MASTER LIST OF TESTS AND ANALYSES

[By Event]

Number (T/A) Location Monitors	Title	Objective - Description	Status - Results - Remarks
		PANEL LOSS	
A-94(T) LRC M. Ellis W. Erickson	Mylar Combustion Tests with Supercritical Oxygen in Simulated Shelf Space	Observe the nature of the combustion of Mylar insulation blanket with supercritical oxygen in a simulated shelf space volume. Measure the resulting pressure rise for various modes of ignition and simulated tank rupture.	C - June 6, 1970. Mylar insulation blanket burns completely when ignited by pyrofuse and exposed to oxygen exhausting from a chamber at 900 psia/-190° F. Duration of combustion process is about 2 to 4 seconds. The pressure rise rate with combustion in these tests is about 7 times that measured with no combustion.
A-95(A) LRC R. Trimpi W. Erickson	Analysis of Temperature by Sensors Outside Shelf Space	Use the flight measured temperature-time histories for sensors outside shelf space to estimate the temperature of the gas which flows from shelf space.	C - June 9, 1970. Examination of the temperature-time histories suggests heat addition outside of oxygen tank.
		SIDE EFFECTS	
13-T-32(T) NR R. Johnson R. Wells	Fuel Cell Valve Module - Reactant Valve Shock Test	Determine the effect of a high g load on the fuel cell reactant shutoff valves.	C - April 20, 1970. This test showed that the reactant valves shut under lower shock loads than the RCS valves. Since a portion of the RCS valves closed at the time of the incident, the reactant valves probably closed due to the shock loading.
13-T-26(T)			See Pressure Rise.

LEGEND: (T) - Test (A) - Analyses C - Completed ECD - Estimated Completion Date TBD - To Be Determined

MSC Form 343 (OT) NASA — MSC

MASTER LIST OF TESTS AND ANALYSES

[By Event]

Number (T/A) Location Monitors	Title	Objective - Description	Status - Results - Remarks
		MISCELLANEOUS	
13-T-43(T) MSC C. Propp S. Himmel	Development of Service Procedure for Apollo 14	Develop new operating procedures for ground operations to prevent stratification in the oxygen tanks.	ECD - TBD. Test has not yet been conducted.
13-T-51(T) NR J. Diaz F. Smith	LOX Tank Fan Motor Examination	Identify nonmetallic motor parts and provide information on their usage. Identify surfaces containing Drilube 822 and look for signs of corrosion.	C - May 12, 1970. The motor parts were identified for the use of Panel 1. Drilube 822 was used on threaded areas of the motor housing and mounting hardware. The motor showed evidence of corrosion at areas of contact of dissimilar metals.
13-T-52(T) WSTF M. Steinthal I. Pinkel	N_2O_4 and A-50 Reactivity with Teflon Insulated Wire	Determine the reactivity of Teflon in N_2O_4 and A-50 when arcing or short circuiting occurs.	ECD - June 12, 1970. The overload test has been completed and the arcing test is being prepared. The overload test shows a maximum temperature rise of 2° F and maximum pressure rise of 2 psi. There have been no reactions with either N_2O_4 or A-50.
13-T-72(T) MSC C. Propp H. Mark	Reactivity of Hydrogen Tank Materials	Hydrogen materials will be ignited in gaseous hydrogen at various temperatures. Ignition will be by a nichrome wire electrically heated until failure occurs.	ECD - June 30, 1970. The test has not yet been conducted.
13-T-73(T) MSC C. Propp H. Mark	Spark Ignition Threshold and Propagation Rates for Hydrogen Tank Material in Gaseous Hydrogen	Determine spark ignition threshold and combustion propagation rates for hydrogen tank material in gaseous and supercritical hydrogen at various temperatures.	ECD - June 19, 1970. The test has not yet been conducted.

LEGEND: (T) - Test (A) - Analyses C - Completed ECD - Estimated Completion Date TBD - To Be Determined

NASA — MSC

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MASTER LIST OF TESTS AND ANALYSES

[By Event]

Number (T/A) Location Monitors	Title	Objective - Description	Status - Results - Remarks
MISCELLANEOUS			
13-T-74(T) MSC C. Propp H. Mark	Ignition of Specific Configurations in Hydrogen	Details depend on results of 13-T-72 and 73. Will mockup hydrogen tank configuration.	ECD - July 1, 1970. The test has not yet been conducted.
A-89(T) ARC E. Winkler H. Mark	Teflon/Aluminum Ignition in Inert Atmosphere	Determine whether it is possible to ignite Teflon and aluminum in an inert atmosphere.	C - May 15, 1970. A Teflon and powdered aluminum mixture could be made to burn. High ignition energies (greater than 10 joules) were necessary and it was found that the aluminum had to be finely divided before it would burn.

LEGEND: (T) - Test (A) - Analyses C - Completed ECD - Estimated Completion Date TBD - To Be Determined

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PART F5

FAULT TREE ANALYSIS - APOLLO 13 ACCIDENT*

INTRODUCTION

This report contains a fault tree analysis of the applicable portions of the electrical power and cryogenic systems involved in the Apollo 13 incident. It was prepared by the Boeing Company under the direction of MSC and at the request of the Apollo 13 Review Board.

PURPOSE

The purpose of this analysis is to identify potential causes that could lead to the loss of the SM main bus power, to show their logical associations, and to categorize them as being true or false for the Apollo 13 incident based upon available data, analyses, and tests. The prime emphasis is to identify the initiating cause, and secondarily, the sequence of events leading to the loss of SM main bus power.

SCOPE

This fault tree identified the applicable ECS/cryogenic system hardware and potential causes, down to the component or groups of components level. The logical association of the potential causes is shown graphically and is developed tracing the system functions backwards. Each potential cause is categorized as being true or false where flight data, ground tests, technical analyses, and/or engineering judgment provide sufficient rationale. The main thread to determine the initiating cause is identified in the fault tree. The tree does not include unrelated or secondary effects of the failure (i.e., quantity gage malfunction, panel blow-off, fire in the service module).

Pages F-108 through F-114 provide information on symbology, terminology, abbreviations, references, and schematics for reference during review of the fault tree. Page F-111 identifies what pages of the fault tree are associated with the various segments of the system. Page F-115 pictorially depicts the required layout of the pages of the fault tree to provide an overview of the complete system.

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*Extracted from "Fault Tree Analysis - Apollo 13 Incident," dated June 5, 1970, under Contract NAS 9-10364 - Task Item 9.0, for MSC Apollo 13 Review Board, Action Item 35.

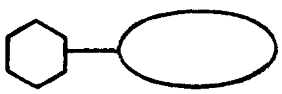
DESCRIPTION OF FAULT TREE DEVELOPMENT PROCESS:

BEGINNING FROM THE DEFINED UNDESIRED EVENT, "FUEL CELL POWER NOT AVAILABLE ON SM BUSES", THE CAUSATIVE FACTORS HAVE BEEN SHOWN BY MEANS OF LOGIC DIAGRAMMING. GIVEN THAT A SPECIFIED EVENT CAN OCCUR, ALL POSSIBLE CAUSES FOR THAT EVENT ARE ARRAYED UNDER IT. IT IS IMPORTANT TO NOTE THAT THIS LISTING INCLUDES ALL POSSIBLE WAYS IN WHICH THE EVENT CAN OCCUR. NEXT, THE RELATIONSHIP OF THESE CAUSATIVE FACTORS TO ONE ANOTHER AND TO THE ULTIMATE EVENT IS EVALUATED AND A DETERMINATION AS TO WHETHER THE DEFINED CAUSES ARE MUTUALLY INDEPENDENT, OR ARE REQUIRED TO COEXIST, IS MADE. THE SYMBOLOGY EMPLOYED TO ILLUSTRATE THE THOUGHT PROCESS IS AS FOLLOWS:

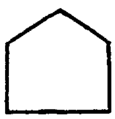
FAILURE/CAUSE STATEMENT - FAILURES ARE SHOWN WITHIN THE LOGIC BLOCKS - TRUE AND FALSE STATEMENTS AND RATIONALE ARE ADJACENT TO THE APPLICABLE BLOCKS.

"OR" GATE - THOSE CAUSES WHICH ARE CAPABLE, INDEPENDENTLY, OF BRINGING ABOUT THE UNDESIRED EVENT ARE ARRAYED HORIZONTALLY BELOW THE "OR" SYMBOLS.

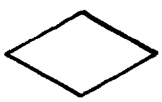
"AND" GATE - THOSE CAUSES WHICH MUST COEXIST ARE ARRAYED HORIZONTALLY BELOW THE "AND" SYMBOLS.



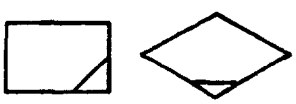
"INHIBIT" GATE - THOSE FACTORS WHICH INTRODUCE ELEMENTS OF CONDITIONAL PROBABILITY, AND WHICH ARE REQUIRED TO COEXIST WITH OTHER CAUSES, ARE DEFINED AS "INHIBIT" FUNCTIONS.



"HOUSE" - THOSE CAUSATIVE FACTORS WHICH ARE NORMALLY EXPECTED TO EXIST, OR TO OCCUR, ARE SHOWN AS "HOUSES".



"DIAMOND" - TERMINATED FOR THIS SUB-BRANCH; FURTHER DEVELOPMENT NOT REQUIRED FOR THIS ANALYSIS.



"CUT CORNER" - INDICATES THIS IS A KEY OR NODAL BLOCK. ANALYSIS OF THESE BLOCKS WAS PERFORMED IN GREATER DEPTH SINCE THEY "CONTROL" SIGNIFICANT PORTIONS OF THE FAULT TREE.

TRUTH STATEMENT CATEGORIZATION:

EACH FAILURE STATEMENT IS REVIEWED TO DETERMINE WHETHER IT IS TRUE OR FALSE. THE TYPE DATA USED TO SUPPORT A STATEMENT BEING TRUE OR FALSE IS IDENTIFIED. IN ADDITION, THE SUPPORTING DATA SOURCES ARE REFERENCED.

CODE KEY

CATEGORY

F = FALSE

T = TRUE

DATA TYPE

FD = PER FLIGHT DATA

A = PER ANALYSIS

GD = PER GROUND DATA

EJ = PER ENGINEERING JUDGEMENT

TE = PER TEST

SL = SUBORDINATE LOGIC (SUPPORTED BY SUB-TIER LOGIC.)

EXAMPLE: F - FD = FALSE PER FLIGHT DATA

REFERENCES:

1. MSC APOLLO INVESTIGATION TEAM PANEL 1, PRELIMINARY REPORT, DATED APRIL 1970
2. APOLLO 13 UNPUBLISHED FLIGHT DATA, AVAILABLE AT NASA/MSC BUILDING 45, 3RD FLOOR, DATA ROOM
3. NASA/MSC TPS 13-T-58, IGNITION OF DESTRATIFICATION MOTOR TEST
4. MSC APOLLO INVESTIGATION TEAM PANEL 1, APOLLO 13 CRYOGENIC OXYGEN TANK 2 ANOMALY REPORT (INTERIM DRAFT), DATED MAY 22, 1970
5. NASA/MSC TPS 13-T-53, HEATER ASSEMBLY TEMPERATURE PROFILE
6. NASA/MSC TPS 13-T-59, OXYGEN TANK IGNITION SIMULATION

LIST OF ABBREVIATIONS

AL.	-	ALUMINUM
ASSY	-	ASSEMBLY
CAP	-	CAPABILITY
CRYO	-	CRYOGENIC
CU	-	COPPER
ECS	-	ENVIRONMENTAL CONTROL SYSTEM
ELEC	-	ELECTRICAL
EOI	-	EARTH ORBIT INSERTION
EPS	-	ELECTRICAL POWER SYSTEM
FAB	-	FABRICATION
FC	-	FUEL CELL
FIG.	-	FIGURE
GEN	-	GENERATE OR GENERATED
H_2	-	HYDROGEN
H_2O	-	WATER
MECH	-	MECHANICAL
MSC	-	MANNED SPACECRAFT CENTER
NASA	-	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NEG.	-	NEGATIVE
NO.	-	NUMBER
O_2	-	OXYGEN
OS-X	-	OXYGEN SUPPLY CONNECTION 1, 2 OR 3
PARA.	-	PARAGRAPH
PRELIM.	-	PRELIMINARY
PRESS	-	PRESSURE OR PRESSURIZED
QTY	-	QUANTITY
REF.	-	REFERENCE
RF	-	RADIO FREQUENCY
S/C	-	SPACECRAFT
SM	-	SERVICE MODULE
STRUCT	-	STRUCTURE OR STRUCTURAL
SYS	-	SYSTEM
TEMP	-	TEMPERATURE

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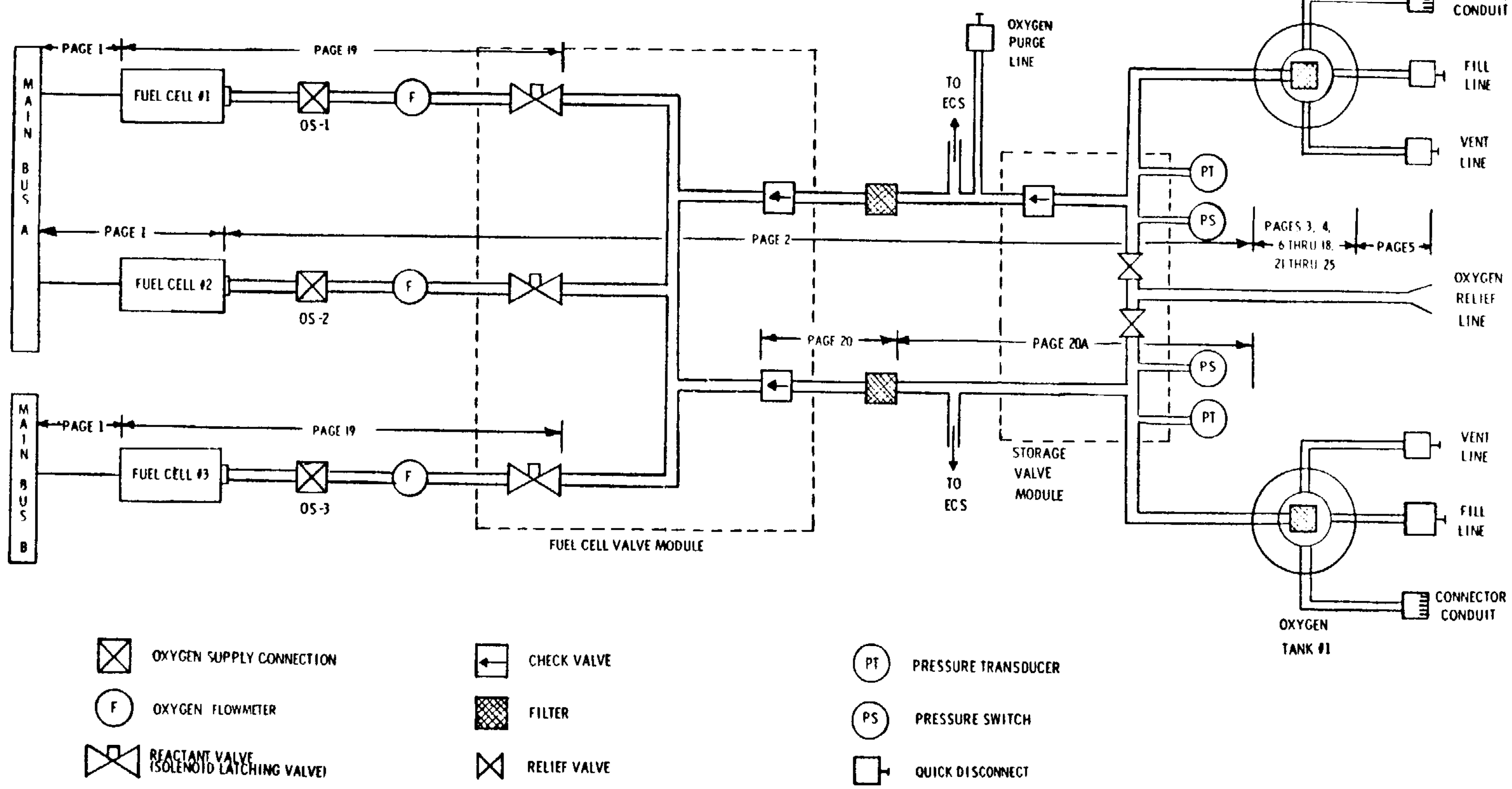
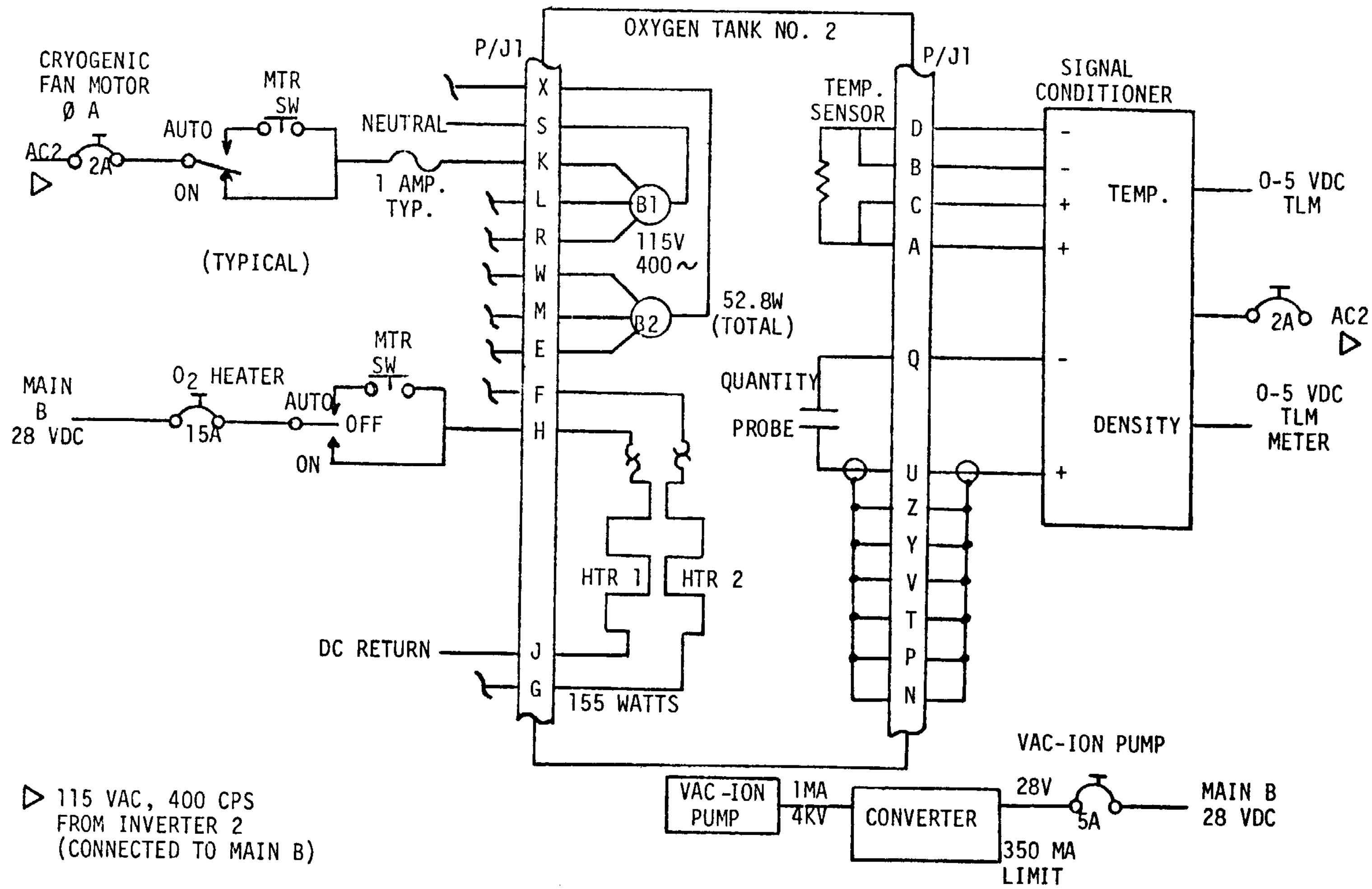
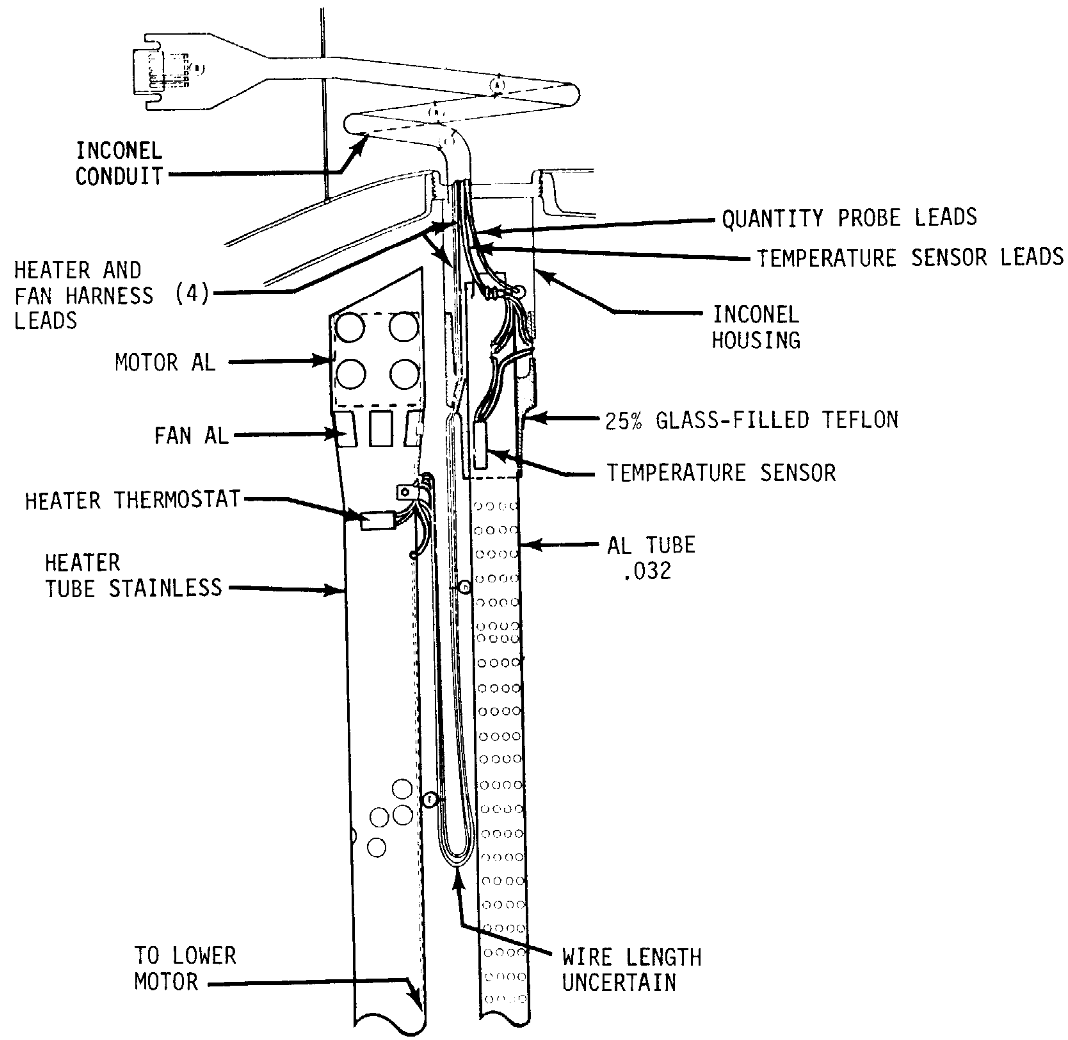
SIMPLIFIED SCHEMATIC OF EPS AND CRYOGENIC OXYGEN SYSTEM





OXYGEN TANK NO. 2 ELECTRICAL SCHEMATIC



UPPER HEATER AND PROBE ASSEMBLY

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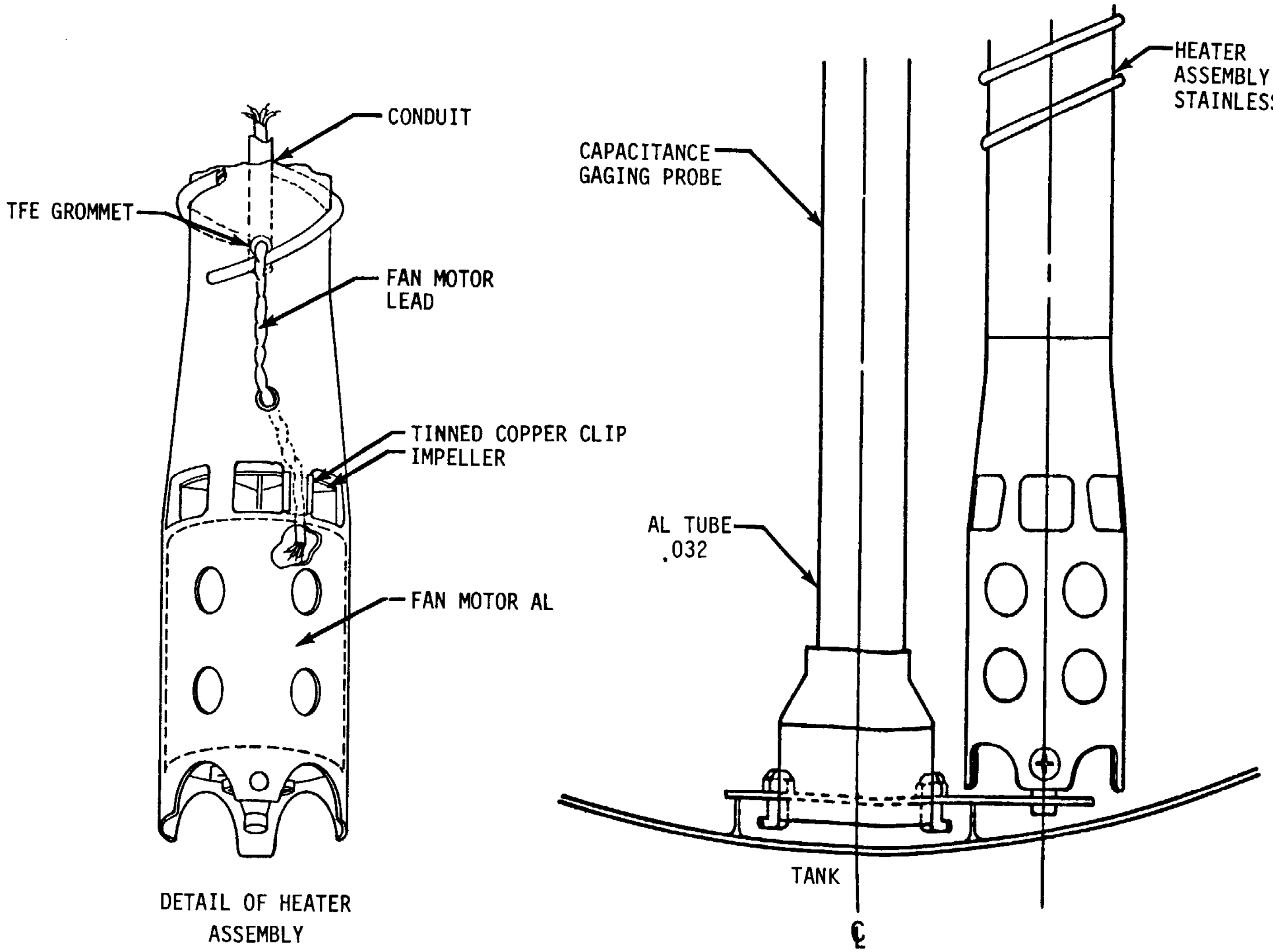
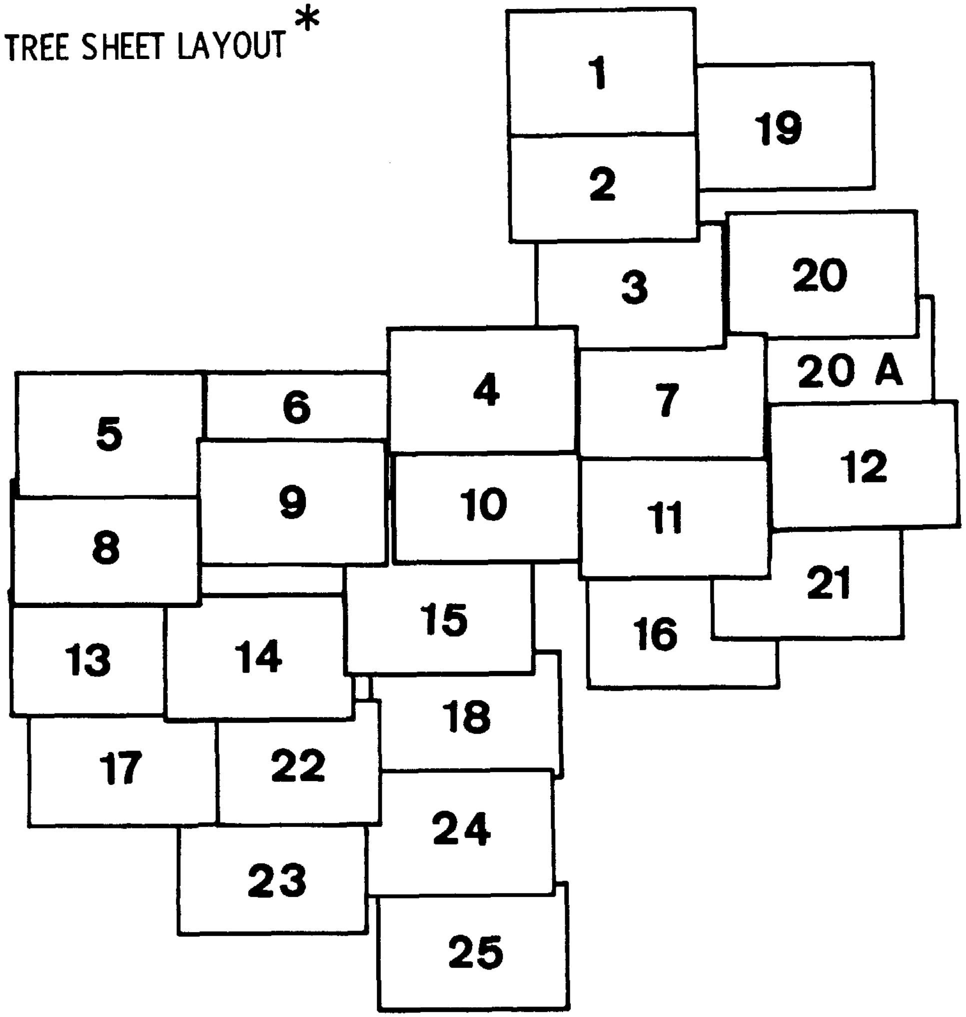


LOWER HEATER AND PROBE ASSEMBLY

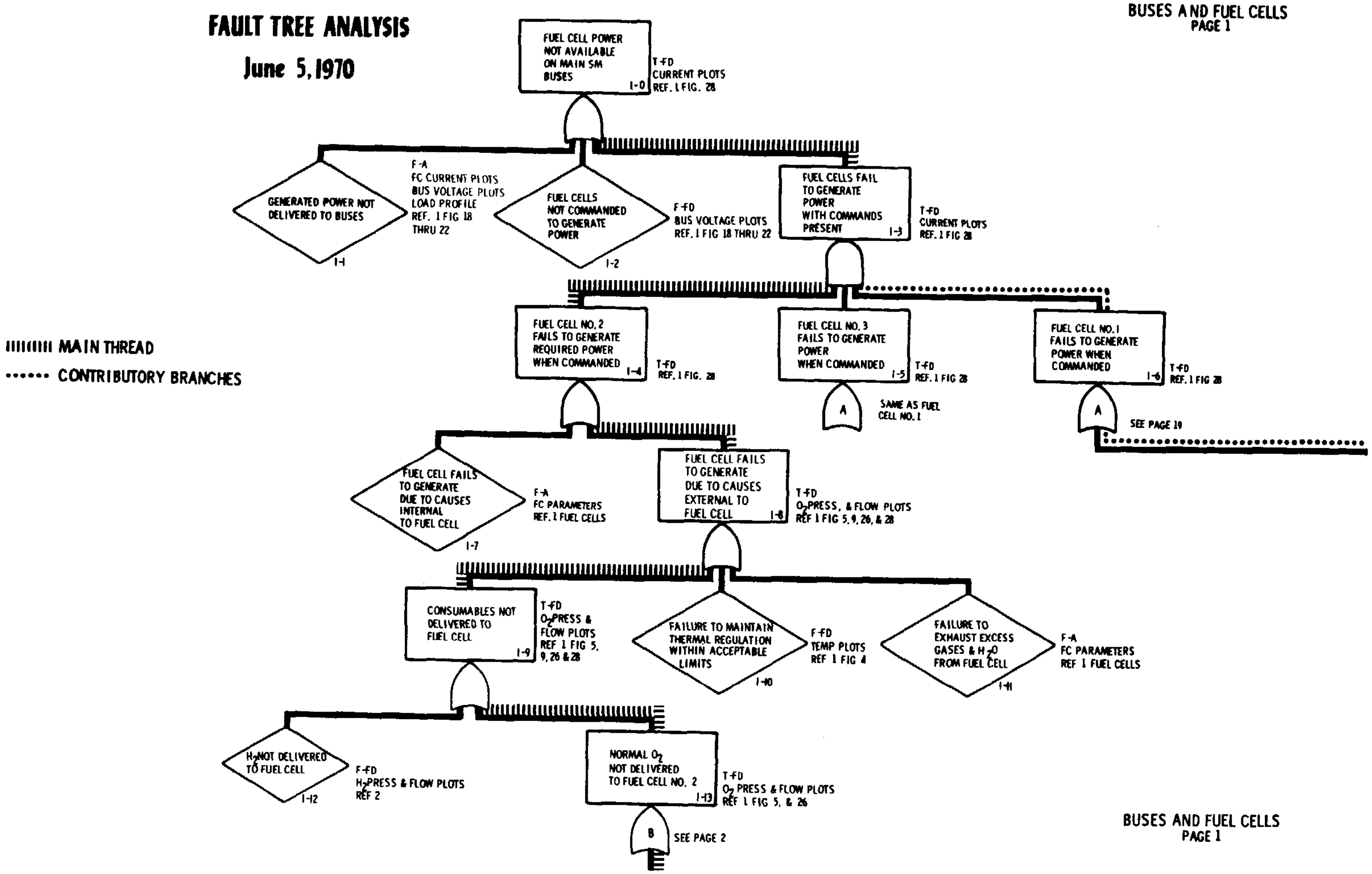
FAULT TREE SHEET LAYOUT*



*TO ASSEMBLE FAULT TREE, LAYOUT PAGES IN THE POSITIONS SHOWN ABOVE

FAULT TREE ANALYSIS

June 5, 1970



BUSES AND FUEL CELLS
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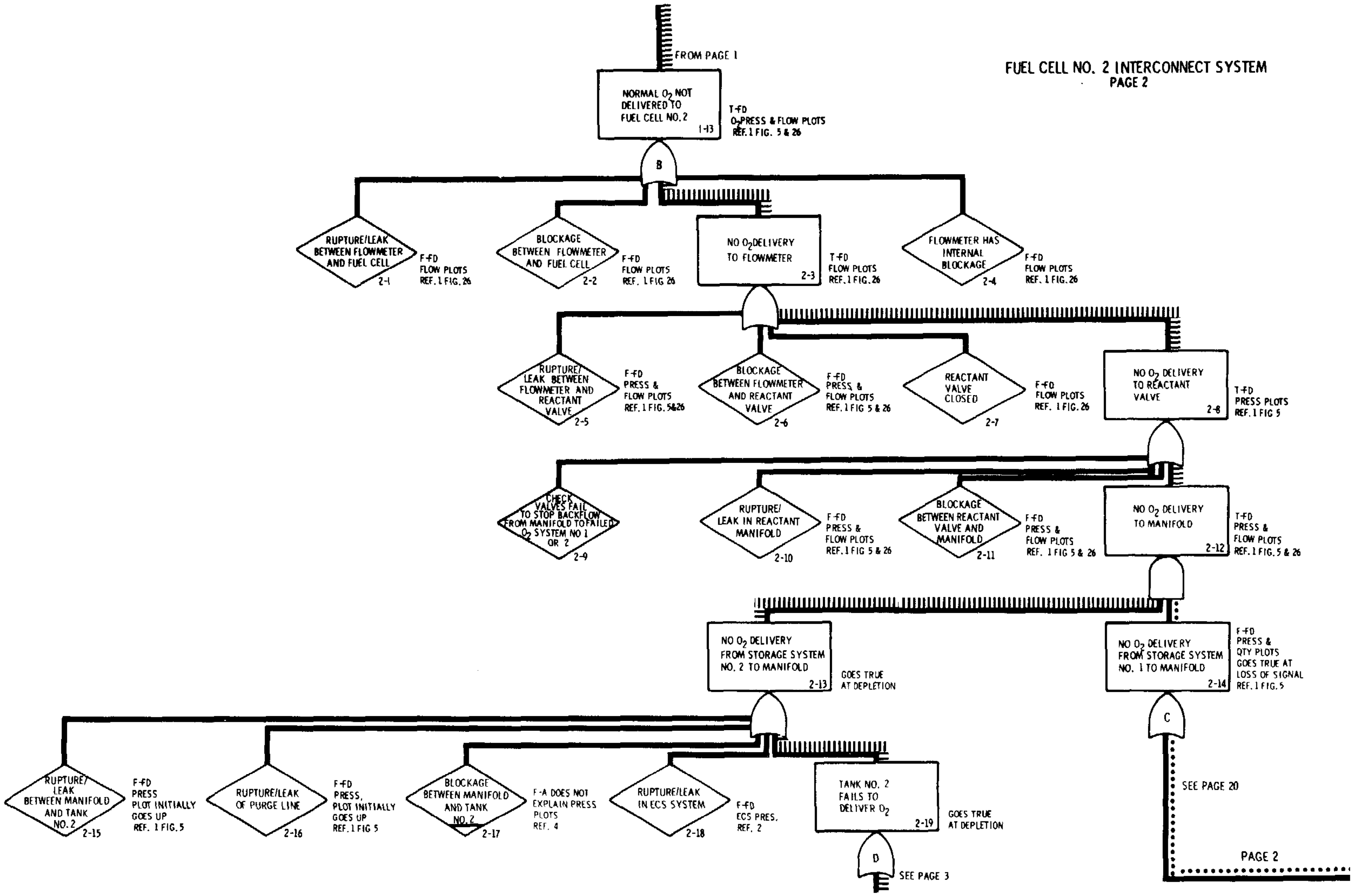

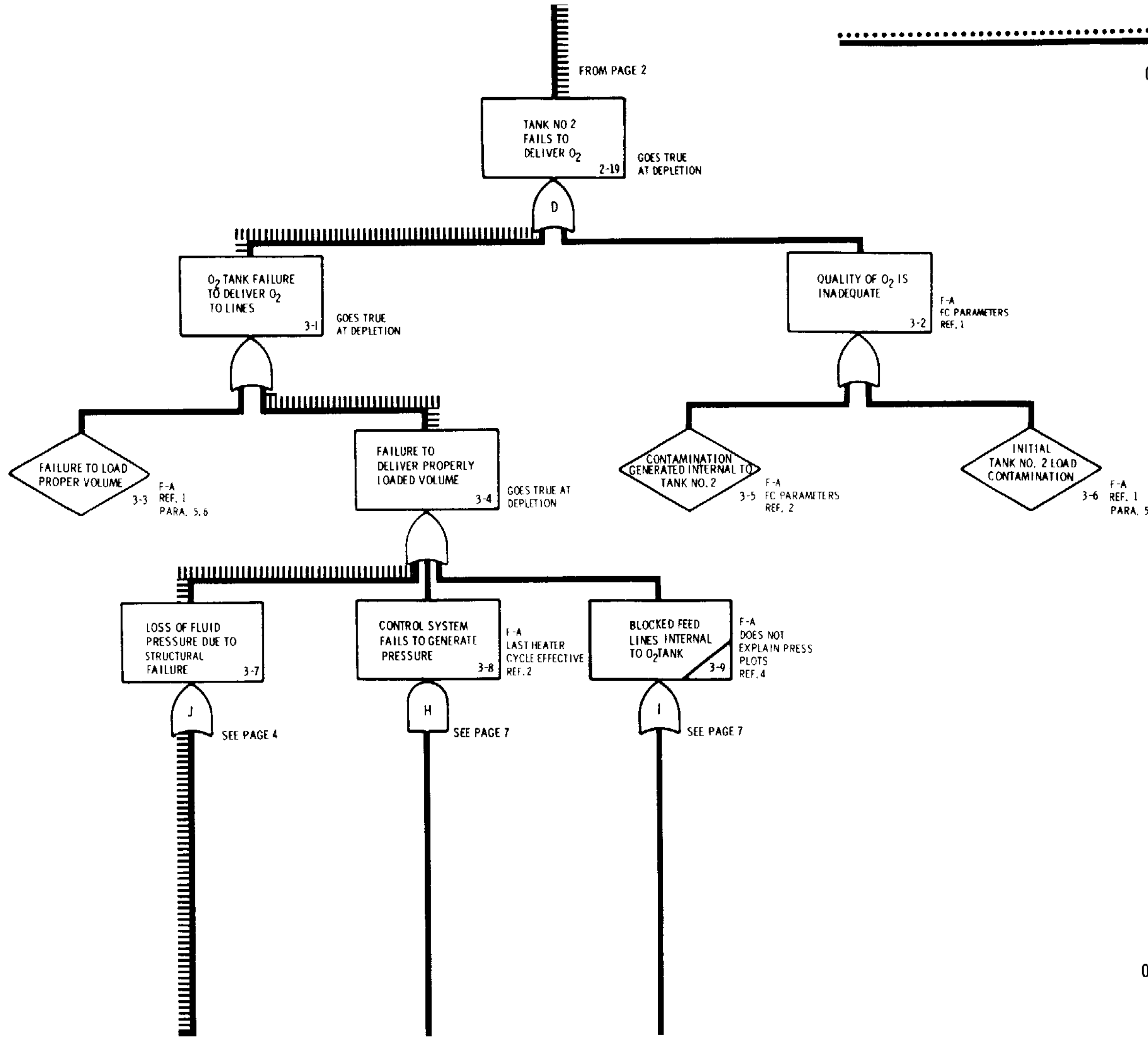

O_2 TANK NO. 2
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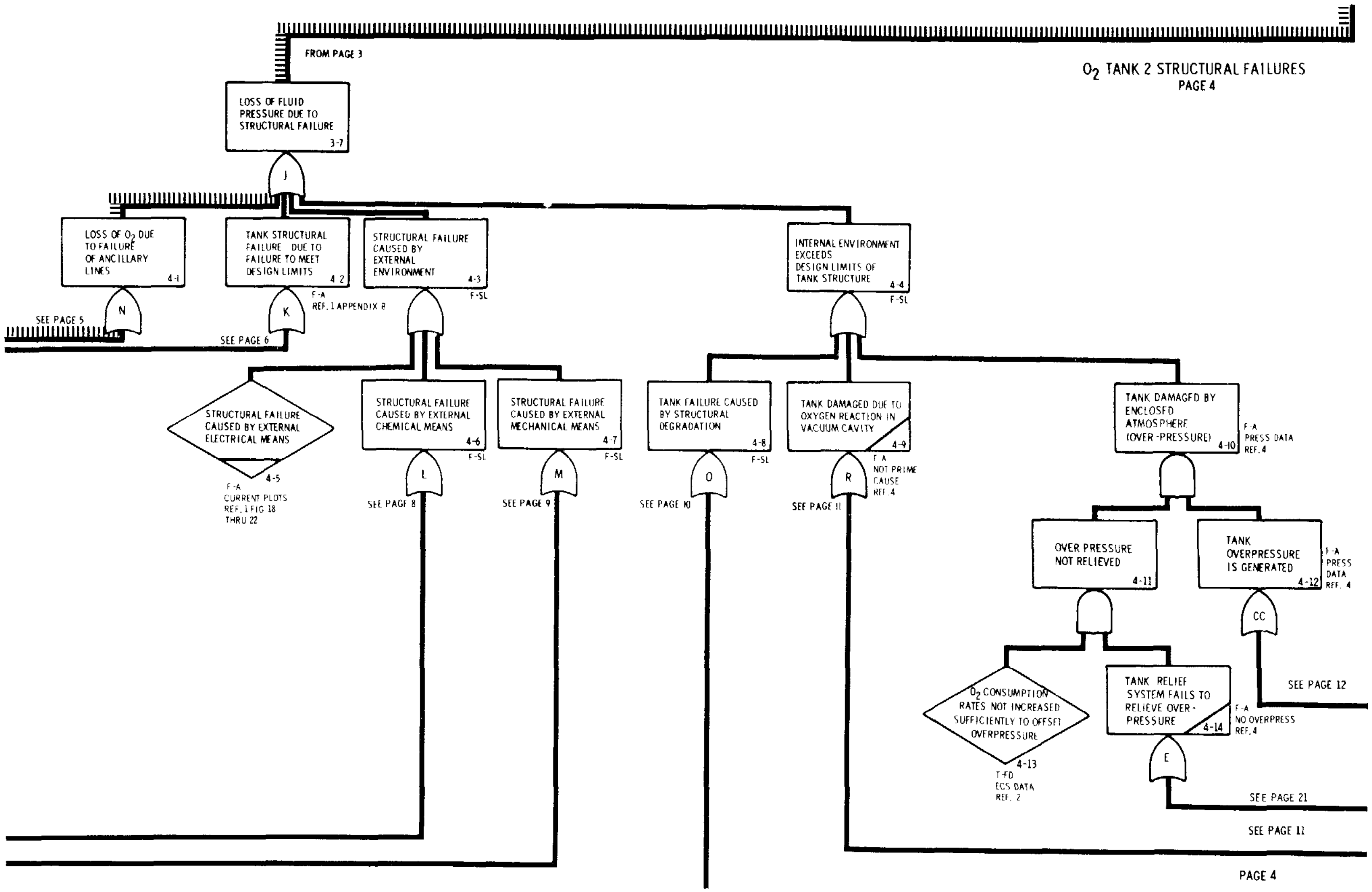

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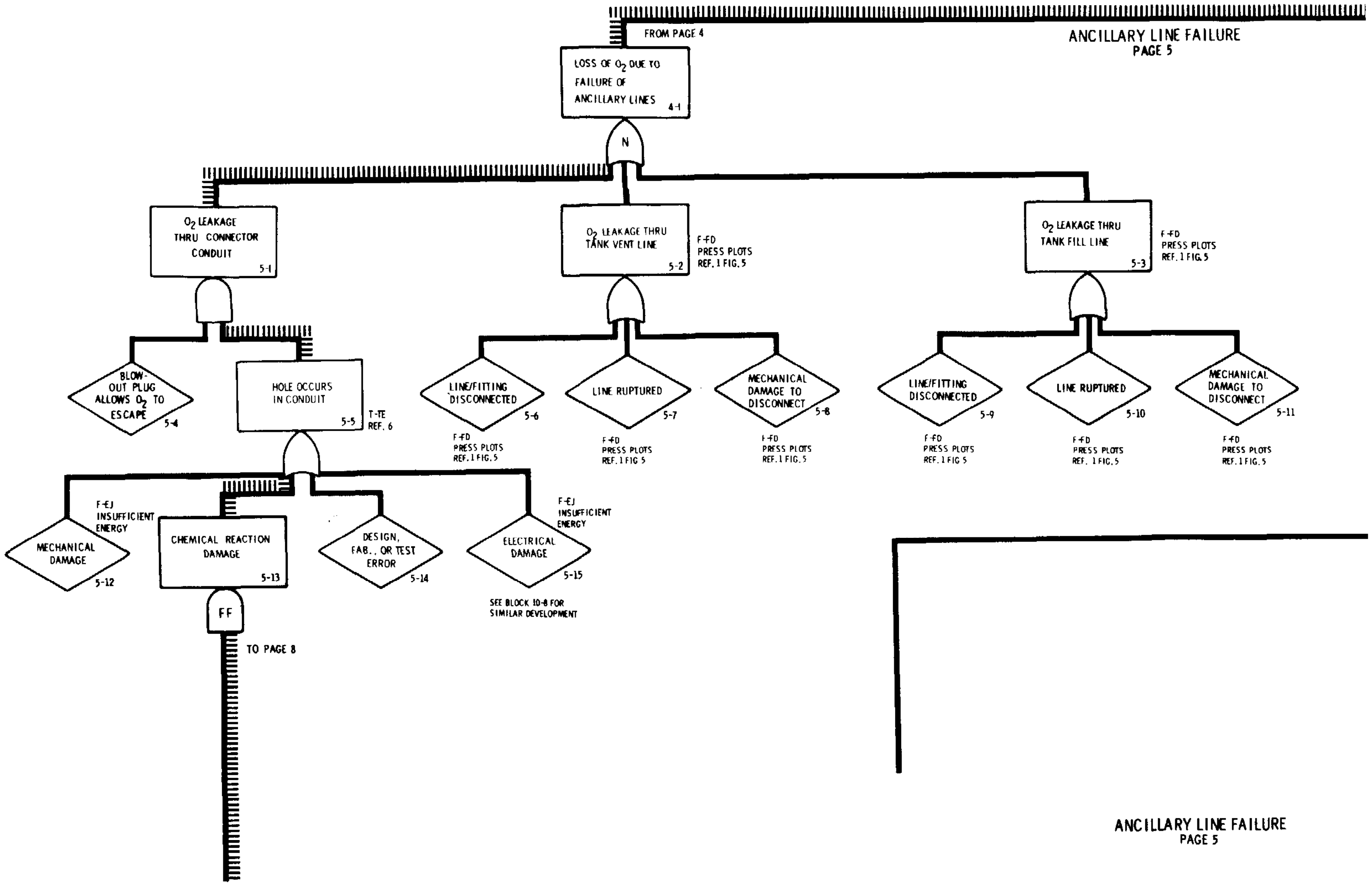

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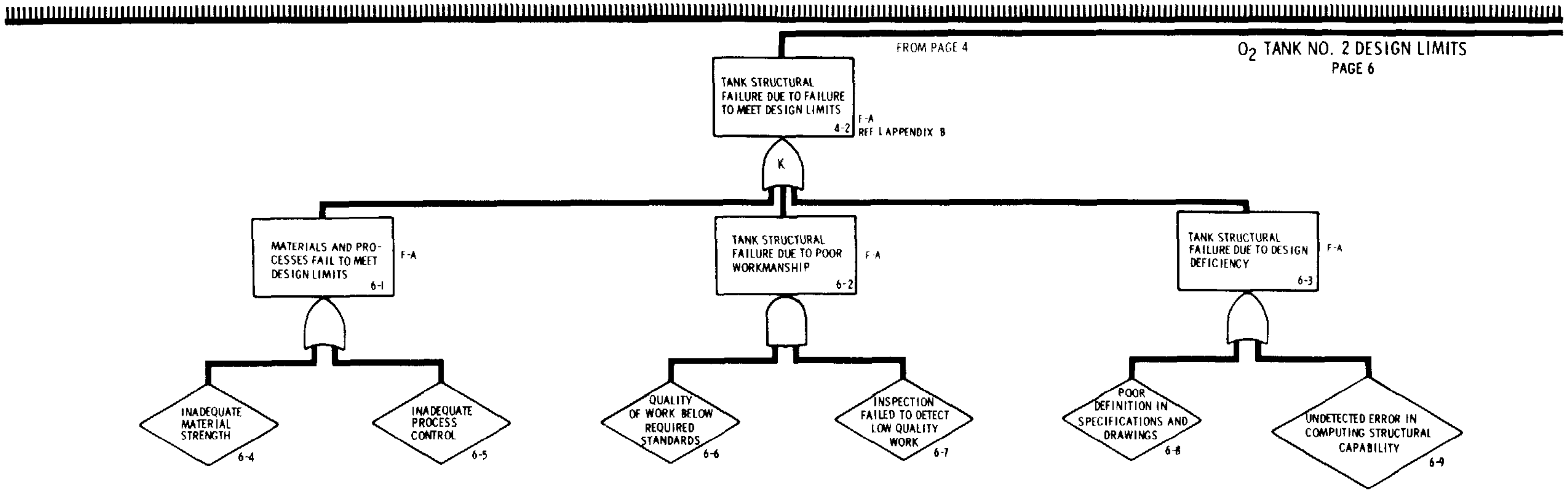

O_2 TANK NO. 2 DESIGN LIMITS
PAGE 6

COMPONENTS: O_2 TANK NO. 2
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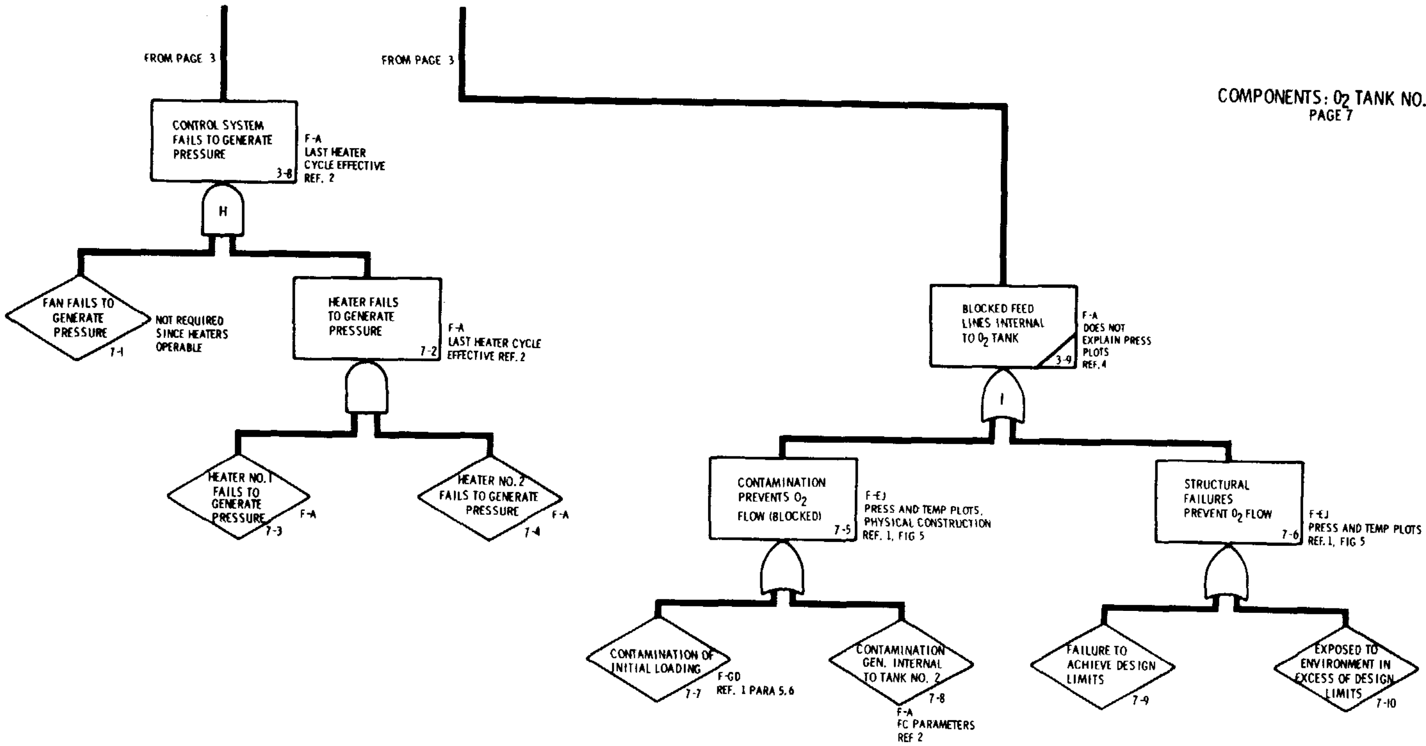

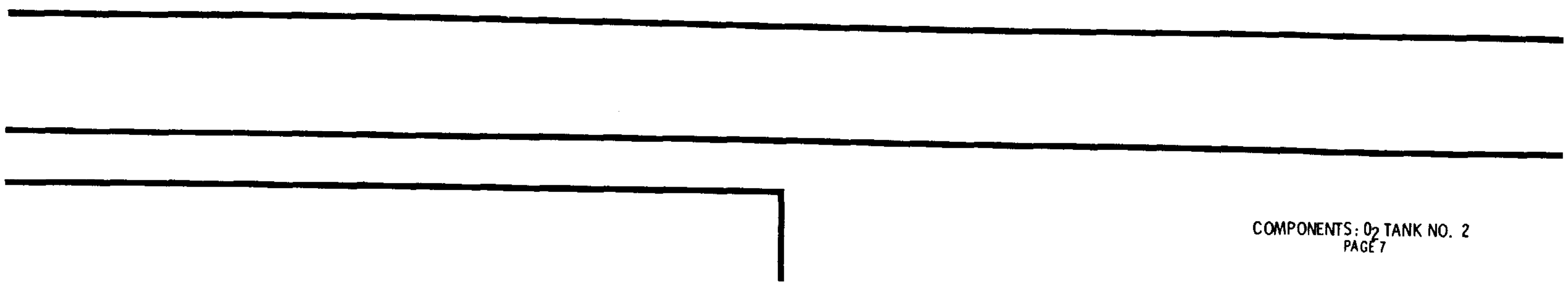

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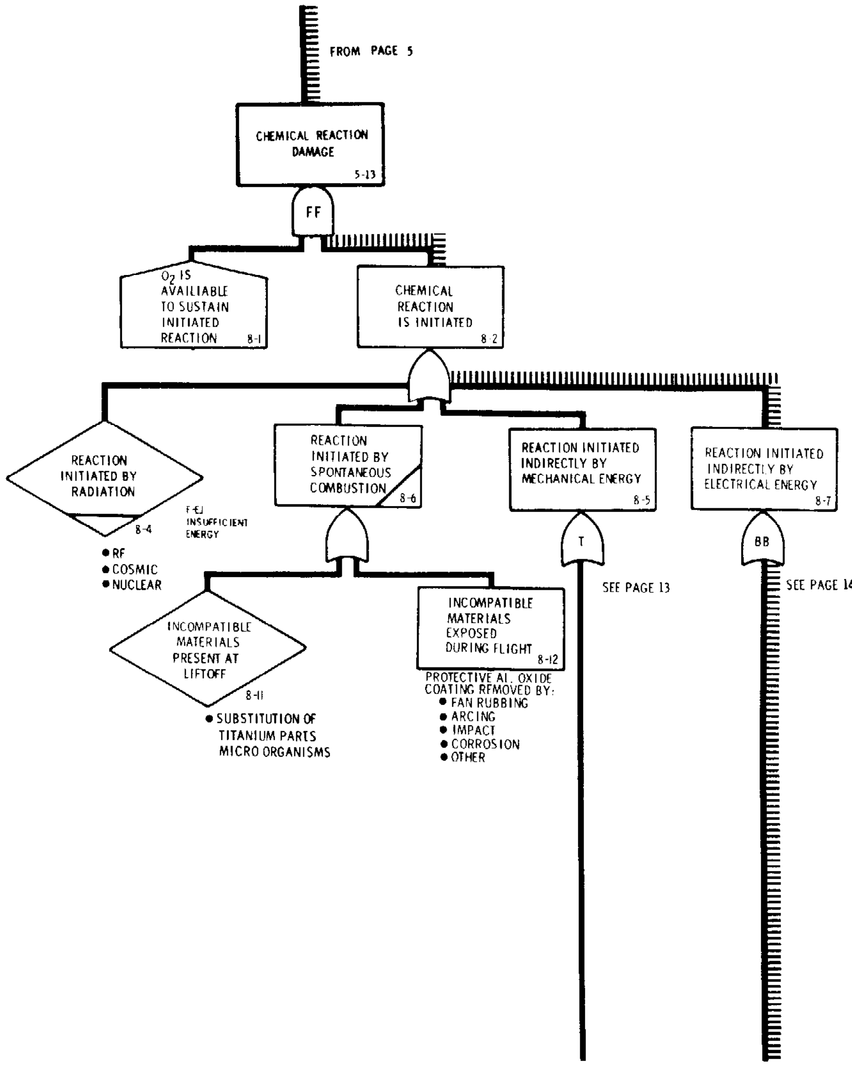
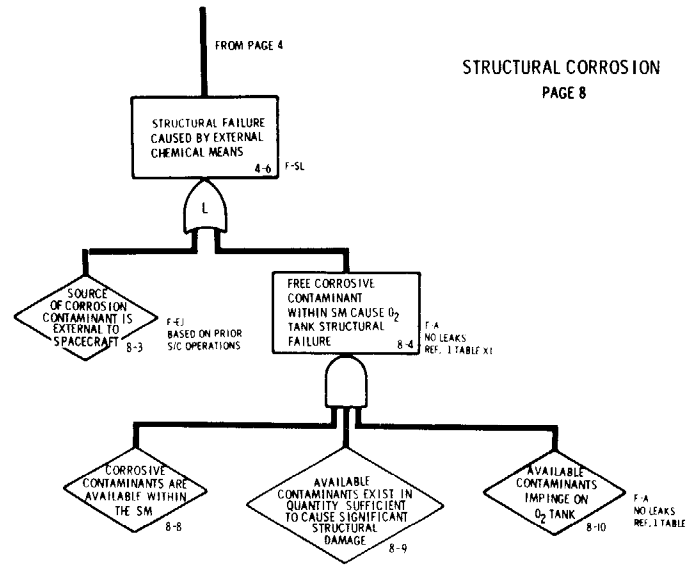
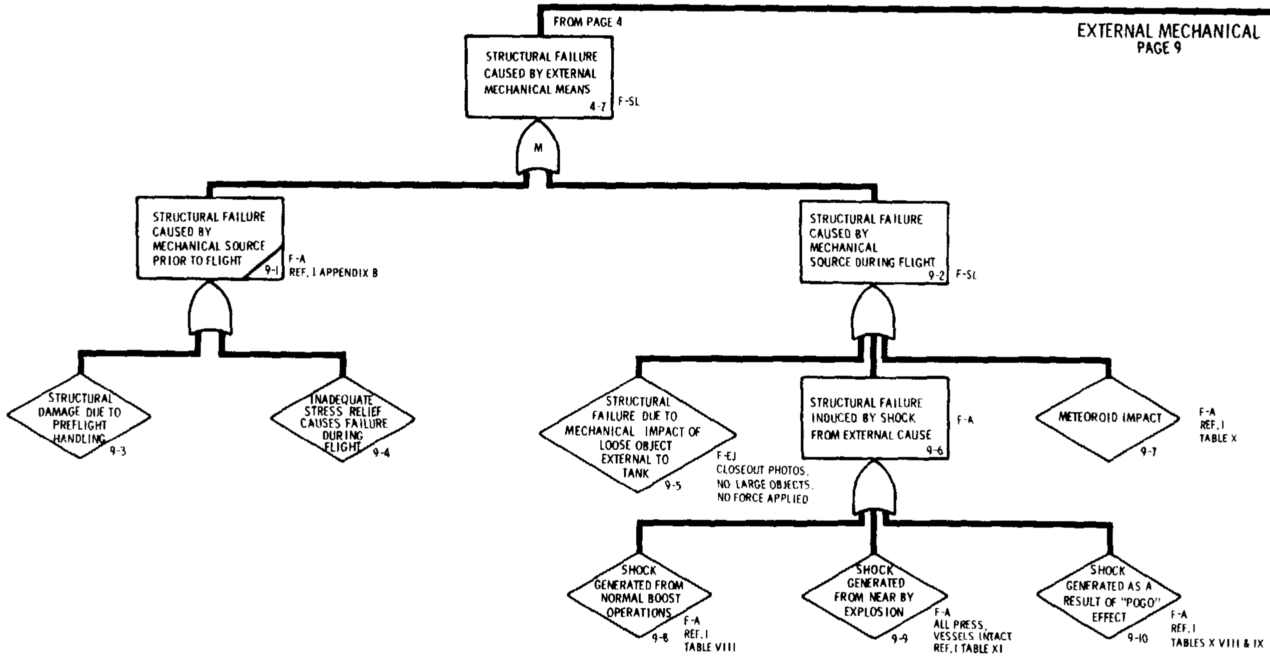




STRUCTURAL CORROSION
PAGE 8



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INTERNAL TANK STRUCTURAL DEGRADATION
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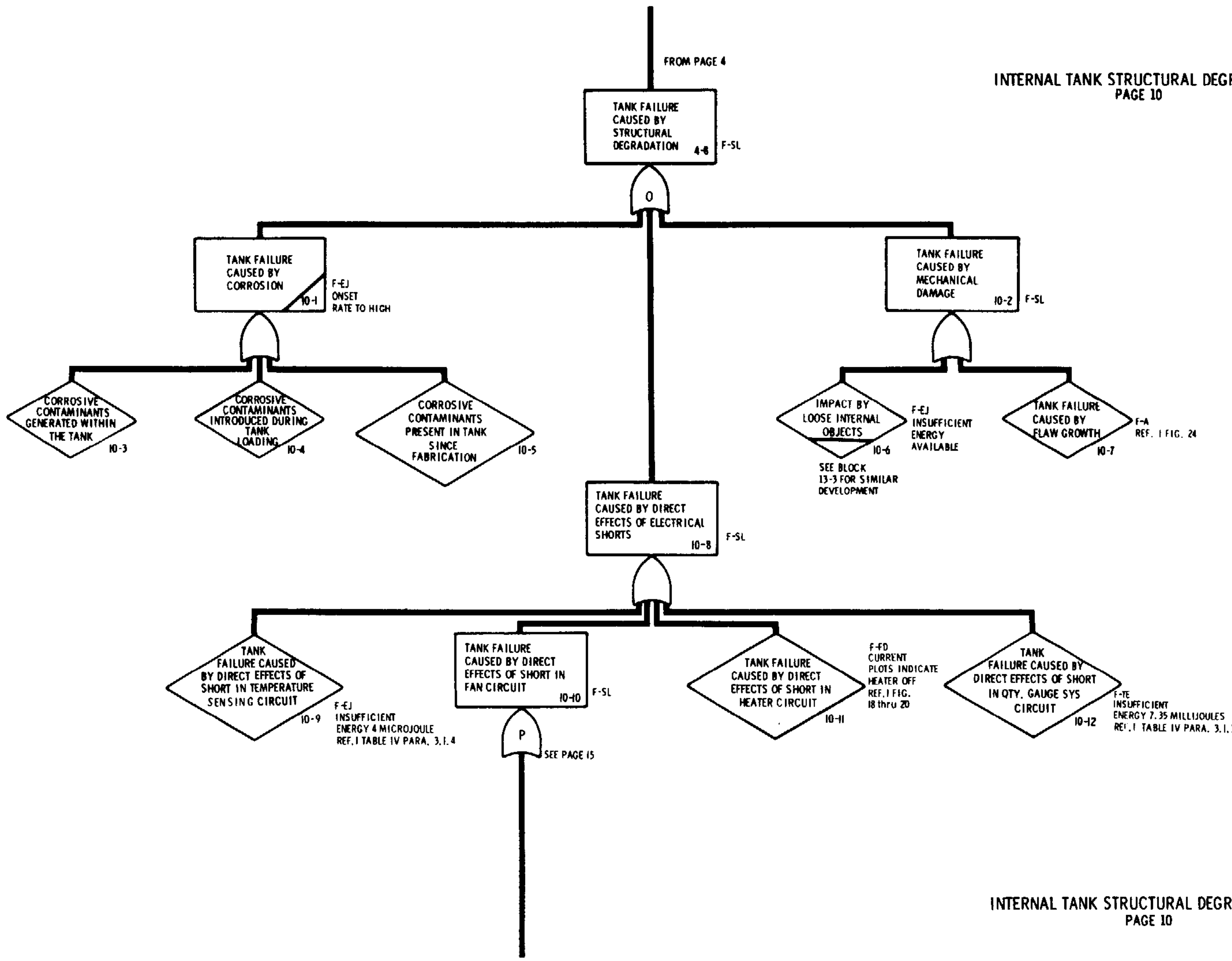

INTERNAL TANK STRUCTURAL DEGRADATION
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O_2 TANK NO. 2 VACUUM JACKET CAVITY
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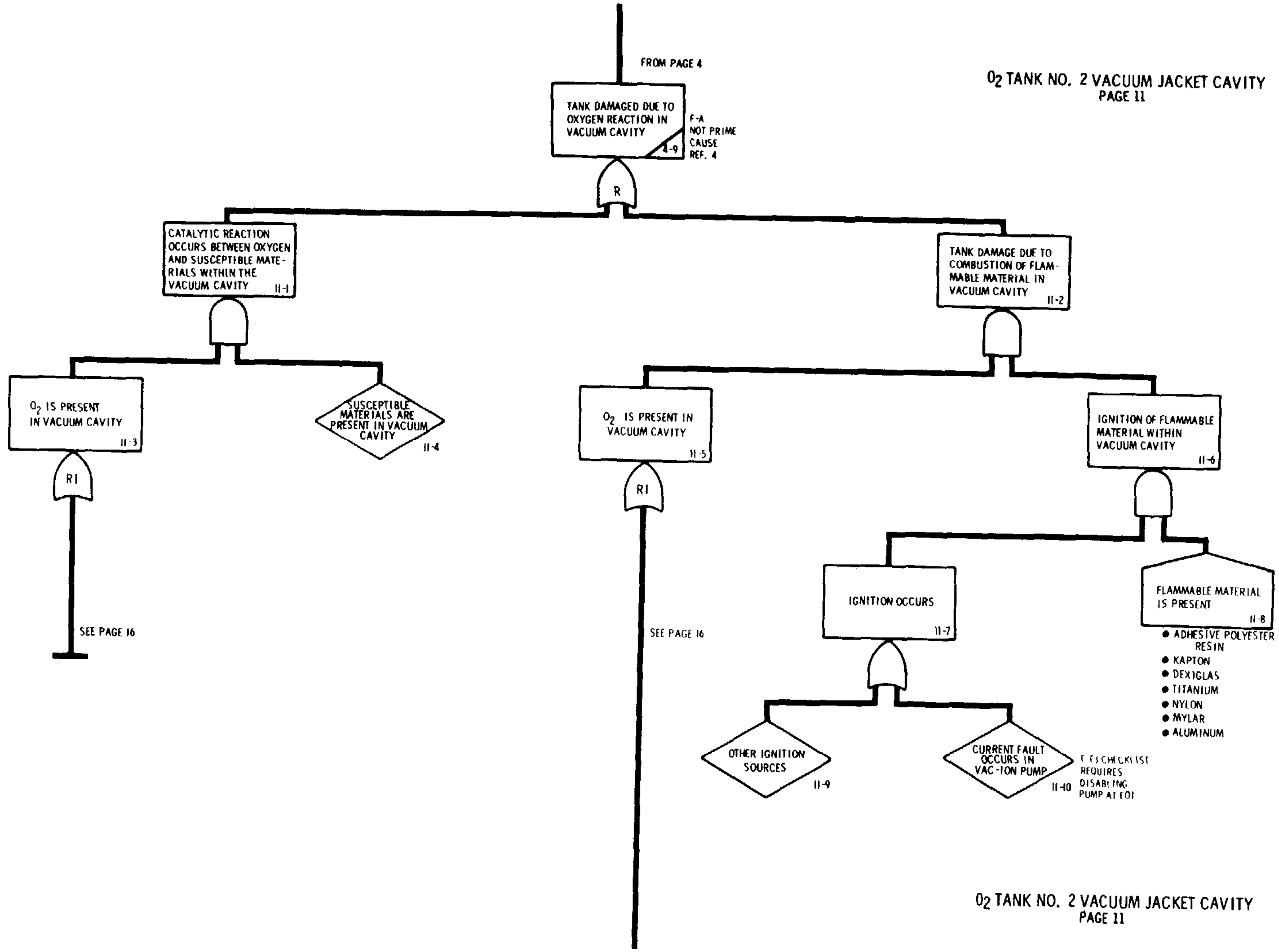

O_2 TANK NO. 2 VACUUM JACKET CAVITY
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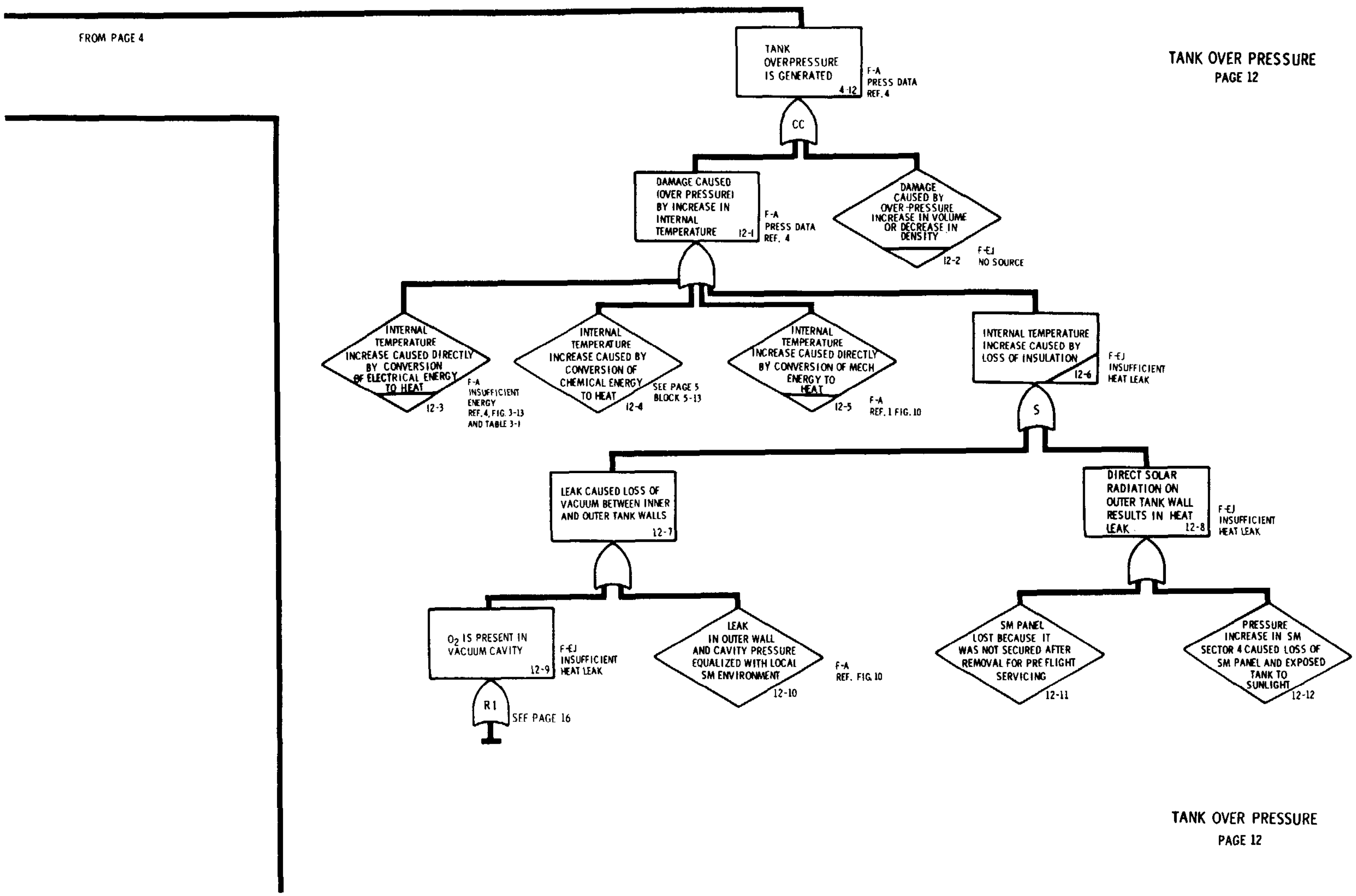

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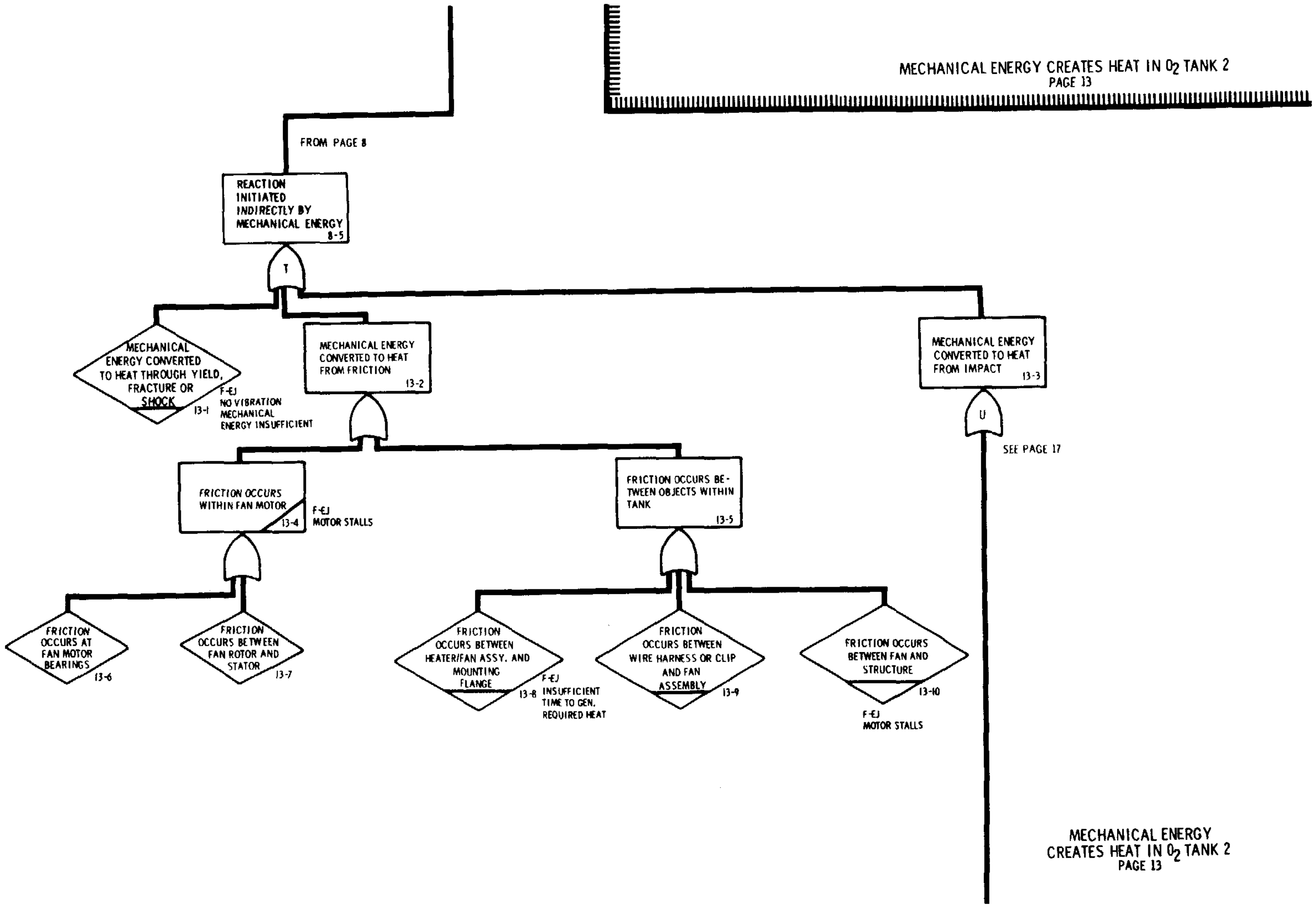
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F-EJ MOTOR STALLS
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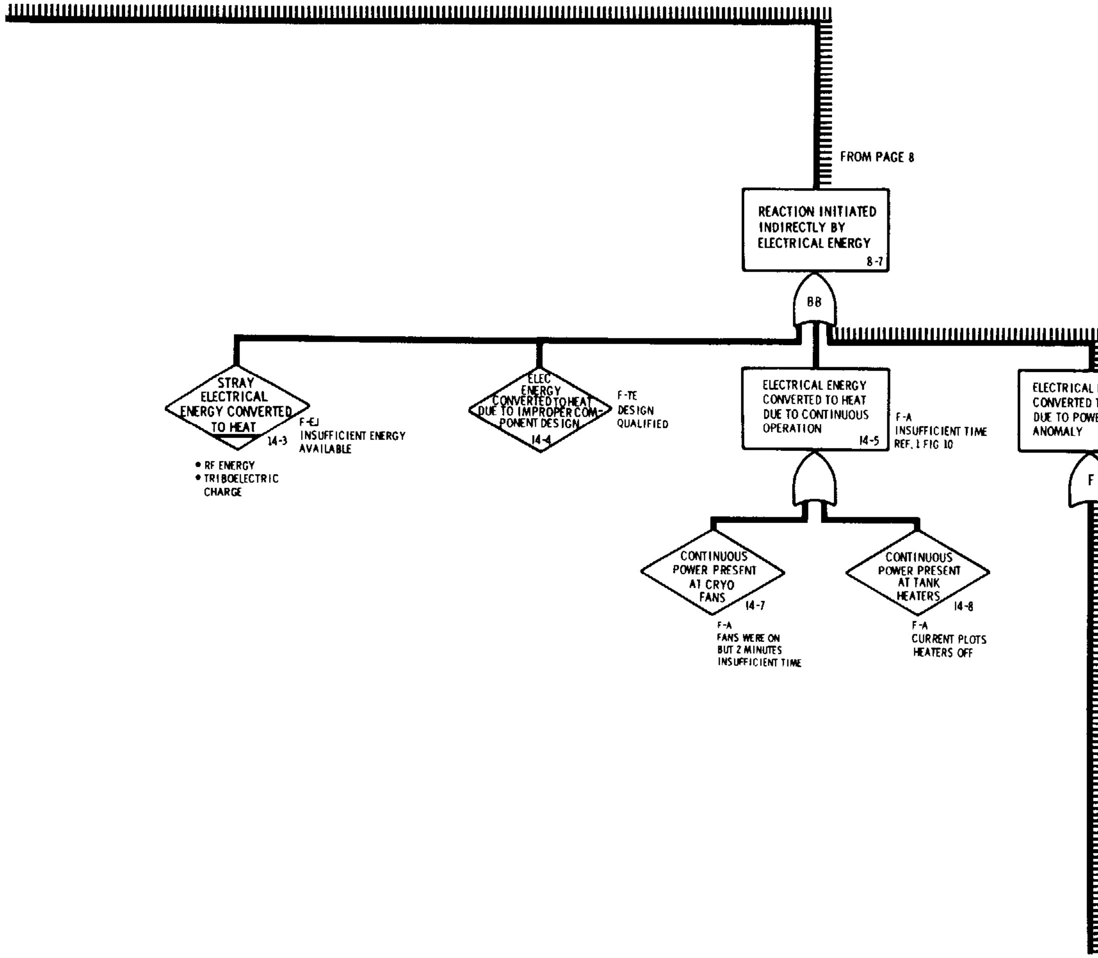

ELECTRICAL ENERGY CREATES HEAT IN O_2 TANK NO. 2
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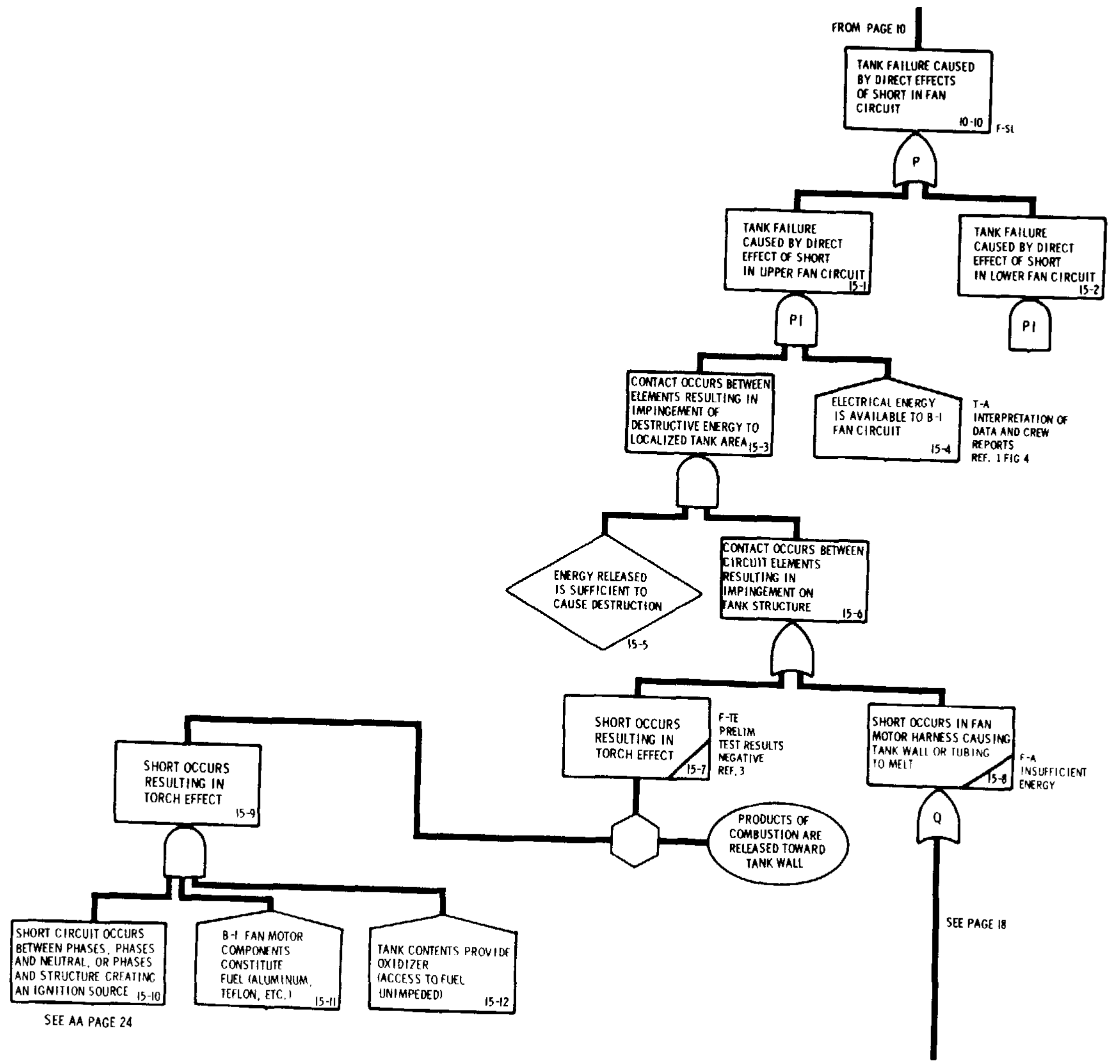

FANS MOTOR SHORT-TORCH EFFECT
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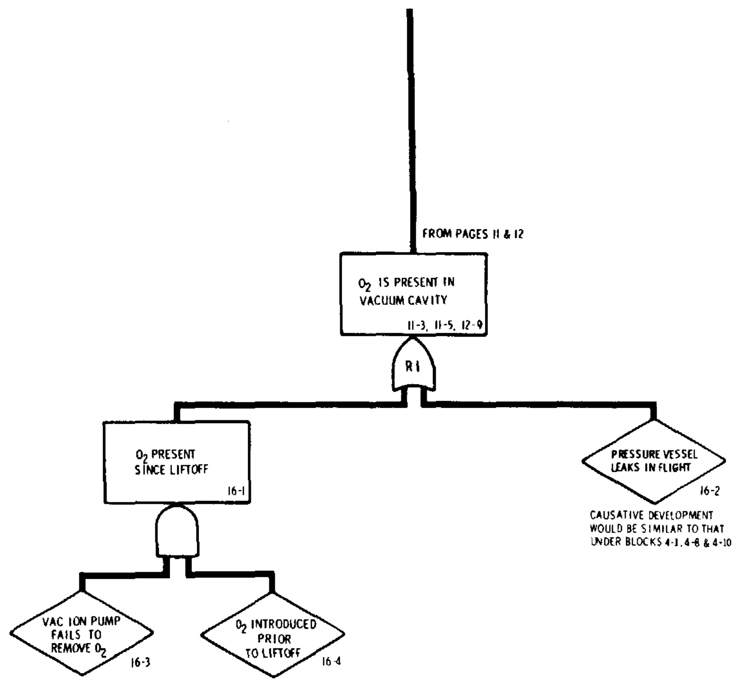

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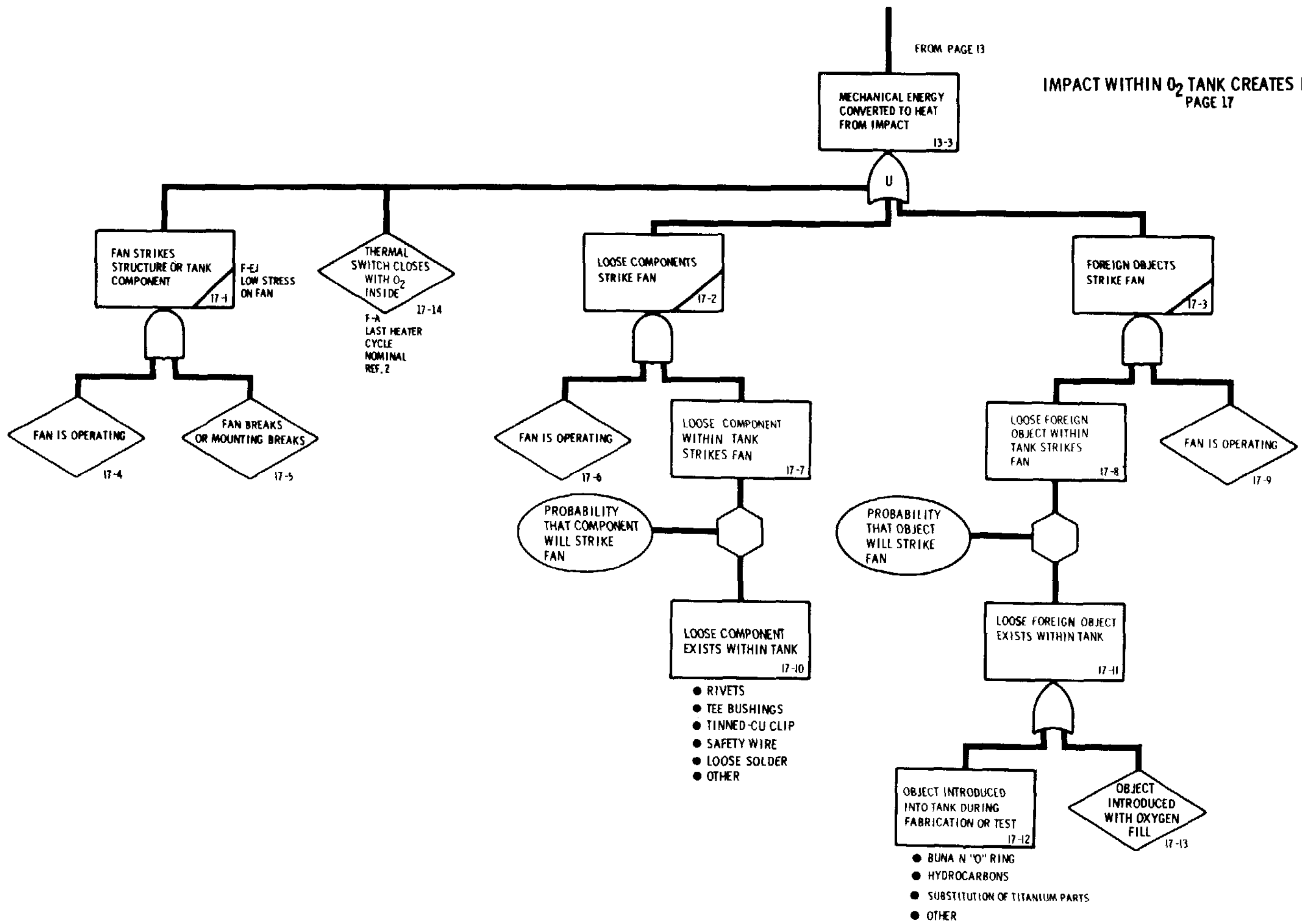

IMPACT WITHIN O_2 TANK CREATES HEAT
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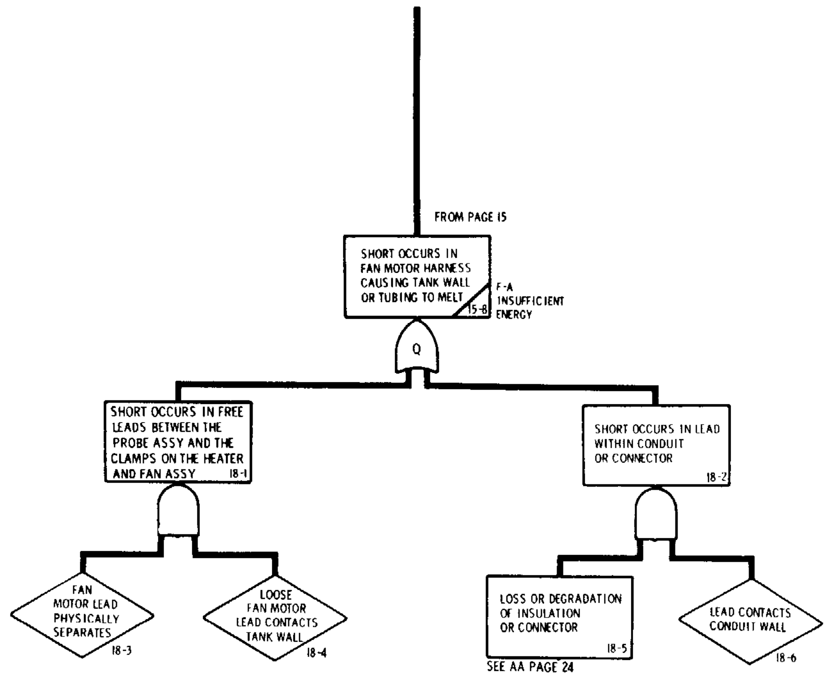
IMPACT WITHIN O_2 TANK CREATES HEAT
PAGE 17



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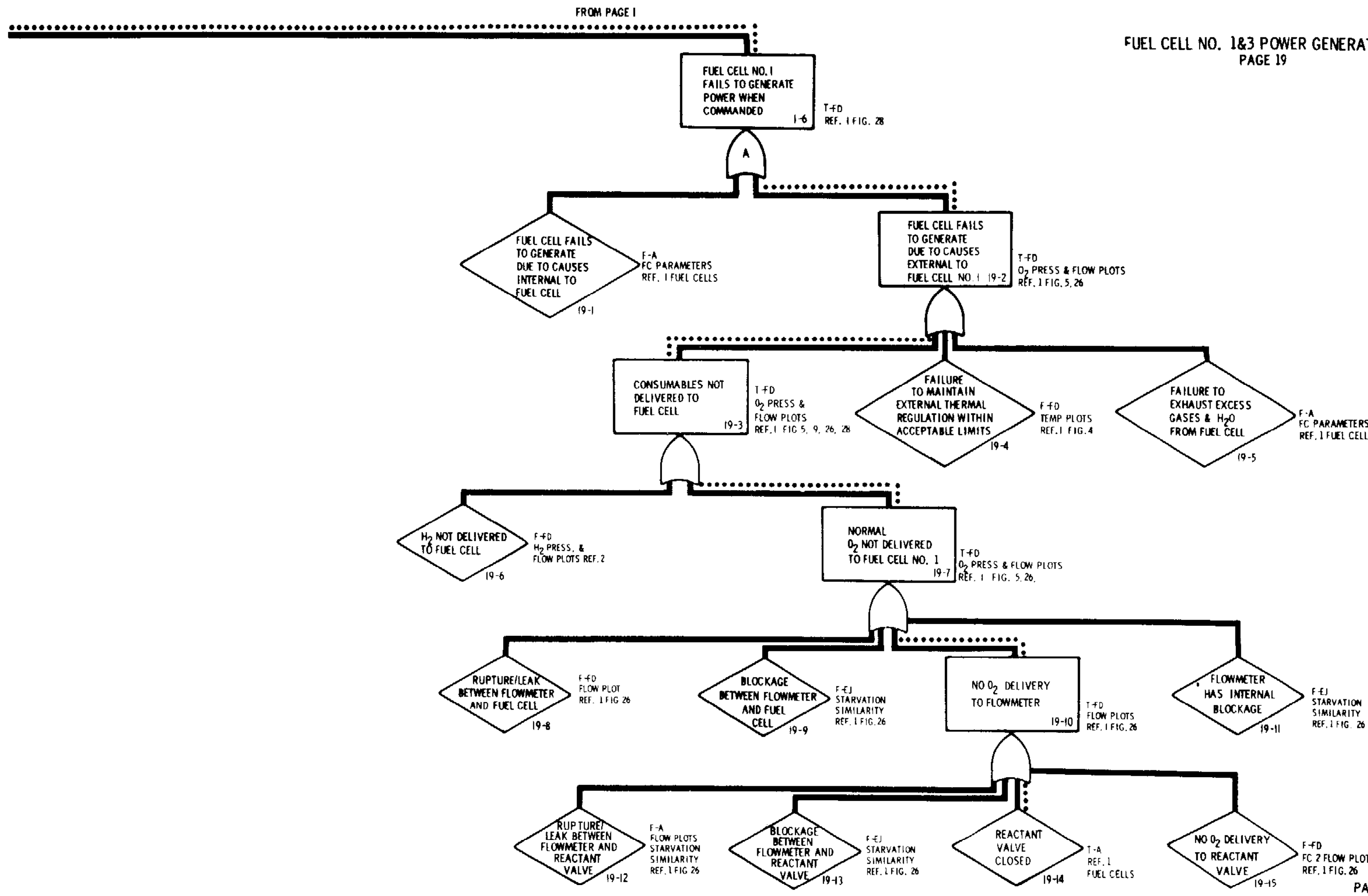
FROM PAGE I
FUEL CELL NO. I FAILS TO GENERATE POWER WHEN COMMANDED 1-6
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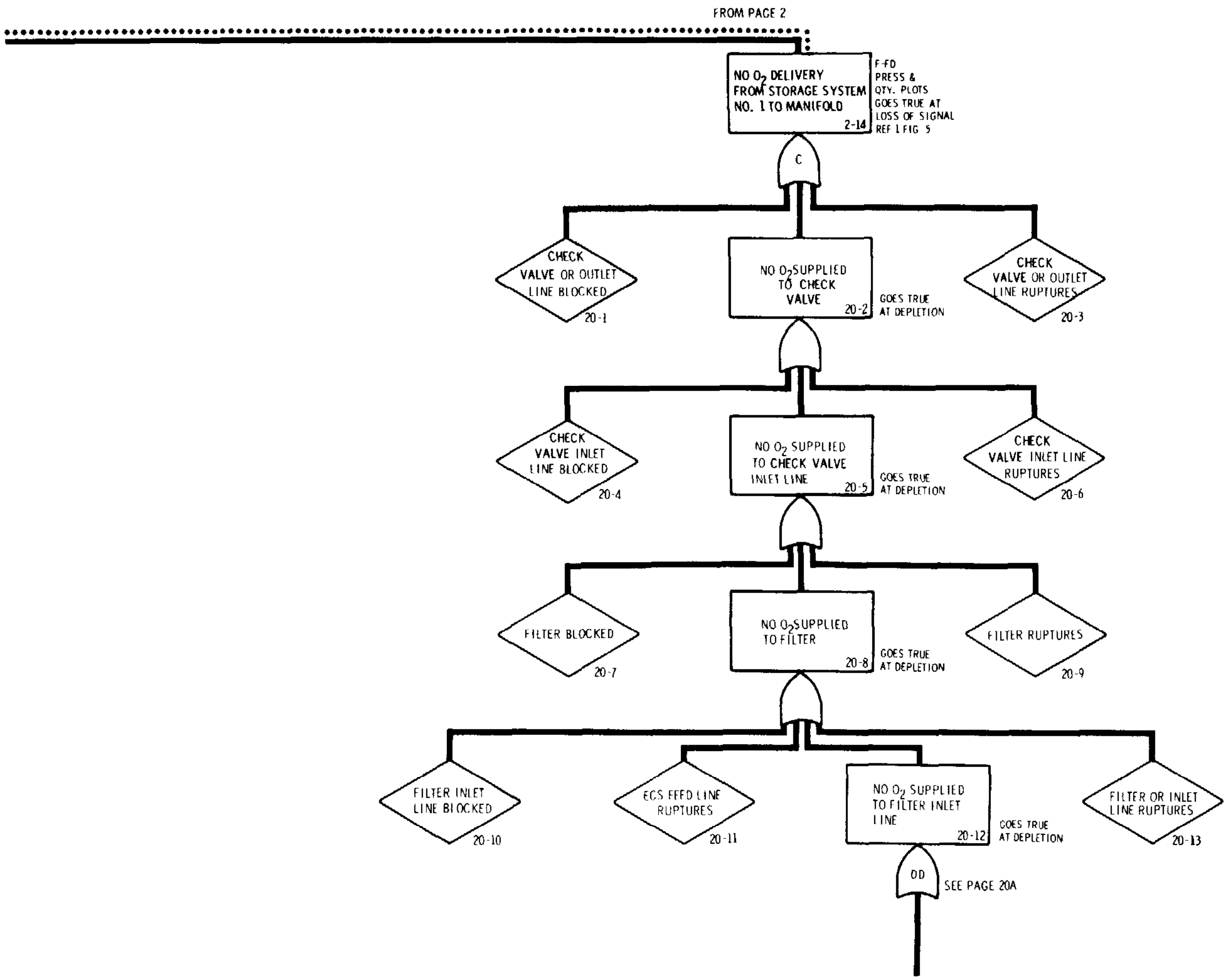

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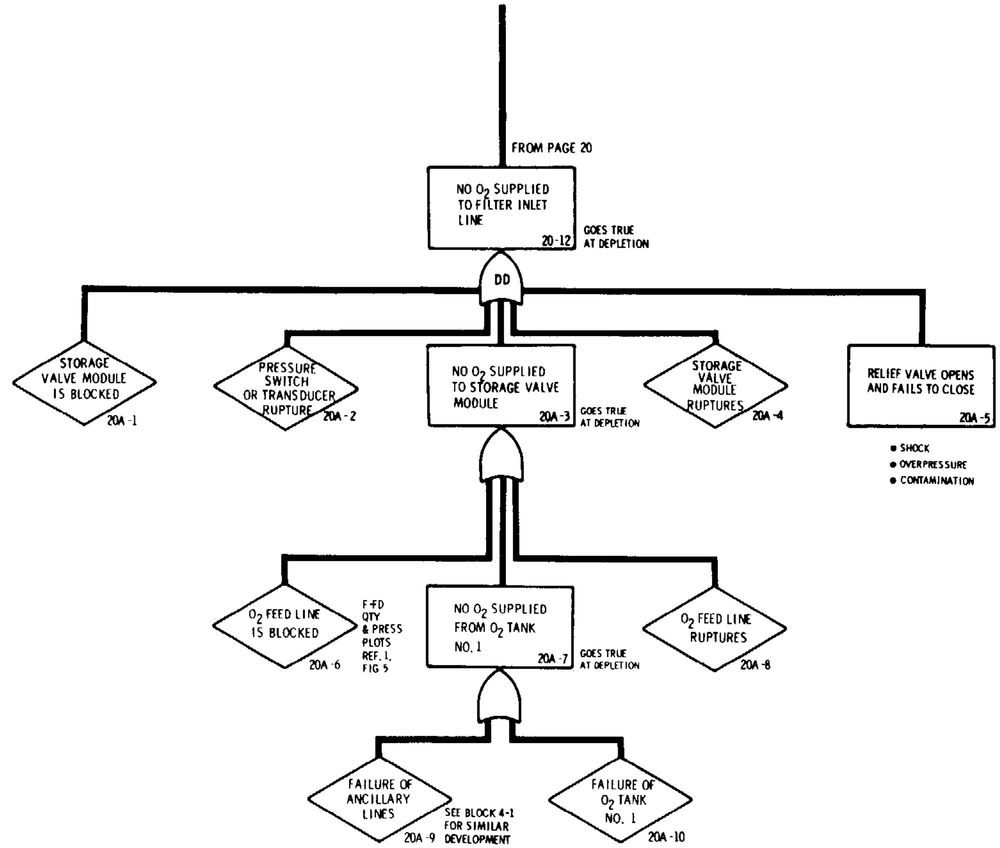

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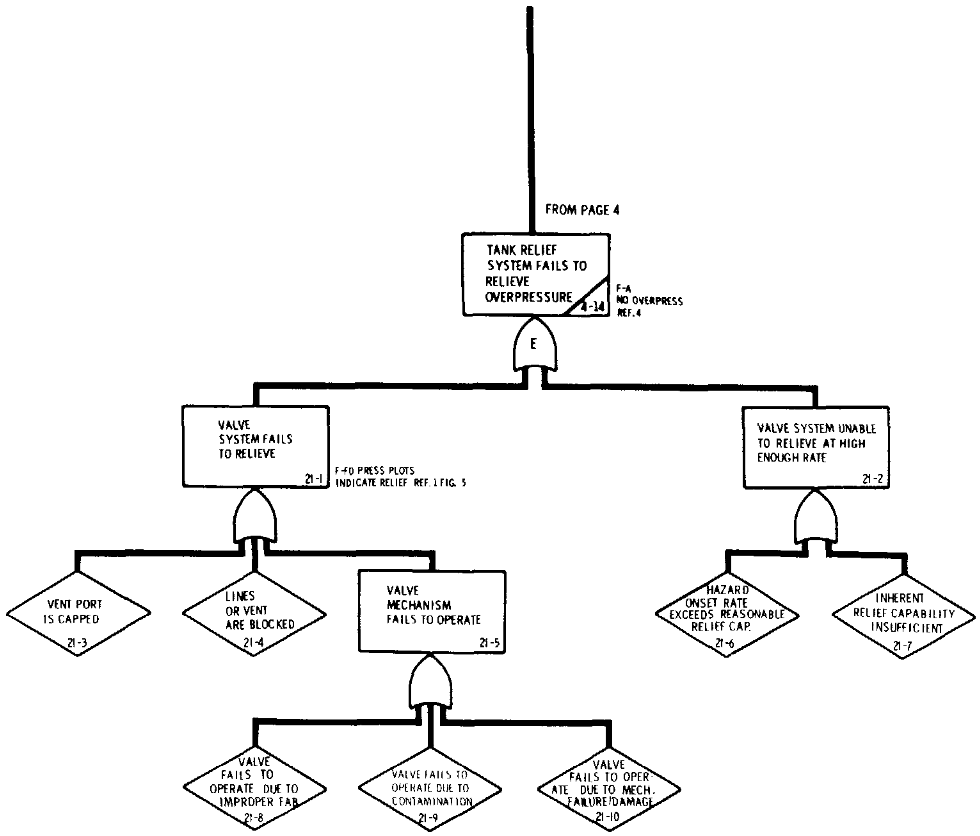

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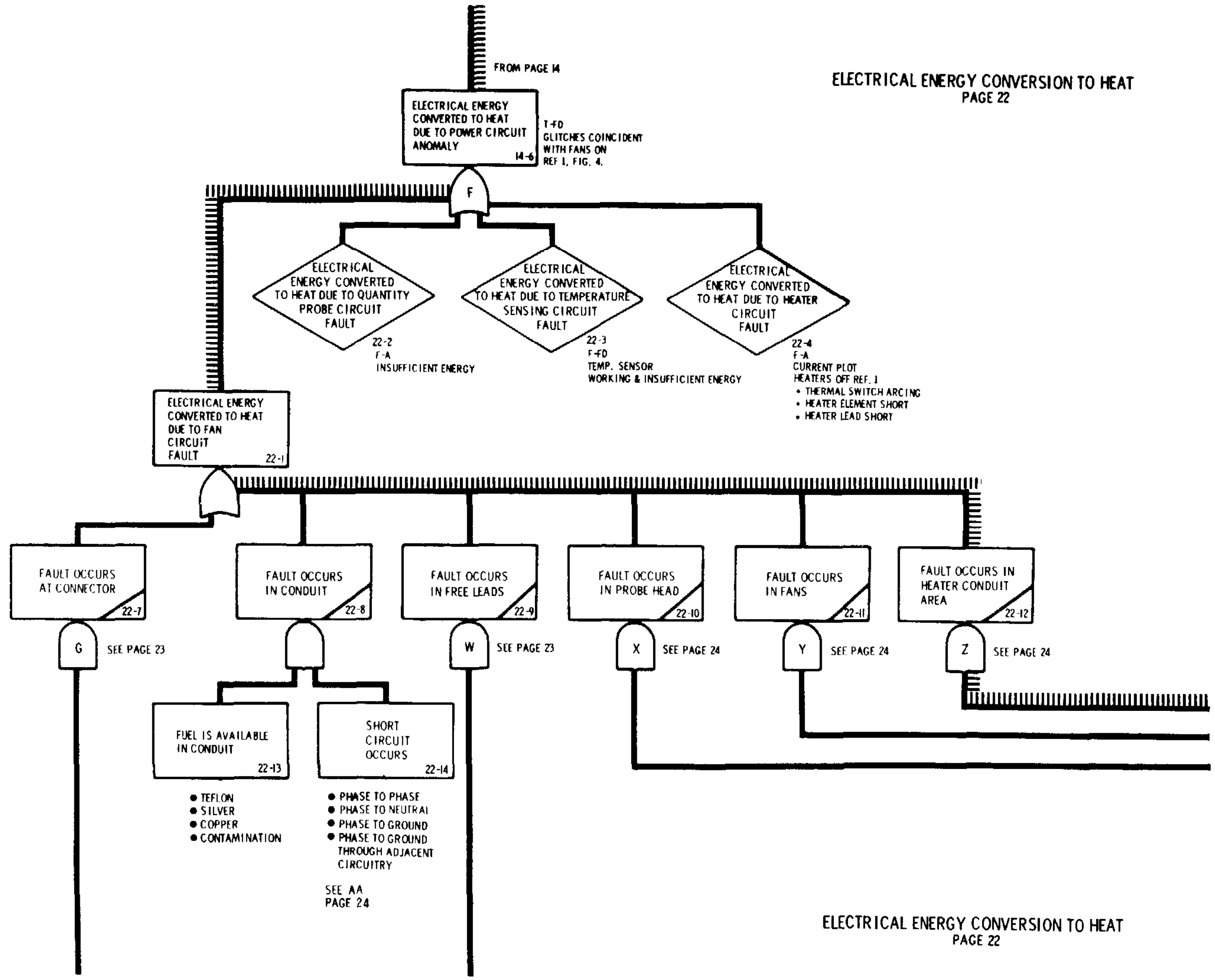

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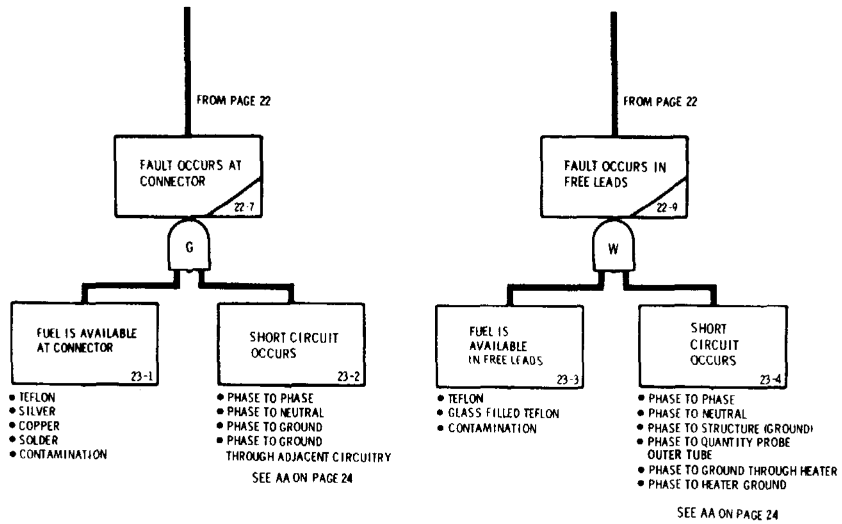

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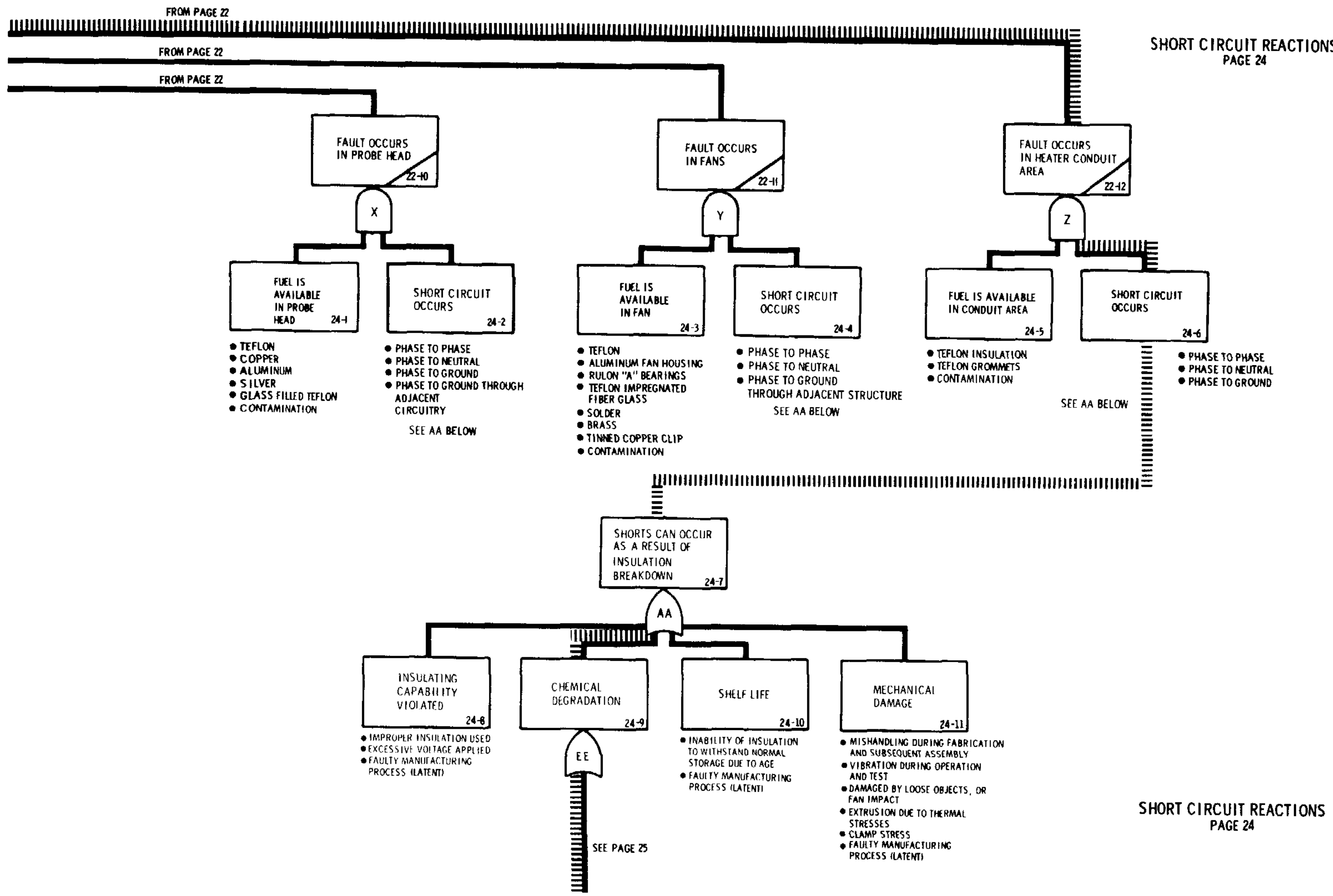
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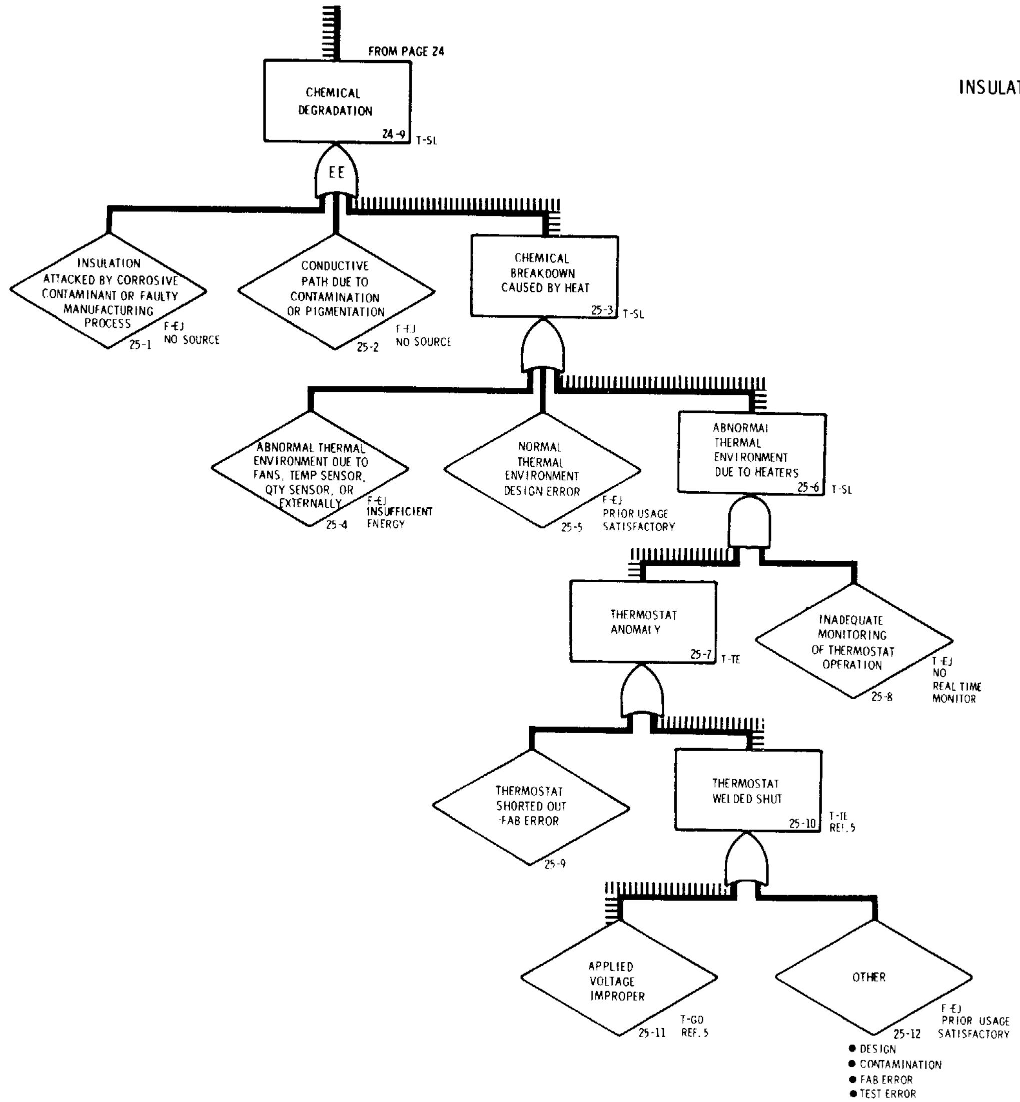

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