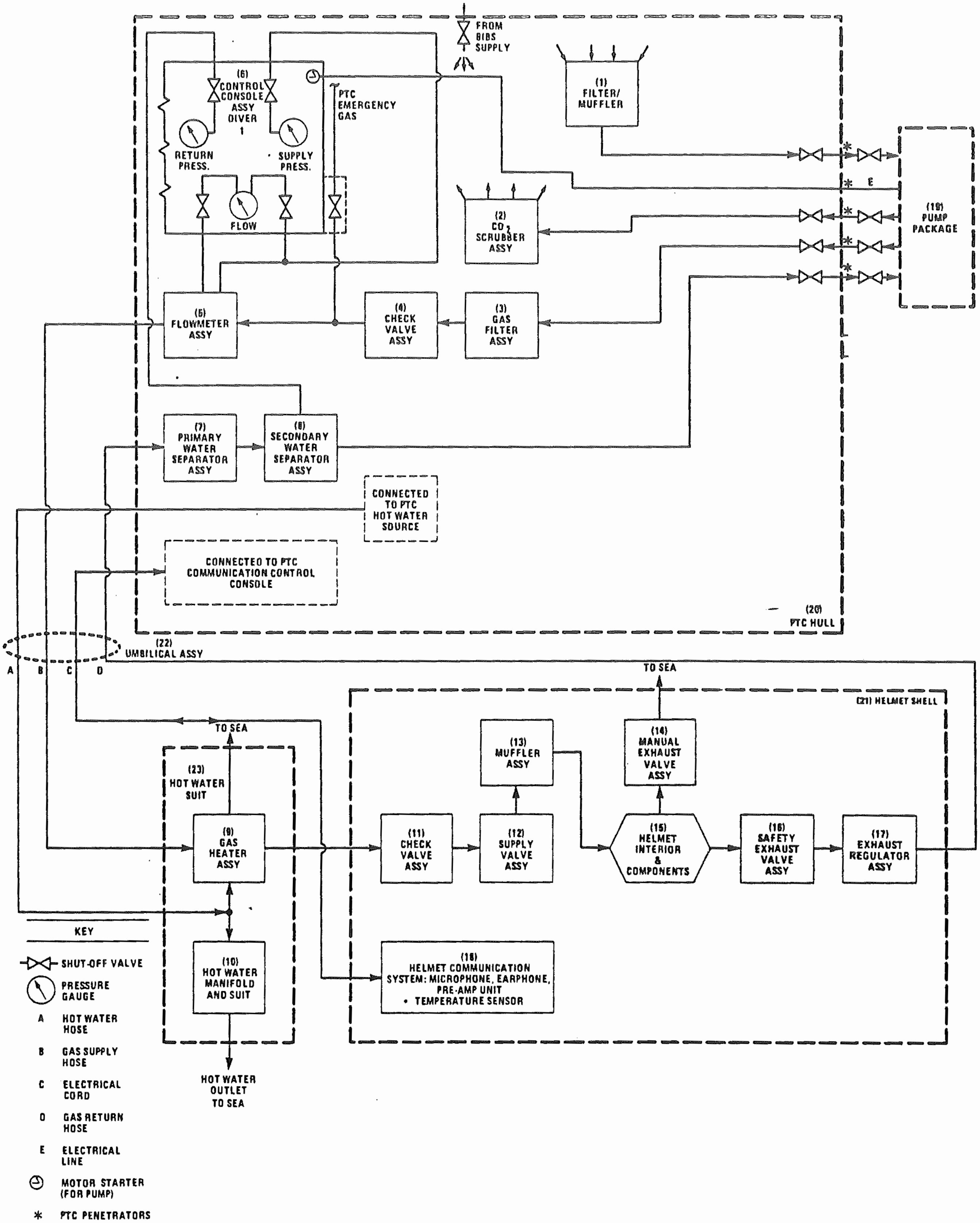


FIGURE 2-1. MK 14 SYSTEM BLOCK DIAGRAM

The assembly is designed to operate in a vertical position, with the return pump uppermost. It is intended to occupy the space of one gas cylinder on the DDS MK 2 PTC. The assembly is 61-1/2 inches high and 19 inches in diameter at the base flange. Figure 2-2 illustrates the block flow diagram of the pump package. Appendix A gives block identification, function and output lists.

2.2 UMBILICAL

The diver's umbilical is stowed coiled up inside the PTC. The umbilical consists of two gas hoses, a hot water hose, and an electrical cable. A 1/2-inch internal diameter supply hose and a 5/8-inch internal diameter return hose carry the gas from the PTC to the helmet and back. The hot water hose provides water to heat both the diver's open circuit suit and his breathing gas. The electrical cable, consisting of 11 cores, is used for diver monitoring as well as two-way communication between the diver, the PTC, and topside.

2.3 DIVER-WORN EQUIPMENT

This subsystem consists of the helmet and suit worn by the diver. The helmet body is constructed of strong, lightweight fiberglass which is impact resistant, and is nonconductive to electricity. The front, side, and upper viewports are constructed of clear, impact resistant plastic. Two clevis and pin arrangements, one on either side of the helmet, provide a positive means of securing the helmet to the neckdam. All external connections are located at the back of the metal base of the helmet. Breathing gas enters the helmet through a nonreturn valve, passes through the supply valve for flow control, and into the helmet interior through a muffler. Gas exits the helmet through the safety exhaust valve and exhaust regulator. A separate manual exhaust valve is provided for open circuit operation in case of exhaust regulator malfunction. A microphone and earphone are provided for communications.

The hot water suit is designed to maintain the diver's body temperature at a safe level by distributing a continuous flow of warm water over the diver's body. Warm water is distributed by a network of perforated tubes attached to the inside of the suit. A hot water manifold mounted on the diver's right hip receives hot water from the umbilical and controls flow rate and distribution of suit and gas heating.

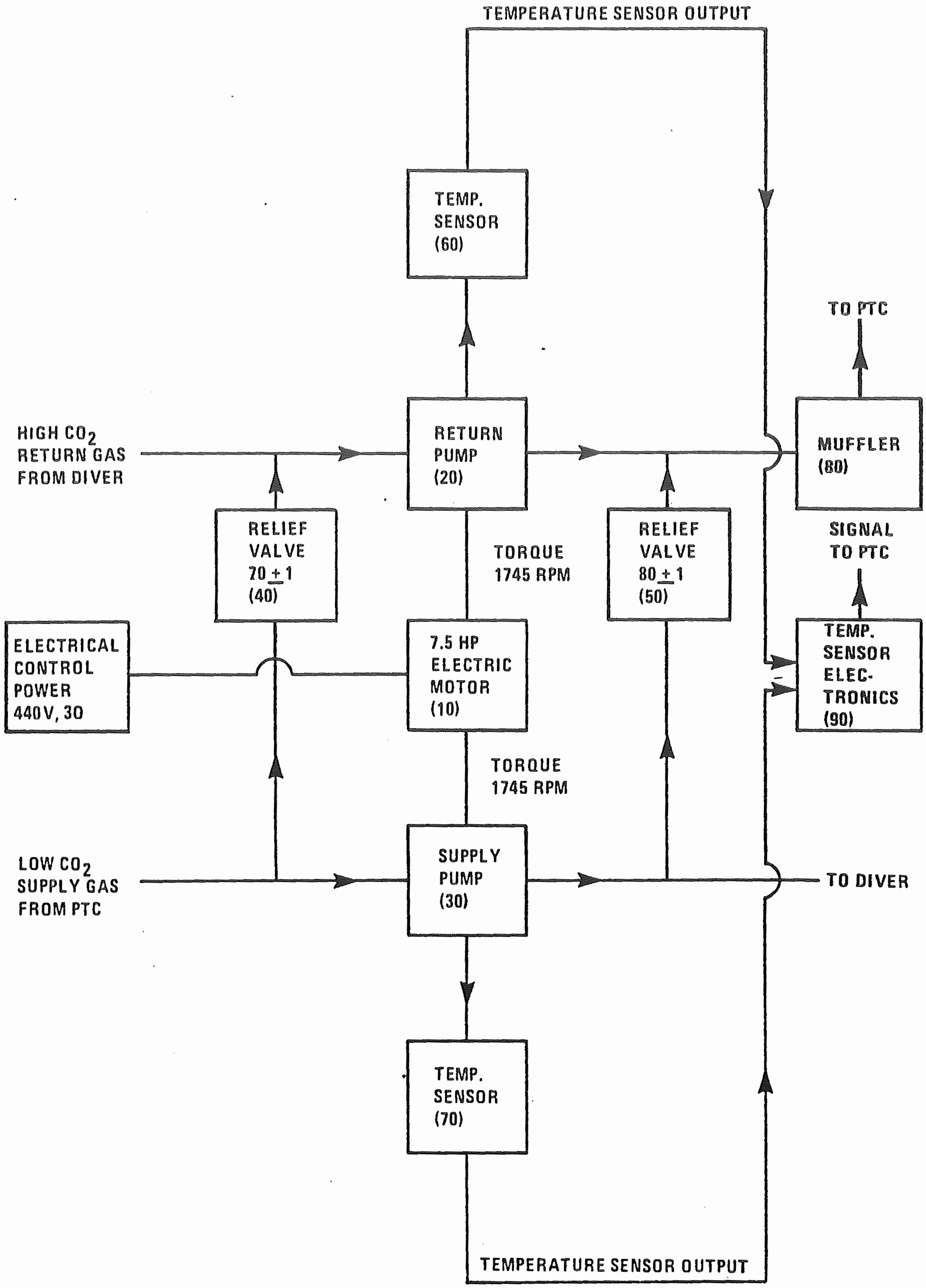


FIGURE 2-2. MK 14 PUMP PACKAGE BLOCK FLOW DIAGRAM

2.4 PTC CONTROL SUBSYSTEM

The PTC control equipment is operated by the tender who remains in the PTC. It controls the operation of the pumps and has readouts to monitor the pressure and suction of the push and pull pumps, respectively. It includes valving to bleed the system, a system filter, and an entrained water separator. It also has control of an emergency gas supply which can be fed directly into the diver's supply hose in the event of a supply pump malfunction.

2.5 HOT WATER SUBSYSTEM

Hot water is provided from the surface control station at the rate of 6 gallons per minute and 110^{o}F to heat both the diver's open circuit suit and his inspired gas. The water is routed from a manifold on the diver's suit to a heat exchanger where it heats breathing gas for the diver. This water is then discharged to sea. Water to heat the suit is received into the suit directly from the manifold, then discharged to sea.

2.6 COMMUNICATIONS SUBSYSTEM

The communications set contains the necessary electronics to allow two-way communications among two divers, the PTC operator, and the set operator topside. The topside set also contains an internal helium speech unscrambler. The divers are provided with microphones/headphones attached inside the helmet but have no control of sound level. The PTC operator communicates using PTC installed equipment; however, in the event of an emergency, the PTC operator acts as No. 3 diver using the standard bandmask and communication microphone/headphone.

SECTION 3

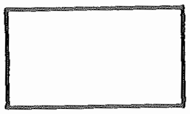
DEVELOPMENT OF THE FAILURE ANALYSIS MODEL

The Failure Modes and Effects Analysis (FMEA) is a systematic examination of all the components of the system to identify how they can fail, and to determine the effects of each component failure on the overall system in relation to its operational performance and the safety of the diver.

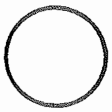
A conventional Failure Modes and Effects Analysis could be constructed for this effort, working from individual component failure modes up to system level effects, and from this analysis a reliability model could be prepared. The major drawback in utilizing this "bottom-up" approach is that the vast detail generated in the Failure Modes and Effects Analysis cannot systematically be incorporated into a system reliability model. Most frequently the Failure Modes and Effects Analysis stands alone (and is of considerable value in itself), and never is fully reflected in the reliability model.

The preferred technique for this analysis is the "Fault Tree" and it offers several major advantages over the conventional FMEA. The fault tree provides for a detailed "top-down" exploration of all possible events and combination of events which can lead to a particular, generally catastrophic, failure. The fault tree has the primary advantage of forcing the same thought processes involved in preparing a Failure Modes and Effects Analysis in such a systematic fashion that a reliability model is essentially generated in the process.

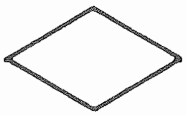
The fault tree is basically a logic diagram which portrays the events and combinations of events at each system hardware indenture level which can contribute to the top-level system fault being analyzed. Figure 3-1 represents the basic fault tree symbols used in this analysis. They are divided into "event symbols" and "connectives." The events include faults or failures, normal events which may need to be shown on the tree if they contribute to a failure in some way, and conditional events which must occur at a prescribed time for a given failure effect to occur. The connectives include AND and OR gates, as well as reference symbols to other parts of the tree or other subsystem fault trees.



AN EVENT, USUALLY A FAULT, RESULTING FROM THE COMBINATION OF MORE BASIC FAULTS.

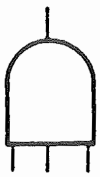


A BASIC COMPONENT FAULT WHICH CAN BE ASSIGNED A PROBABILITY OF OCCURRENCE BASED ON TEST RESULTS OR PHYSICS OF FAILURE ANALYSIS.

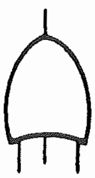


A FAULT NOT DEVELOPED FURTHER AS TO ITS CAUSES BECAUSE OF LACK OF INFORMATION, TIME, OR VALUE IN DOING SO.

A CONDITIONAL EVENT, ONE WHICH MUST OCCUR IN ORDER FOR AN INPUT FAULT (CAUSE) TO RESULT IN AN OUTPUT FAULT (EFFECT).

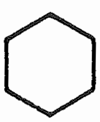


AND GATE – THE OUTPUT EVENT OCCURS ONLY WHEN ALL OF THE INPUT EVENTS ARE PRESENT.

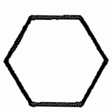


OR GATE – THE OUTPUT EVENT OCCURS WHEN ONE OR MORE OF THE INPUT EVENTS ARE PRESENT.

REFERENCE KEY TO ANOTHER PART OF THE FAULT TREE WHERE THE IDENTICAL SEQUENCE OF EVENTS IS SHOWN OR A LOGICAL SEQUENCE IS CONTINUED.



INHIBIT GATE – USED TO INDICATE APPLICATION OF A CONDITIONAL EVENT, WHICH MAY BE A FAULT IN ITSELF OR AN EVENT NORMAL TO SYSTEM OPERATION.



REFERENCE KEY TO ANOTHER FAULT TREE – PERHAPS FOR ANOTHER MAJOR SUBSYSTEM.

FIGURE 3-1. BASIC FAULT TREE SYMBOLS

Figure 3-2 illustrates the application of the fault tree to a Failure Modes and Effects Analysis of the MK 14 system. The analysis would be initiated by considering that the top-level fault or failure is "MK 14 System Failure." This situation can by caused by the failure of any one of the six major subsystems described in Section 2 outlined below:

- Breathing gas subsystem failure
- PTC mounted control subsystem particular to MK 14 failure
- Hot water subsystem failure
- Umbilical subsystem failure
- Diver-worn equipment subsystem failure
- Communications subsystem failure

Each of these events would be further examined in the fault tree to determine the causes of the malfunctions. For example, under "Breathing gas subsystem fails" the effects on the diver can be as follows:

- Diver receives no breathing gas
- Diver receives breathing gas of inadequate pressure and flow rate
- Return side of breathing circuit failure
- Diver receives noxious or toxic breathing gas
- Diver breathing gas temperature too high

Proceeding further in this logical analysis, the probable causes of malfunction or failure would be developed in each of the basic subsystem areas. As an example, Figure 3-2 shows that the continuation of the development for "Diver receives no breathing gas" results in the conclusion that both MK 14 breathing subsystems must satisfy the following:

- Standard breathing gas subsystem failure
- Emergency breathing subsystem failure

The failure of the emergency breathing subsystem can then be traced to the following possible causes:

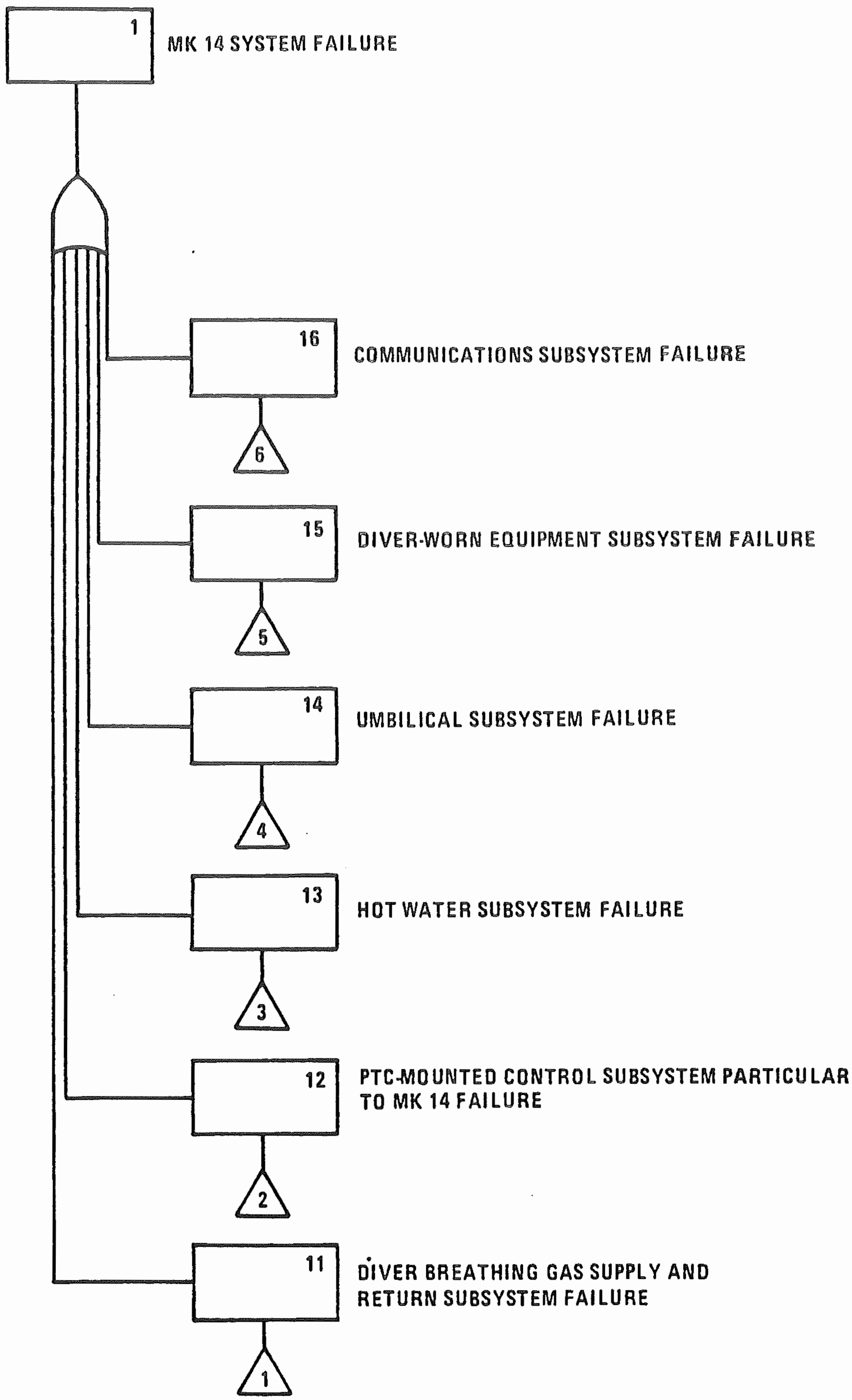


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL

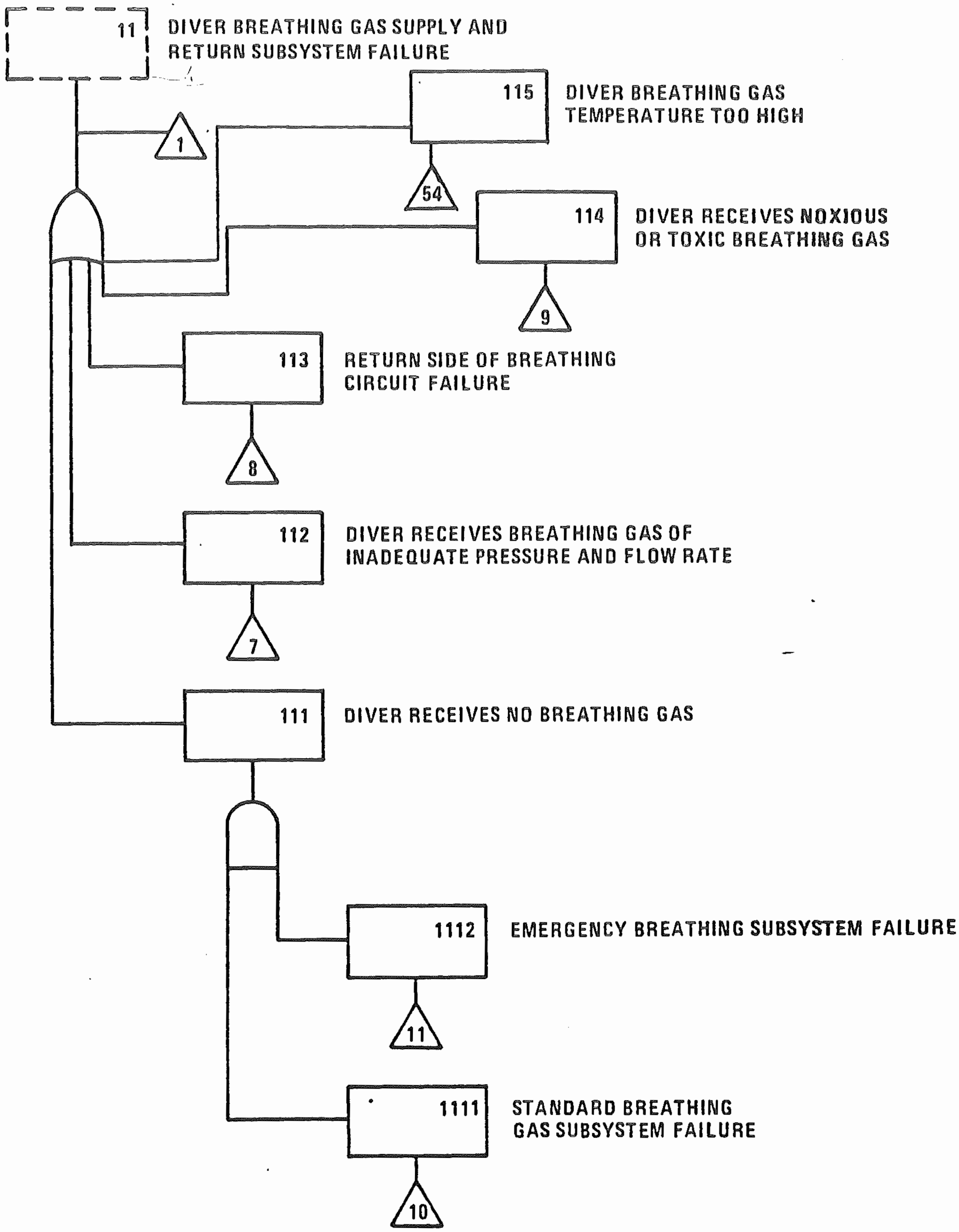


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

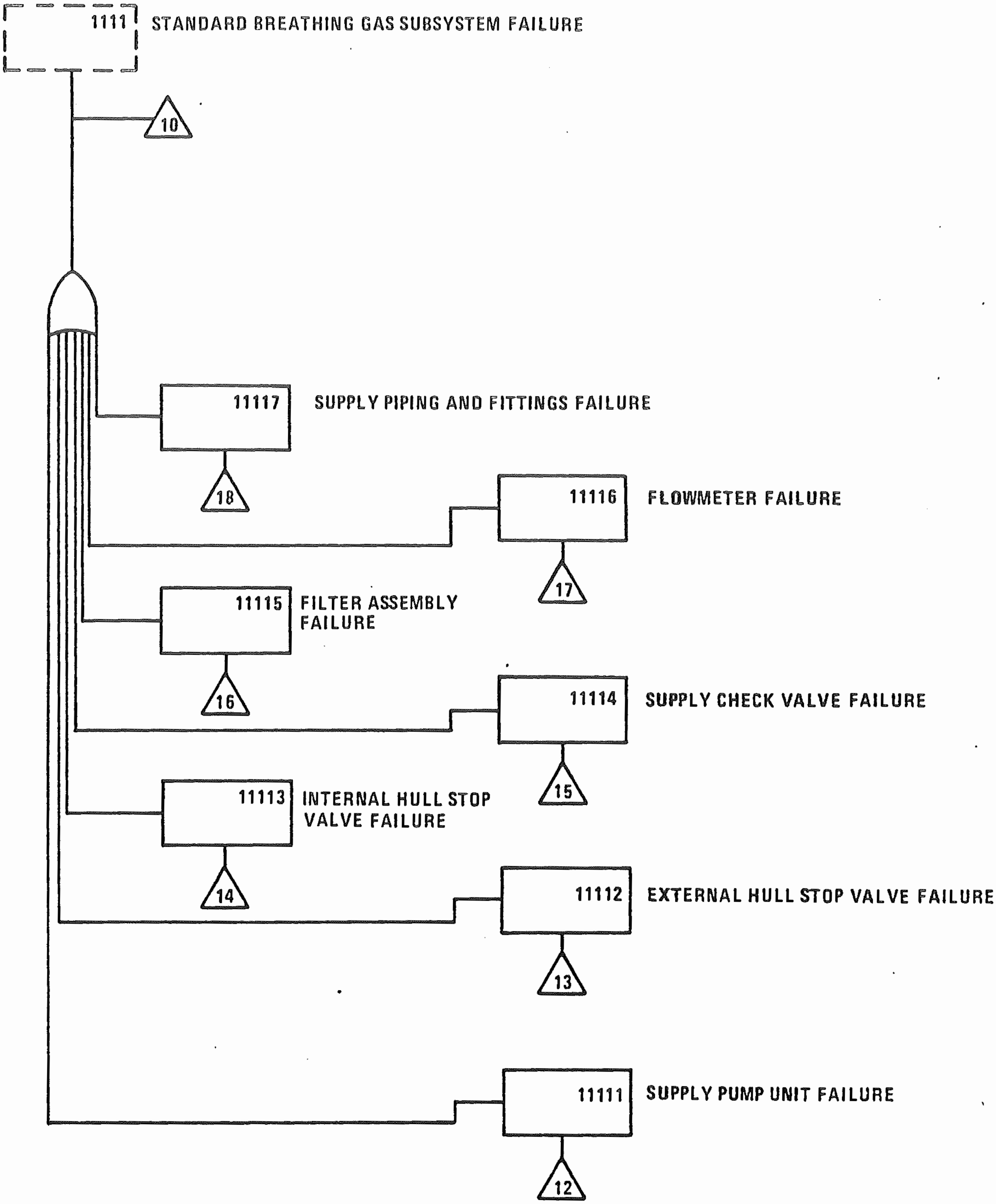


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

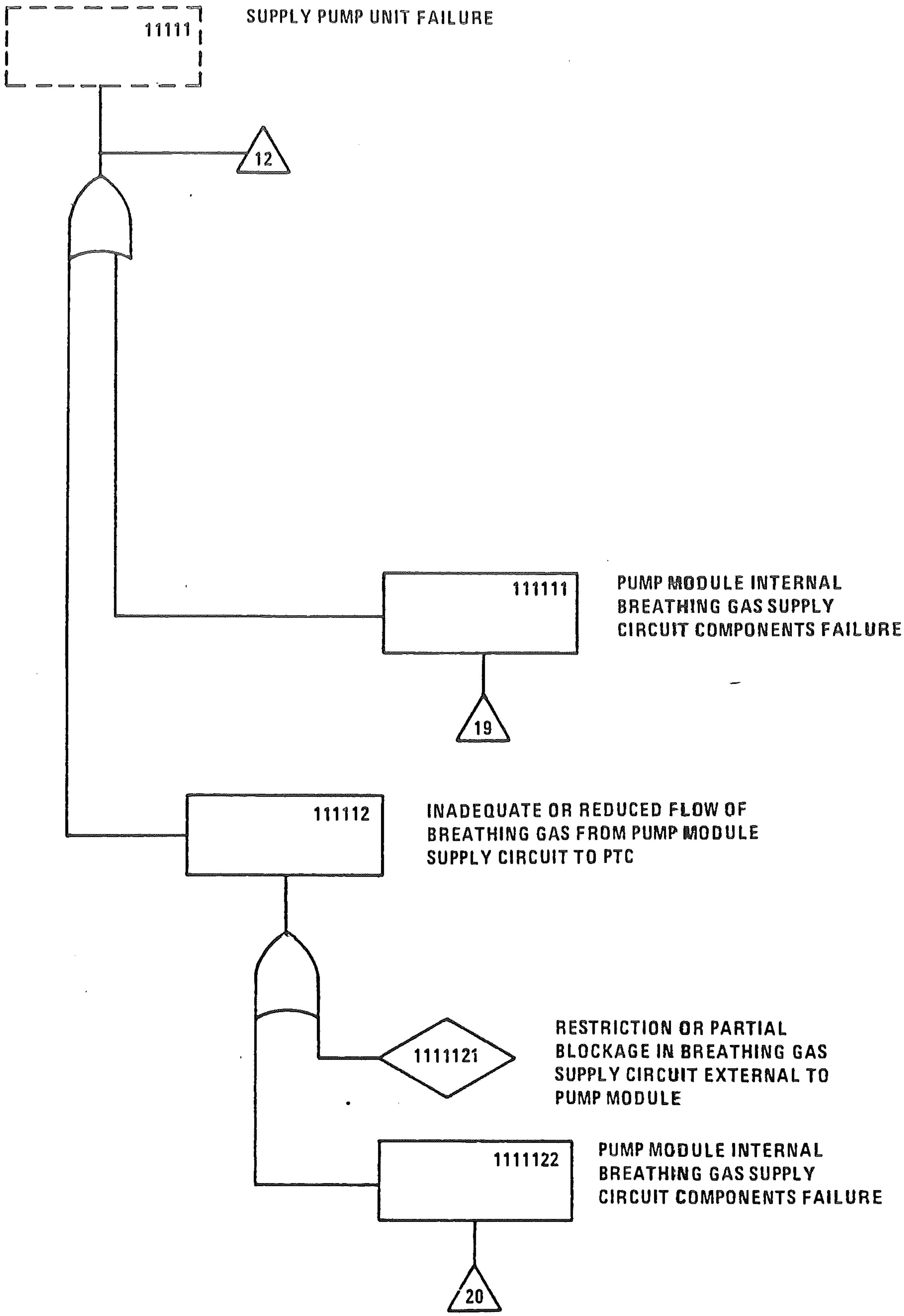


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

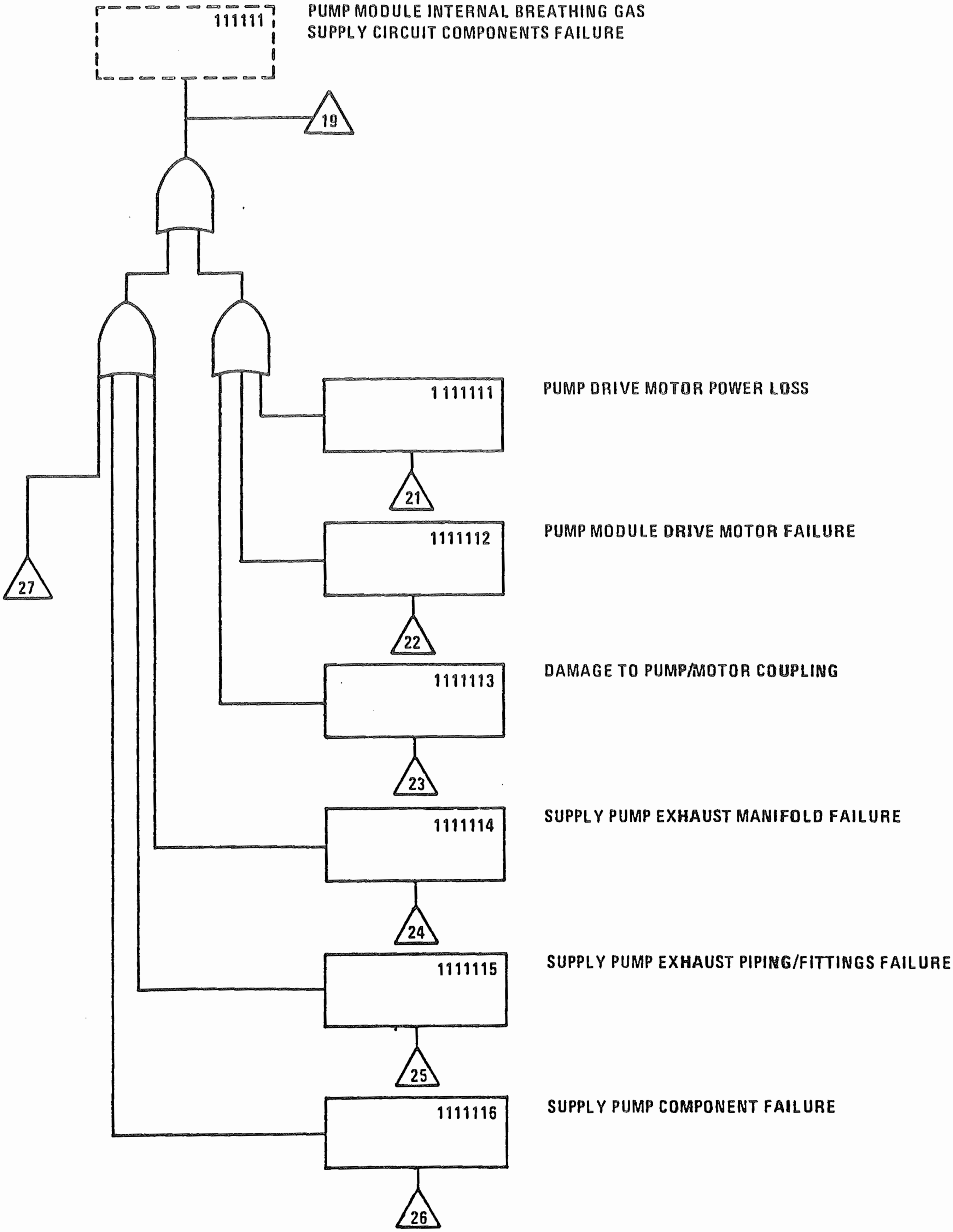


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

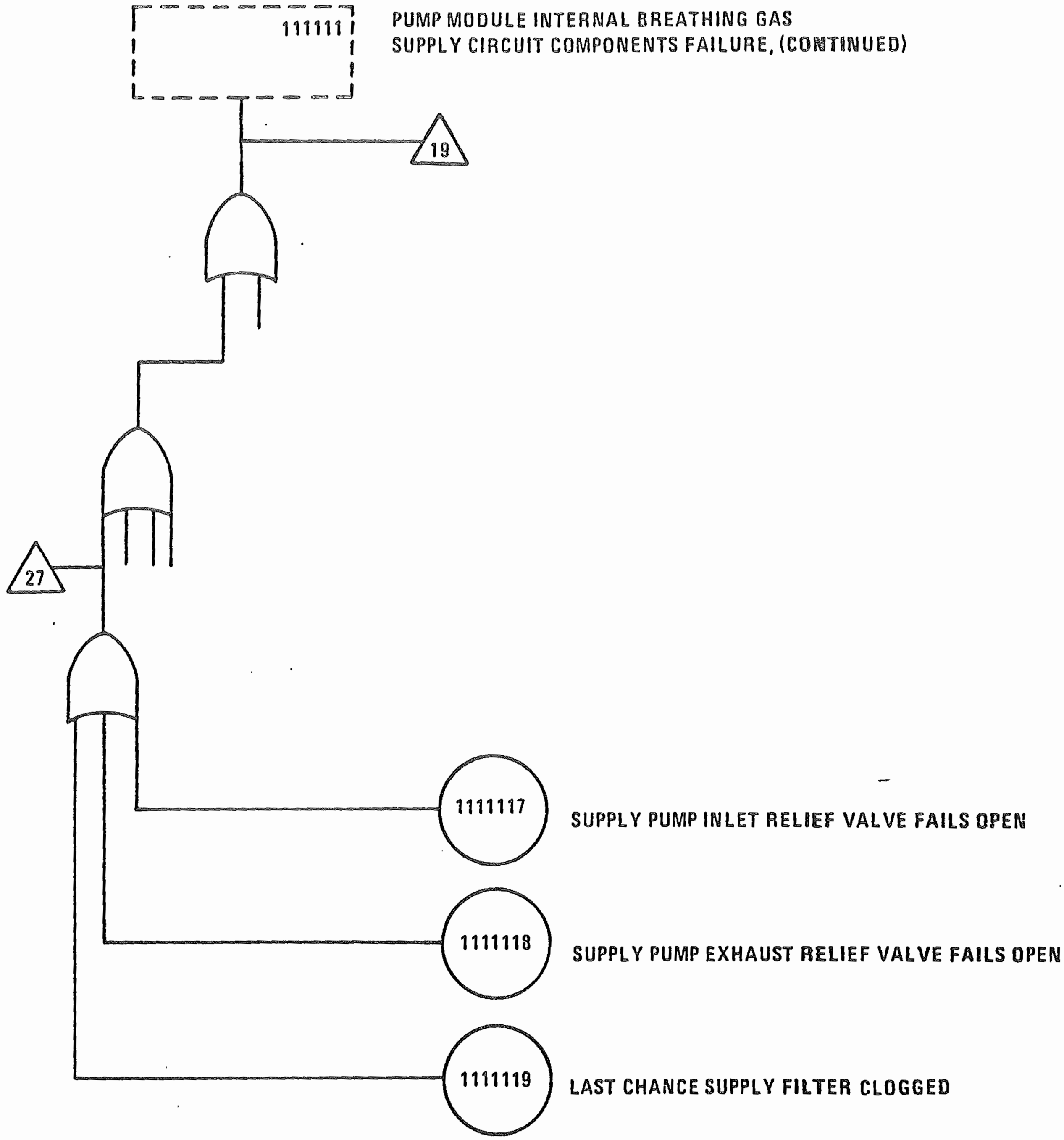


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

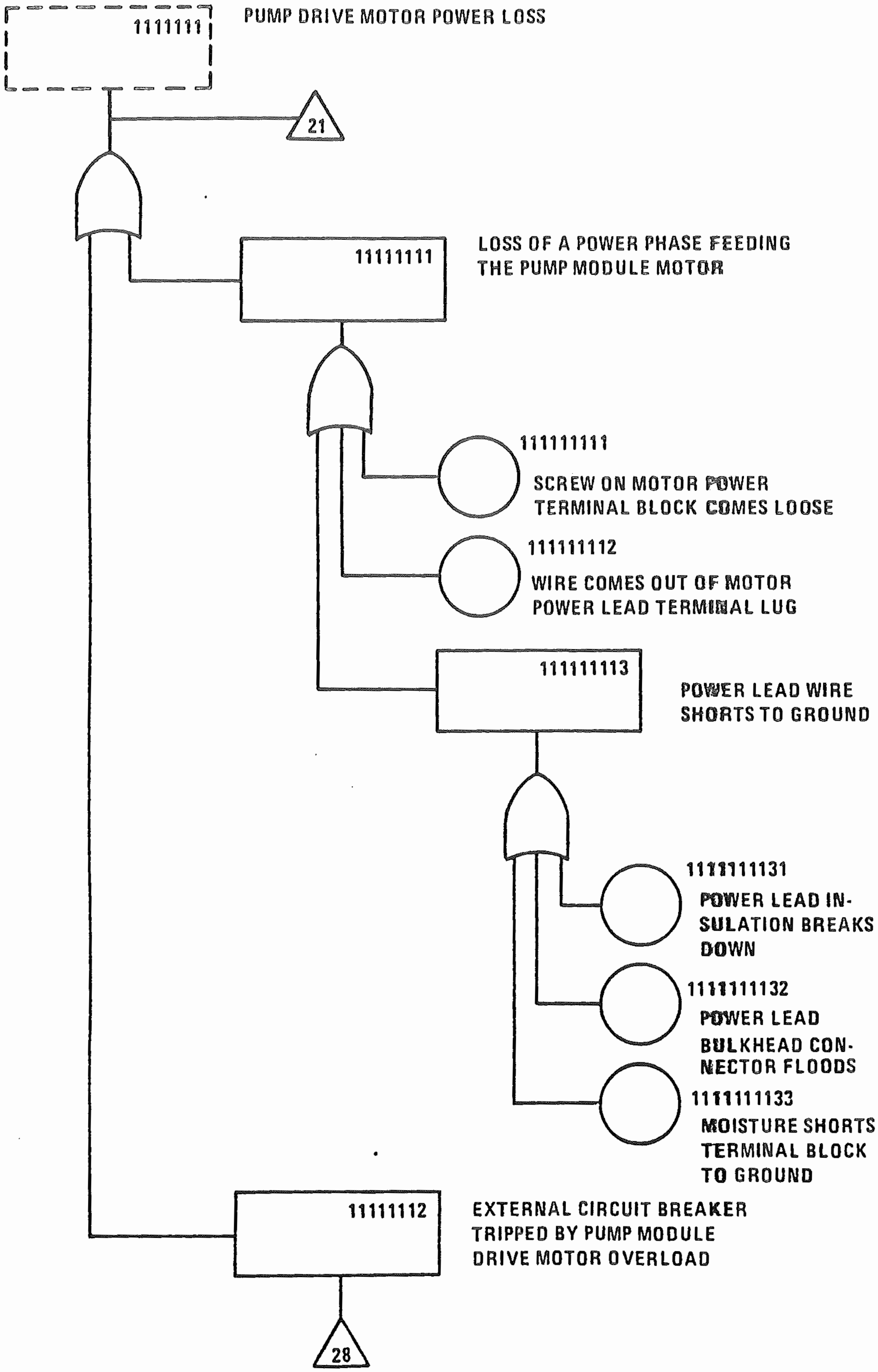


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

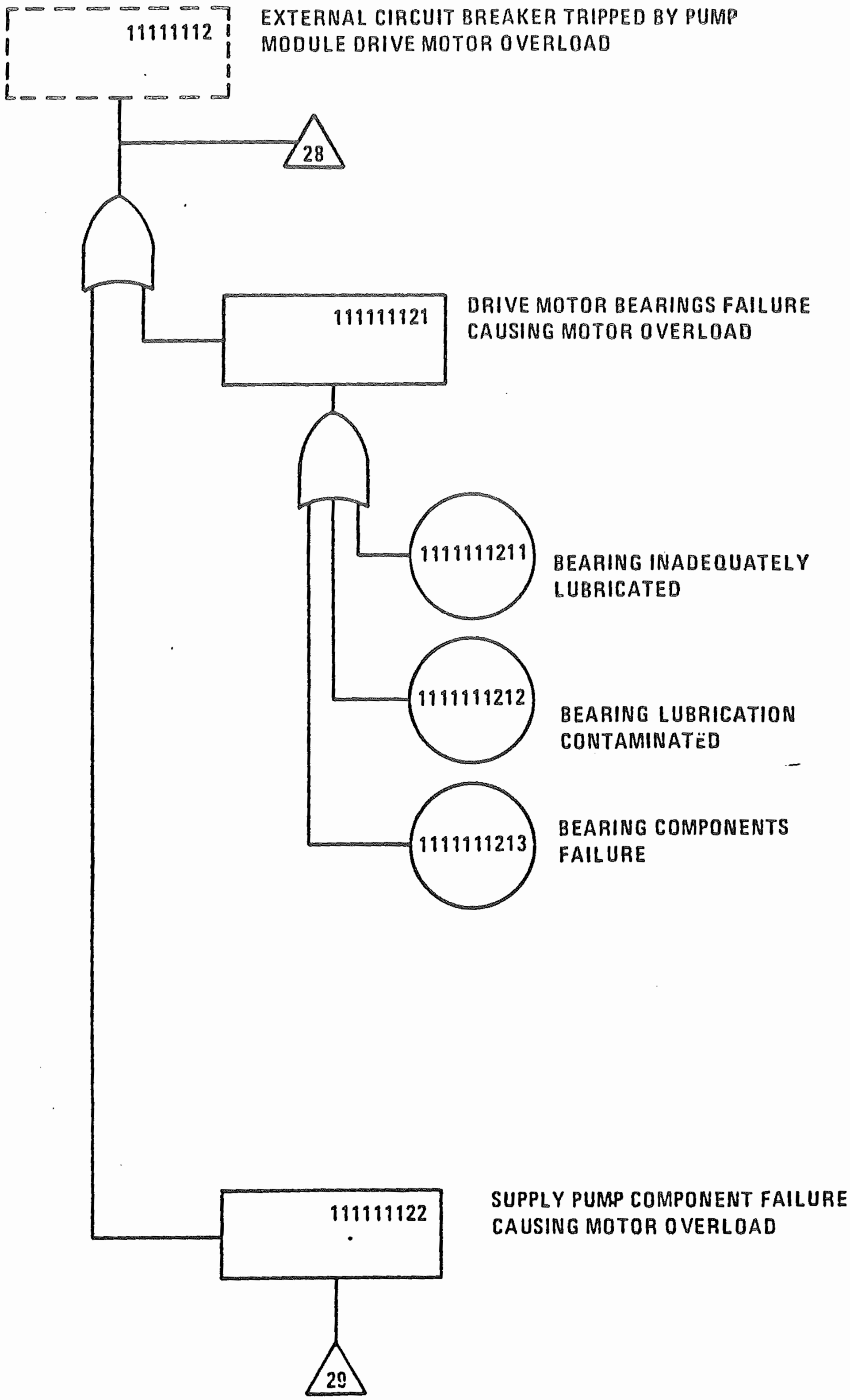


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

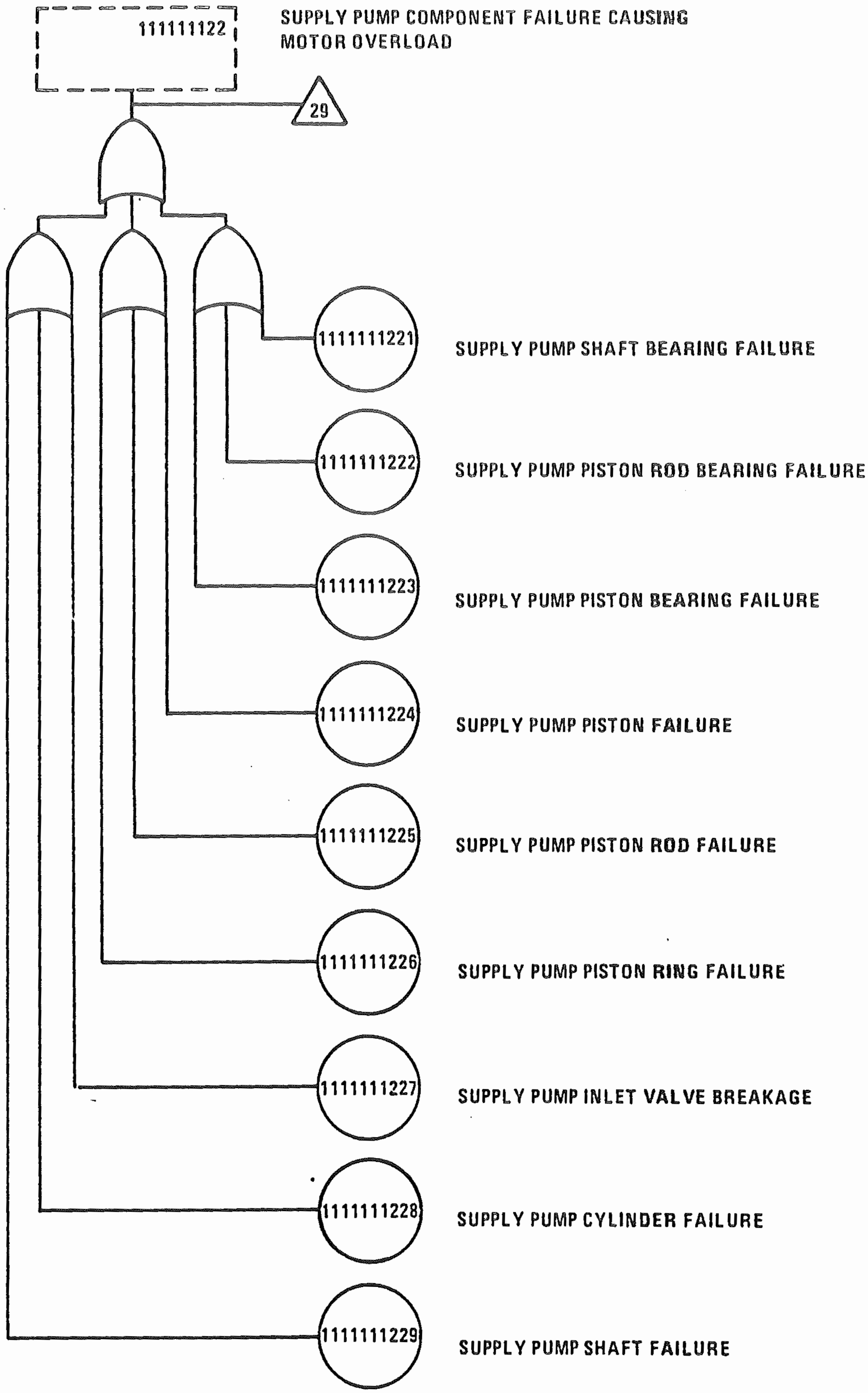


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

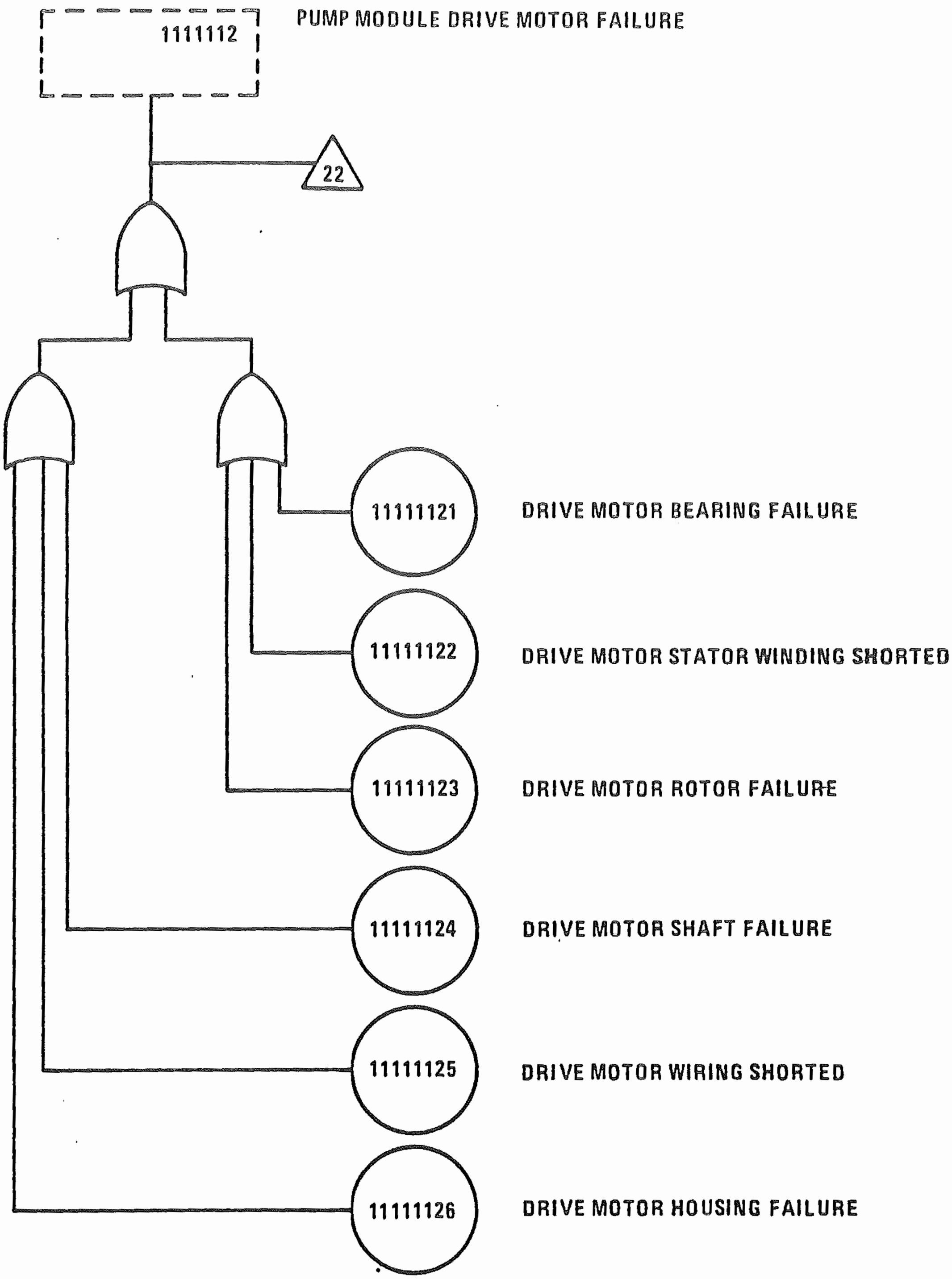


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

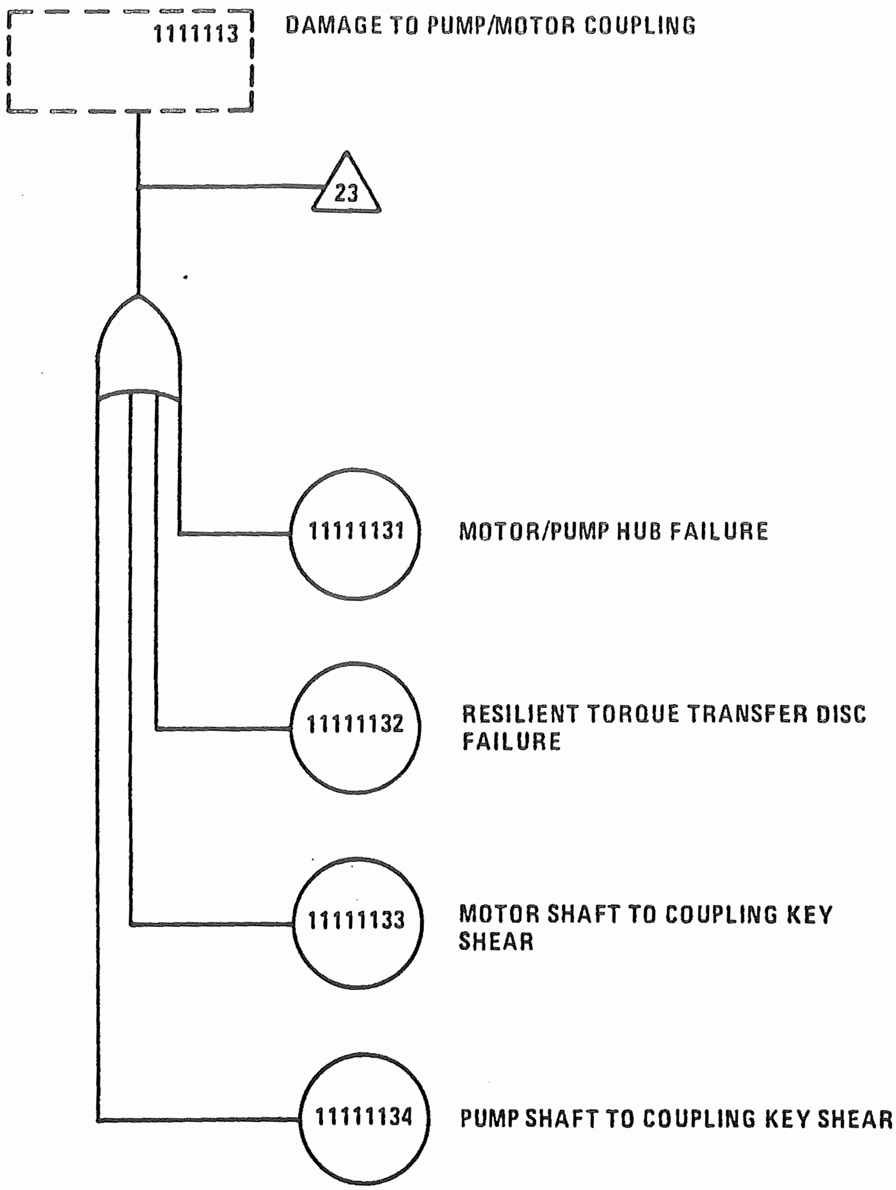


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

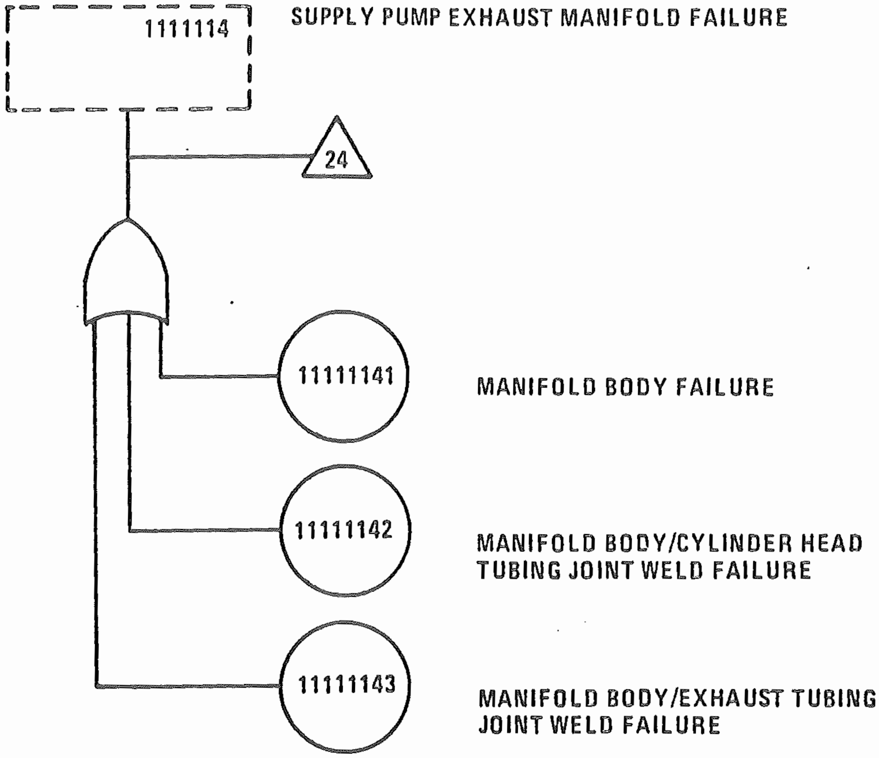


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

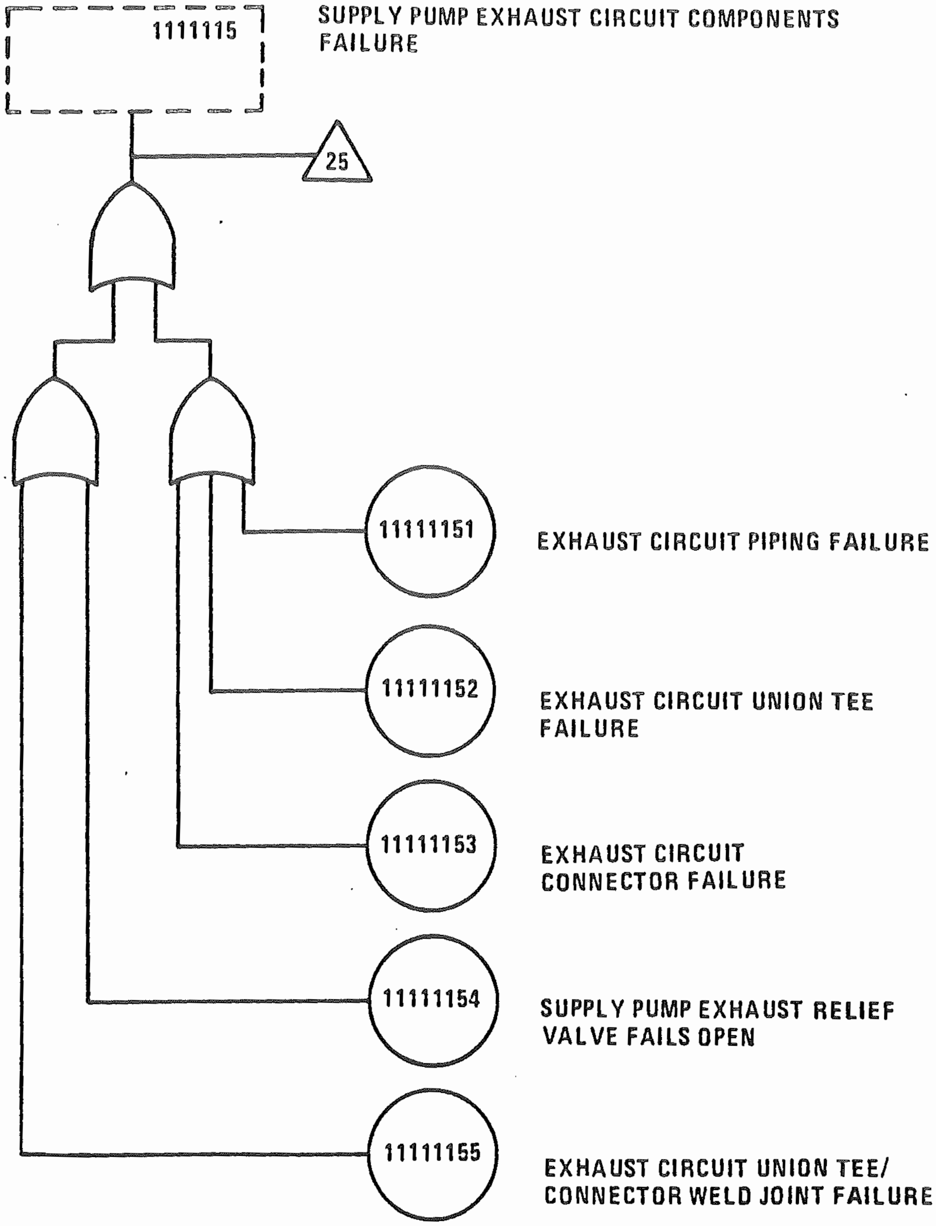


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

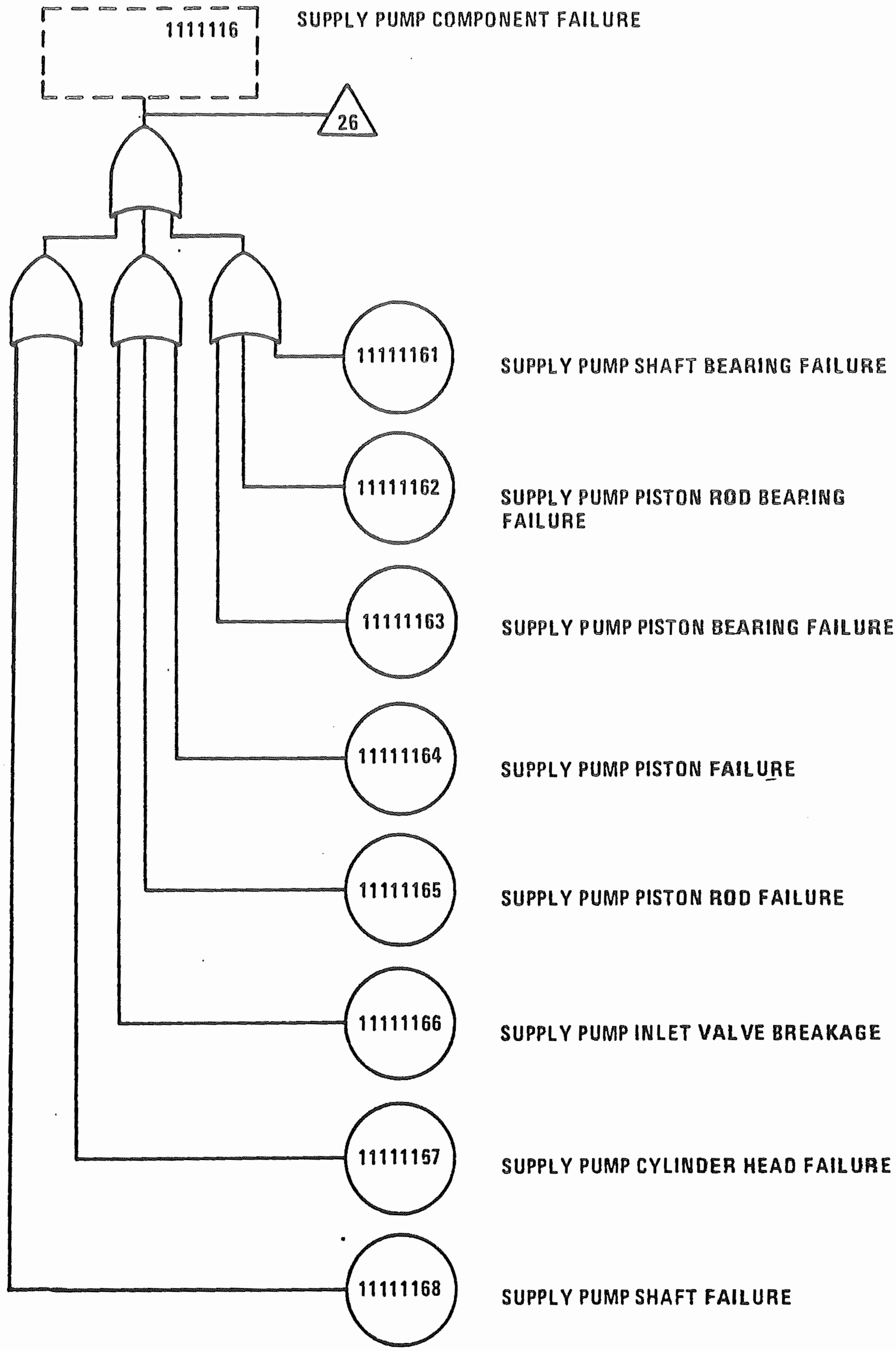


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

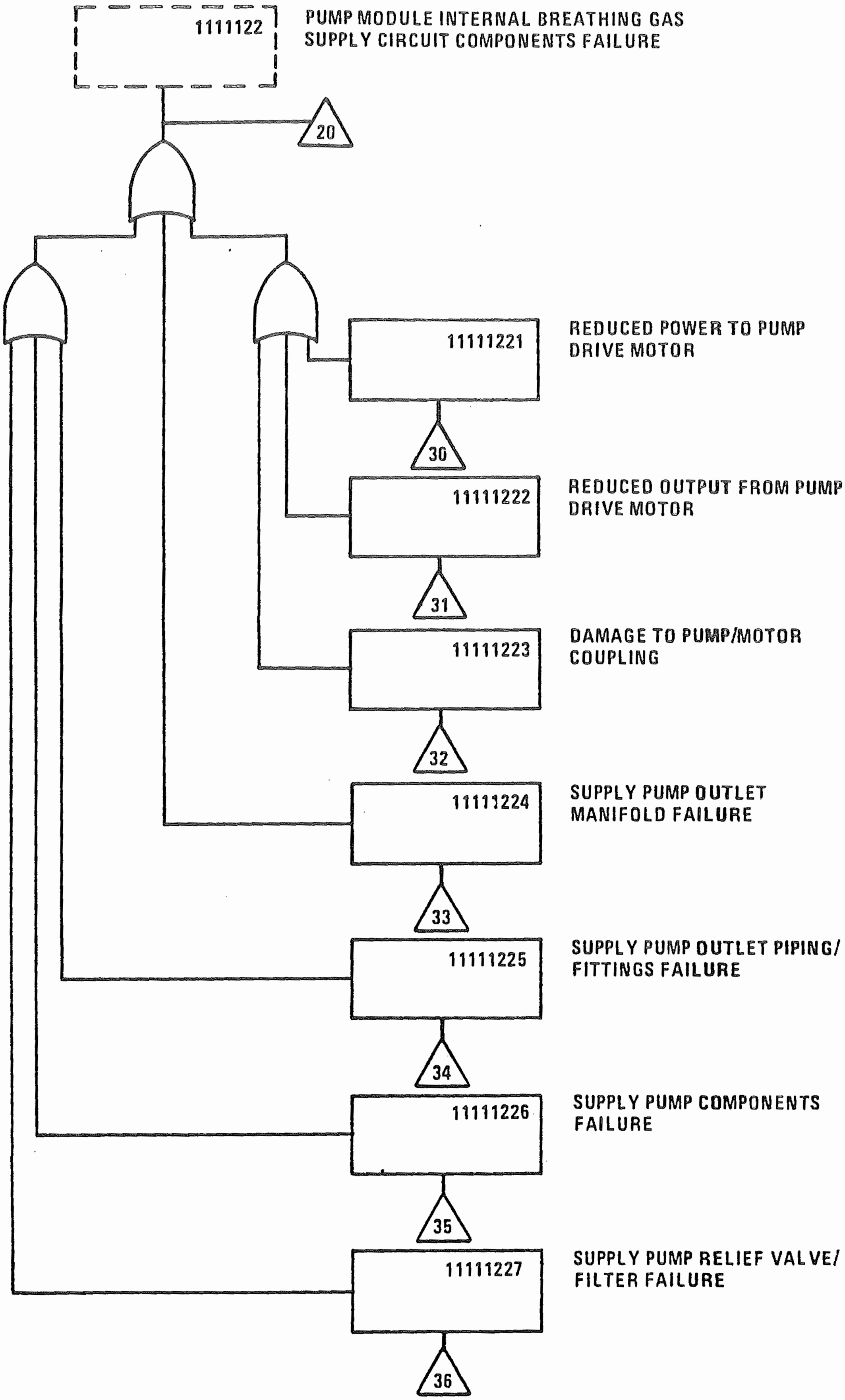


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

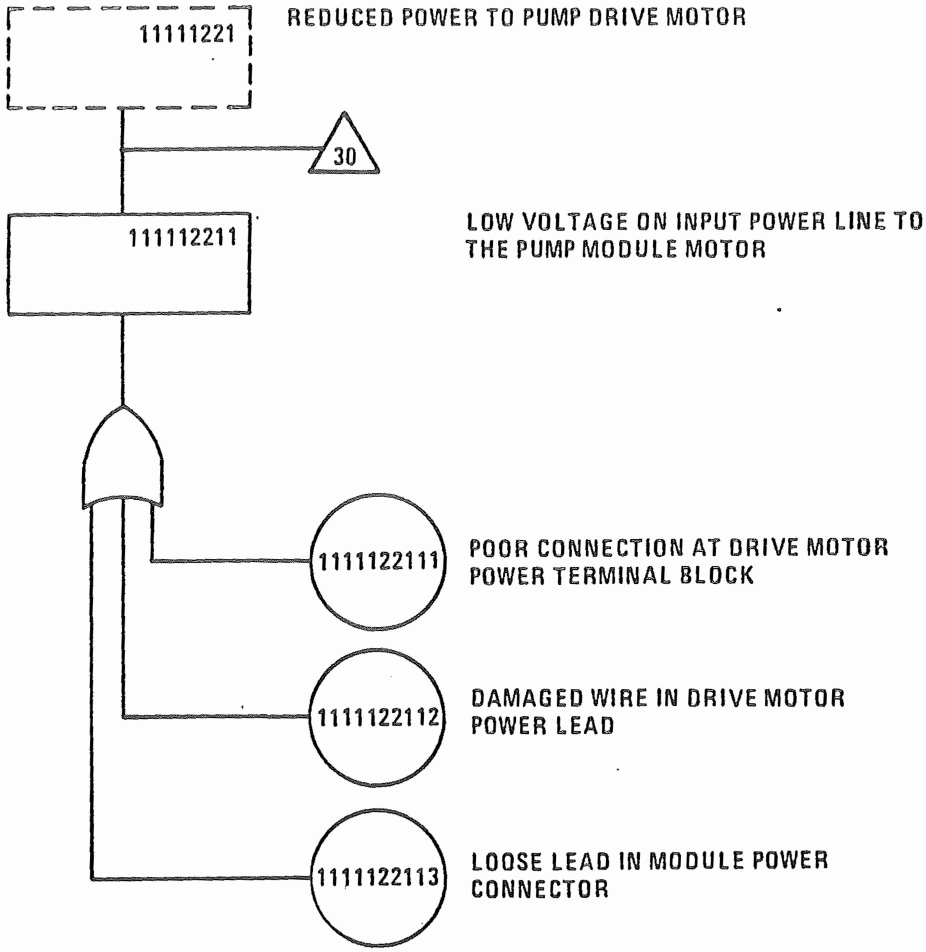


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

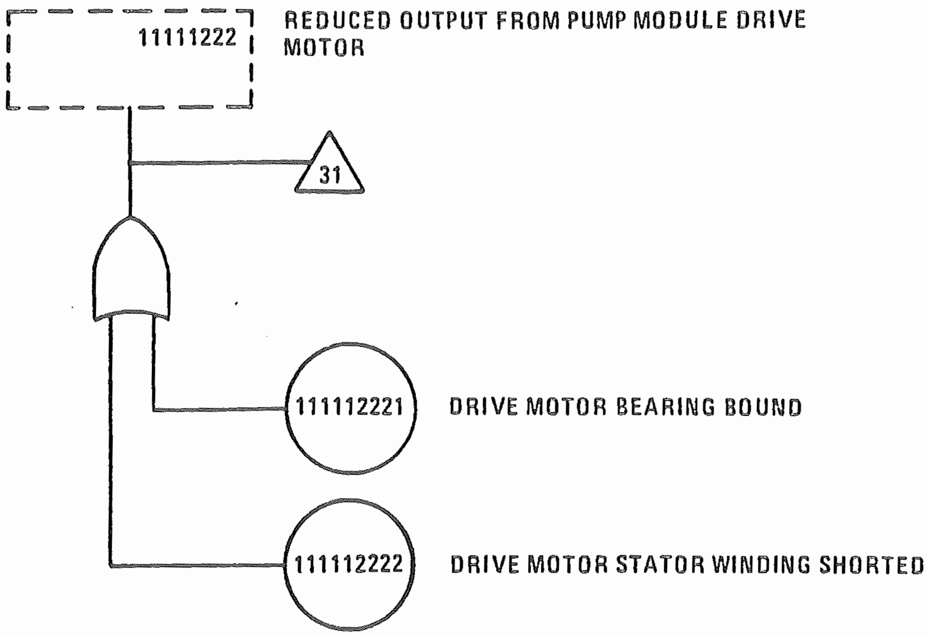


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

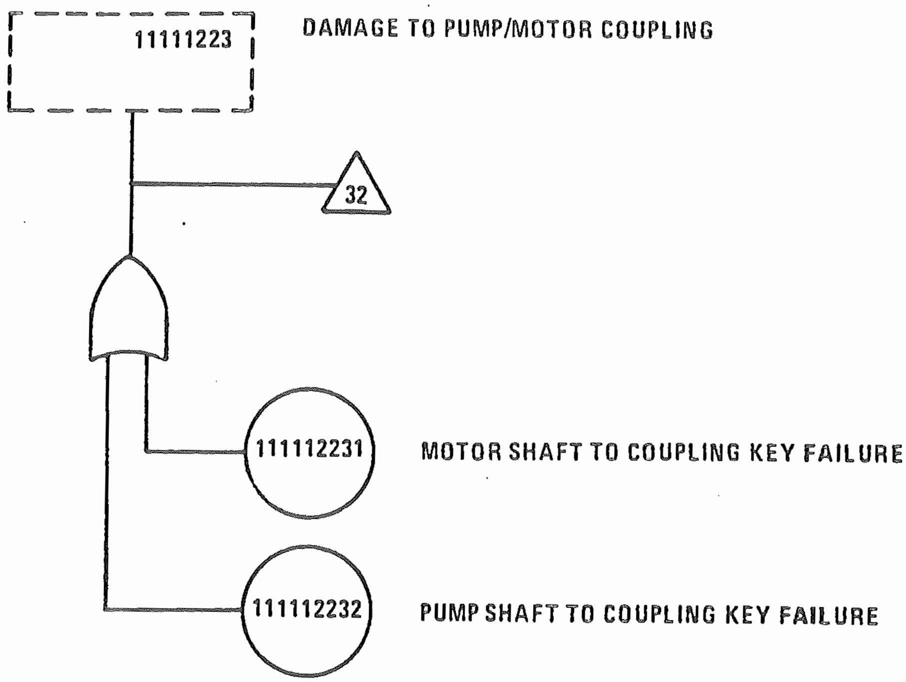


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

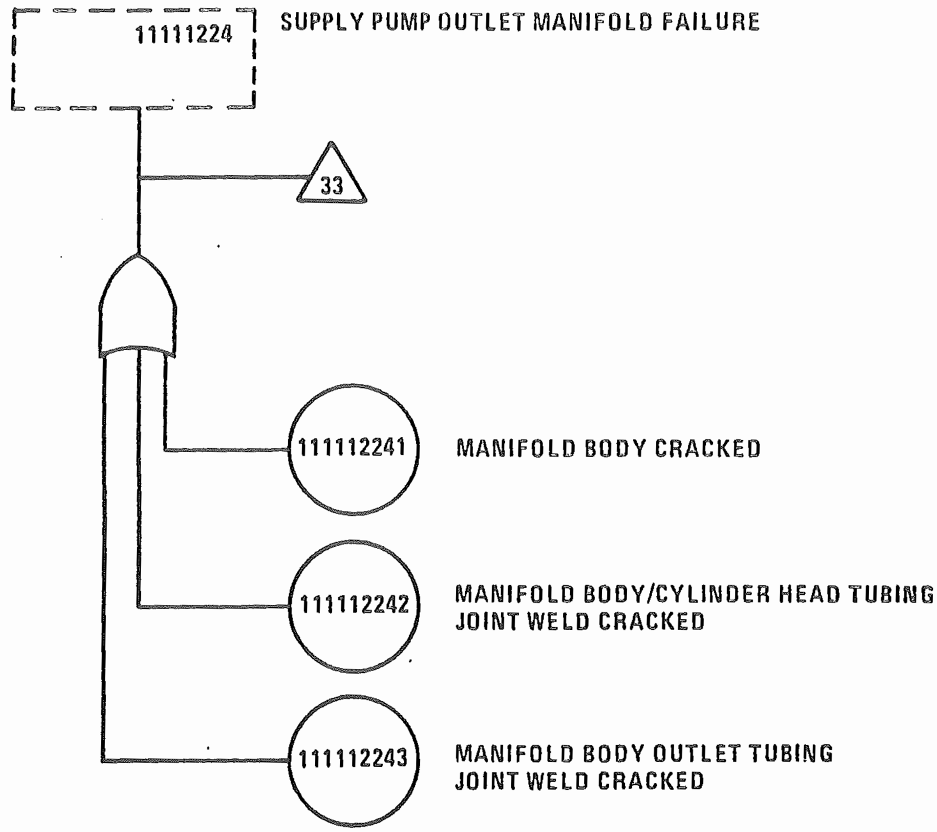


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

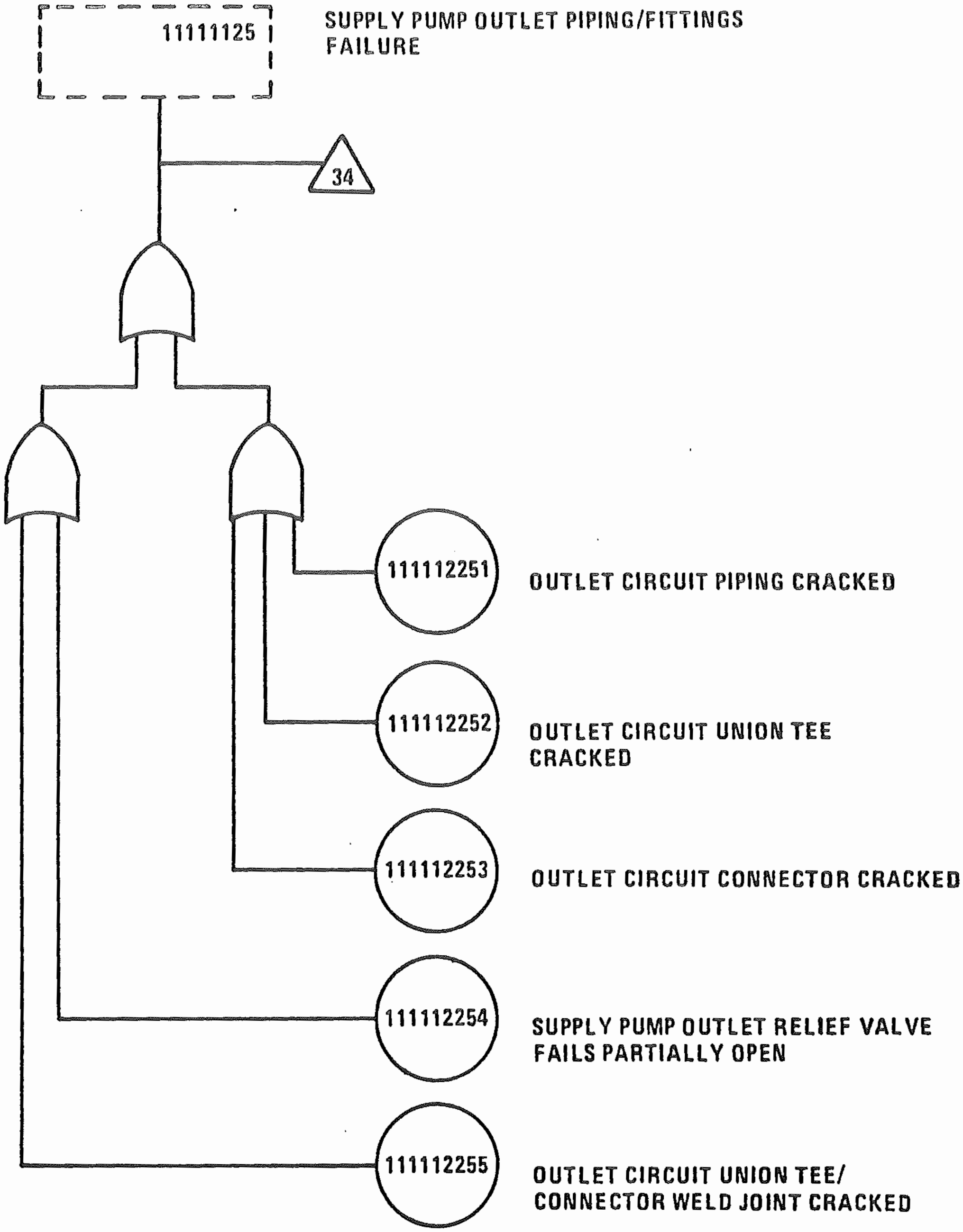


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

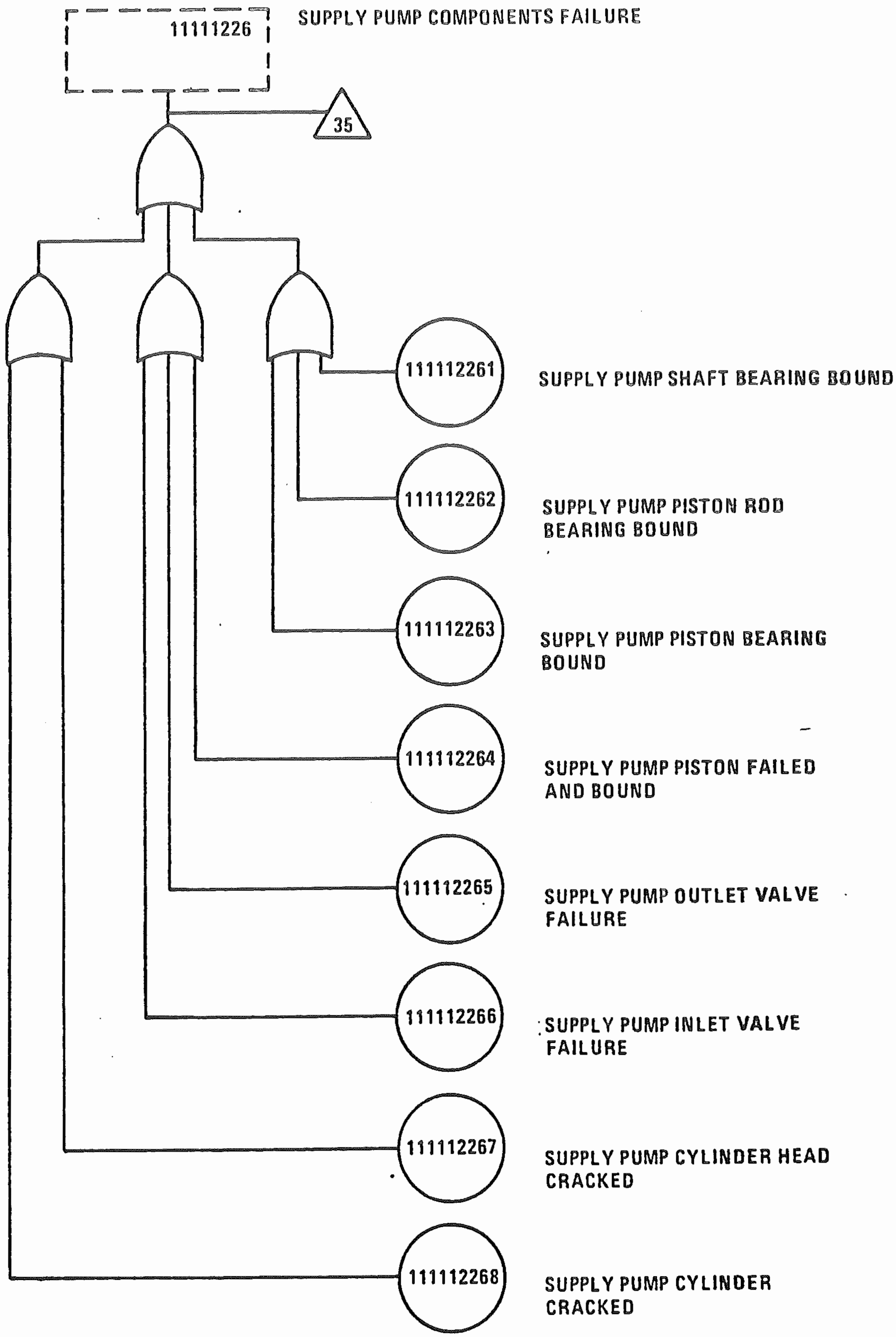


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

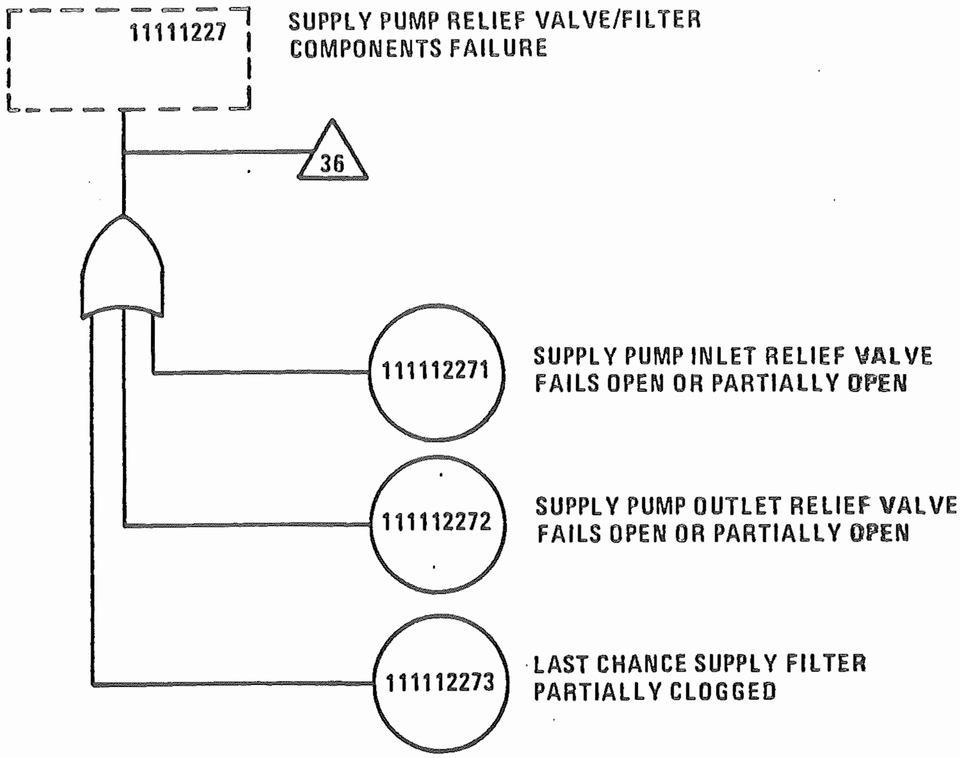


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

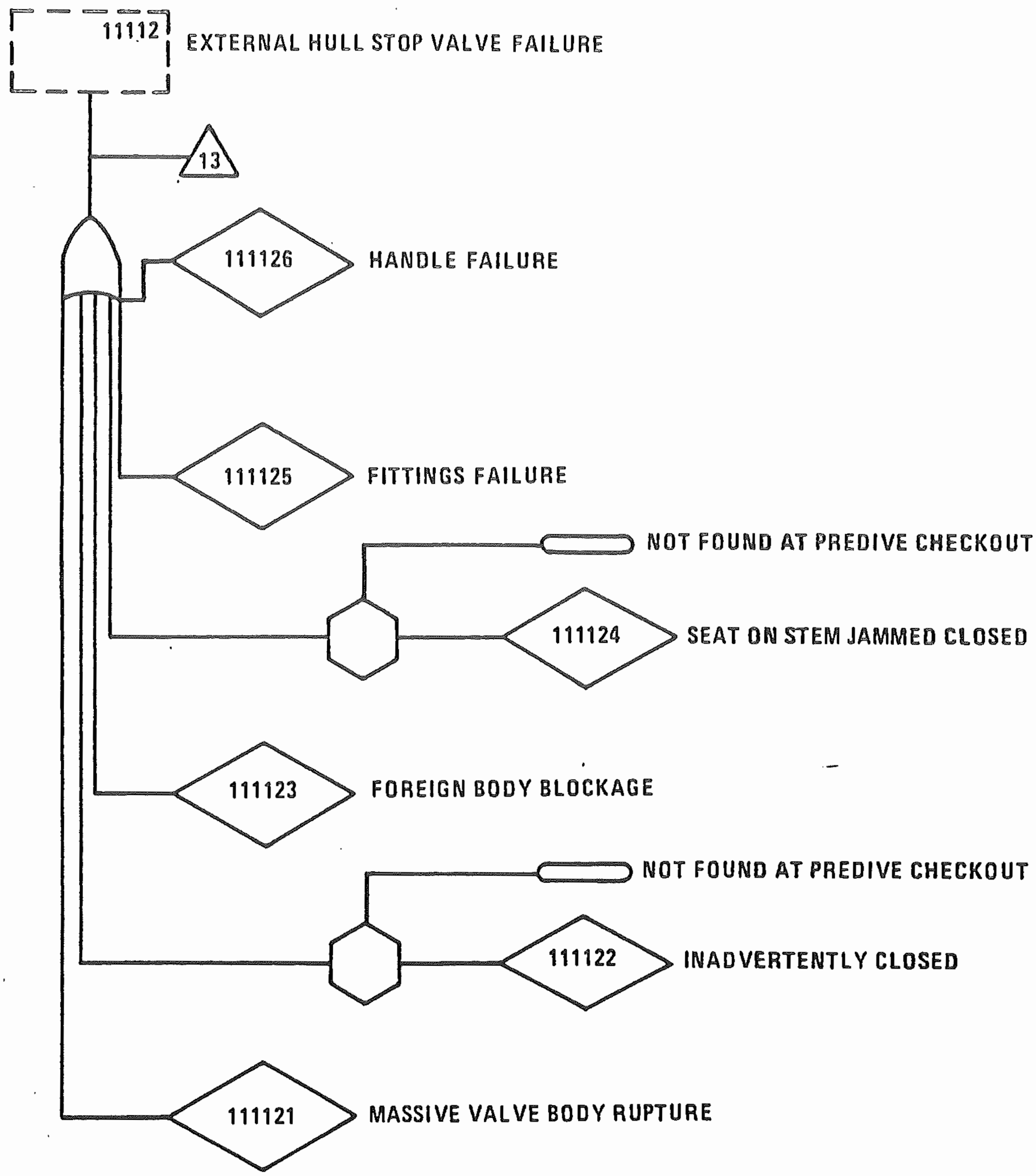


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

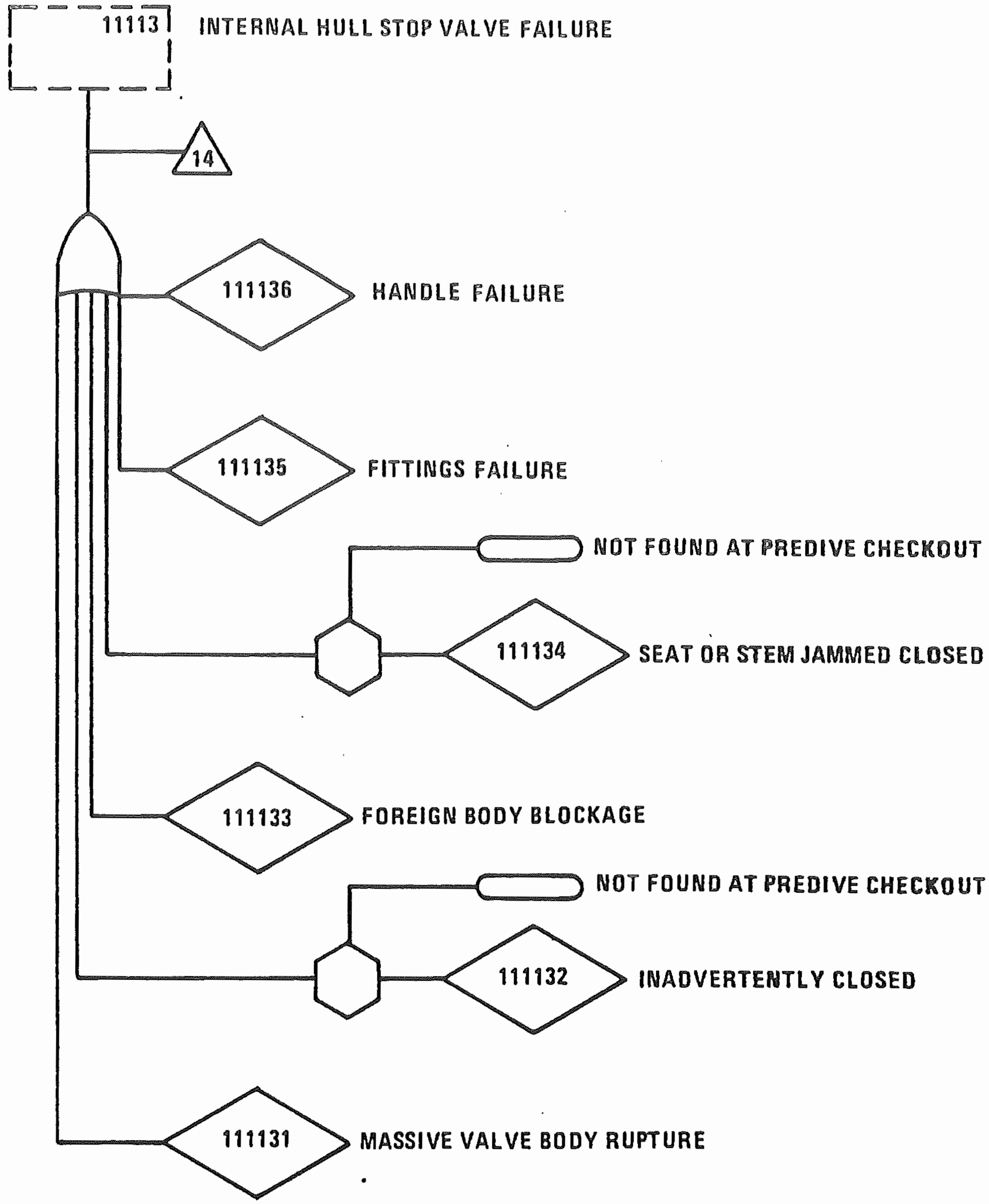


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

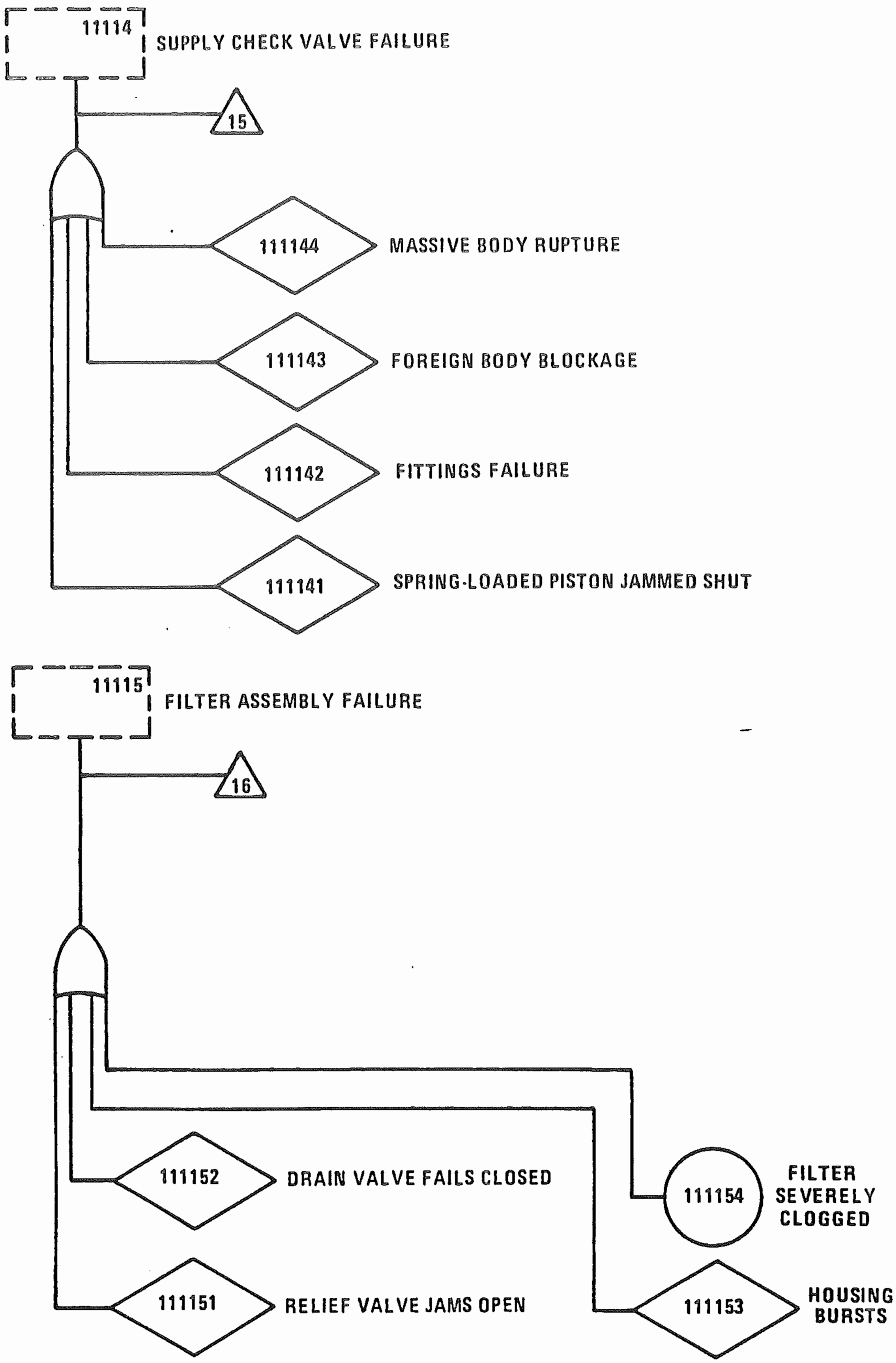


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

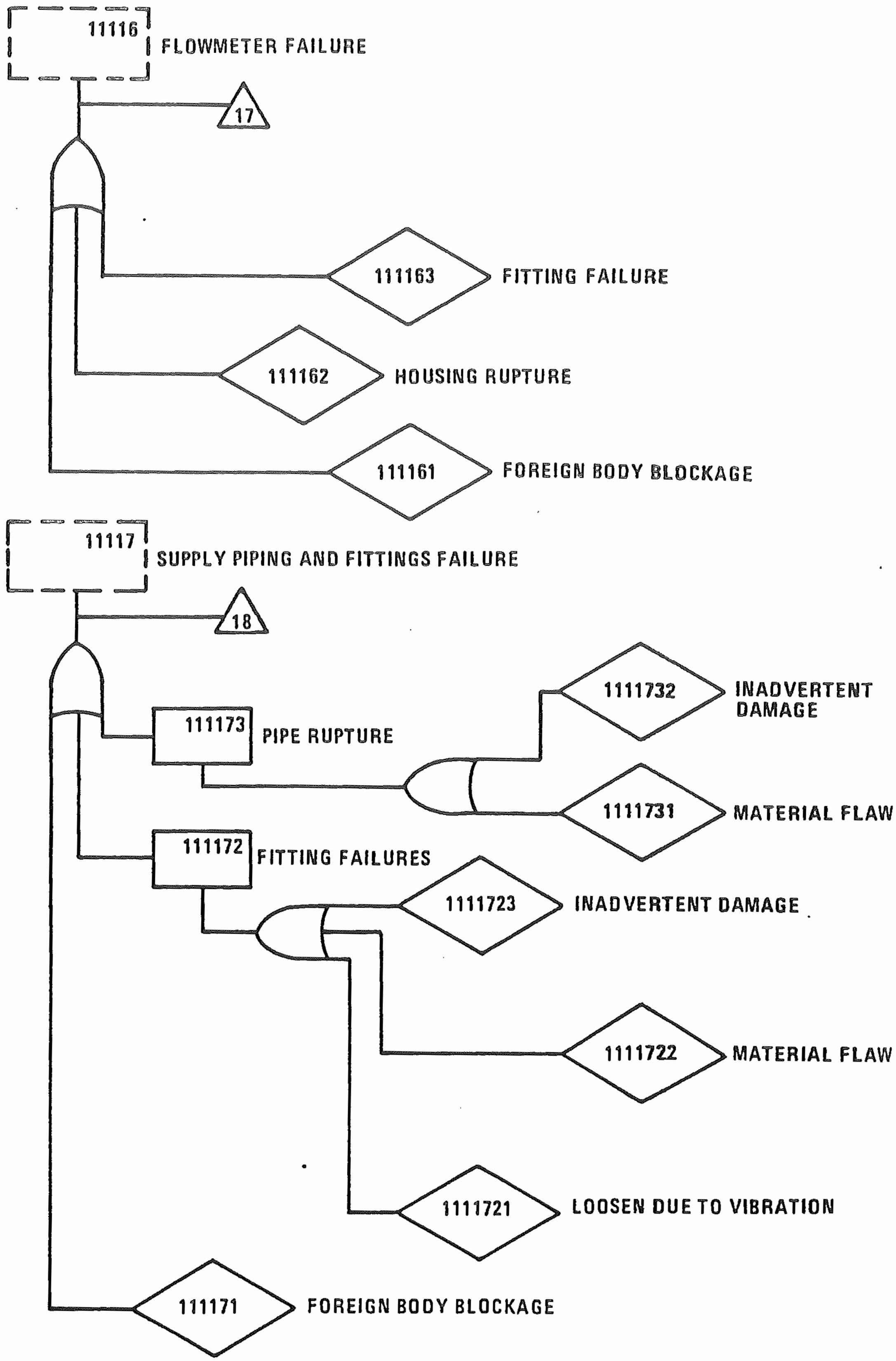


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

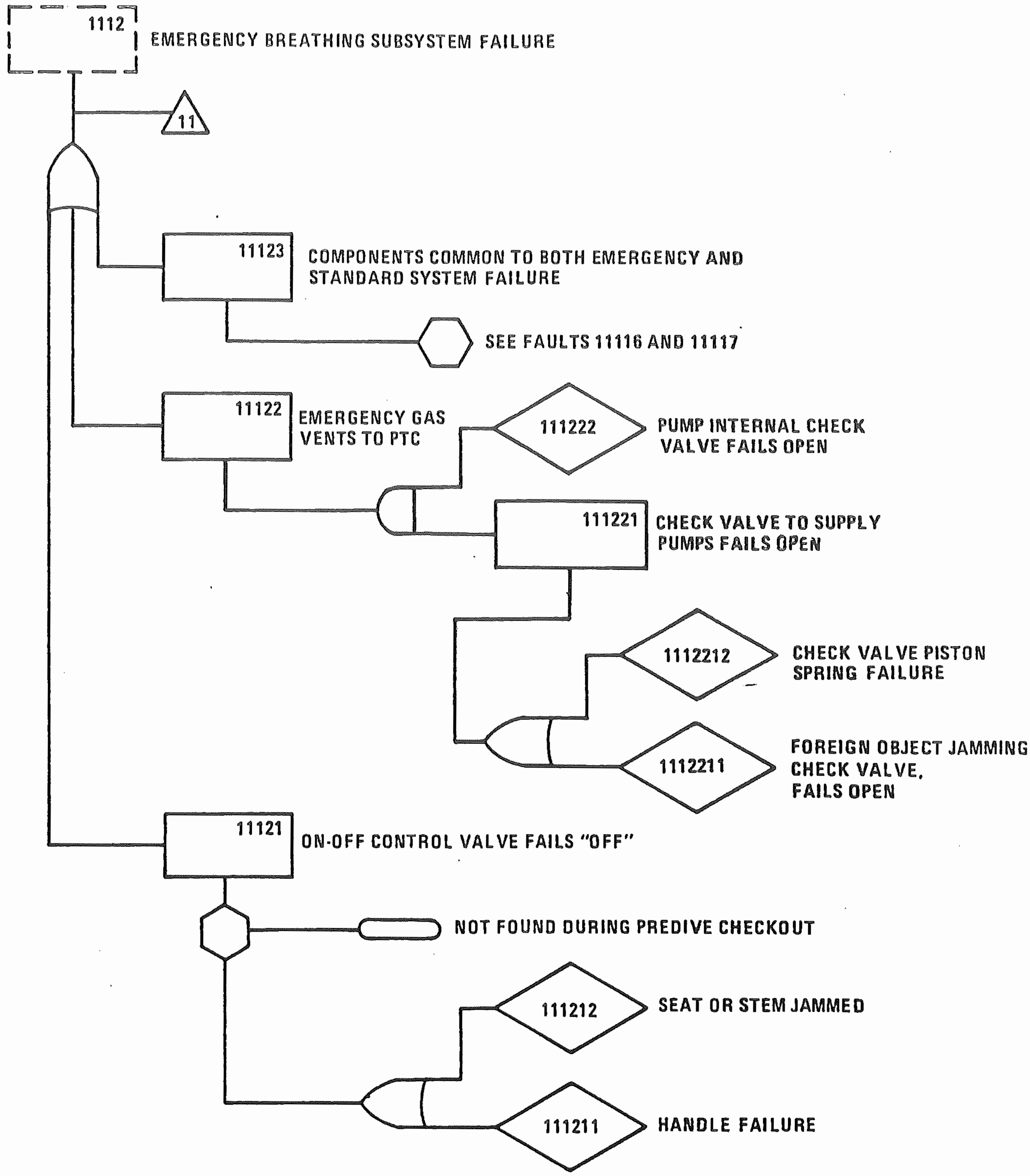


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

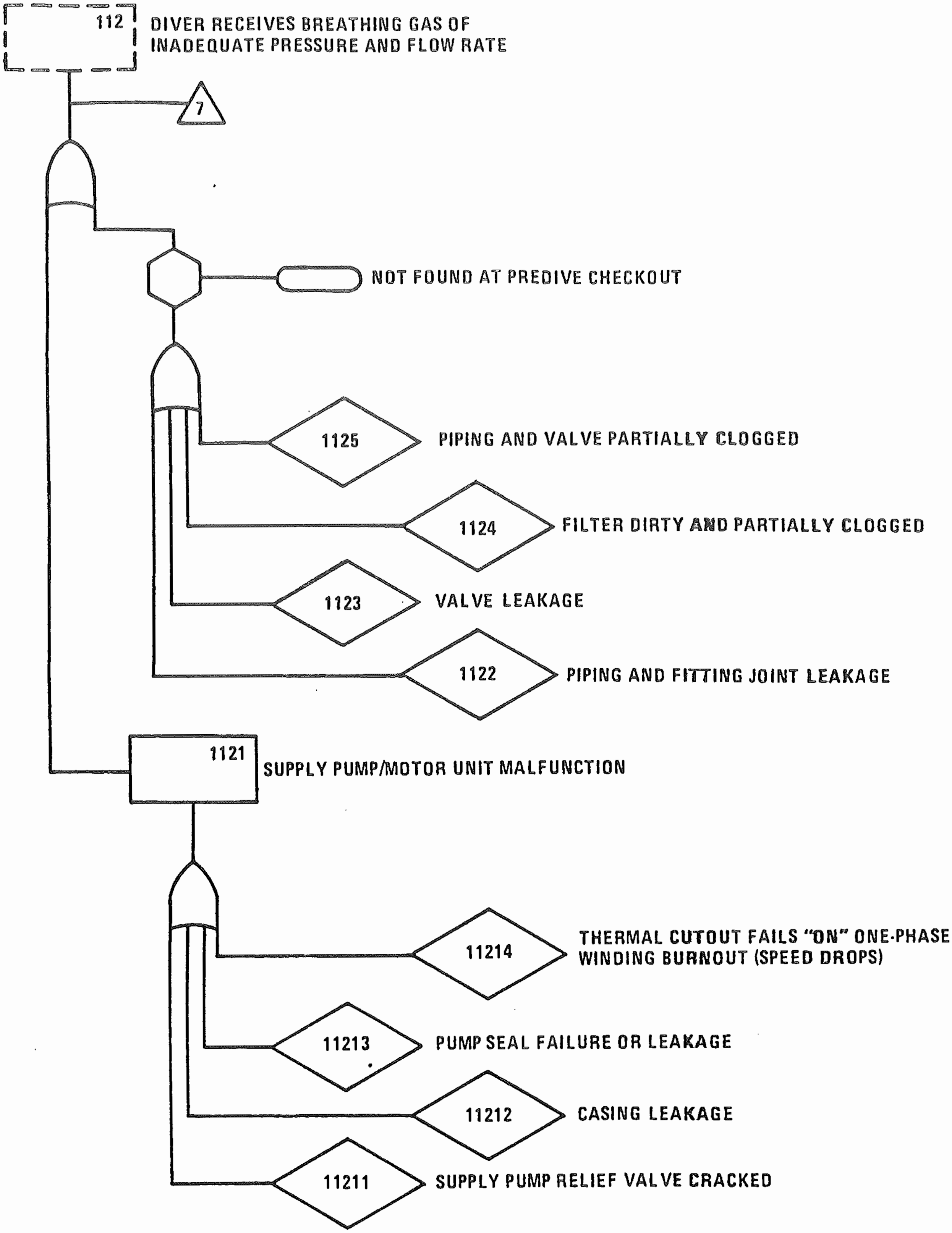


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

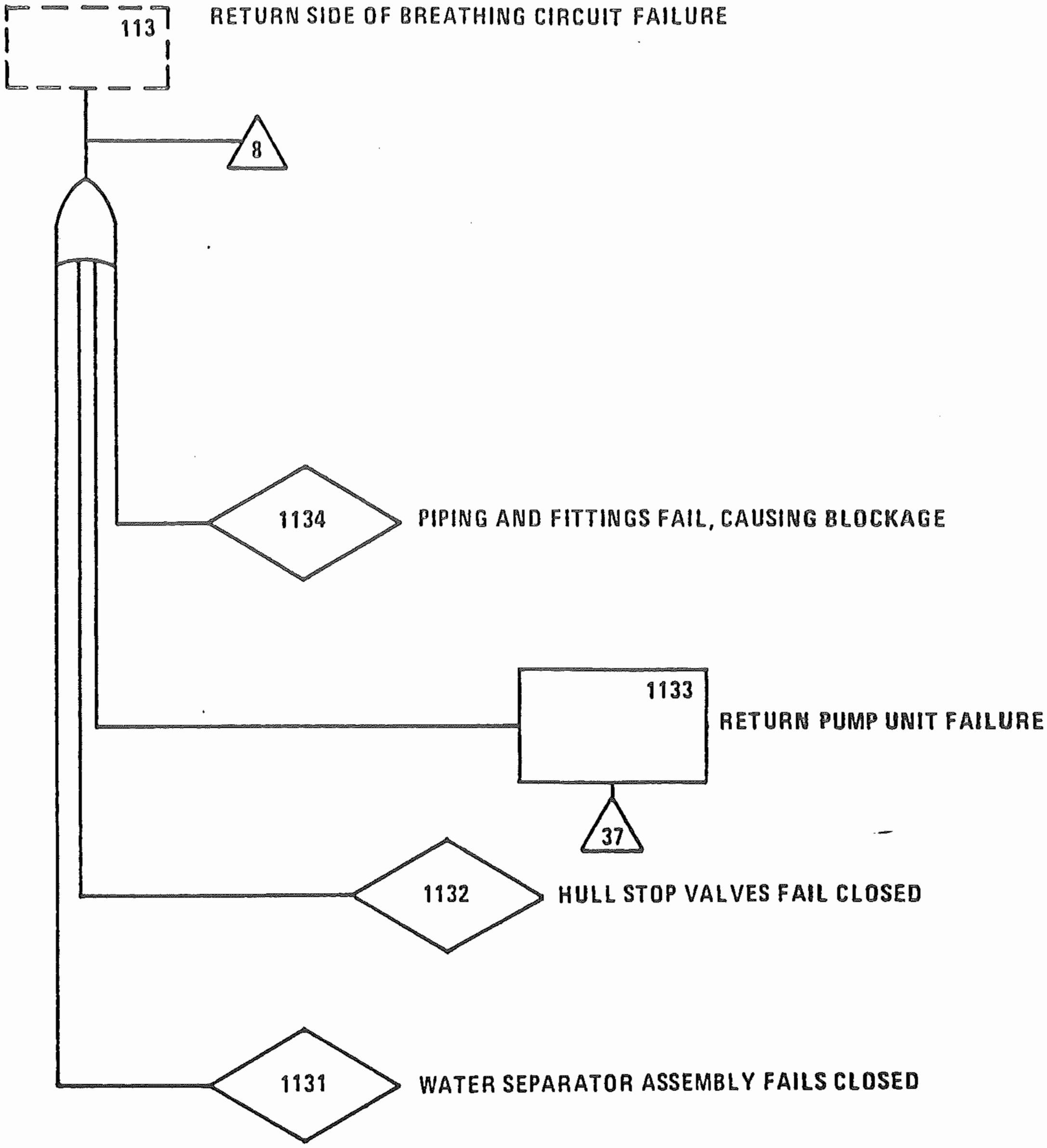


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

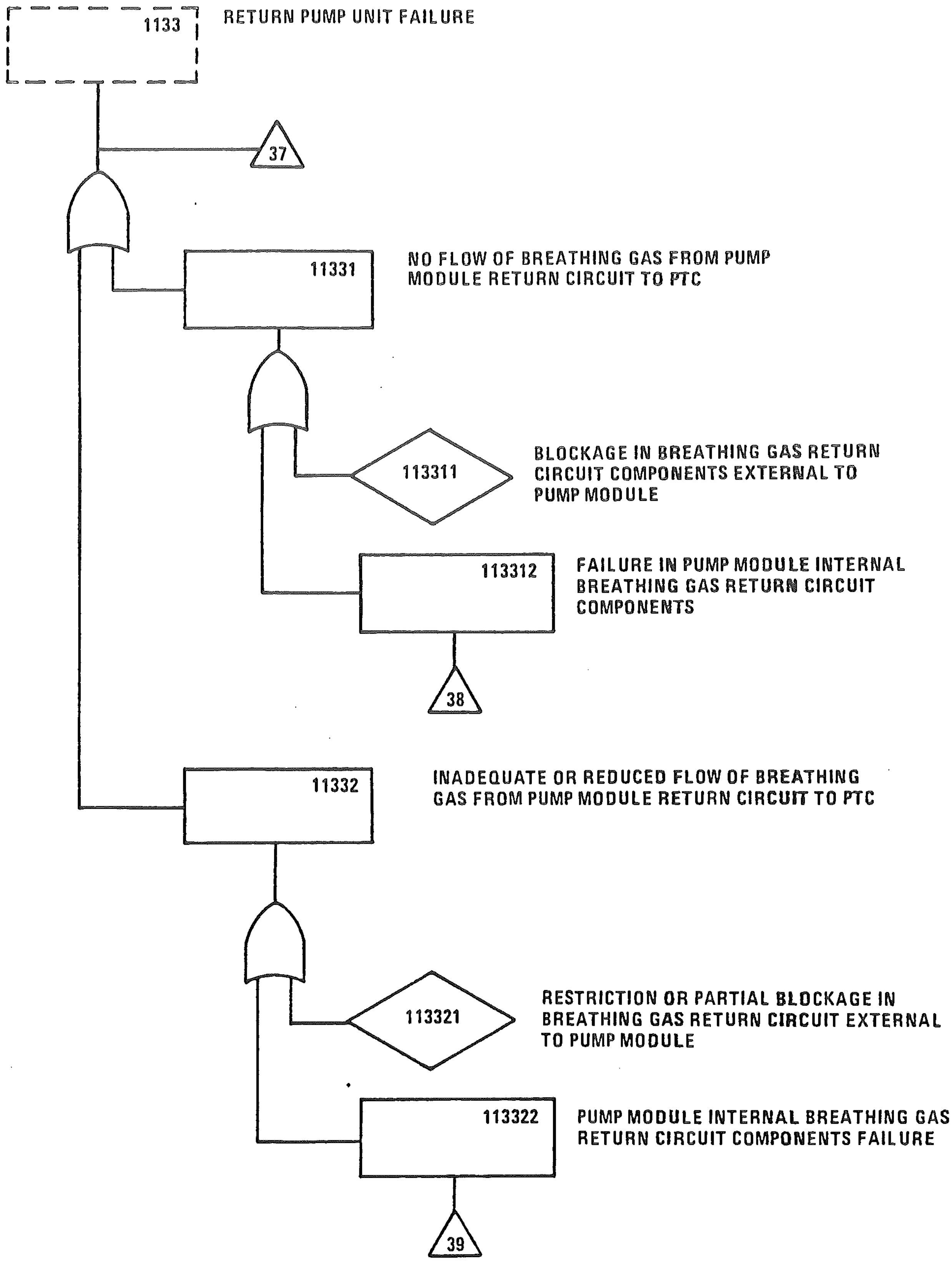


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

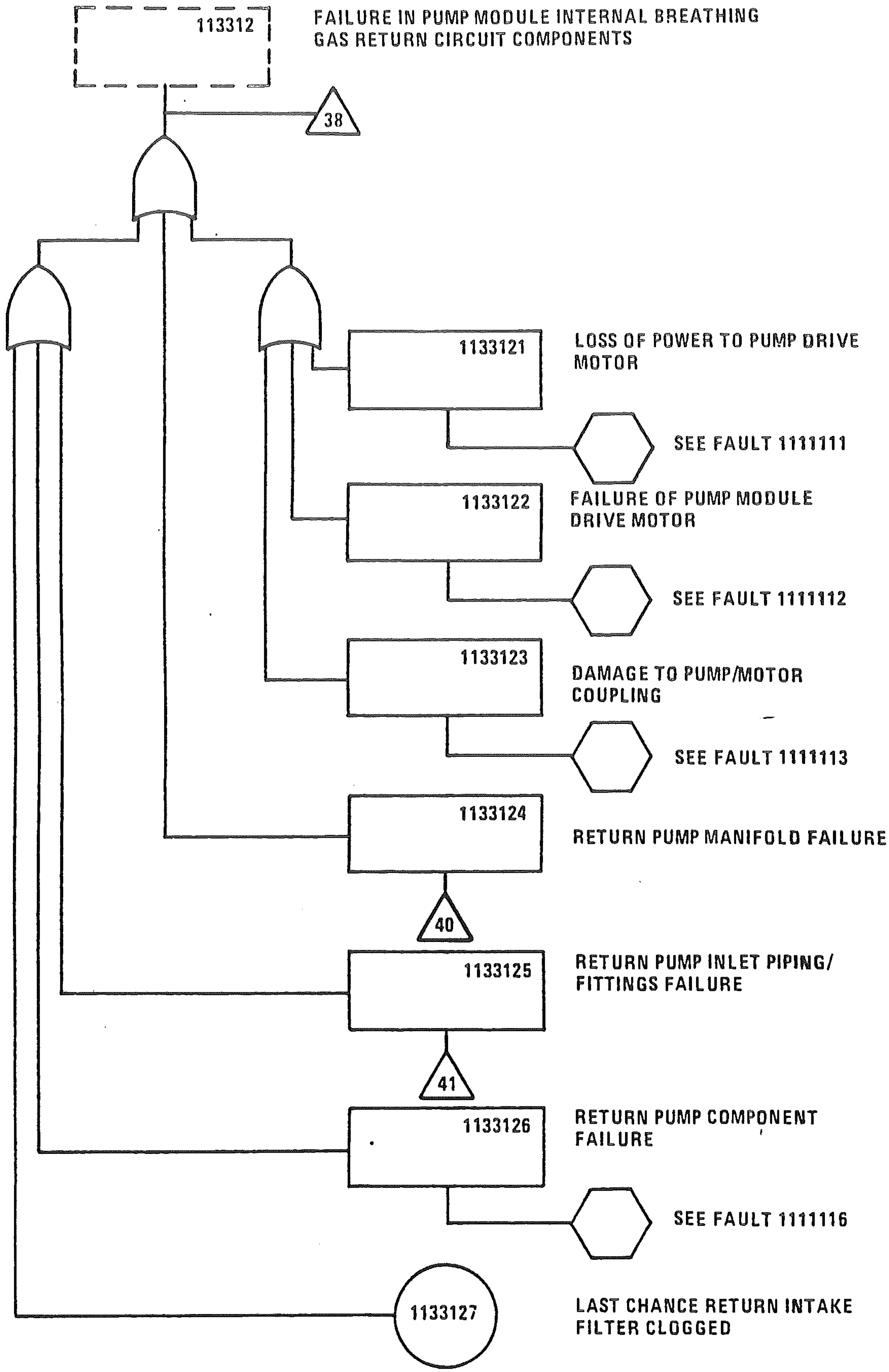


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

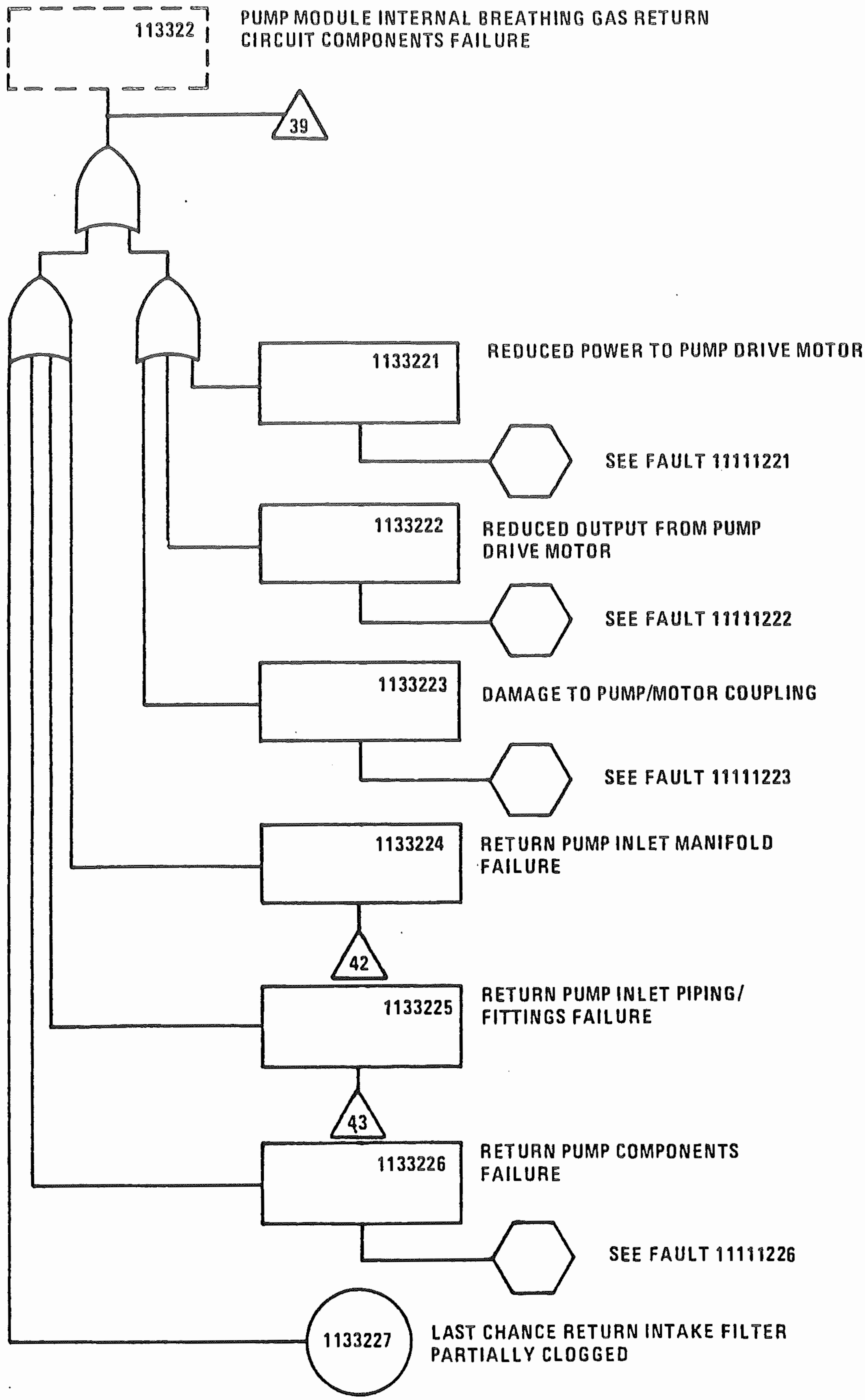


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

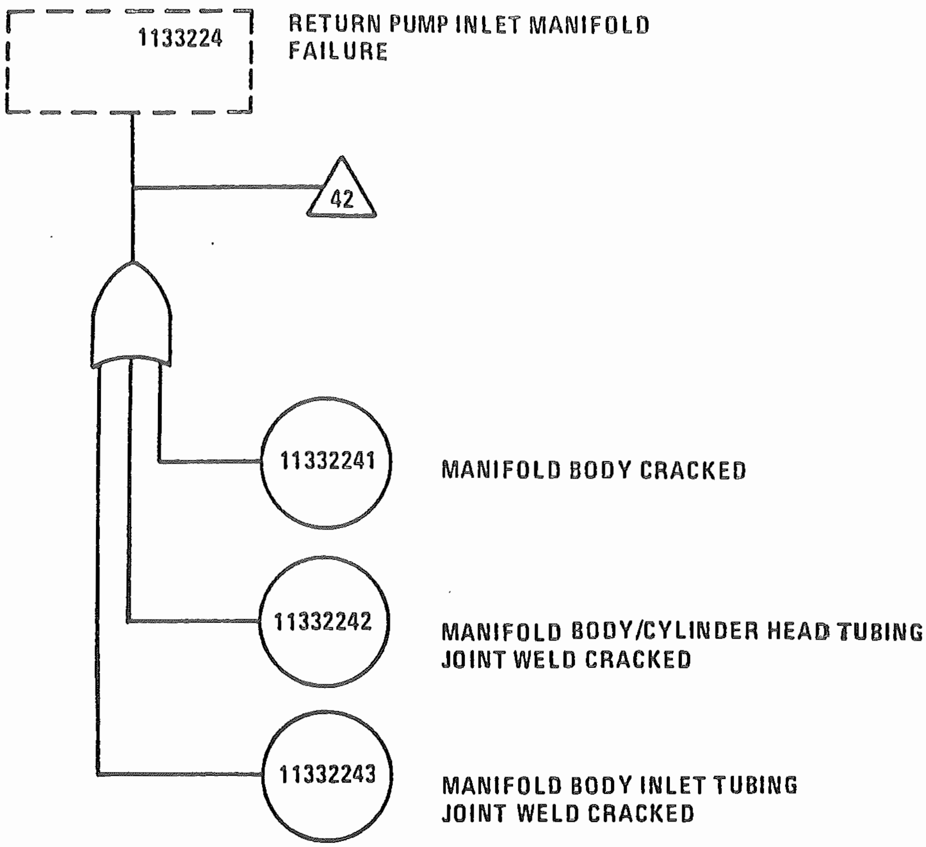


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

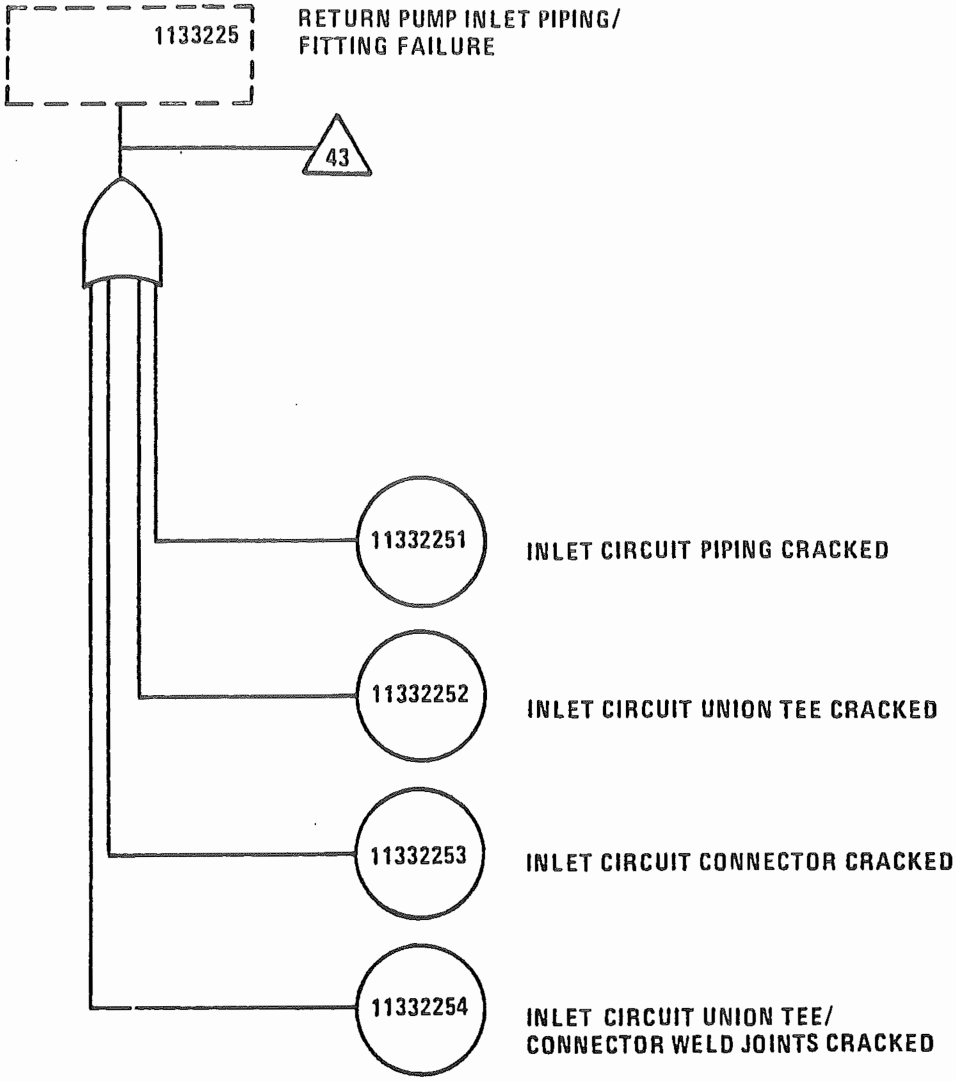


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

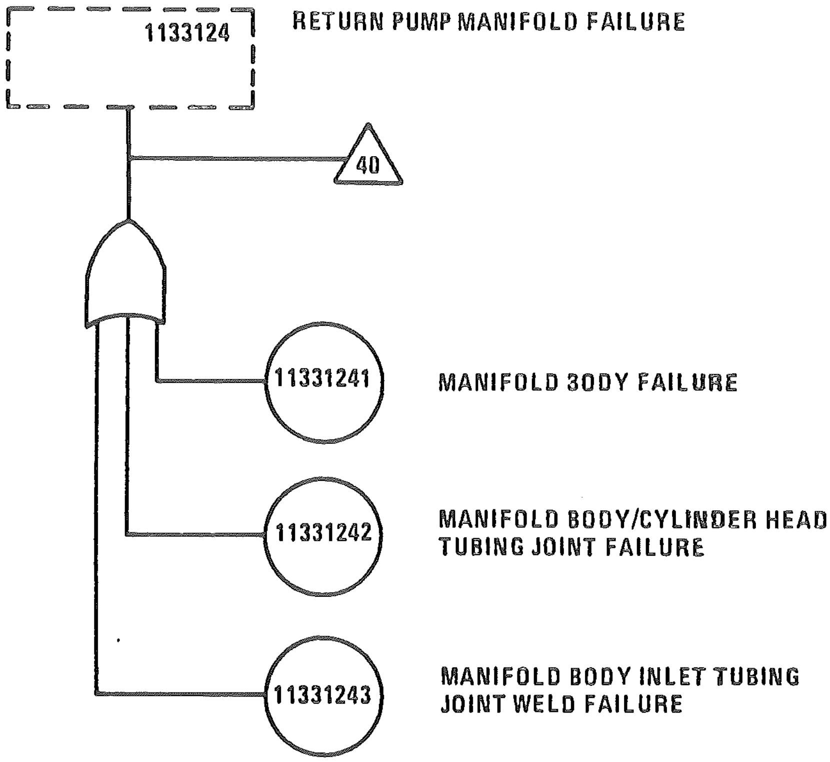


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

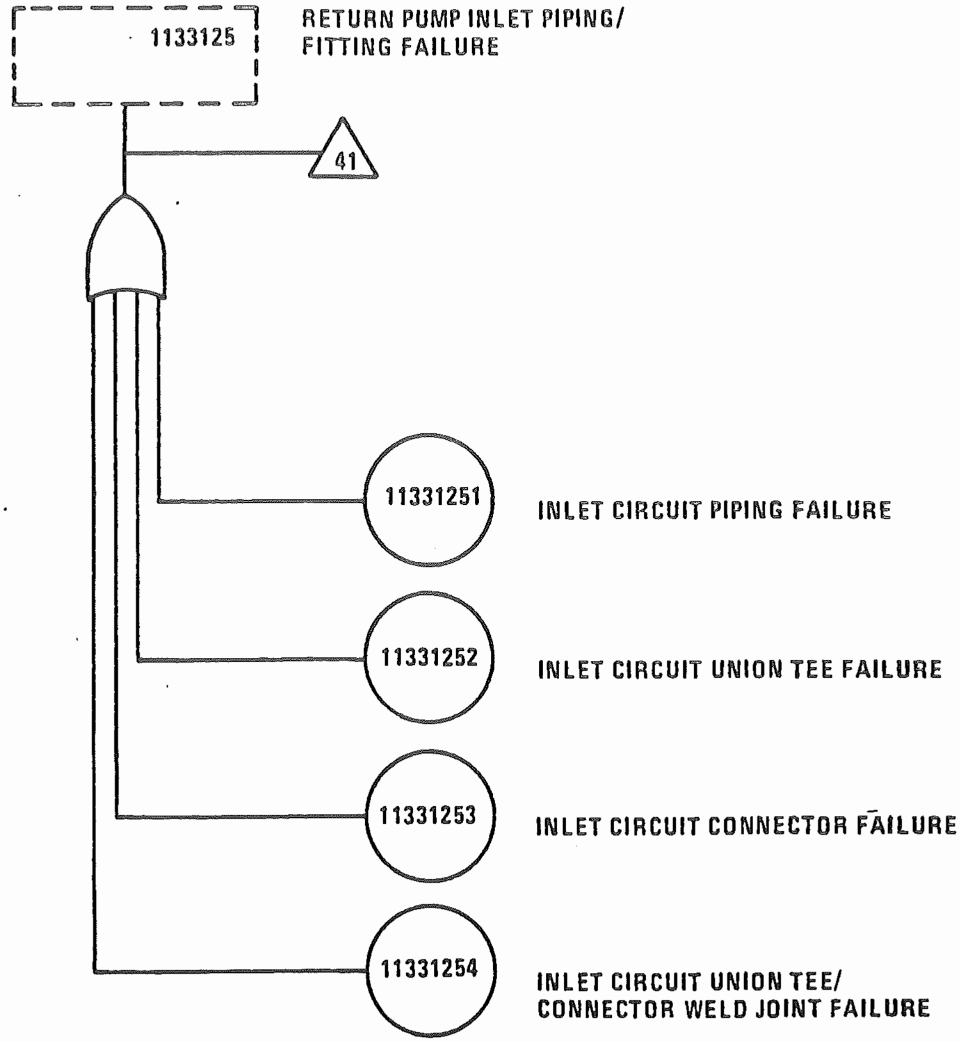


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

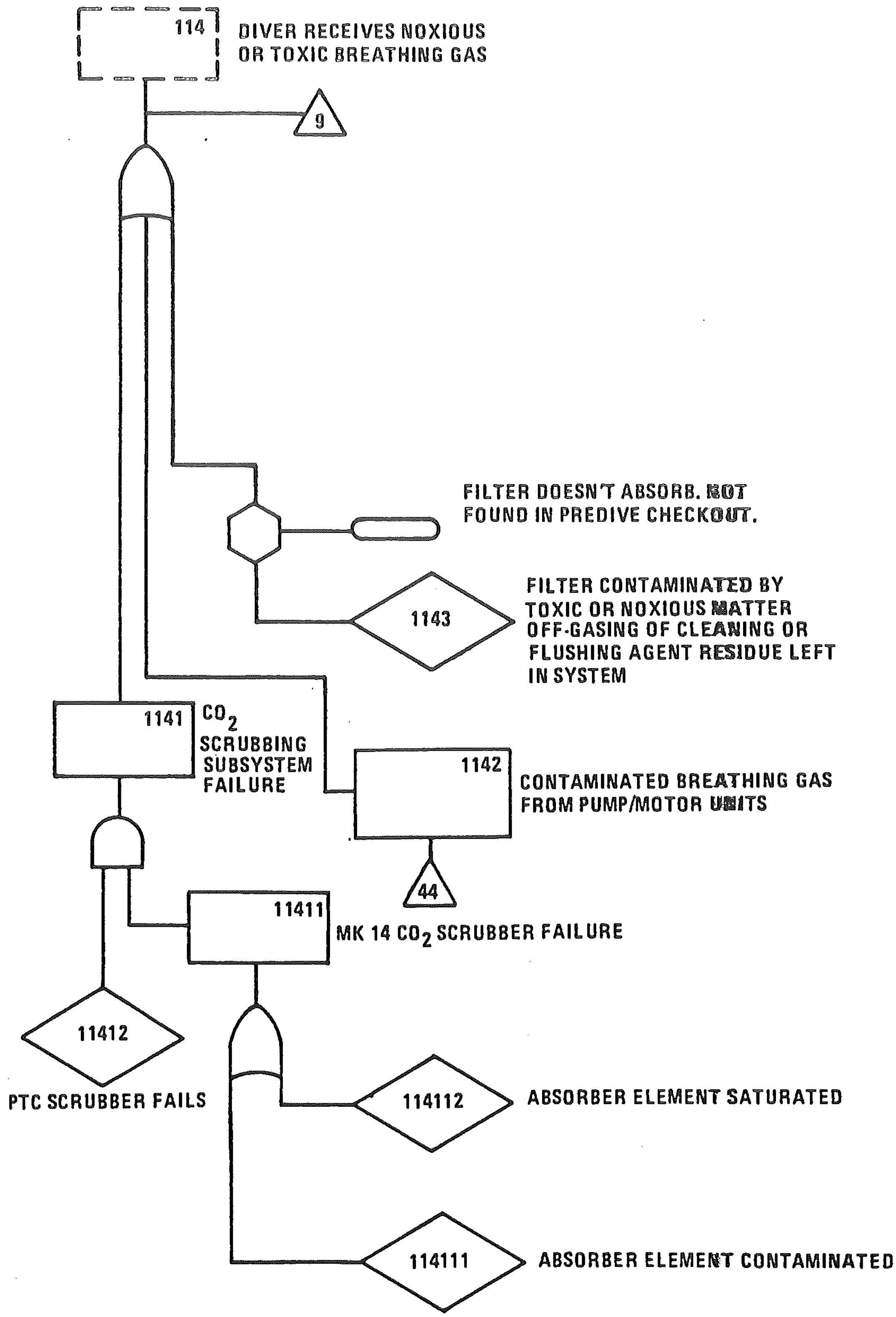


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

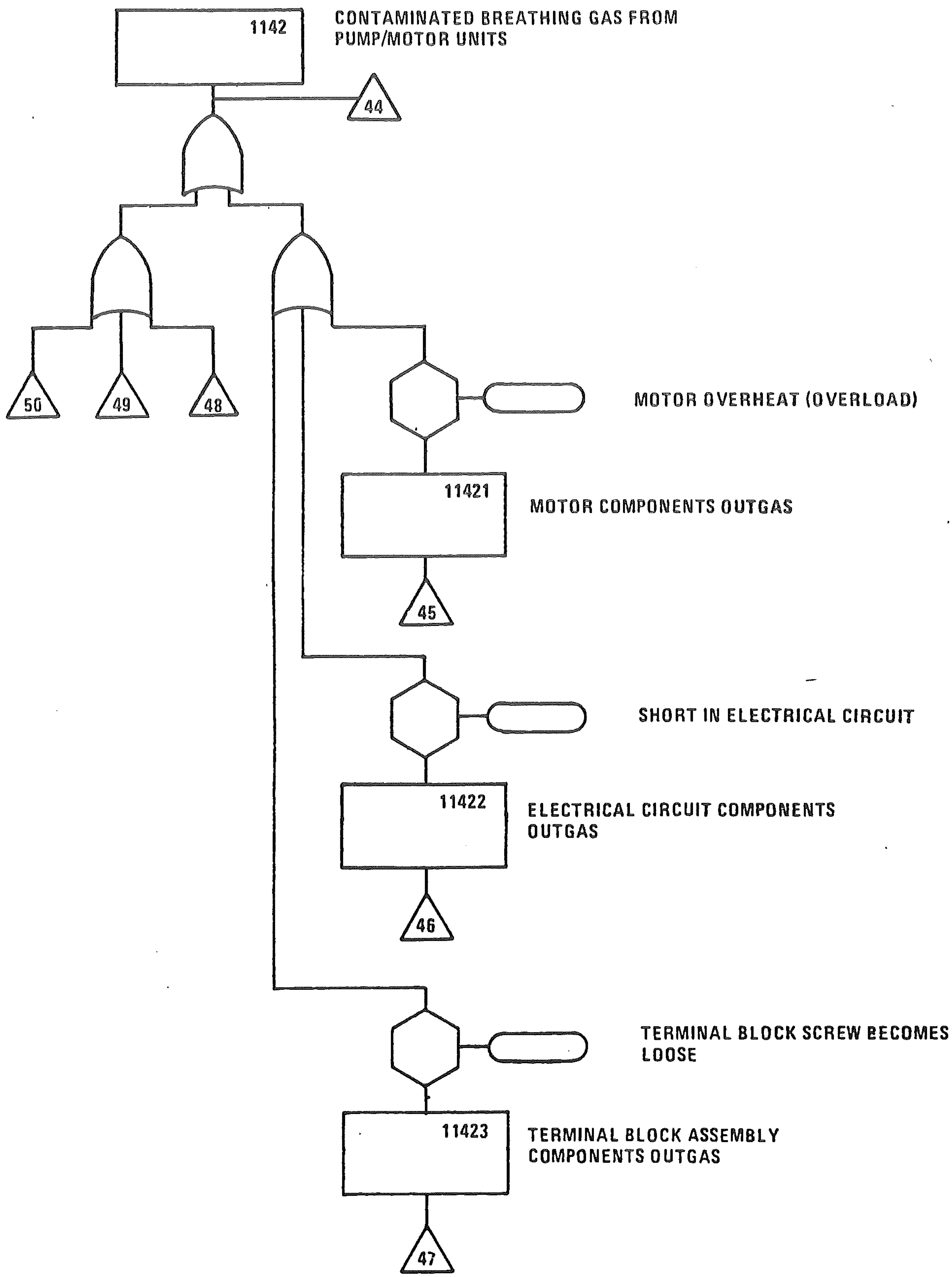


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

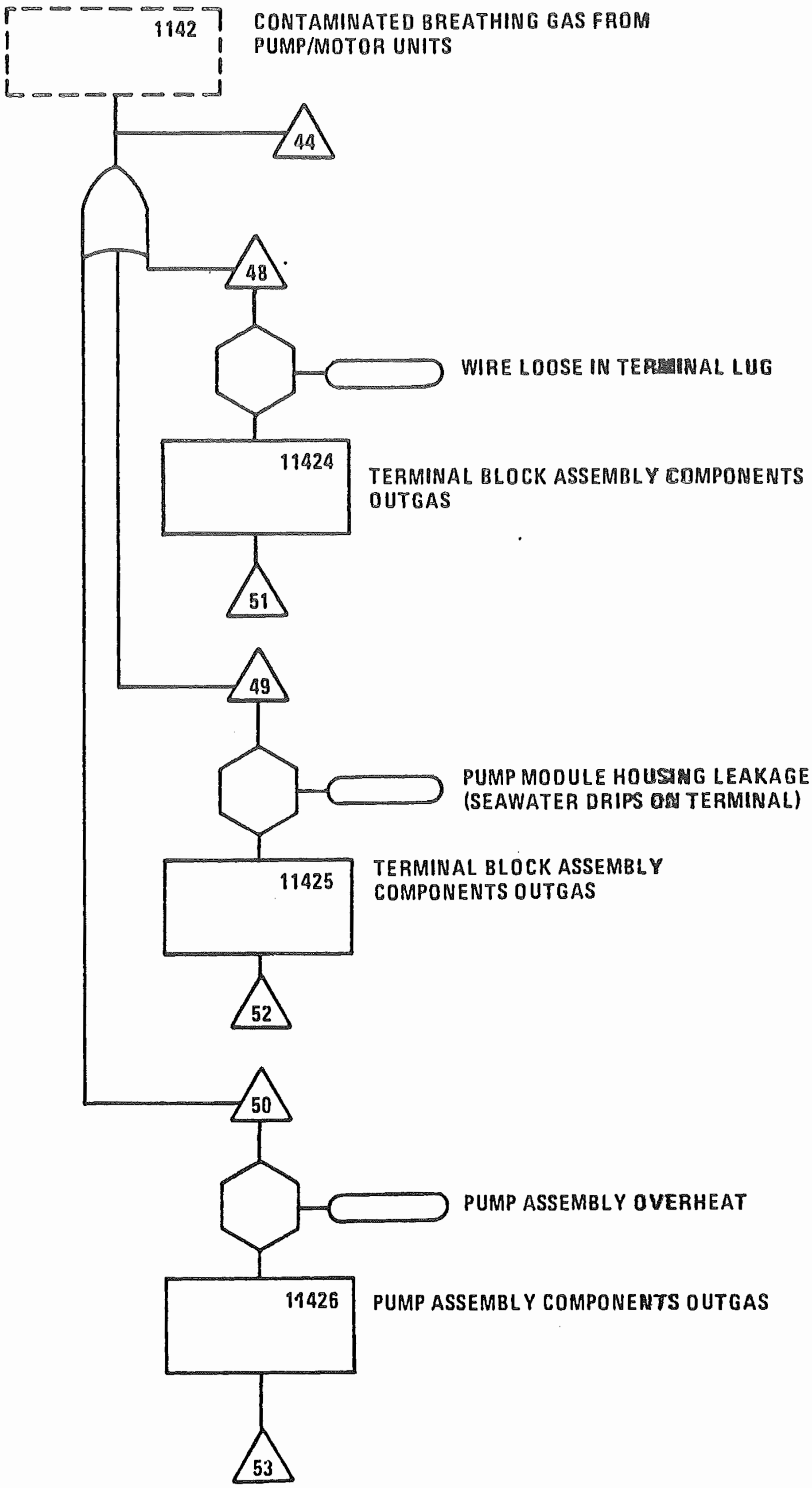


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

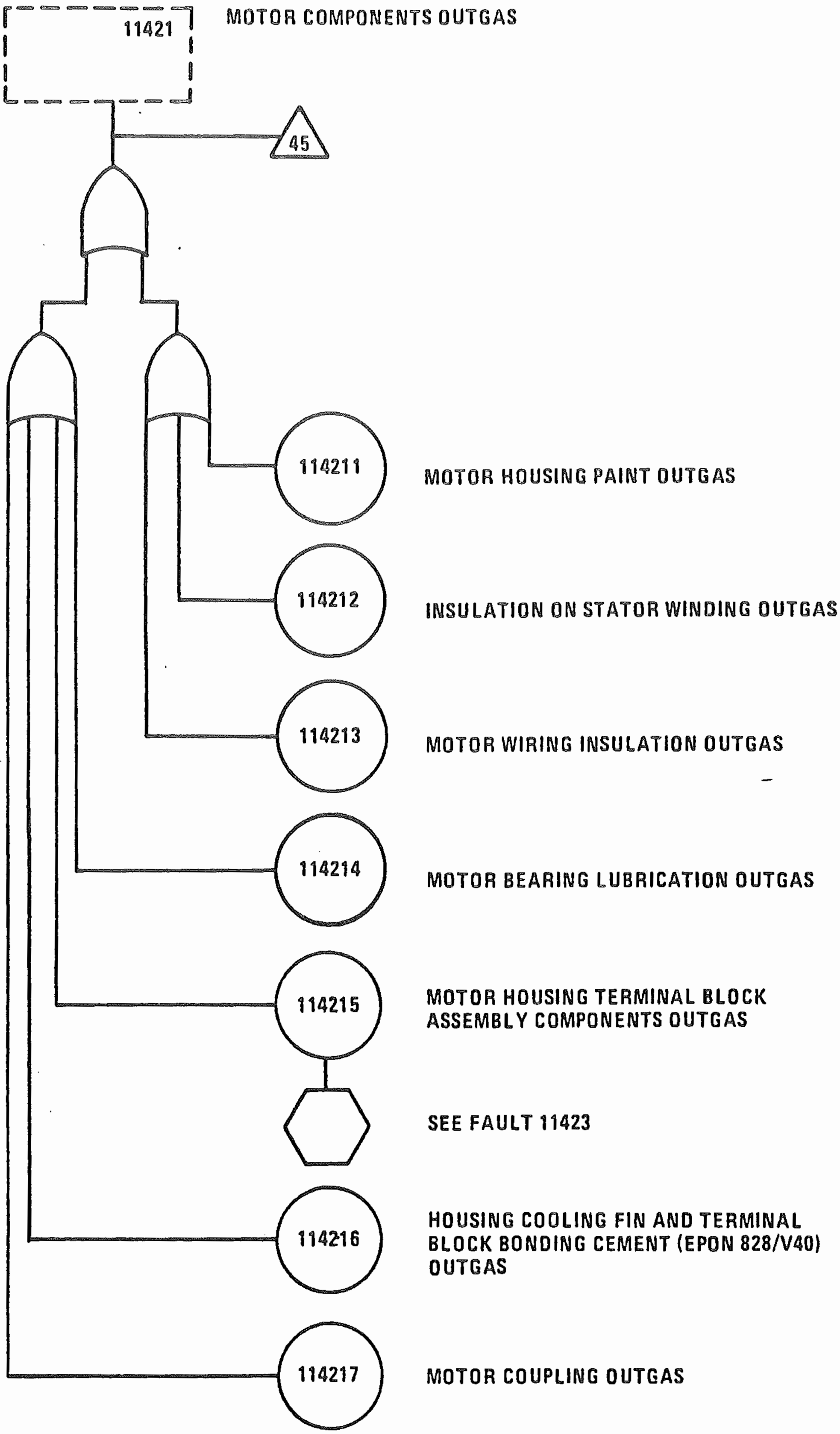


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

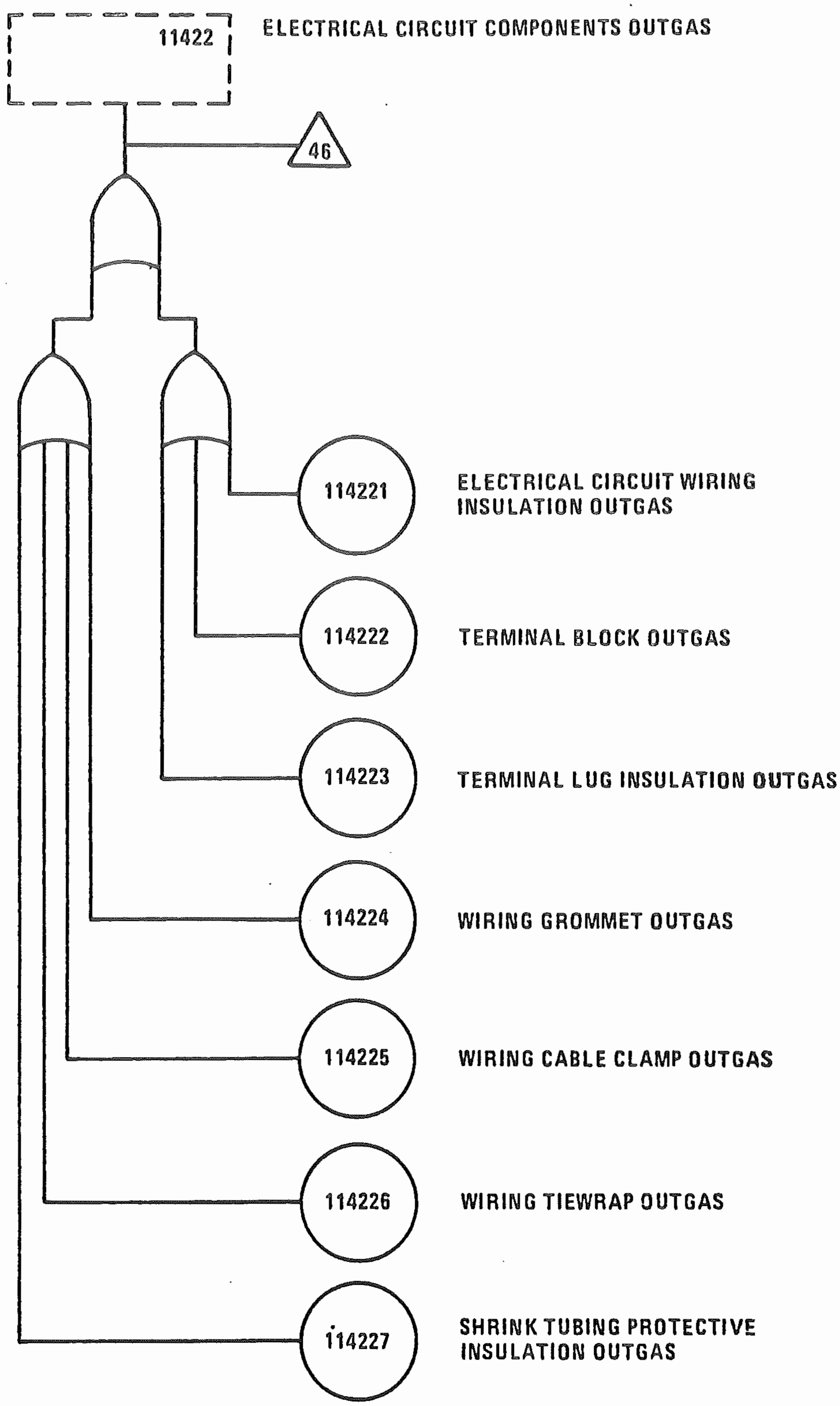


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

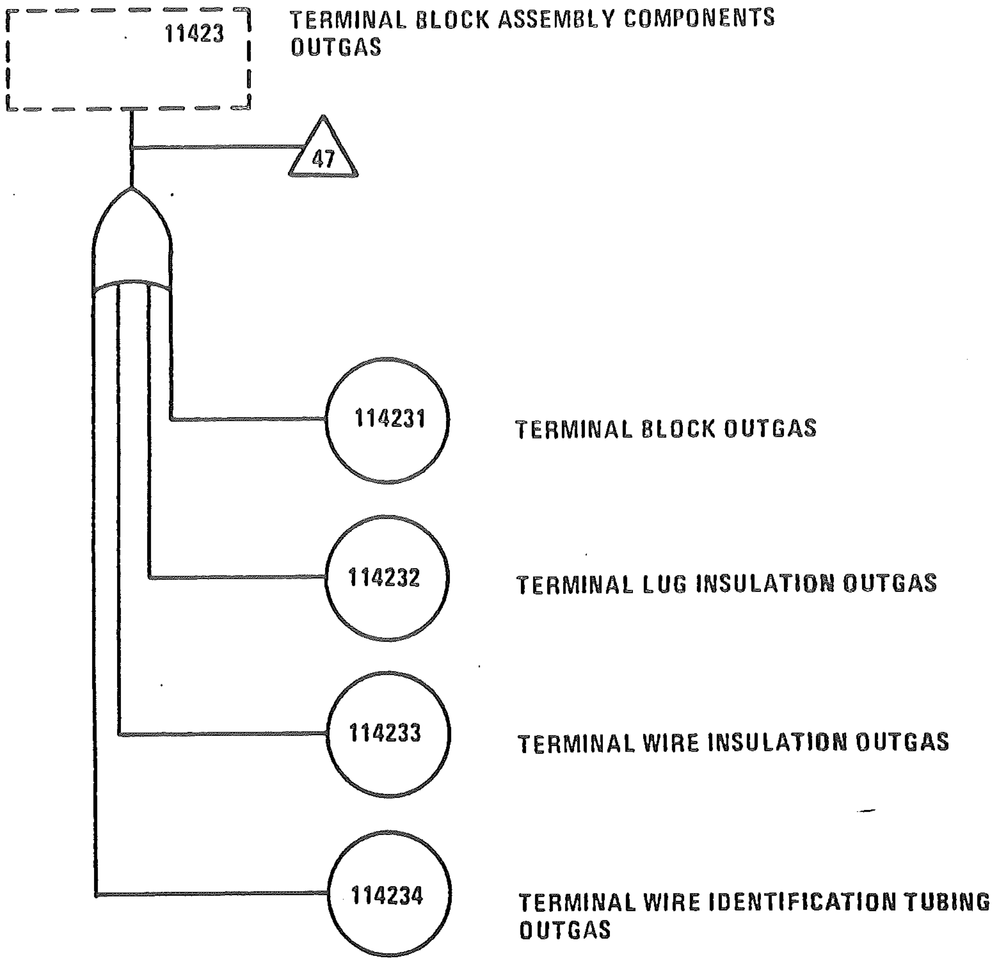


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

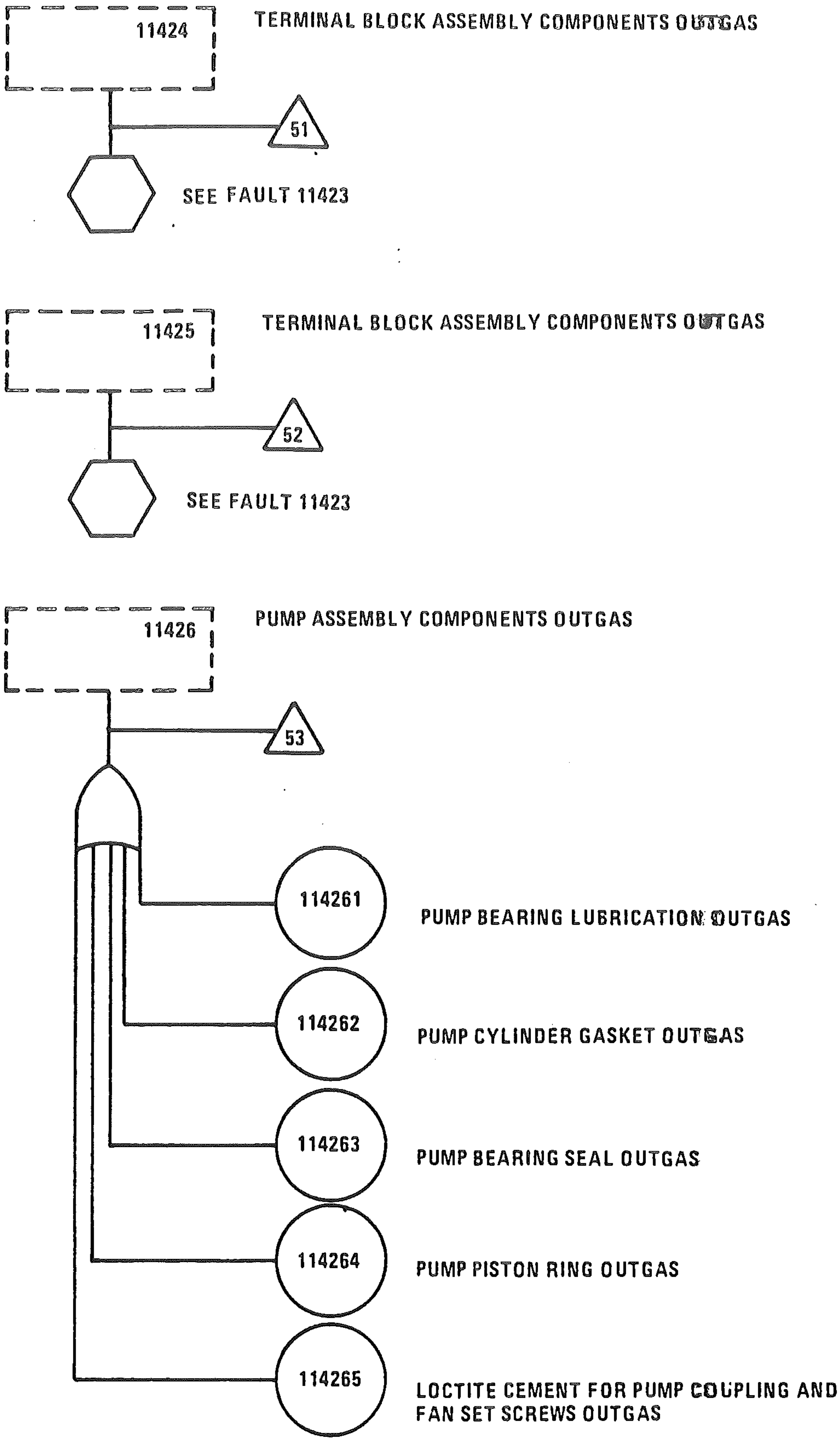


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

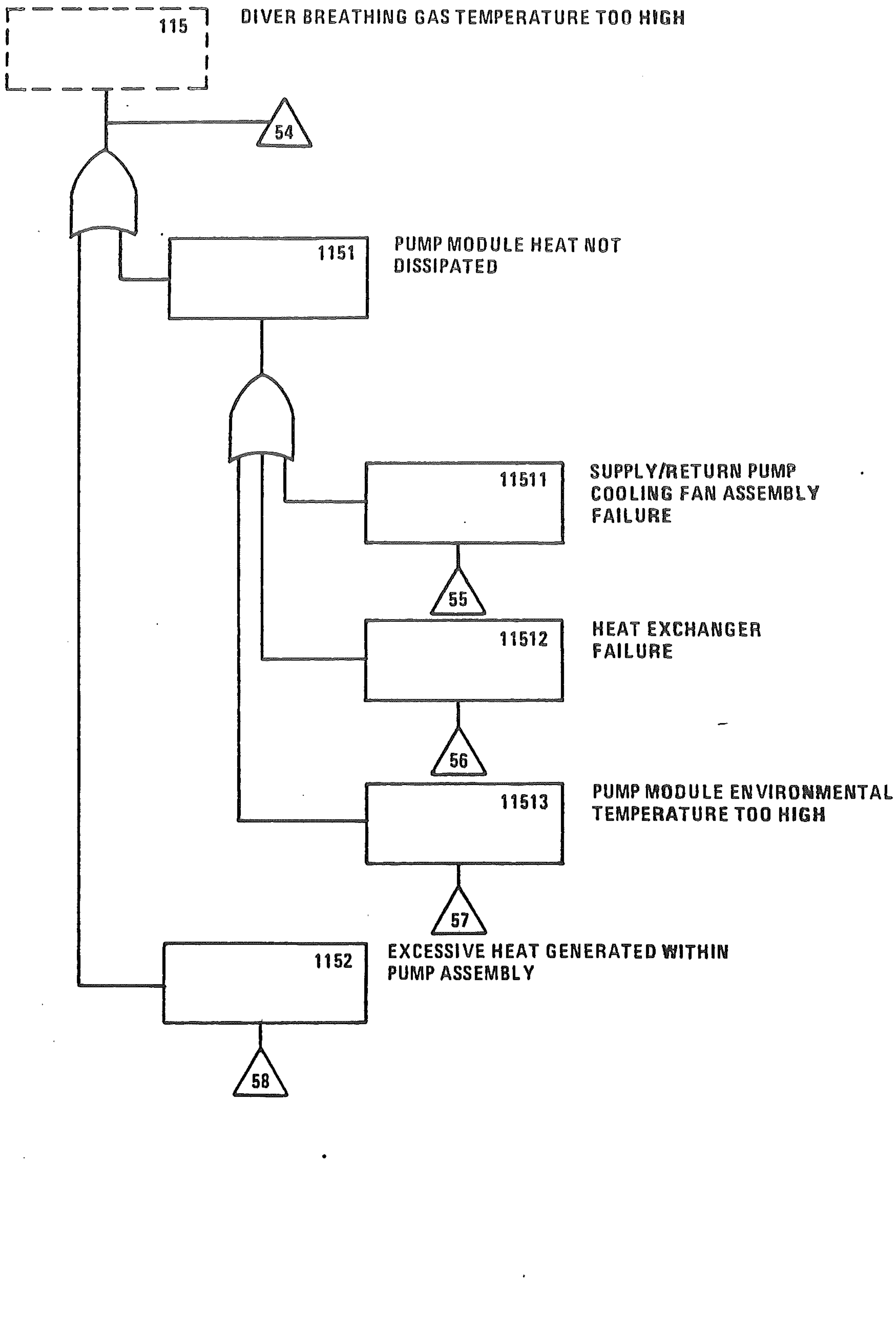


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

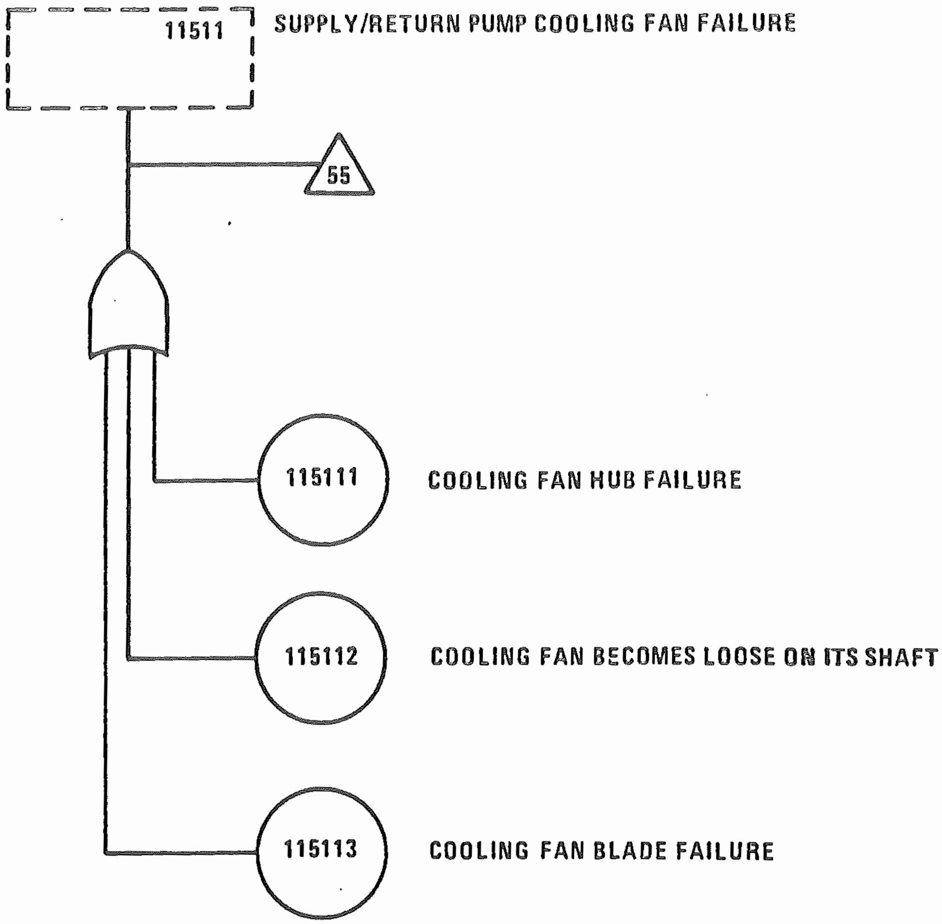


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

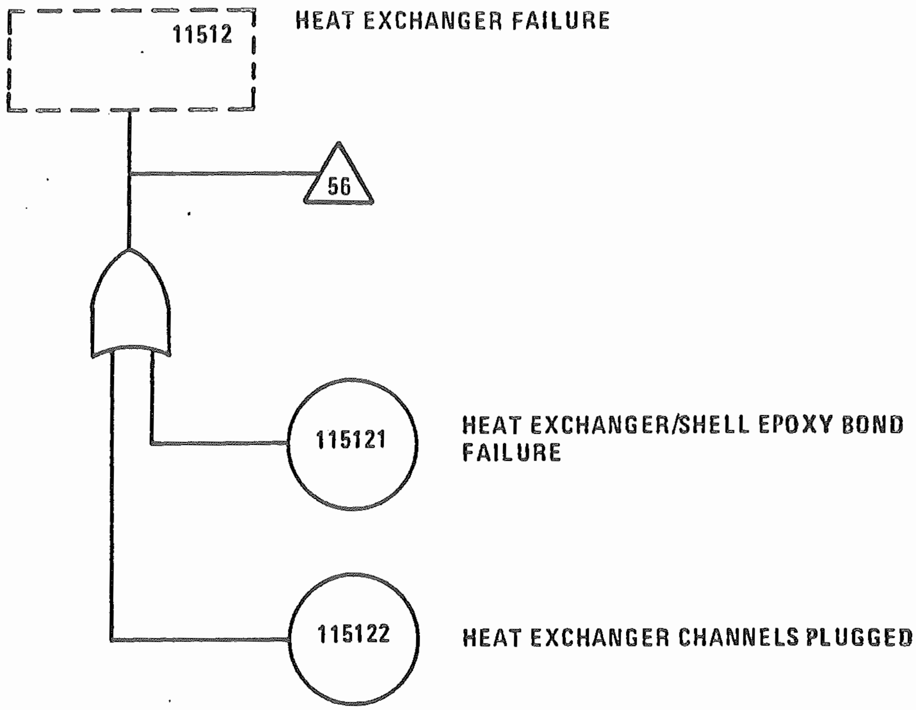


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

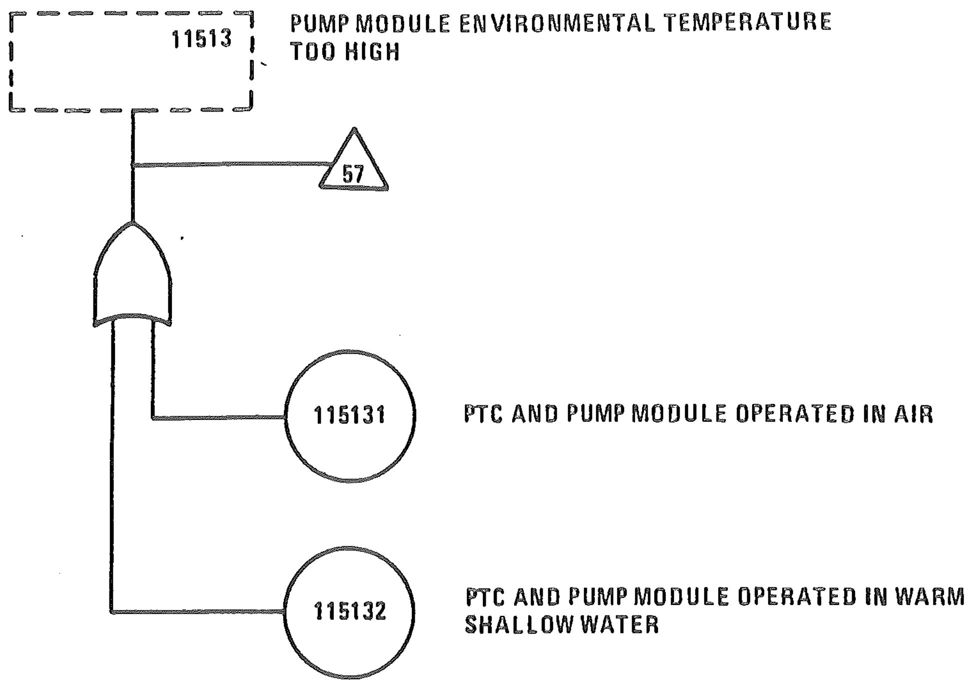


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

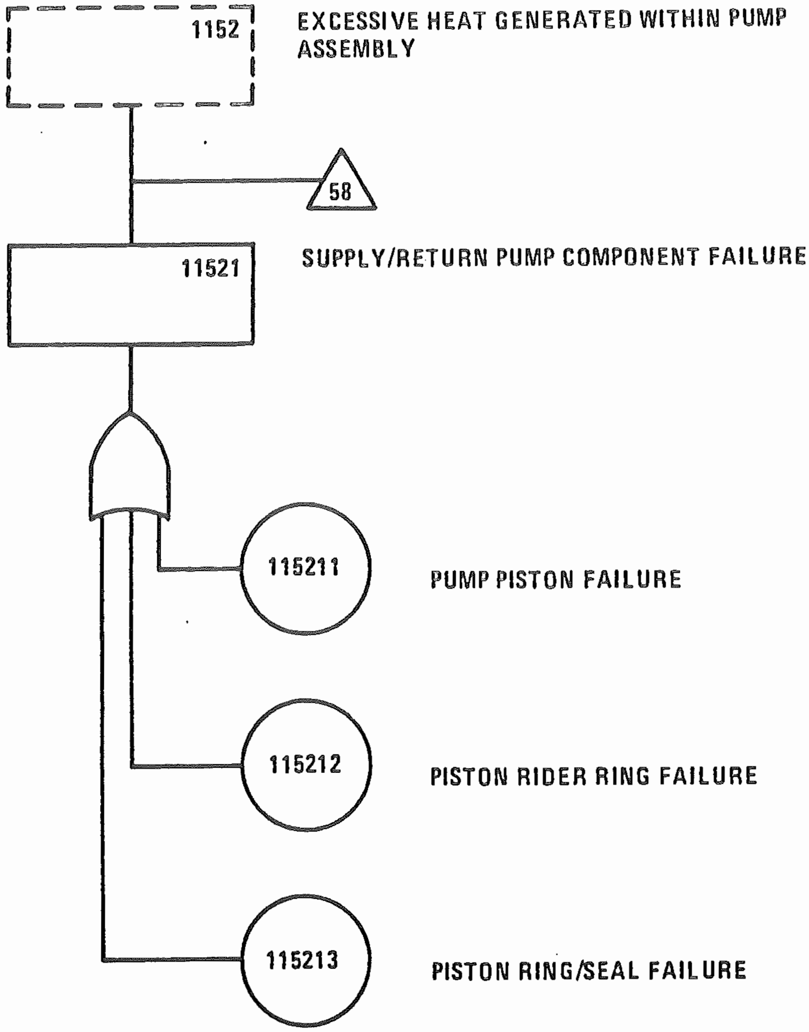


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

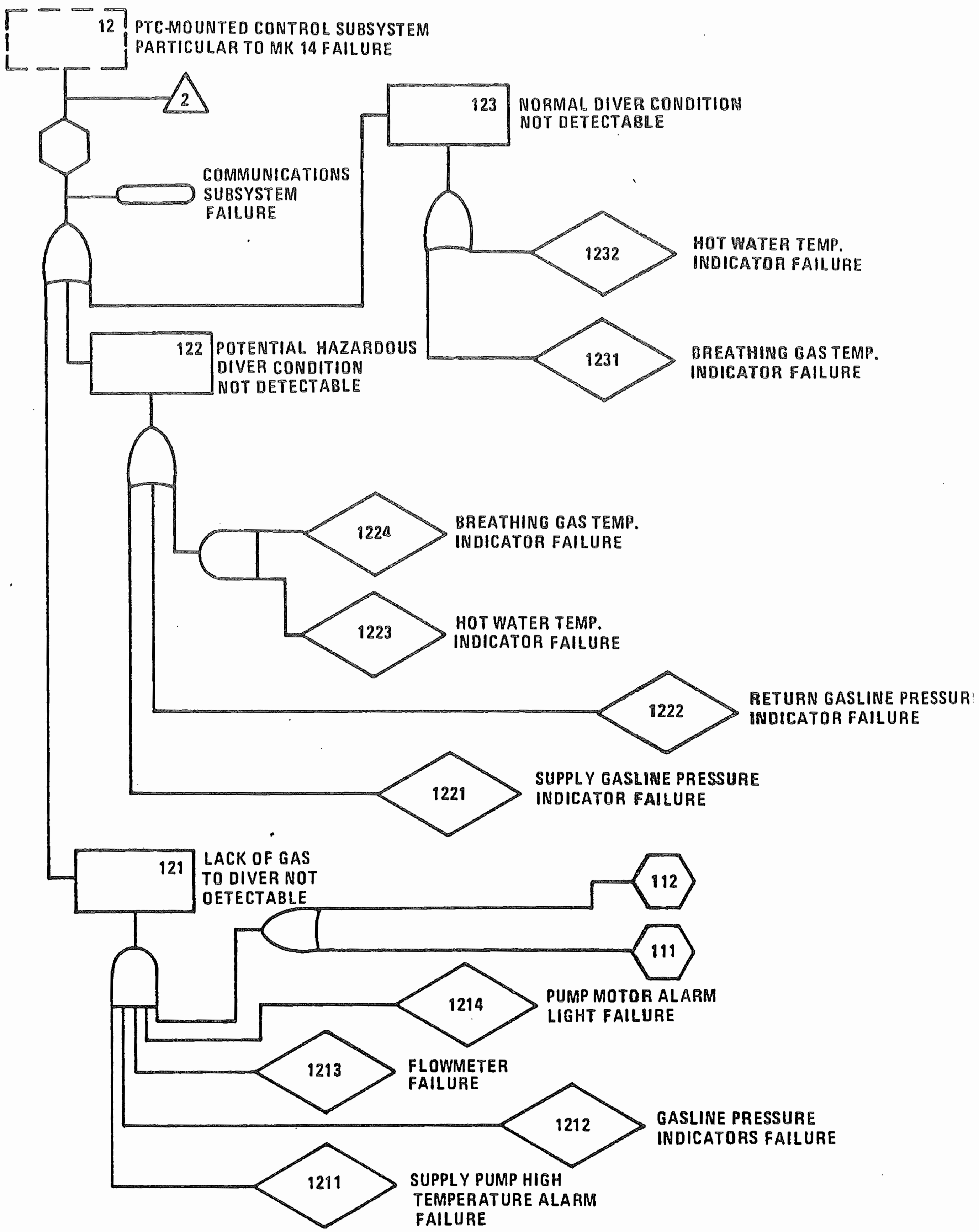


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

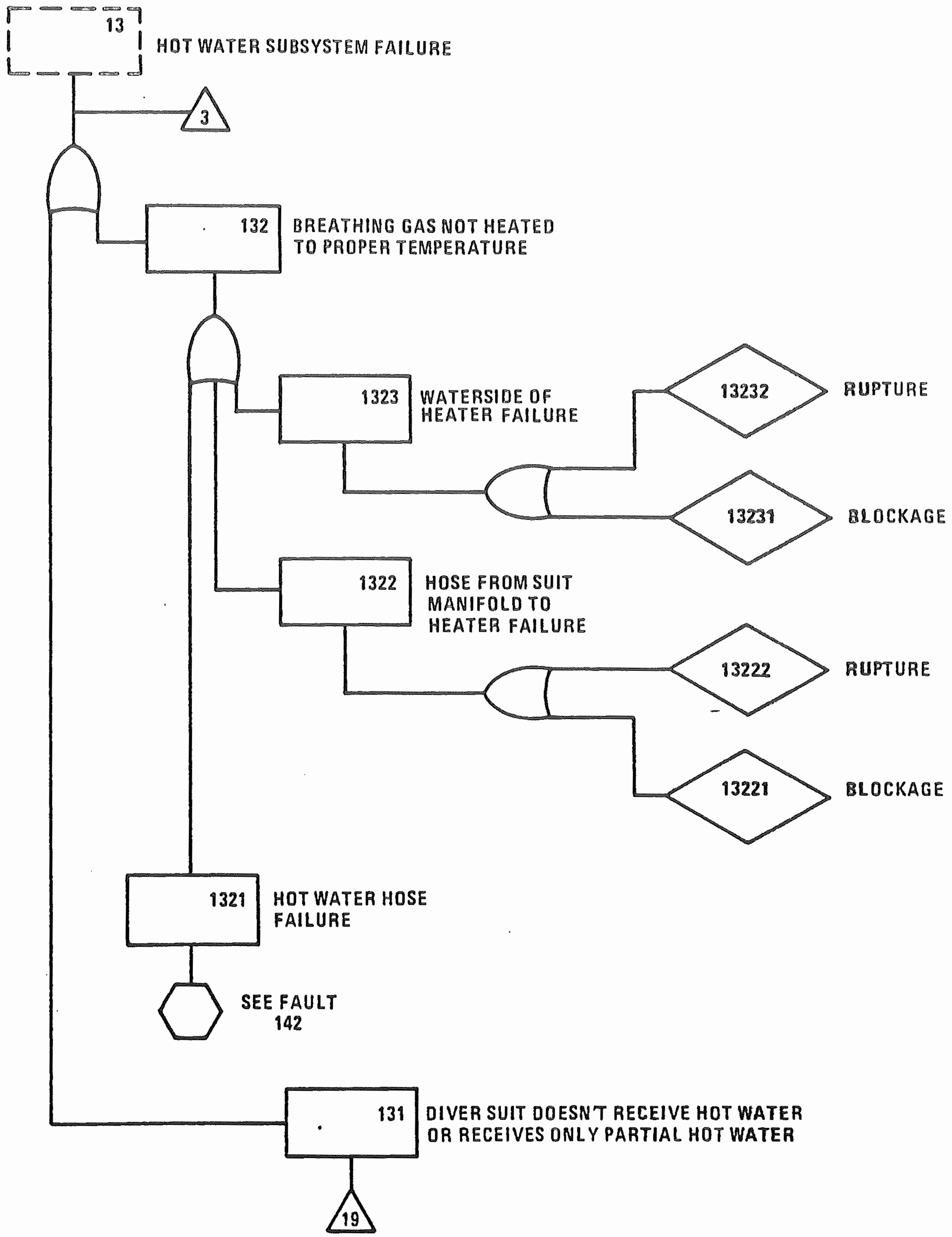


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

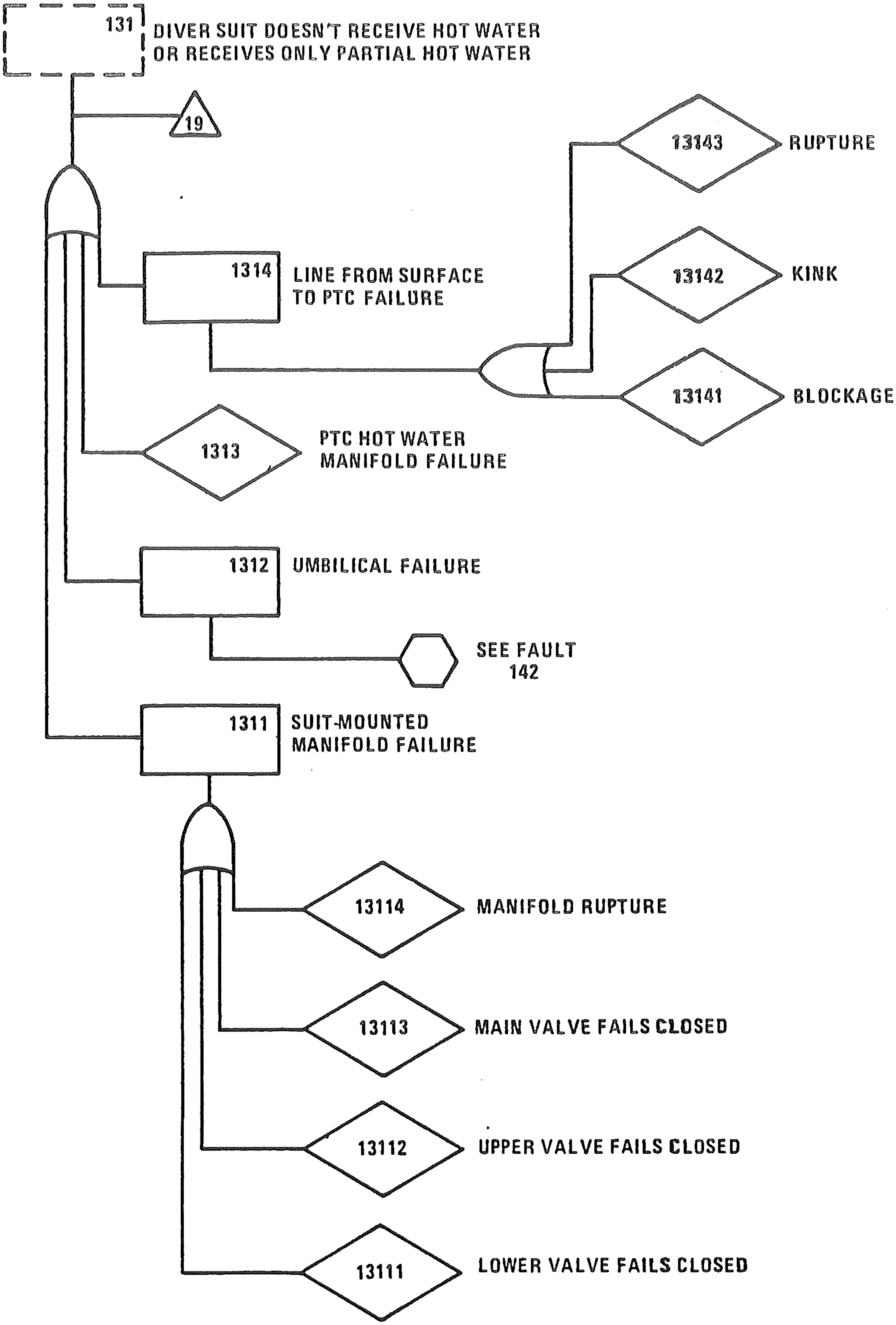


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

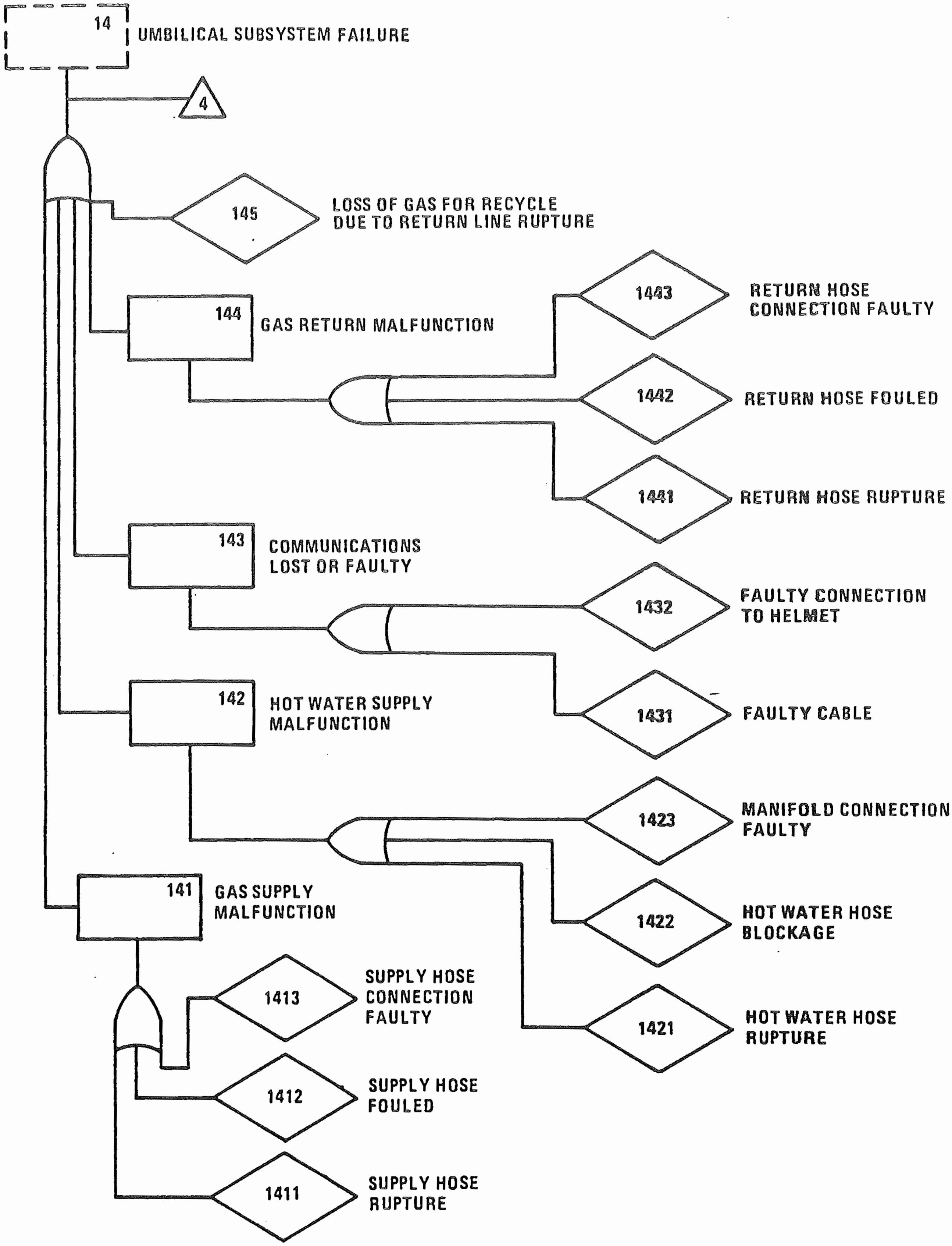


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

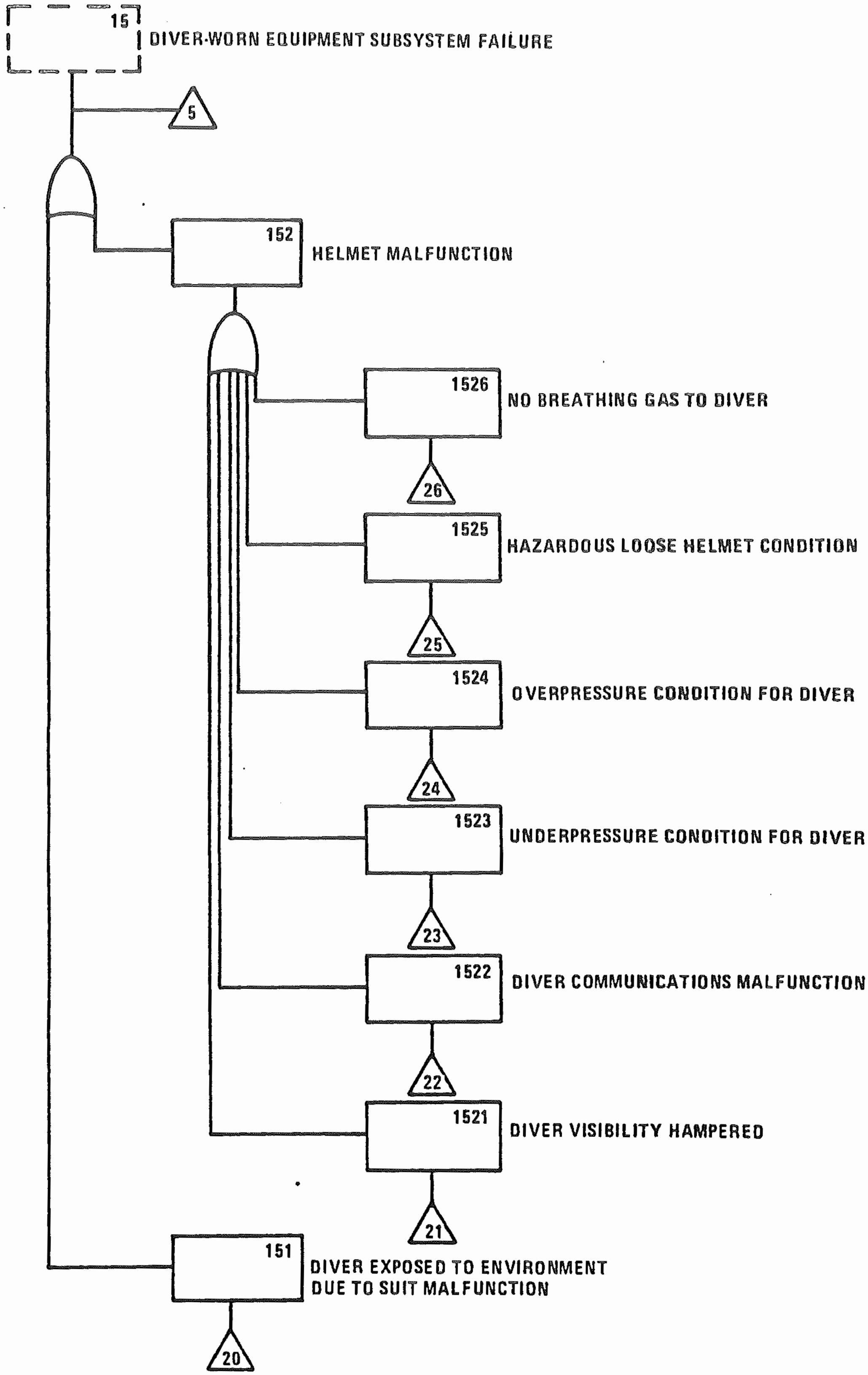


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

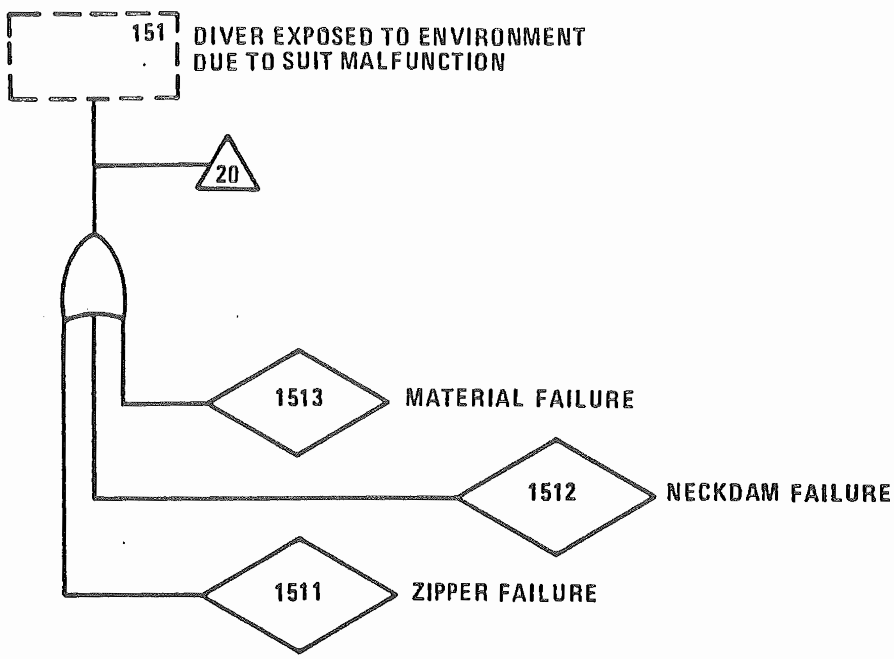


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

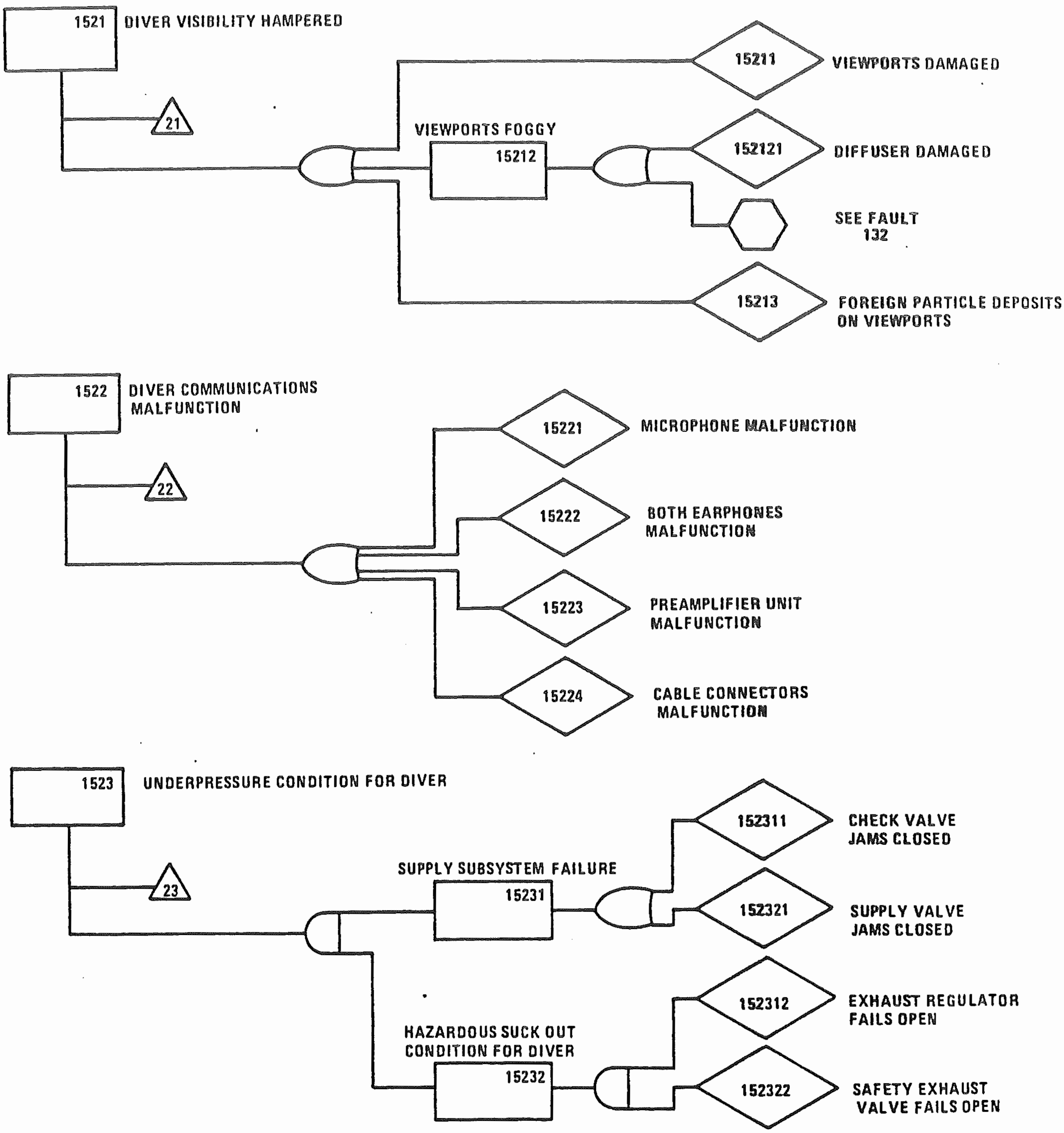


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

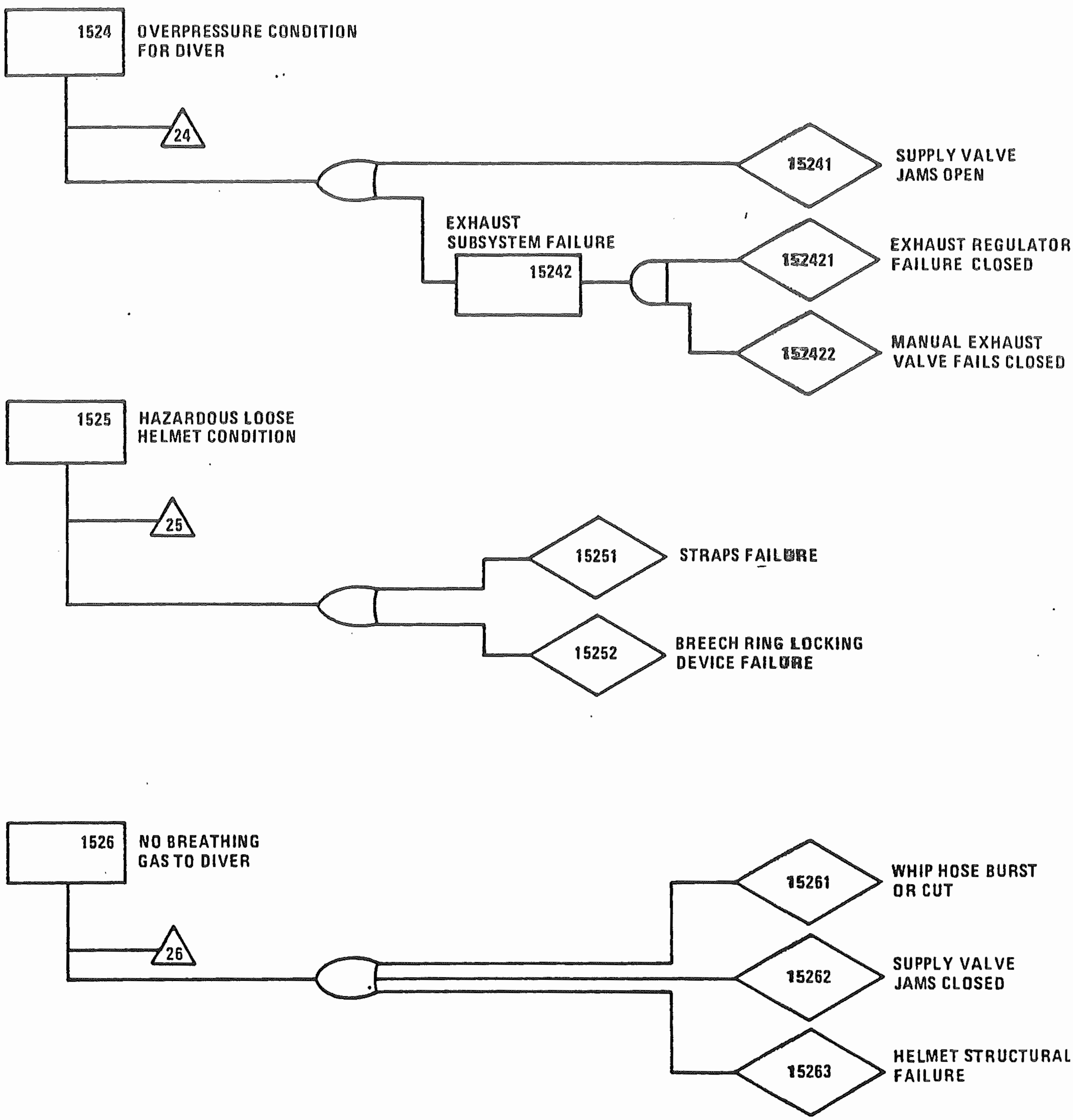


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

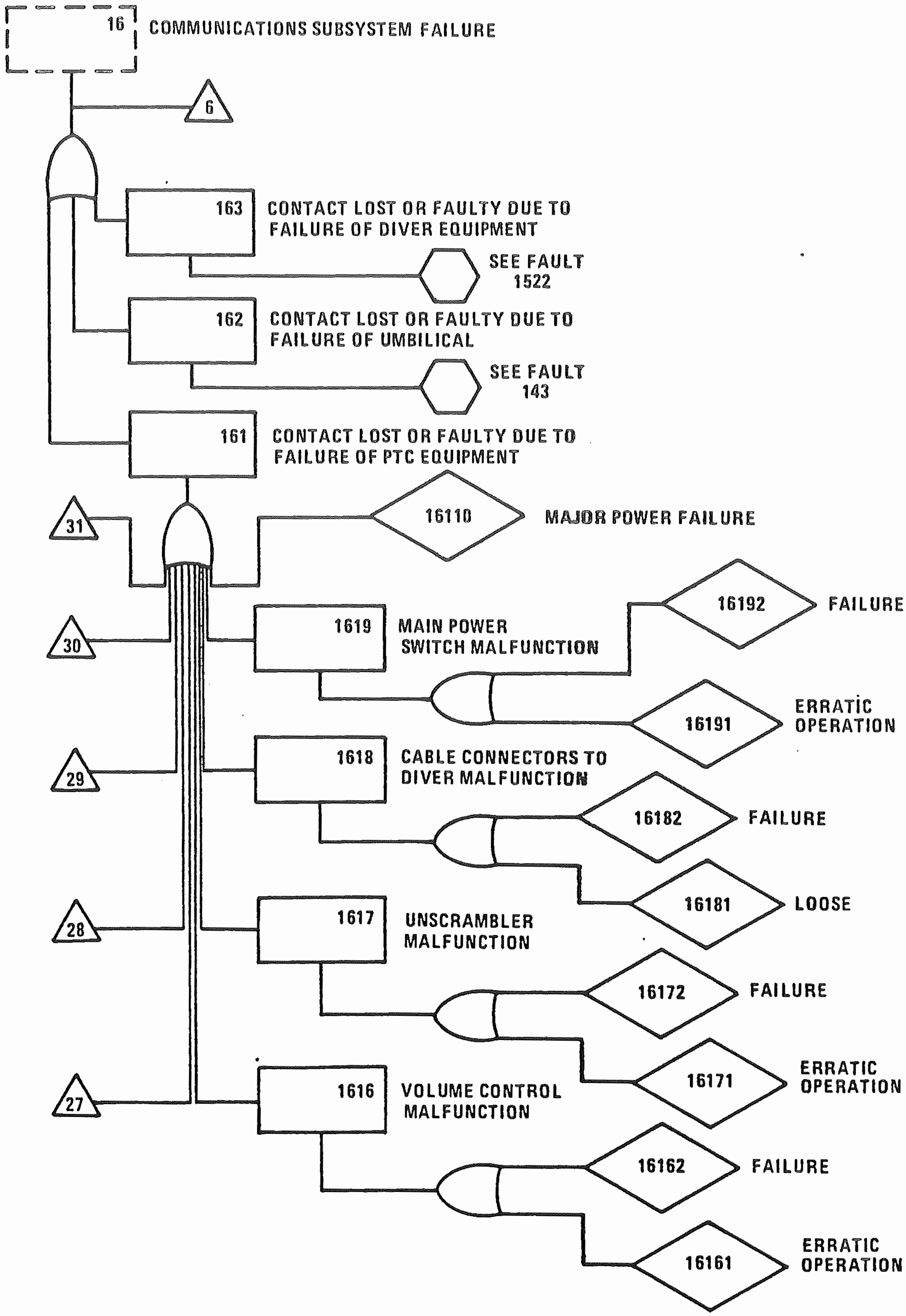


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

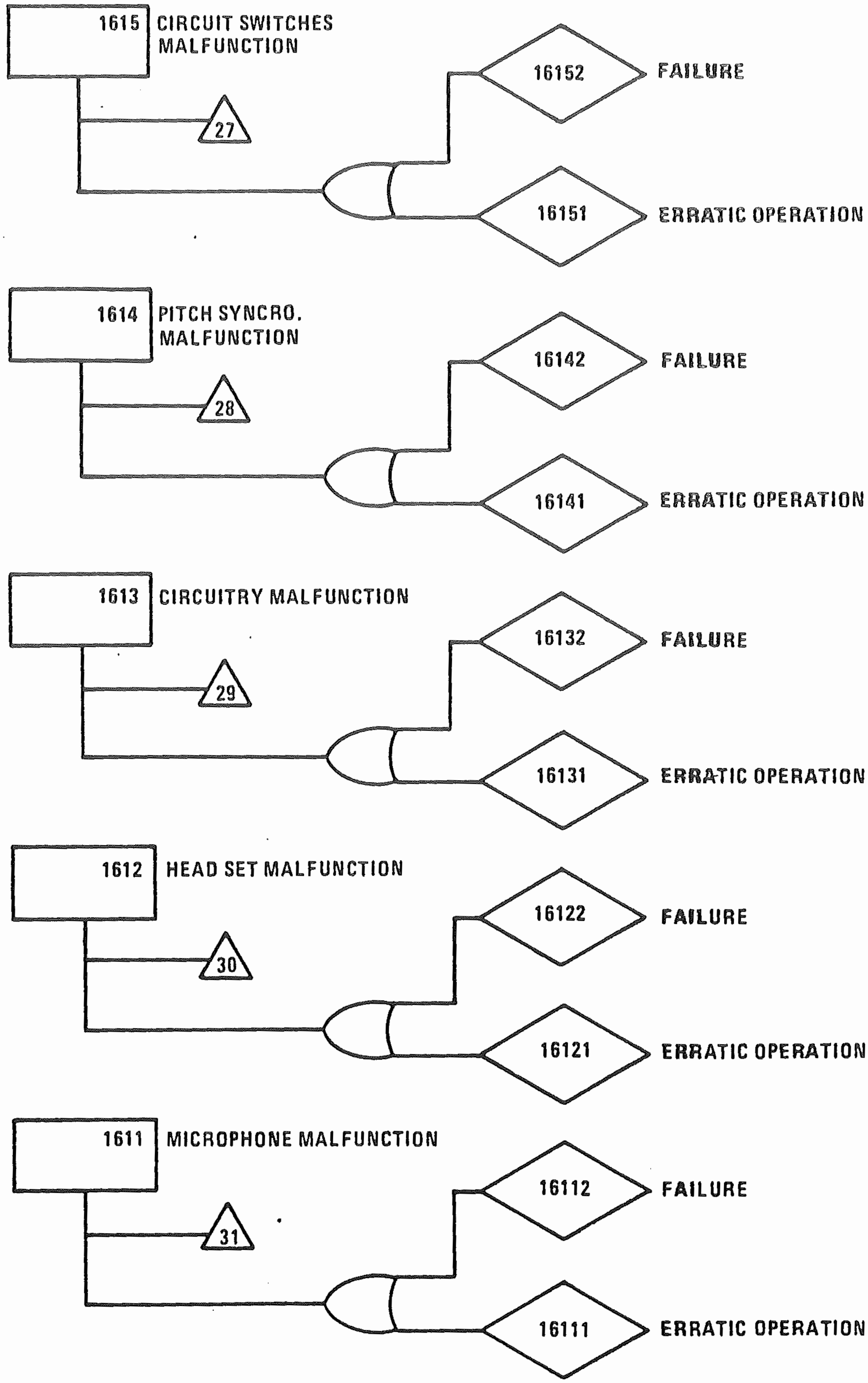


FIGURE 3-2. MK 14 FAILURE ANALYSIS MODEL (CONTINUED)

- ON-OFF control valve fails "OFF"
- Check valves to supply pumps fail open (emergency gas vents to PTC)
- Components common to both emergency and standard system failure

Further analyses carried to lower levels in the other branches of the fault tree isolate specific faults and failures causing the malfunctioning of the system. It should be noted that throughout the fault tree a probability of occur rence can be associated with each of the causes or events, if failure rate data are available. These probabilities might be determined from failure rate data sources, testing, or by other analytical and/or intuitive means.

After the completion of a system fault tree, a classification of failures is undertaken to determine the severity of each failure mode and its related effect on the system's capability to perform its mission. This classification is shown in Figure 4-3.

In Section 5, the system's critical failure paths are examined. This further develops the basis upon which a critical failure reliability model for the system can be constructed.

SECTION 4

CLASSIFICATION OF FAILURE MODES AND CAUSES

The initial assessment of failure modes for the MK 14 System was accomplished in Section 3 of this document. In this analysis, the "Fault Tree" system was employed to provide a detailed "top-down" exploration of all possible events leading to failure. In Section 4, this analysis is developed further to investigate causes, effects, frequency, and severity of these failure modes. By means of this classification, the system equipment can be evaluated at a detailed level and the critical modes of failure indicative of potential system weaknesses identified. Figure 4-3 tabulates and attempts to break down such information for all system components. Failure mode serial numbers in this table are referenced to the numbering system established in the MK 14 Failure Analysis Mode. Failure modes are considered for single failures of a component only, and no attempt has been made to evaluate a series of or multiple failures in the same component.

Figure 4-3 contains Probability of Occurrence and Level of Severity values for each failure mode. These values have been given a numerical rating which is defined in the following paragraphs.

4.1 PROBABILITY OF OCCURRENCE

Detailed reliability data for MK 14 System components are not available such that a precise determination of mean-time-between-failures could be made and used to establish failure probabilities for each component. To arrive at these levels, all available equipment data were utilized along with information obtained through technical consultations, and an engineering estimate was made based on the consolidation of all such data. As a result, each failure mode evaluated in the analysis has been assigned one of the probability levels specified in Figure 4-1A and Figure 4-1B.*

---

*Due to the fact that the probability of occurrence levels for the pump module, as defined by Westinghouse, are rather different from those defined by NSI for the components of the rest of the system and to avoid confusions in interpretation, both definitions of probability of occurrence levels are given as shown in Figures 4-1A and 4-1B.

LEVEL	DESCRIPTION
1A (Extremely Low)	Failure Mode probability extremely low. A negligible chance of occurrence during item operating time interval.
2A (Very Low)	Failure Mode probability very low. A highly unlikely chance of occurrence during item operating time interval.
3A (Low)	Failure Mode probability low. An unlikely occurrence during item operating time interval.
4A (Medium)	Failure Mode probability medium. A random chance of occurrence during the item operating time interval.

FIGURE 4-1A. PROBABILITY OF OCCURRENCE LEVELS FOR MK 14 CCSDS EXCLUDING THE PUMP MODULE

LEVEL	DESCRIPTION
1B (Very Low)	Failure that is estimated to occur once or less in a two (2) year operating period; a negligible chance of occurrence.
2B (Low)	Failure that is estimated to occur one or two times in a two (2) year operating period; a rare, random occurrence.
3B (Medium)	Failure that is estimated to occur two or three times during a two (2) year operating period; a remote chance of occurrence.
4B (High)	Failure that is estimated to occur more than three times during a two (2) year operating period.

FIGURE 4-1B. PROBABILITY OF OCCURRENCE LEVELS FOR MK 14 PUMP MODULE

4.2 LEVEL OF SEVERITY

Levels of severity resulting from a failure in the MK 14 System were established and are defined in Figure 4-2A and Figure 4-2B.*

*To avoid confusion in interpretation, Levels of Severity of the MK 14 CCSDS (excluding the pump module) as defined by NSI and Levels of Severity of the pump module as defined by Westinghouse are shown individually in Figure 4-2A and Figure 4-2B.

LEVEL	DESCRIPTION
1A	Minor - A failure that does not have a significant effect on the ability of the system to perform its mission and may easily be deferred for repair until the completion of the mission.
2A	Major - A failure that significantly degrades the performance of the system to perform its mission, but does not require that the mission be aborted.
3A	Critical, Mission - A failure that causes system performance or operation to be degraded to the extent that the system can no longer function in a manner to support its mission and necessitates aborting operations.
4A	Critical, Life - A failure that results in degradation of system performance or operation such that hazards to operating personnel are present or may be brought about if system operation is not aborted.

FIGURE 4-2A. LEVELS OF SEVERITY FOR MK 14 CCSDS EXCLUDING PUMP MODULE

LEVEL	DESCRIPTION
1B	Minor - A failure that allows continued operation without change in required output. The mission need not be terminated in order to make repair. There is no hazard to the diver.
2B	Major - A failure which may cause change in output if not corrected. The mission must be terminated in order to make necessary repairs. The failure does not cause an immediate hazard to the diver.
3B	Critical - A failure which will cause loss of output and damage to equipment if not corrected immediately. A failure that creates an immediate hazard to the diver, but one that can be managed by corrective or compensating action to protect the diver or the equipment. Mission must be terminated.
4B	Catastrophic - A failure that causes loss of output, destruction of equipment, and loss of life or severe injury to the diver. The level of severity is classified as catastrophic even though the damage may be repairable.

FIGURE 4-2B. LEVELS OF SEVERITY FOR MK 14 PUMP MODULE

FIGURE 4-3
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Motor Power Terminal Block Screw	To attach the incoming power leads to the motor leads at the terminal block	Any one of 3 screws on motor terminal (111111111)	Improper installation, vibration	No gas to diver	3B	3B	Activate Emergency Gas Subsystem
Pump Motor Power Terminal Block Lug	Wire lug connects the motor power lead to the terminal block	Wire comes loose from the terminal lug (111111112)	Excess stress on the wire, vibration damages, improper crimping	No gas to diver	2B	3B	Activate Emergency Gas Subsystem
Pump Module Circuit Wiring Insulation	Protects wires and prevents short circuits	Wire insulation breaks down thus causing a short circuit (1111111131)	Age, wear, excess heat breaks down the insulation	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Pump Module Power Receptacle	To connect power source to pump module at the module's base	Connector seal fails, allowing seawater to short circuit the three phase power (1111111132)	Faulty installation, faulty o-rings, condensate entering improperly potted connector back shell	No gas to diver	2B	3B	Activate Emergency Gas Subsystem
Pump Motor Power Terminal Block	To connect the three phase power leads to the drive motor	Any one of three phase power lead wires shorts to ground over the terminal block surface (1111111133)	Condensate collecting on terminal block surface provides a conductive path between adjacent conductors	No gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Pump Motor Bearings	Bearings support rotating rotor shaft in the drive motor housing	Either one of two sets of bearings seize on the motor shaft (1111111211) (1111111212) (1111111213) (111111221)	Inadequate or contaminated lubricant, faulty alignment or defective bearing	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply and Return Pump Bearings in Web Block	Support shaft on web block	The bearing in either web block seizes on the shaft, stalling the drive motor and stopping both the supply and return pumps (1111111221) (11111161)	Inadequate lubrication, dirt or other foreign material causes the bearing to seize	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply and Return Pump - Large and Small Eccentric Bearings	Supports the piston rod on the pump shaft eccentric	Any one of four large eccentric bearings or four small eccentric bearings seizes on the shaft, stalling the drive motor and stopping both the supply and return pumps	Inadequate lubrication, dirt or other foreign material causes the bearing to seize	No gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		(1111111222) (11111162)					
Supply and Return Pump Piston Needle Bearing	Allows piston rod to rotate on the piston pin	Any one of eight sets of needle bearings (1 set per piston rod assembly) seizes on the piston pin thus stalling the drive motor (1111111223) (11111163)	Insufficient lubrication, faulty materials, wear	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply and Return Pump Piston	To pump the breathing gas through the diving system	Any one of eight pistons in the supply/return pump breaks thus allowing a piece of the piston to become lodged in the supply/return pump cylinder causing the motor to draw excess current (1111111224) (11111164)	Faulty materials, corrosion, or wear damage during installation	No gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply and Return Pump Piston Rod	Connects the piston to the eccentric on the pump shaft	Any one of eight rods in the supply/ return pump fail and become jammed in the cylinder causing the motor to draw excess current (1111111225) (11111165)	Faulty materials, fatigue	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply and Return Pump Piston Rings	To keep a tight seal between the pump piston and the cylinder wall	Any one of 16 rings (2 rings per cylinder) in the supply pump fail and become jammed between the piston and cylinder causing the motor to draw excess current (1111111226)	Wear, damage, faulty materials	No gas to diver	2B	3B	Activate Emergency Gas Subsystem
Supply and Return Pump Inlet Reed Valve	Controls gas flow into the pump cylinders	The inlet reed valve fails, and jams the piston causing the motor to draw excess current	Faulty materials, fatigue, damage	No gas to diver	2B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		(1111111227) (11111166)					
Supply and Return Pump Shaft	Transmits motor torque to the supply pump pistons	The shaft fails and becomes jammed thus stalling the electric motor (1111111228) (11111168)	Material fatigue, faulty materials	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Motor Stator Windings	Provides the electric field required for the drive motor torque	Motor Stator Windings short circuit (11111122)	Insulation breaks down because of defective materials, insulation damage or excessive heat	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Drive Motor Power Supply Leads	Provides electrical power for drive motor	Motor power short, tripping external circuit breaker (11111125)	Insulation breaks down from defective material, damage or exposure to excessive heat	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Motor Shaft	To transmit motor forces to the supply and return pump shafts	The motor shaft fails (11111124)	Defective materials, fatigue or damage	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Drive Motor Rotor	Reacts with the magnetic field produced by the Motor Stator Windings to produce rotational torque	Rotor fails (11111123)	Faulty materials, fatigue, damaged during installation	No gas to diver	1B	3B	Activate Emergency Gas Subsystem
Pump Motor Housing	To support the motor	The motor housing fails allowing the motor shaft	Damaged or defective housing material, improper installation	No gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		to become misaligned with the supply and return pump's shafts causing a motor overload (11111126)	during overhaul and maintenance				
Supply Pump Exhaust Manifold	Used as a gas reservoir to collect gas output from pump assembly	The supply pump exhaust manifold body ruptures or any manifold welds fail (11111141) (11111142) (11112241) (11112242) (11112243)	Defective materials, faulty welds, inadequate stress relief after welding	Reduced or no gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Exhaust Piping	Used to direct gas to the diver supply line	Supply pump exhaust piping ruptures or develops a leak (11111151) (111112251)	Excess pressure, faulty materials, improper installation, not properly stress relieved after welding	Reduced or no gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Exhaust Piping - Union Tee	Directs supply exhaust gas flow to relief valve or to diver supply line	The union tee ruptures or develops a leak (11111152) (111112252)	Faulty materials, corrosion or damage	Reduced or no flow of gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSOS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply Pump Exhaust Piping - Union Tee Connectors	The connectors join the supply/exhaust tubing with the union tee	Any one of three union tee connectors rupture or develop a leak (11111153) (111112253)	Faulty installation, faulty materials, age, corrosion, damaged	Reduced or no gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Exhaust Piping - Union Tee Connector Weld Joints	To join the union tee connectors to the supply exhaust piping	Any one of three welded joints of the union tee connectors rupture or develop a leak (11111155) (111112255)	Faulty welds, defective material or improper stress relief after welding	Reduced or no gas to diver	2B	3B	Activate Emergency Gas Subsystem
Supply Pump Cylinder Head	Chamber above valves in pump cylinder directing gas flow to and from cylinder, also has ports for intake and exhaust lines	The cylinder head ruptures or develops a leak (11111167) (111112267)	Defective material, damage, faulty installation	Reduced or no gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Outlet Relief Valve	To bleed off excess pressure at the supply pump outlet	Supply pump outlet relief valve fails in the completely open position (1111118) (11111154)	Faulty materials, corrosion, damage, during maintenance or dirt or some other foreign material lodging between the poppet and seal	Reduced or no gas to diver	2B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply Intake Last Chance Filter	The filter removes large particules from the return pump intake line	The last chance filter becomes completely clogged (1111119)	Dirt, impurities in the system	Reduced or no gas to diver	2B	2B	Activate Emergency Gas Subsystem
Pump Drive Motor Terminal Block	Terminal for incoming power and motor windings leads	Poor connection at drive motor power terminal block causes high resistance and excessive voltage drop (1111122111)	Loose terminal hardware, lock washer omitted, corroded or contaminated contact surfaces or poor crimp joint	Reduced or no gas to diver	1B	3B	Activate Emergency Gas Subsystem
Drive Motor Power Lead Wiring	Power lead wires that run from the pump module connector to the actual motor stator windings	Damaged wire in drive motor power lead causes high resistance in lead and lowers voltage available at motor (1111122112)	Pinched or partially broken power wires either in the motor or the leads to the motor	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Drive Motor Power Connector Receptacle	Electrical connector that is at the base of the pump unit	Poor connection in the connector/ wire joint in the connector back shell causes high resistance in circuit and	Faulty assembly, cold solder joint or insufficient crimp pressure	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		lowers voltage available at the motor (1111122113)					
Drive Motor Bearing	Motor shaft bearing allows free rotation of the motor rotor within the motor housing	Drive motor bearing binds (111112221)	Improper installation, excess wear, insufficient lubrication or contaminated lubricant	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Drive Motor Stator	Stator windings provide magnetic field coupling to the rotor windings	Drive motor stator winding shorts, reducing effective torque (111112222)	Winding insulation breaks down from damage, defective material, excess heat	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Motor Coupling Key	Key holds the hub to the motor shaft on the supply pump side of the motor	Key fails (111112231)	Defective material, fatigue	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Coupling Key	Key holds the hub to the supply pump shaft	Key fails (111112232)	Defective material, fatigue	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply/Return Reed Valves	Reed valves control gas flow through the pump cylinders	Any of the inlet or outlet reed valves fail open thus reducing gas flow to the diver (1133226)	Foreign material on the metal reed, defective material, wear or fatigue	Reduced gas to diver	2B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply Pump Bearings	Supports shaft on the web block	Either one of two web block bearings bind (1133226)	Faulty bearings, corrosion, wear, dirt in bearings, insufficient lubrication	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Piston Rod Bearing	Allows rotation of the pump shaft within the piston rod assembly	Any one of eight rod bearings bind on the shaft (111112262)	Faulty bearings, corrosion, wear, dirt in bearings, insufficient lubrication	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Piston Needle Bearings	Allow rotation of the piston rod within the piston	Either of two needle bearings in the piston rod assembly bind (111112263)	Faulty bearings, corrosion, wear, dirt in bearings, insufficient lubrication	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Piston	To pump gas through the diving system	Any one of 8 pistons crack or bind thus reducing the amount of gas being pumped to the diver (111112264)	Faulty materials, wear, corrosion damaged	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem
Supply Pump Cylinder	Provides a chamber for the piston to compress the gas	Any one of 8 cylinders fail by allowing compressed gas to escape from the piston/cylinder assembly (111112268)	Faulty materials, damages, wear, or corrosion	Reduced gas to diver	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply Pump Inlet Relief Valve	Relieves gas from the supply pump inlet whenever the return pump inlet gas is restricted	Supply pump inlet relief valve fails partially open (111112271)	The poppet does not seal properly because of wear, defective material or damage to the poppet and/or or spring or because of improper spring setting	Reduced gas to diver	2B	3B	Activate Emergency Gas Subsystem
Supply Pump Outlet Relief Valve	Relieves excess pressure at the supply pump outlet	Supply pump outlet relief valve leaks or fails partially open (111112272)	Poppet closure spring fails due to faulty materials, corrosion, damage during maintenance or dirt or some other foreign material lodges between the poppet and seat	Reduced gas and pressure to diver	2B	3B	Activate Emergency Gas Subsystem
Supply Pump Last Chance Filter	To screen any foreign material from the supply pump intake circuit	Last chance supply filter becomes partially clogged (111112273)	Unexpectably high amount of foreign particles in supply pump inlet line, filter not cleaned during maintenance	Reduced gas to diver	2B	3B	Activate Emergency Gas Subsystem
PTC Hull Stop Valves	Isolate breathing gas supply lines from PTC to pump package - internal & external	Valve body rupture (111121) (111131)	Defective, age	No gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Valve inadvertently left shut (111122) (111132)	Not found at predive checkout	No gas to diver	1A	2A	Open Valves per Emergency Procedures

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		Foreign body blockage (111123) (111133)	Entry of foreign matter into sys-tem	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Valve seat jammed shut (111124) (111134)	Age, corrosion	No gas to diver	2A	3A	Activate Emergency Gas Subsystem
		Fittings fail (111125) (111135)	Vibration, incor-rect installation	Reduced or no gas to diver	2A	3A	Activate Emergency Gas Subsystem
		Handle fail (111126) (111136)	Age, corrosion	Reduced or no gas to diver	1A	3A	Activate Emergency Gas Subsystem
Gas Supply Check Valve	Ensure gas flow in one direction only (to diver) and prevent flow of emer-gency gas to pumps	Piston jammed shut (111141)	Corrosion, age, wear or entry of foreign matter into system	No gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Failure of fittings (111142)	Vibration, in-correct instal-lation	Reduced gas to diver	2A	3A	Activate Emergency Gas Subsystem
		Foreign body blockage (111143)	Entry of foreign latter into sys-tem	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Valve body rupture (111144)	Defective, age	No gas to diver	1A	3A	Activate Emergency Gas Subsystem
Filter Assembly	Remove foreign matter from breathing gas	Relief valve jammed open (111151)	Age, corrosion, entry of foreign matter	Supply line vents to PTC; no gas to diver	1A	3A	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		Drain valve, fails closed (111152)	Age, corrosion, defective	No operational effect	1A	1A	None Required
		Housing bursts (111153)	Defective, corrosion, impact damage	No gas to diver	2A	3A	Activate Emergency Gas Subsystem
		Filter severely clogged (111154)	Excessive foreign matter present	Reduced gas to diver	3A	3A	Activate Emergency Gas Subsystem
Flowmeter	Measure gas flow to diver (common to standard & emergency subsystems)	Foreign body blockage (111161)	Entry of foreign matter into system	Reduced gas to diver	1A	4A	Abort Dive
		Housing rupture (111162)	Defective, corrosion	No gas to diver	1A	4A	Abort Dive
		Failure of fittings (111163)	Vibration, incorrect installation	Reduced gas to diver	2A	4A	Abort Dive
Supply Piping & Fittings	Route gas flow through standard subsystem	Foreign body blockage (111171)	Entry of foreign matter into system	No gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Failure of fittings (111172)	Vibration, defective, incorrect installation, corrosion	No gas to diver	2A	3A	Activate Emergency Gas Subsystem
		Pipe rupture (111173)	Defective, corrosion	No gas to diver	1A	3A	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Emergency Breathing Gas Supply Piping and Valve	Route gas flow from emergency supply	On-off control fails "Off" (11121)	Corrosion, wear, misuse	No gas to diver (if normal supply has failed)	1A	4A	Abort Dive; Backup Diver Assistance
		Both supply line check valves fail open (11122)	Spring fatigue, foreign matter	No emergency gas to diver	1A	4A	Abort Dive; Backup Diver Assistance
Supply Piping & Fittings Common to Standard & Emergency Subsystem	Route gas flow through standard & emergency subsystem	(11123)	See failure modes 11171-73 supply piping and fittings		1A	4A	Abort Dive
Pump/Motor Unit	Power supply to compressor which supplies breathing gas to diver	Relief valve cracked (11211)	Corrosion, age, wear, vibration	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Casing leaks (11212)	Age, corrosion	Reduced or no gas to diver	1A	3A	Activate Emergency Gas Subsystem if remaining pump sections cannot supply sufficient gas
		Pump seal failed or leaking (11213)	Age, corrosion, wear	Reduced or no gas to diver	2A	3A	Activate Emergency Gas Subsystem
Piping and Valve	Provide gas passage in the breathing gas subsystem	Piping and fitting joing leaks (1122)	Defective, corrosion	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		Valve leaks (1123)	Age, wear, corrosion	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Filter dirty and partially clogged (1124)	Entry of foreign matter into system	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem
		Piping and valve partially clogged (1125)	Entry of foreign matter into system	Reduced gas to diver	1A	3A	Activate Emergency Gas Subsystem
Water Separator	Removes water from breathing gas return to pump	Separator assembly fails closed (1131)	Corrosion, age, defective	Pressure in helmet increases	1A	2A	Open Manual Exhaust Valve in helmet; Makeup gas required in PTC
PTC Hull Stop Valves Return	Isolate breathing gas return lines from PTC to pump package	Hull stop valves fail closed (1132)	See failure modes 111125 PTC hull stop valves supply		2A	2A	Manual Exhaust Valve opens; Makeup gas required in PTC
Return Pump Inlet Manifold	Serves as the supply chamber for the inlet to the return pump cylinders	The return pump intake manifold body ruptures or any manifold welds fail (11331241) (11331242) (11331243) (11332241) (11332242) (11332243)	Defective material, faulty welds, high residual weld stress	Little or no gas is returned from diver; overpressure in helmet	1B	3B	MEV opens to relieve overpressure; Makeup gas required

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Return Pump Inlet Piping	To direct gas flow to the return pump inlet manifold and cylinders	Any of the inlet circuit piping cracks or ruptures (11331251) (11332251)	Defective materials, poor weld joints, high weld stress	Little or no gas is returned from diver; overpressure in helmet	1B	3B	MEV opens to relieve overpressure; makeup gas required
Return Inlet Line Union Tee	To accept gas flow from the supply pump inlet line relief valve into the return pump inlet line	The union tee cracks or ruptures (11331252) (11332252)	Faulty materials, excess stress during installation, damage	Little or no gas is returned from diver; diver gas bypasses PTC CO_2 scrubber	1B	3B	Activate Emergency Gas Subsystem
Return Pump Inlet Piping Connectors	The connectors are used to join the piping to the various components in the return pump inlet line	Any one of the connectors develops a leak or ruptures (11331253) (11332253)	Faulty materials, improper installation, faulty o-ring, damaged during installation	Little or no gas is returned from diver; diver gas recirculates within pumps and bypasses PTC CO_2 scrubber	1B	3B	Activate Emergency Gas Subsystem
Return Pump Inlet Piping Union Tee - Connector Weld Joint	Weld joint is used to join the piping to the connectors for the inlet circuit components	The welded joint develops a leak or ruptures (11331254) (11332254)	Faulty weld, excess stress during installation, or from welding	Little or no gas is returned from diver; diver gas recirculates within pumps and bypasses PTC CO_2 scrubber	2B	3B	Activate Emergency Gas Subsystem
Return Pump Intake Lines Last Chance Filter	To filter foreign particles from the gas flow in the intake line of the return pump immediately before reaching the intake manifold	Last chance filter element becomes partially or completely clogged (1133227) (1133127)	Foreign matter in the return line, inadequate maintenance, moisture, corrosion particles	Reduced or no gas to diver; overpressure in helmet	2B	3B	MEV opens to relieve overpressure Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
CO_2 Scrubber	Remove CO_2 from breathing gas	MK 14 Scrubber failure (11411)	Absorber element contaminated or saturated	Diver air saturated with CO_2 when discharged into PTC	1A	2A	PTC Scrubber provides redundant capacity
		PTC Scrubber failure (11412)	Absorber contaminated or saturated, motor fails	Diver air contains high CO_2 level	2A	3A	Activate Emergency Gas Subsystem
Filter Assembly	Remove foreign matter from breathing gas	Toxic material in gas supply not removed by filter (1143)	Material such as cleaning or flushing agents left in system	Contaminated gas to diver	2A	4A	Abort Dive (Immediately switch to Emergency Gas & Manual Exhaust to eliminate as much of contaminated system as possible)
Pump Motor Enamel Coating	Motor housing protective coating	Grey enamel becomes heated to a temperature at which the enamel smolders and releases toxic phthalic anhydride and acrolein gases in addition to CO and CO_2 (114211)	Excess heat from motor--Inadequate cooling from the heat exchanger, motor overload, loss of a phase	Toxic phthalic anhydride, acrolein, CO and CO_2 enter the return pump exhaust line and are pumped to the PTC. The toxic gases pass through the CO_2 scrubber which removes the CO_2 and phthalic anhydride gas. The acrolein and CO gases are not removed and contaminate the PTC's atmosphere	1B	4B	One part per million of acrolein in air is immediately detectable by its odor. The tender upon identifying the odor should switch the diver to the Emergency Gas Subsystem, shut down and isolate the pump module from the PTC Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Pump Motor Winding Insulation Varnish	Insulates the motor windings within the motor stator	Varnish insulation becomes heated to a temperature at which the varnish releases toxic phthalic anhydride, phenol, CO, CO_2 and acrolein gases (114212)	Short circuit in the motor or motor overload which causes motor to overheat	Toxic gases enter the return line and are pumped to the PTC. The toxic gases pass through the CO_2 scrubber which removes the phenol, CO_2 and phthalic anhydride gases. The acrolein and CO gases are not removed and contaminate the PTC atmosphere	1B	4B	One part per million of acrolein in air is immediately detectable by its odor. The tender upon identifying the odor should switch the diver to the Emergency Gas Subsystem, turn off the pump, isolate the pump module, and swith to his BIB System. Abort Dive
Pump Motor Wiring	Motor Power leads connecting the motor with the terminal block	Hypalon wire insulation becomes heated to a temperature at which the hypalon insulation releases toxic HCL, CO CO_2 and H_2S (114213)	Short circuit, loose terminal connection, damaged insulation, motor overload causing motor to overheat	Toxic gases enter the return exhaust line and are pumped to the PTC where they are removed by the CO_2 scrubber. The absorption of HCL and H_2S gases by the scrubber reduces its capacity to remove CO_2. CO would not be removed and would accumulate	1B	4B	When small amounts of the HCL and H_2S not removed by the scrubber are detected by the tender, he must switch the diver to the Emergency Gas Subsystem shut down and isolate the pump module, and switch to his BIB System. Abort Dive
Pump Motor Lubrication Grease	To lubricate the bearings in the motor	Braycote 631A grease becomes heated to a temperature above 500^{0} F thus releasing the toxic gas	Friction in the bearings due to reduced lubrication or dirt in bearings; overheating of motor due to excessive load	The toxic carbonyl fluoride, CO and CO_2 gases enter the return exhaust line and are pumped to the PTC where they contaminate the PTC's atmosphere.	1B	4B	The attendant upon identifying the odor should switch the diver Emergency Gas Subsystem, turn off the pump, and isolate the pump module from the PTC.

FAILURE MODES & EFFECTS ANALYSIS WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		carbonyl fluoride, COF_2 along with CO and CO_2 (114214)		Carbonyl fluoride and CO are not removed by the CO_2 scrubber			The attendant should go on the BIB System. Ref. Bray Oil Company, Inc. the manufacturers of Braycote 631A. Abort Dive
Pump Motor Terminal Block Bonding Material	To bond the terminal block to the motor housing	The epoxy becomes heated to a temperature at which the epoxy breaks down thus releasing ammonia, CO and CO2 (114216)	High temperature of motor housing caused by motor overload or loss of phase	The toxic gases enter the return exhaust line and are pumped to the PTC. The CO_2 is removed by the CO_2 scrubber. The ammonia and CO gases are not removed and contaminate the PTC's atmosphere	1B	4B	The odor of ammonia gas can be noticed at a concentration of 50 ppm. The attendant upon identifying the ammonia odor should switch the diver to the Emergency Gas Subsystem, shutdown and isolate the pump module and go on the BIB System himself. Abort Dive
Pump Housing Cooling Fin Bonding Agent	To hold the heat exchanger fin stock to the module shell	Epoxy becomes heated to a temperature at which the epoxy breaks down releasing ammonia, carbon monoxide, and carbon dioxide gases (114216)	High temperature in the pump module caused by motor overload or excess friction in the pumps; improper installation of heat exchanger to module shell	The gases enter the return exhaust line and are pumped to the PTC. The CO_2 is removed by the CO_2 scrubber. The ammonia and CO gases are not removed and contaminate the PTC's atmosphere	1B	4B	The odor of ammonia gas can be noticed at a concentration of 50 ppm. The attendent upon identifying the ammonia odor should switch the diver to the Emergency Gas Subsystem, shut down and isolate the pump module and switch to his BIB System. Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Pump Motor Coupling	GNA Neoprene elastomer coupling which couples the motor with the return and supply pumps (2 couplings, 1 for each pump)	Coupling becomes heated to a degree at which toxic HCL, CO, CO_2, COS, and carbon disulfide gases are released (114217)	Friction and/or excess heat given off by the pump and motor, heat developed from loss of coupling hardware	Toxic gases enter the return exhaust line and are pumped to the PTC. HCL and CO_2 are absorbed by the CO_2 scrubber but the CO, COS, and carbon disulfide (CS_2) are not absorbed and contaminate the PTC	1B	4B	Carbon disulfide gas has a strong sulfurous odor and it can be detected when the concentration reaches 1.2 ppm. Diver must go on the Emergency Gas Subsystem and tender must go on the BIB System. The pump module must be shut down and isolated from the PTC. Abort Dive
Pump Module Circuit Wiring Sensor Leads	Connects parameter sensor leads from terminal block to bulkhead connector Polyamide insulated wire	Polyamide insulation smolders from excess heat giving off a mildly toxic diamine and toxic CO and CO_2 (114221)	Short circuit caused by damage to insulation of two wires in the cable bundle	Mildly toxic diamine, CO and CO_2 will enter the return exhaust line and pass into the PTC. Diamine and CO will not be removed by the CO_2 scrubber and will build up in concentration	1B	4B	Pump module must be shut down and isolated from the PTC. Diver must be switched to emergency breathing gas and tender must go on the BIB System. Abort Dive
Pump Module Circuit Wiring Current Sensor--Temperature Sensor, Water Sensor, and Pressure Sensor Wiring	Connects parameter sensors with terminal block. PVC or Teflon insulations as supplied by manufacturer	Polyvinylchloride (PVC) wire insulation smolders giving off toxic CO, CO_2, HCL and carcinogenic vinyl chloride-monemer; Teflon wire gives off toxic carbonyl flouride	Short circuit caused by damage to insulation of both wires in the cable bundle	Toxic gases CO, CO_2, HCL, and vinyl chloride-monemer enter the return exhaust line and are pumped to the PTC. The CO_2 and HCL are removed by the CO_2 scrubber but the CO and vinyl chloride-monemer or the carbonyl fluoride are not removed	1B	4B	Pump module must be shut down and isolated from the PTC, diver switched to the Emergency Gas Subsystem, and the tender switched to the BIB System. Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		(114222)					
Pump Module Circuit Wiring	Connects instrumentation terminal blocks with connector at the module base	Polyamide wire insulation smolders giving off toxic CO and CO_2 gases and mildly toxic diamine gas (114221) (114233) (11424) (11425)	Short circuit at the terminal block or the connector at the module base resulting from moisture accumulation or a loose terminal screw causing poor contact and a temperature buildup	Toxic gases enter the return exhaust line and are pumped to the PTC. CO_2 is removed by the CO_2 scrubber. CO and diamine gases contaminate the PTC's atmosphere	1B	4B	Pump module must be shut down and isolated from the PTC. Diver must be switched to the Emergency Gas Subsystem and tender must go on the BIB System. Abort Dive
Pump Module Circuit Wiring Wire	Connects the motor terminal block with the connector at the module base	Polyamide wire insulation smolders giving off toxic CO and CO_2 gases and mildly toxic diamine gas (114221) (114233) (11424) (11425)	Short circuit at the terminal block or at the connector at the module base resulting from moisture accumulation or a loose screw causing poor contact and a temperature buildup	Toxic gases enter the return exhaust line and are pumped to the PTC. CO_2 is removed by the CO_2 scrubber. CO and diamine gases contaminate the PTC's atmosphere	1B	4B	Pump module must be shut down and isolated from the PTC. Diver must be switched to the Emergency Gas Subsystem and tender must go on the BIB System. Abort Dive
Pump Module Circuit Wiring Terminal Block	Terminal for the electric motor three phase power leads	Phenolic terminal material burns or becomes heated to a temperature at which toxic and noxious CO, CO_2,	Short circuit at the motor terminal block; vibration causes terminal screw to become loose and poor contact causes increased localized heating	Toxic and noxious gases enter the return exhaust line and are pumped to the PTC. The CO_2 and phenol are removed by the CO_2 scrubber. CO and formaldehyde are	1B	4B	NASA tests show that this class of material has a very low flammability. Pungent odor of formaldehyde is detectable at or below 1 ppm. The attendant upon identifying the odor should switch the

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		phenol, and formaldehyde gases are released (114222) (114231)		not removed and contaminate the PTC's atmosphere. Phenol absorption by the CO_2 scrubber inhibits CO_2 absorption			diver to the Emergency Gas Subsystem and then shut down pump module. Attendant goes to BIB System. Abort Dive
Pump Module Circuit Wiring Terminal Blocks - Instrumentation (2)	Terminals for the pressure transducer, water sensor return and supply pump thermistors, and current sensor	Phenolic terminal material burns or becomes heated to a temperature at which toxic and noxious CO, CO_2, phenol, and formaldehyde gases are released (114222) (114231)	Short circuit at any of the instrumentation terminals on the terminal block resulting from moisture accumulation or a loose terminal screw causing poor contact and a temperature buildup	Toxic and noxious gases enter the return exhaust line and are pumped to the PTC. The CO_2 and phenol and removed by the CO_2 scrubber. CO and formaldehyde are not removed and contaminate the PTC's atmosphere. Phenol absorption by the CO_2 scrubber inhibits CO_2 absorption	1B	4B	NASA tests show that this class of material has a very low flammability. Pungent odor of formaldehyde is detectable at or below 1 ppm. The attendant upon identifying the odor should switch the diver to the Emergency Gas Subsystem, shut down and isolate the pump module and switch to BIB System himself. Abort Dive
Pump Module Circuit Wiring Terminal Crimp Lug Insulation	Insulation for crimp lug at terminal block	Nylon insulation burns or becomes heated to a temperature at which toxic gases are given off (114223) (114232) (11424) (11425)	Short circuit at lug terminal, loose hardware causing poor contact and high localized heat	Toxic gases, CO, CO_2, and mildly toxic diamine enter the return pump exhaust line and are pumped to the PTC. The scrubber will remove CO_2 but the CO and diamine gases will contaminate the PTC atmosphere	1B	4B	The tender must switch the diver to the Emergency Gas Subsystem, shut down and isolate the pump module and switch to his BIB System. Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Pump Module Circuit Wiring Terminal Lug Insulation	Insulation for lug at terminal block. PVC insulation	PVC insulation burns or becomes heated to a temperature at which toxic, gases are given off (114223) (114232) (11424) (11425)	Short circuit at lug terminal from moisture collection, foreign material or over heating from a poor contact caused by loose hardware	Toxic gases, CO, CO_2, HCL and vinyl chloride monemer enter the return pump exhaust line and are pumped to the PTC. CO_2 and HCL will be removed in the scrubber but CO and vinyl chloride monemer (a carcinogen) will contaminate the atmosphere in the PTC	1B	4B	Small quantities of HCL are detectable. When noticed tender must switch diver to emergency breathing gas, shut down and isolate the pump module and transfer to his BIB System. Abort Dive
Pump Module Frame Grommets	Protects instrumentation wires at the bottom baffle plate penetrator; to direct air flow around the supply and return pumps; and to protect piping at the top and bottom baffle plates	Neoprene and vulcanized rubber grommets become heated to a temperature at which they release toxic HCL, SO_2, CO_2, and CO gases (114223) (114224)	Excess heat is caused by a short circuit or friction from vibration	The toxic gases enter the return exhaust line and are pumped to the PTC. HCL and CO_2 are absorbed by the CO_2 scrubber. CO and SO_2 gases contaminate the PTC's atmosphere	1B	4B	The SO_2 gas is a strong suffocating odor which can be noticed at a concentration of 3 ppm. The pump module must be shut down and the diver must go on the Emergency Gas Subsystem. Tender switches to BIB System. Abort Dive
Pump Module Circuit Wiring Cable Clamp	To attach thermistor leads to the frame channel	Nylon cable clamps smolder or become heated to a temperature at which toxic CO, CO_2 and diamine gases are given off (114225)	Short circuit in wiring bundle caused by damage to the insulation	Toxic gases CO, CO_2 and diamine enter the return pump exhaust line and are pumped to the PTC. CO and diamine will not be removed by scrubber and will build up and contaminate the PTC atmosphere	1B	4B	The outgassing material from the nylon may not be detectable in small quantities but the outgassing from the other materials involved will be detectable. When noticed, the tender must transfer the diver to the Emergency Gas Subsystem, then shut down

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
							and isolate the pump module and switch to his BIB System. Abort Dive
Pump Module Wiring Circuit Nylon Wire Ties	Nylon wire ties are used to fasten the power input wires of the motor to the supply outlet line and the instrumentation wires to the return intake line	Nylon ties become heated to a degree at which the nylon releases mildly toxic diamine gas and toxic CO and CO_2 gases (114226)	Excess heat in the pump module caused by the electric motor overload, friction heat from bearings and other moving parts in the pump module or a short circuit in the wiring	Mildly toxic diamine and toxic CO and CO_2 will enter the return exhaust line and pass into the PTC. Diamine and CO will not be removed by the CO_2 scrubber and their concentrations will build up	1B	4B	Pump module must be shut down and isolated from the PTC. Diver must be switched to the Emergency Gas Subsystem and tender must go on to the BIB System. Abort Dive
Pump Module Circuit Wiring Protective Shrink Tubing	Wire protection, .375ID, .025TK Polyolefin clear insulation tubing	Polyolefin clear insulation sleeving burns or becomes heated to a temperature at which toxic, CO and CO_2 gases are given off (114227)	Excessive heat in the pump module, short in wire bundle, short in connector back shell	Toxic CO and CO_2 enter the PTC through the return pump exhaust line and contaminate the atmosphere. CO_2 is removed in the scrubber but CO concentration will continue to build up to lethal levels	1B	4B	CO and CO_2 are odorless and warning odors will have to come from the breakdown of adjacent materials. Tender must immediately transfer diver to the Emergency Gas Subsystem, shut down and isolate the pump module and switch to his BIB System. Abort Dive
Pump Module Circuit Wiring Identification Tubing	Identifies various wires at the motor and instrumentation terminal blocks	Polyolefin wire identification tubing smolders giving off toxic CO and CO_2 gases (114234)	Short circuit at terminals or connector at the module base resulting from moisture accumulation or damaged insulation, loose	Toxic CO and CO_2 gases enter the return pump exhaust line and are transmitted to the PTC. CO_2 is removed in the scrubber but CO will build up and	1B	4B	CO and CO_2 gas evolution will not be detectable but sufficient heat to decompose the polholefin will also decompose other detectable gaseous byproducts. When noticed by

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
			terminal screw develops high resistance contact and results in overheating	contaminate the capsule			the tender the diver must be switched to emergency gas system, the pump module shut down and isolated and the tender transferred to his BIB System. Abort Dive
Supply and Return Pump Lubrication Grease	Lubricates the bearings in the Return and Supply Pumps	Braycote 631A grease becomes heated above 500°F and releases toxic carbonyl flouride, CO and CO_2 (114261)	Increased friction in the bearings resulting from inadequate lubrication, foreign material in bearing, damaged or faulty bearing results in excess heat	The toxic carbonyl flouride CO and CO_2 gases enter the return exhaust line and are pumped to the PTC and contaminate the PTC atmosphere. Carbonyl flouride and CO will not be removed by the CO_2 scrubber	1B	4B	Pump module must be shut down and isolated from the PTC, the diver switched to the Emergency Gas Subsystem and the tender switched to the BIB System. Abort Dive
Supply and Return Pump Cylinder Gaskets	To keep a tight seal between the cylinder head and outlet reed valve and between the inlet reed valve and cylinder	The gaskets become heated to a temperature at which toxic and/or noxious gases are released (114262)	Increased friction in the pump cylinder resulting from damaged piston or piston rings	Toxic gases pumped to PTC and not removed by CO_2 scrubber	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)
Supply and Return Pump Bearing Seals	To keep bearing lubrication in the bearing assembly	Bearing seals become heated to a temperature at which they release toxic and/or noxious gases	Insufficient bearing lubrication, dirt or some other foreign material in the bearing assembly damaged or faulty	Toxic gases pumped to PTC and not removed by CO_2 scrubber	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSOS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
			in excessive heat				
Supply and Return Pump Piston Rings	To keep a tight seal between the piston and the cylinder wall	The piston rings become heated to a temperature at which toxic and/or noxious gases are released (114264)	Increased friction due to ring wear, damage or from material lodging between the rings and cylinder wall	Toxic gases pumped to PTC and not removed by CO_2 scrubber	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)
Supply and Return Pump Hub Assembly	Loctite 222 methylacrylate ester is used to bond the return and supply pump fans to their respective shafts, bond the baffle and hub, and bond the socket screw, lock washer, and nut	The methylacrylate ester becomes heated to a temperature at which it gives off methylacrylic acid, CO, and CO_2 (114265)	Friction in the baffle/hub assembly, excess heat given off by the motor and/or pumps	Toxic gases pumped to PTC and CO gas not removed by CO_2 scrubber	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)
Pump Module Gronmets Cement	To fasten rubber gronmets to the shroud assembly and cover plate	Cyanoacrylate ester glue becomes heated to a temperature at which highly toxic cyanogen gas is given off	Excess heat given-off by the pump and/or motor; friction from pump rubbing on gronmet	Highly toxic cyanogen gas pumped to the PTC	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Pump Module Last Chance Filter Cement	To secure the last chance filters in the return and supply intake lines at the base of the pump module	The polyamide epoxy resin becomes heated to a temperature at which mildly toxic diamine gas and toxic CO and CO_2 gases are released	Excess heat given off by the motor and/or pumps	Toxic CO gas pumped to PTC and not removed by CO_2 scrubber	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)
Pump Module Foam Ring	Filters gas inside the pump module that enters the return pump exhaust line to the PTC	The polyurethane foam ring gives off highly toxic phenyl isocyanate and cyanogen gases and toxic CO and CO_2 gases	Excess heat given off by the pump/motor heats the polyurethane foam ring to a degree where the polyurethane breaks down and releases toxic gases	Toxic gases pumped to PTC and not removed by CO_2 scrubber	1B	4B	Abort Dive (Immediately activate Emergency Gas Subsystem; tender switches to BIB System)
Return and Supply Pumps Cooling Fan Adaptor	The fan adaptor adapts the supply and return pump cooling fans to their respective pump shaft	Either of the two cooling fan hubs fail or come loose on the shaft (115111)	Defective materials, damage, faulty installation	Diver breathing gas temperature becomes too high	2B	3B	Activate Emergency Gas Subsystem
Return and Supply Pumps Cooling Fans	To circulate gas in the pump module thus cooling the motor and pumps	Either of the fans come loose on its shaft and no longer cools the pump cylinders (115112)	Improper installation, defective epoxy	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSOS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
		Any of the blades on either fan fails (115113)	Faulty materials, damage during installation	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem
Heat Exchanger Epoxy Bond	Epoxy glue is used to bond the heat exchanger to the pump module shell	The epoxy bond fails, thus allowing the heat exchanger to come loose from the pump module shell (115121)	Faulty epoxy glue, improper installation of heat exchanger	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem
Heat Exchanger	To dissipate heat from inside the pump module to the water outside the pump module	The heat exchanger channels become plugged (115122)	Foreign matter inside the pump module	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem
Pump Module	Provides breathing gas under pressure to diver and recovers spent gas from diver	Temperature of gas delivered to the diver is too high (115131)	Pump module operated while the pressure transfer capsule is in air on deck	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem
		Temperature of gas delivered to the diver is too high (115132)	Pump module operated while the pressure transfer capsule is in shallow warm water	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: Breathing Gas Subsystem, Standard SN 11

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply and Return Pump Pistons	To pump gas through the MK 14 Diving System	Any one of 8 pistons in either pump fail and bind on the cylinder wall thus increasing the temperature of the pump and the gas (115211)	Damage, faulty installation, defective material	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem
Supply and Return Pumps Rider Rings	To provide a bearing or wearing surface for the piston assembly	Any one of the rider rings in either pump fail and bind thus increasing the temperature of the pump cylinder assembly and gas (115212)	Wear, faulty installation, damage, defective material	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem
Supply and Return Pumps Piston Ring Seals	To prevent gas blow-by between the piston and the cylinder wall	Any one of the rings or seals in either pump fail and bind, increasing the temperature of the pump and the gas (115213)	Damage, faulty installation, defective material, wear	Diver breathing gas temperature becomes too high	1B	3B	Activate Emergency Gas Subsystem

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: PTC MOUNTED CONTROL SUBSYSTEM SN 12

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Equipment Monitoring Indicators	Monitor vital motor and gas flow functions	Loss of indication only; power monitor, pressure, high temperature, flow, alarm light (121)	Electrical component failure, defective, or damaged	Adequacy of diver breathing gas supply unknown	3A	2A	Abort Dive; rely on diver communication for assessment of gas supply
Diver Monitoring Indicators	Indications of vital functions to diver	Loss of indication only; B/G TEMP, H/W TEMP, gas return pressure, gas supply pressure (122, 123)	Electrical component failure, defective, or damaged	Diver condition not certain	3A	2A	Abort Dive; rely on diver communication for assessment of condition

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: HOT WATER SUBSYSTEM SN 13

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Suit Manifold	Hot water distribution to heater & suit	Leakage or blockage (1311)	Defective or damaged	Reduced or no hot water to heat breathing gas or suit	1A	4A	Abort Dive
Hot Water Hose from PTC to Diver	Hot water supply to gas heater and suit	Line rupture or blockage (1321) (1312)	Defective or damaged	No hot water to heater & suit	1A	4A	Abort Dive
PTC Hot Water Manifold	Hot water distribution to diver	Leakage or blockage (1313)	Defective or damaged	Reduced or no hot water to heat breathing gas & suit	1A	4A	Monitor breathing gas temp. Abort Dive if below limit
Hot Water Line Surface to PTC	Hot water transfer	Line rupture or blockage (1314)	Defective or damaged	No hot water to heat breathing gas	1A	4A	Abort Dive
Line from Suit Manifold to Heater	Hot water supply to heater	Line rupture or blockage (1322)	Defective or damaged	No hot water to heat breathing gas	1 A	4 A	Abort Dive
Heater Hot Water Leakage	Diver gas supply heater	Heater rupture or blockage (1323)	Defective or damaged	No hot water to heat breathing gas	1A	4A	Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: UMBILICAL SUBSYSTEM SN 14

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Gas Supply Line	Gas supply to diver	Rupture, fouled or faulty connection (141)	Defective or damaged	No breathing gas to diver, or flooding	1A	4A	Abort Dive, backup diver assistance
Hot Water Supply Line	Heating water for diver & breathing gas	Rupture, blockage, or faulty manifold connection (142)	Defective or damaged	Breathing gas not heated	1A	4A	Abort Dive
Communications Line	Audio communications between diver & PTC	Circuit open or interference (143)	Defective, damaged, or presence of detrimental electrical effects	No Audio communication between divers & PTC	2A	2-3A	Use of hand signals may permit mission completion; otherwise Abort Dive
Gas Return Line	Gas return from diver	Line fouled or blocked (144)	Foreign matter or damage	Loss of gas for recycle	1A	2A	Manual Exhaust Valve open. Makeup gas required in PTC.
		Line ruptured (145)	Defective or damaged	Loss of gas for recycle	1A	3A	Manual Exhaust Valve opens. Makeup gas required in PTC Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: DIVER-WORN EQUIPMENT SN 15

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Hot Water Suit	Diver protection against environment	Suit fastener fails (1511)	Defective, age, fouling	Diver exposure to environment	2A	3A	Abort Dive
		Neckdam fails (1512)	Defective, age	Flooding of river breathing environment	2A	4A	Abort Dive
		Suit material fails	Defective, age, fouling	Diver exposure to environment	2A	3A	Abort Dive
Helmet Viewing Window	Diver visual contact with ambient surroundings	Reduction or elimination of visibility (1521)	Fogging due to cold gas or damaged diffuser, formation of deposits	Diver can't see to perform mission	2A	3A	Abort Dive
Diver's Microphone	Provides communication from diver to PTC	Failure or erratic operation (15221)	Defective, age, damaged	Inability to communicate mission	3A	2-3A	Abort Dive
Diver's Earphones	Receive communication messages from PTC	Failure or erratic operation (15222)	Defective, age, damaged	Inability to receive messages	2A	2-3A	Abort Dive
Diver's Pre-amplifier Unit	Increase weak signals to audible level	Failure or erratic operation (15223)	Defective, age, damaged	Inability to receive messages clearly from PTC	2A	2-3A	Use of std. hand signal may permit mission completion; otherwise Abort Dive
Helmet Comm. Cable Connectors	Transmit signals to and from helmet end to PTC	Failure or erratic operation (15224)	Loose connection, defective or disconnected	Inability to communicate with PTC	3A	3A	Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: DIVER-WORN EQUIPMENT SN 15

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Helmet/ Exhaust Regulator	Regulates flow of gas and pressure in helmet	Fails open (152321)	Wear, corrosion, foreign matter, flooding	Underpressure in helmet	3A	3A	SEV shuts to prevent excessive underpressure
		Fails shut (152421)	Wear, corrosion, foreign matter, flooding	Overpressure in helmet	3A	2A	MEV open to relieve overpressure
Manual Exhaust Valve	Relieves helmet operpressure and exhausts gas to ambient surrounding	Fails open (15242)	Wear, corrosion, foreign matter	Continuous loss of gas to ambient	2A	2A	Continue operations if gas supply permits, makeup gas in PTC required
		Fails shut (152422)	Wear, corrosion, foreign matter	No effect unless exhaust regulator fails closed also, then overpressure in helmet	2A	2A	Gas escapes through neckdam to relieve pressure. Makeup gas in PTC required
Safety Exhaust Valve	Prevents excessive underpressure condition in helmet	Fails open (152322)	Age, corrosion, foreign matter, flooding	No effect unless exhaust regulator fails open, then underpressure in helmet	2A	4A	No alternate system
		Fails shut (1524)	Defective, age, flooding	Pressure buildup in helmet	2A	3A	MEV open to relieve overpressure. Makeup gas in PTC required
Supply Valve	Controls gas flow into helmet	Fails open (15241)	Wear, age, corrosion	Possible over-pressure in helmet	1A	2A	MEV open to relieve overpressure. Makeup gas in PTC required
		Fails shut (152312) (15262)	Wear, age, corrosion	No gas to diver	1A	4A	Abort Dive; backup assistance

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: DIVER-WORN EQUIPMENT SN 15

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
Supply Check Valve	Prevents helmet pressure drop upon loss of supply line pressure	Fails shut (152311)	Wear, corrosion, foreign matter	No gas to diver	2A	4A	Abort Dive; backup diver assistance
		Fails open	Wear, corrosion, foreign matter, defective	No effect unless additional failures occur	2A		
Helmet Straps	Secure helmet to suit	Straps broken (15251)	Corrosion, age, defective	Flooding of diver breathing environment	1A	4A	Three straps give redundancy. Neckdam gives some restraint
Helmet Breech Rings	Secure helmet to neckdam	Locking device failure (15252)	Defective, age, corrosion	Flooding of diver breathing environment	1A	4A	Abort Dive
Helmet Whip Hose	Provides heated gas to helmet	Burst or cut (15261)	Age or accident	No gas and flooding of diver breathing environment	1A	4A	Abort Dive
Helmet Housing	Provides breathing gas atmosphere to diver	Structural failure (15263)	Defective material, age	Loss of breathing gas and entry of water	1A	4A	Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSDS
SUBSYSTEM: COMMUNICATIONS SUBSYSTEM SN 16

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
PTC Microphones	Communications trans. pickup	Comm. failure or erratic information (1611)	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
PTC Head Set	Communications reception	Comm. failure or erratic information	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
Subsystem Circuitry	Communications transmission	Comm. failure or erratic information (1613)	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
Pitch Synchro	Voice pitch synchronization	Failure or erratic operation (1614)	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
Circuit Switches	Open & close subsystem circuits	Failure or erratic operation (1615)	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
Volume Control	Regulate volume	Comm. failure or erratic information (1616)	Defective, age, damaged	Reduce clarity of transmission	3A	1-2A	None required unless signal is lost
Speech Unscrambler	Neutralize undesirable helium effect on speech	Failure or erratic operation (1617)	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive

FIGURE 4-3 (CONT'D)
FAILURE MODES & EFFECTS ANALYSIS
WORKSHEET

SYSTEM: MK14 CCSOS
SUBSYSTEM: COMMUNICATIONS SUBSYSTEM SN 16

ASSEMBLY/ COMPONENT	FUNCTION OR DESCRIPTION	FAILURE MODE AND SN	PROBABLE CAUSE	EFFECT ON SYSTEM	PROBABILITY OF OCCURRENCE	LEVEL OF SEVERITY	COMPENSATING PROVISION OR ACTION TO RESTORE OPERATION
PTC Circuit Connections	Interconnect circuits & components	Failure or erratic operation (1618)	Defective, age, damaged	Inability to coordinate mission activity	3A	2-3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
Subsystem Power	Power for equipment operation	Power switch malfunction (1619)	Defective, age, damaged	Inability to coordinate mission activity	2A	3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive
		Failure or erratic operation (16110)	Defective, damaged	Inability to coordinate mission activity	3A	3A	Use of std. hand signals may permit mission completion; otherwise Abort Dive

SECTION 5

DISCUSSION OF FAILURE ANALYSIS

5.1 LIFE-CRITICAL FAILURES

System failure modes in the Life-Critical category were considered of greatest significance in analysis of the data in Figure 4-3 because of their obvious impact on human safety. These failure modes are discussed in detail by subsystem.

5.1.1 Gas and Supply Return

5.1.1.1 Breathing Gas, Standard SN 11. Release of Toxic Gas due to System Contamination or Pump-Motor Components Failure SN 114211-7, 114221-7, 114231-4, 114261-5, 1143. Both of these failure modes are extremely hazardous, although the probability of occurrence is low. Motor failure would most likely be preceded by a high temperature alarm and by thermal cutoff which would shut the motor down. Only a limited amount of toxic gas could be drawn into the breathing line before shutdown. Toxic material in the gas supply would probably be caused by improper cleaning or checkout procedures. This would be more hazardous, as it is only detectable by the diver or the PTC tender and there is no automatic shutdown, but only manual bypass via the emergency supply. However, this hazard is more predictable and preventable than motor burnout. The most unpredictable and hazardous conditions would be generated by toxic gases released by non-metallic materials within the MK 14 Pump Module.

The possible release of toxic gases from non-metallic material within the MK 14 Pump Module was judged to be a remote possibility; failures that would be expected to occur once or less than once in a two-year operating period. The generation of toxic gases would be the result of some other type of failure such as overheating of the electric motor, overheating of a pump component, or a loose electrical wire that could cause an arc. In all cases the non-metallic decomposes as a result of heat. The rate and amount of such decomposition is determined by the nature of the material, the amount of exposure, and the intensity of the heat. The quantity of toxic gas generated would be difficult to determine, and the detection of toxic gases, in some cases, depends on the senses of tender and diver themselves since there are no instruments onboard for toxic gas detection specifically.

Toxic compounds generated by the thermal decay of non-metallic substances are difficult to identify completely. There is an almost infinite variety of combinations of chemical compounds and elements that can be formed, most of which are toxic to some degree. Decomposition products from the pyrolysis of organic polymers include alkenes, alcohols, aldehydes, keytones, acids, aromatic compounds, and esters, all of molecular weights approximating that of the base polymer. If halogens, nitrogens, or sulfur are built into the polymer, amines, amides, thiols, amine oxides, and various sulfur oxide products can be formed. In the presence of adequate amounts of oxygen, organic peroxides and peracids are formed but these decompose to alkenes and carbon monoxide. (Oxygen will be present in very low quantities in general, however,) The types and amounts of decomposition products are unique to each particular polymer such that a polymer may be positively identified by an analysis of its decomposition products. To determine the type and amount of potentially toxic gases formed from paint or plastic material decomposition, samples of each material involved would have to be run separately, simulating the breakdown conditions, and the resultant gases analyzed by gas chromatograph mass spectrograph instrumentation.

The level of breathing gas contamination would depend on the quantity of toxic gas and the total volume of breathing gas in the system. Any contamination of the breathing gas by a toxic substance, however small, must be considered unacceptable. In such a circumstance the mission must be terminated and the cause determined and corrected.

<u>Gas Supply Flowmeter Failures SNs 11161-63</u>. Flowmeter failure causing leakage or blockage would result in reduction or elimination of breathing gas to the diver. Since the flowmeter is common to both the standard and emergency gas subsystems, this failure mode would not permit either subsystem to supply gas to the diver, making it a critical failure mode for which there is no alternative system to restore operation.

Gas Supply Piping and Fittings Common to both the Standard and Emergency Subsystems SN 11123. This type of failure would likewise eliminate both the standard and emergency subsystems from supplying gas to the diver because this piping is common to both. Failure probabilities of this mode, however, is low.

5.1.1.2 Breathing Gas Emergency SN 1112. On-Off Control, Check Valve, Piping and Flowmeter Failures SNs 11121, 11122, and 11123. Failures of this subsystem equipment are considered level 4A Life-Critical; however, a failure of this subsystem will most likely occur only after a failure in the Standard Gas Subsystem has already occurred. Thus, double failures will have to occur and the probability of this is extremely low.

5.1.2 Hot Water Subsystem SN 13

Hot Water Line, Manifold or Heater Failure SNs 1131-14 and 1321-23. Loss of hot water is considered Life-Critical as conditions of low temperature water operation result in improper heating of breathing gas and a subsequent hazardous environment for the diver. The effect of such a failure, however, is not instantaneous so that there is time for emergency procedures, and the probability of occurrence is very low.

5.1.3 Umbilical Subsystem SN 14

Gas and Hot Water Supply Line Failure SNs 141 and 142. Failure of the umbilical is Life-Critical if such failure prevents breathing gas or hot water for heating or breathing gas from reaching the diver. The probability of such failure occurrence is low because of the inherent simplicity and low stress level of the umbilical. Externally caused damage to the umbilical is the only significant factor that would cause such a failure.

5.1.4 Diver-Worn Equipment Subsystem SN 15

Diver's Suit Failure SN 1512. Failure of the diver's neckdam which results in helmet flooding exposure to the environment is considered Life-Critical. Damage, and not malfunction, is the primary cause of this type of failure,; thus, the probability of occurrence is low.

Helmet Safety Exhaust Valve Fails Open SN 152322. The exhaust regulator will have to fail open simultaneously for this failure occurrence to become Life-Critical. When both failures occur simultaneously, underpressure condition develops inside the helmet. Failure of safety exhaust valve and exhaust regulator would be found in predive checks and probability of failure is low.

Helmet Gas Supply Valve Fails Shut SN 152312 and Supply Check Valve Fails Shut SN 152311. Both of these failures would be hazardous to the diver by eliminating the breathing environments and creating a suck-out condition for the diver, which is Life-Critical; however, the probability of occurrence in either case is low and failures of these valves would be found in predive checks.

Helmet Housing Structure Failure SN 1526, Helmet Breech Ring Locking Device Failure SN 15252, Helmet Straps Failure SN 15251, and Helmet Whip Hose Failure SN 15261. All these failures would be hazardous to the diver by eliminating the breathing environment and exposing the diver to low temperature sea water. These failures are all Life-Critical to the diver; however, the probability of occurrence is very low, as they all involve structural failure of essentially unstressed parts.

5.2 MISSION-CRITICAL FAILURES

The second most significant group of failure modes identified by this analysis are those on the Mission-Critical level (level 3, A & B) and which show a high probability of occurrence (3-4, A & B). This type of failure would be responsible for system operation that would result in a high number of incomplete or aborted missions.

Included in this group, based on current equipment expectations and indicated by the assessment made in Figure 4-3, are the following:

- Gas Pump Motor Power Terminal Block Screw Failure
- Gas Filter Clog
- Helmet Exhaust Regulator Failure
- Communication Equipment Failure

Failures of this type are, in all cases, supported by backup equipment or procedures will prevent development of conditions that are hazardous to the diver in the event of such a failure; however, completion of the mission is jeopardized and in most cases must be discontinued.

5.3 SPECIAL FAILURE MODES

Special failure modes identified because of their significance in diving safety are considered at this point, even though they involve the failure of multiple components and should, therefore, exhibit a very low probability of failure occurrence. Failures addressed in this analysis include:

a. Failures which could result in a diver squeeze.

- Should the combined failure (open) of the helmet non-return valve and a severed gas supply hose at some depth above the diver occur, the pressure differential between the point at whch the hose is severed and the diver's helmet can be sufficient to be hazardous to the diver. It is, therefore, essential that the helmet nonreturn valve be designed with a high degree of reliability so that it operates correctly when required under such conditions.

- The combined failure (open) of the exhaust regulator and the Safety Exhaust Valve (SEV) will result in a helmet pressure drop which will be hazardous to the diver. These components must be designed to high reliability levels. In addition, the SEV must operate effectively when required despite its inactivity prior to operation. These components must also be designed to operate in the presence of moisture which may, at times, enter the system.

b. Failures which could result in diver blowup.

- The combined failure (shut) of the exhaust regulator and the manual exhaust valve will result in a helmet overpressure which can be hazardous to the diver. It is, therefore, essential that the exhaust regulator and the manual exhaust valve be designed with a high degree of reliability so that they can operate correctly under the worst conditions.

c. Effect of collected water which has entered the helmet and gas return line.

- Water may enter the diver's breathing gas circuit by leakage through the neckdam into the helmet and then be carried into the gas return line. Such water will, obviously, be passed through components such as the helmet exhaust regulator and safety exhaust valve as it travels from the helmet through the gas return line and is removed by the water separator. The effect of this water on the operation of the regulator and SEV must be determined and the design of both components must consider operation in the presence of moisture to ensure most effective obtainable performance.
- Water entry into the gas return line may also be a problem as a result of entrapment of such water in low points of the umbilical return hose. Such water buildup may slowly accumulate in sufficient volume at temporary low points to result in a flow surge through the hose when the hose changes position and the low point is eliminated. The results could possibly be hazardous to a diver and damaging to equipment such as the pump. The development test program should study this potential problem area and determine if corrective action must be taken.

d. Failures which result in PTC flooding.

- The PTC will begin to flood if a condition exists in which one or both divers are operating in the free-flow mode and the pumps are operating. In such a situation the tender should switch the divers to the emergency gas supply and shut off the pumps. At this point, flooding should cease. If no action were taken, continuation of flooding would eventually result in intake of water to the pump suction and flooding of the breathing gas system.

SECTION 6

RECOMMENDATIONS

The following recommendations are made based on analysis of the system failure modes which have been evaluated in this report. These recommendations are intended to present preventive or corrective actions useful in eliminating the criticality of certain failure modes or reducing it to acceptable proportions.

a. To ensure a low probability of toxic gas release due to system contamination or pump-motor burnout, the following should be provided for:

- Motor control and shutoff equipment should frequently be checked to maintain operability within specifications. Maximum possible checkout prior to a dive should be performed.

- Breathing gas system contamination should be reduced to a minimum by controlling all operations which could result in entry of foreign material into the breathing gas circuit.

The following precautions and adjustments should be considered to prevent and detect toxic gases in the system:

- Provide a carbon monoxide gas level detector with an audible alarm. (Carbon monoxide build-up can result from overheated components and may or may not be accompanied by other detectable gases.)

- Eliminate, wherever possible, all materials which could give off toxic gases when subjected to excessive heat. Where elimination is not possible, substitution of materials with less toxic heat byproducts should be chosen. (Substitute methyl type silicone/glass or nylon for phenolic terminal boards, metal mesh filter for polyurethane foam filter, polymide wire insulation instead of PVC, teflon or rubber now in use.)

- Relocate all non-metallic items that decompose when subjected to excessive heat away from potential heat source. (Move motor power lead terminal block from motor housing to structural frame.)

- Direct diver tender to transfer divers to the emergency gas system whenever a foreign odor is detected. Follow immediately with the shut-down and isolation of the Pump Module and abort the dive until the source and/or cause of the odor can be determined.

b. Some provisions should be considered to ensure that leakage or blockage of the gas system flowmeter which is common to both the standard and emergency gas subsystem does not disable both systems when such a failure occurs. A bypass around the meter, which can be selected in such an event, is one potential solution.

c. The gas piping and fittings which are common to both standard and emergency systems must be designed with a very low probability of failure to prevent disabling of both systems that such a failure would cause. With the exception of the flowmeter, the components in the line between the emergency gas connection and the umbilical are tubing and fittings. This design can be expected to have an inherently high reliability.

d. Provide audible alarms for other parameters being monitored, such as breathing gas temperature, motor phase loss, power line voltage, Pump Motor Drive Current, ground detecting. Audible alarm prevents problems arising from temporary periods when PTC tender attention is directed away from control panel. An independent back-up monitoring system can be used to minimize hazardous conditions by taking corrective action as quickly as possible so as to avoid damage to equipment, and endangering diver. In addition, audible alarms can also aid in identifying source of problem.

e. Probability of failure of the hot water subsystem piping and heating equipment is relatively low; however, to ensure that hazards to the diver are minimized, hot water temperature monitoring equipment should be maintained in good operating condition and monitoring of water temperatures during the dive should be accurate and continuous to permit early response to a failure.

f. Failures of the umbilical subsystem which occur primarily from damage or abrasion-related problems should be minimized by design for prevention of the effect of such factors as bending, kinking, wear, impact loading, and rough handling. Operating procedures that minimize the possibility of encountering these problems should also be implemented.

g. Minimizing the failure probability of diver-worn equipment which has been designed based on previously certified equipment, such as the helmet and suit, requires that this equipment be reevaluated to ensure that the design conforms to the specific requirements of the MK 14 System and that modifications be amply considered. Design of the helmet gas supply valve should provide minimum fail-shut possibility and be subject to procedures for regular operational and predive checkouts. The suit design should provide for maximum resistance to damage and abrasion and utilize an effective neckdam seal design.

h. System failure modes which are on the level of severity of Mission-Critical and at the same time show an expected probability of occurrence which is high (3-4) should be closely monitored during system design and development. These failure modes should be given high priority in influencing the design and operational doctrine of the system in order to ensure that the failure probability be reduced to the lowest possible or to a level consistent with system performance requirements.

i. Multiple failure modes or failure modes combined with the use of proper emergency procedural actions which have special significance in MK 14 diving safety have been fully considered in this analysis. The various combinations of failures and the use of proper emergency procedures which have a direct effect on the diver's safety in the MK 14 System should be investigated in detail as part of a separate MK 14 Safety Analysis.

APPENDIX A

MK 14 PUMP PACKAGE FUNCTION AND OUTPUT LIST

APPENDIX A. MK 14 PUMP PACKAGE FUNCTION AND OUTPUT LIST

Block Diagram Identification	Function and Output Description	Specified Limits	Classification		
			Primary	Secondary	Ancillary
10 Motor	Torque to Supply Pump No. 30 and Return Pump No. 20	460± 10% 3Ø 60 Hz, 7.5 HP 1745 RPM	X		
20 Return Pump	Raises return air from diver to PTC pressure level.	Nominal 609 cu. ft./min. cap.	X		
30 Supply Pump	Raises supply air from PTC level to diver pressure.	Nominal 609 cu. ft./min. (6.6 cu. ft./min. @ 80 psi 8.6 cu. ft./min. @ 72 psi.)	X		
40 Relief Valve	Prevents return pump starvation.	70± psi	X		
50 Relief Valve	Limits Supply Pump output pressure.	80± psi	X		
60 Temperature Sensor	Sense Return Pump Cylinder Temperature.			X	
70 Temperature Sensor	Sense Supply Pump Cylinder Temperature.			X	
80 Muffler	Filter Return Pump Exhaust		X		
90 Temperature Sensor Electronics	Provides Power to PTC Indicator Lamps	28 VDC Power on at 145°F			X