RES 608.1

Confidential

The Reliability Study of the VCM Low Pressure Storage System

March 27, 1980

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Key Words

Reliability Study
Vinyl Chloride
Low Pressure Storage
Water Shipments

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ABSTRACT

Level II and Level III Reliability Studies were done for the future Lake Charles Dock Area VCM Low Pressure Storage Unit.

The Level II Study was an overview of the P&I diagrams for process and utility piping, and resulted in three sets of marked P&I diagrams:

1. P&ID changes to be made. These were for omissions and mistakes on the drawings. There were 62 of these items corrected.
2. Process changes. These were for changes recommended in order to accomplish the various process steps. There were approximately 25 of these changes.
3. Reliability suggestions. These were possible changes which could result in a safer unit. There were approximately 15 of these. All but three of these suggestions were implemented. It was later found that the items not implemented had little effect on the overall hazard rates.

Due to the stage of detailed engineering at which this project was, the P&ID and process changes were presented at a meeting on 10-19-79.

The Level III study consisted largely of the generation of fault trees for hazards, with accompanying hazard calculations. The fault trees were based on the implemented Level II study items mentioned above. Additional fault trees were developed to show the implementation of Level III study recommendations. A gas dispersion model was not run, since the adjudged main hazard is release of highly flammable gas, and also since the acute toxicity of VCM is not nearly as severe as, say, chlorine or phosgene (the gas dispersion calculations are based on various toxicity hazard classes).

Release of VCM vapor from T-1/T-2 relief valves can be expected once every 3.4 years, and release of VCM vapor or liquid from other sources at the unit can be expected once every 14.1 years. The resultant then is that VCM release from the unit regardless of source and regardless of amount (except for very small amounts) can be expected once every 2.7 years.

A VCM fire or explosion may be expected once every 68.8 years. Implementation of the Level III recommendations will decrease the vapor releases to once every 8.0 years and fires and explosions to once every 201 years.

General recommendations are given for design, construction and operation. Then, specific recommendations based on the Level II study of the P&ID's are given. Finally, Level III study recommendations are given, which could increase the duration between T-1/T-2 relief valve releases and reduce the incidence of fires and explosions.

INTRODUCTION

In the PPG Industries Chemicals Group, every capital project request is to include a Level I and Level II reliability study, or an explanation should be made why a reliability study is not considered necessary. Funds are to be included for the Level III through V studies.

For this particular project, time constraints were such that it was not possible to do a Level II study prior to project authorization. That is the reason why Level II and Level III studies were done in subsequent fashion, one following directly after the other. The studies were done during the latter phases of detailed engineering work.

Reliability studies are especially important for VCM due to its high flammability and severe environmental restrictions, and that is the overriding purpose of these studies and this report.

DISCUSSION

The number one top event for this unit was judged to be a VCM vapor fire or explosion. Ranked below it are other top events, such as: storage tanks at pressure below atmospheric; VCM vapor release; storage tanks' relief valves operating; flow of combustibles to incinerator area when incinerators are down, back flow from incinerator line, and liquid into vapor lines.

Listed below are given events and under each event is shown the contributors to that event. These contributors, in turn, are events themselves, and they have their own contributors. This subdivision listing will portray how the fault trees were generated at and near the top events for this unit. Items marked * will not be further subdivided.

VCM Vapor Explosion, caused by:

A. System with VCM and air mixture in the explosive range, internal in the system (such as in the main storage tanks), and

B. An ignition source; or

C. System with VCM and air mixture in the explosive range, external to the system, and

D. An ignition source.

(Subdividing the Above)

A. Internal Explosive Mixture, caused by:

1. Improperly purged equipment or piping, or
2. Improper degassing or regassing of main storage tanks, or
3. Air admitted into VCM operating equipment or piping.

B. Internal Ignition Source, possibly by:

1. Static electricity*, or
2. Lightning*, or
3. Hot metal*.

C. External Explosive Mixture, caused by VCM vapor release, from:

1. Operating events, or
2. Equipment or piping damage due to external forces.

D. External Ignition Source, possibly by:

1. Hot metal*, or
2. Matches or cigarettes*, or
3. Weld sparks or oxy-acetylene burning torch*, or
4. Electrical spark from unit equipment*, or
5. Lightning*, or
6. Static electricity*, or
7. Passing trucks, automobiles*, or
8. Miscellaneous sources*.

(Subdividing Some of the Above)

A. 1. Improperly Purged Items, caused by:

a. Improper nitrogen purging*, or
b. Air mistakenly connected for purging, instead of nitrogen*.

A. 2. Improper Storage Tanks Degassing or Regassing, caused by:

a. Improper degassing operation leaves VCM-air mixture in tank*, or
b. Improper regassing operation leaves VCM-air mixture in tank*.

A. 3. Air Admitted into Equipment or Piping, caused by:

a. A leak to admit air, and
b. Internal pressure below atmospheric.

C. 1. Explosive Mixture from Operating Events, caused by:

a. Release from main storage tanks relief valves, or
b. Partial rupture of main storage tank from overpressure*, or
c. Equipment or piping damage from thermal expansion of liquid VCM*, or
d. Leak source, such as: open valve, loose pipe joint, faulty equipment*, or
e. Broken dock hose*, or
f. Storage tank contents siphon out through broken mixing eductor line*.

C. 2. Explosive Mixture from Externally-Caused Damage, caused by:

a. Severe weather*, or
b. Sabotage*, or
c. Shifting of main storage tank base*, or
d. Strain on bottom tank nozzles*.

(Subdividing Some of the Above)

A. 3. a. Leak to Admit Air, caused by:

1) Partial collapse of main storage tank from vacuum*, or
2) Other leak source, such as: open purge connections, loose pipe joints, faulty equipment*.

A. 3. b. Internal Pressure Below Atmospheric, caused by:

1) Main loading pump pumping to barge*, or
2) 300 CFM compressure running while its suction is lined up to main storage tanks*, or
3) VCM condensers condensing at low temperatures*.

C. 1. a. Release from Main Storage Tanks Relief Valves, caused by:

1) High VCM operational pr ssure, or
2) High nitrogen pressure*, or
3) High source of energy (such as an external fire) rapidly boils off VCM*.

(Subdividing One of the Above)

C. 1. a. 1) High VCM Operational Pressure, caused by:

a) Normal source of high pressure VCM, and
b) Inadequacy of 300 CFM compressor to hold down pressure*, or
c) Vapor rate from ship, higher than pressure control system can handle*, or
d) Incorrect valving*

(Subdividing One of the Above)

C. 1. a. 1) a) Normal Source of High Pressure VCM, caused by:

I. No refrigeration for VCM condensers*, or
II. Vaporizer on*, or
III. Heat exchange area in VCM condensers reduced by nitrogen blinding*.
IV. High temperature VCM to main building storage tanks*

Also, if a VCM-air mixture burns instead of exploding, this in itself is an event which can be considered to be ranked only slightly lower than an explosion. Further, the fire could be an ignition source for a subsequent vapor explosion.

One other top event is the release of combustibles into the incinerator line while the incinerator is down. The analysis carries to the storage tank area boundary, and does not take into account safety shut-off valves, etc., at the incinerators area; this would entail a separate study.

Failure Rates - The following rates were used, either suggested from ICI sources, or assumed based on experience.

Item	Failures/Year
Temperature Transmitter	0.20
Pressure Transmitter	0.10
Controller	0.20
Pressure Switch	0.03
Alarm	0.1
Control Valve	0.03
Positioner	0.03
Automatic Shutoff Valve	0.052
Solenoid Valve	0.02
Transducer (P/I or I/P)	0.25
Common Mode	0.03

Frequencies - The assumed frequencies for items such as "operator fails", "ignition", "VCM not completely removed", etc., may be seen on the individual fault trees.

Information Utilized - Main information came from the four unit P&ID's:

27A-10003
27A-10004
27A-10005
27A-10007

Other information came from sources such as:

The Process Flow Diagram
Instrument Loop Sketches
Ladder Diagrams (Partial)
Equipment Specifications
Utility P&ID's
Penjerdel Refrigeration P&ID's
Other Penjerdel Drawings
Vaporizer Controls Diagrams
ICI Failure Rate Data
ASME Pressure Code Section VIII Division 2 Appendix II (concerning stop valves in pressure relief lines)
PPG Interoffice Letter of 11-22-77 from G. B. Edwards to K. W. Richardson (concerning Puerto Rico VCM Storage Area Reliability Study)
PPG Interoffice Letter of 8-1-79 from L. W. Carter to J.S. Murch (concerning signals to be sent to VCM II Control Room)
Various Conversations with Specialists

Assumptions - The major assumption made in regard to fault tree construction is that instruments and loops (except for analyzers) will be proof tested once a year.

RESULTS

The following tabulation lists the calculated frequency of major hazards (or events) with system as designed:

Item		Rate, Once Per x Years
1)	VCM Vapor Explosions or Fires	68.8
2)	Major VCM Vapor Release	2.8
3)	VCM Vapor Release	2.7
4)	VCM Vapor Release from T-1/T-2 Safety Valves	3.4
5)	High Pressure Due to Nitrogen	476
6)	High VCM Pressure in T-1/T-2	3.5
7)	High Temperature VCM to T-1/T-2	45.7
8)	Normal Source of High Pressure VCM	0.018 (see page A11)
9)	Flow of Combustibles to Incinerator Area after Incinerator Shutdown	32.5
13)	Oxygen in T-1/T-2 Vapor Space (possible catalyst for polymerization)	37.8
14)	Backflow from Incinerator Line	9.2
15)	Liquid to C-4/C-5	20.9
16)	Liquid to C-6	5017

The Reliability Team has used conservative figures through most of the calculations. Thus it may be quite safely assumed that the hazard rates represented above are the most often that they may occur, and most probably they will occur much less frequently; say 1-1/2, 2, 3 or more times less frequently. But in order to come up with one rate for each hazard, and owing to the uncertain nature of reliability calculations due to published failure rates and assumed frequencies, a conservative approach was used.

The following general recommendations are offered, which should help to stretch out the hazard rates and justify the statements of the above paragraph:

A. Design

1. Specification of high quality equipment, especially instruments, and secondarily, electrical components.
2. Careful attention made on area electrical classification and its implementation.
3. Special care to see that T-1/T-2 nozzles will not break due to thermal or other stresses. This is especially true of the 14" pump suction lines.
4. Design of piping anchors at the dock so that if a ship's motion straightens the hoses, the hoses will break instead of the pipeline breaking beyond a safety shutoff valve and allowing a very large quantity of VCM to be released.
5. Careful design of purge points for equipment and piping, to insure that purging can be done quickly and completely.
6. Careful analysis of the procedures used for degassing and regassing the storage tanks, in order to determine if all the proper connections are allowed for, if they are in the proper locations, and if they are the proper size.
7. Design of instruments (valving, location, isolation, etc.) and loops and electrical diagrams such that proof testing can be carried out periodically, safely, and with a minimum of spurious trips and alarms.
8. Issuing clear, unambiguous design documents.
9. Elimination of static electricity hazards by good design (grounding, etc.).

B. Construction

1. Selection of a competent and experienced general contractor.
2. If a schedule must be met, and it is felt that a proposed shortcut or solution will jeopardize a reliability feature, then deal with it by authorizing required overtime or paying a premium for quick delivery, rather than creating a situation that risks the entire unit.
3. Close monitoring of field work to see that work is done according to design.
4. Calling quick attention to design or work that seems to create a possible hazard, in order that it might be evaluated and acted upon if necessary.

C. Operation

1. Issuance of a complete and understandable operating manual.

2. Careful training of operators.

3. Avoidance of the stigma that operation and monitoring of this unit is a second-class or helper's job, thus leading toward carelessness and bad habits.

4. Operators should know what to do if an emergency arises during any of the various operations at the unit (degassing, cooling transfers in, pumping to barges, etc.).

5. Elimination of as many ignition sources as possible in the vicinity of the unit. This would be elimination of flames, smoking, matches, etc., and strict enforcement of burning and welding permits, also limits on vehicles in the area.

6. Adherence made to the proof testing periods for instruments and loops; testing to be done by high quality technicians; components after testing to be carefully reassembled and/or re-installed, if such is necessary (this should be at a minimum).

7. Regular testing of fire loops, monitors, sprays, etc.

The following specific recommendations have been made for the P&ID's. These were a result of the Level II study and no figures were generated for them; rather, most Level II reliability studies made of the same P&ID's by other teams would have come up with similar suggestions. The changes resulting from those recommendations are included in the hazard rates in the results tabulation. Th items not completed are not considered serious.

27A-10003

1. A discharge high pressure switch for each of the vent compressors C-4 and C-5, located between the compressor and the discharge shutoff valve - (Done).

2. An alarm signaling high temeprature at E-2 outlet and sounding in the local control room - (Done).

3. Discharge check valves for P-1, P-2, P-3, P-4 should be a quality, reliable brand - (Done).

27A-10004

1. For the dip-pipe in T-3, from 1" line 1604: size the vapor relief holes at the top of the dip-pipe according to how much vapor might be generated when VCM moves from T-7 to T-3 through level control valve LV-6215 - (Done).

2. F-1 filter cartridges to be compatible with VCM - (Done).

3. From the LT6215 signal at T-7:

   a. Add a local level indicator (from level transmitter).
   b. Add a local high-low l vel switch and local alarm (level switch and alarm in control room).

27A-10005

1. The 6" line 1551 which feeds material from E-2 to tanks T-1 and T-2: A check valve in this line would prevent possible siphoning of tank contents through an eductor if the line had a break or open valve down near ground level (no check valve).

27A-10007

1. Adequate thermal expansion to be allowed for in all three major lines: 8" - 1575; 10" - 1546; 4" - 1569. (Done)

2. On the 8" vapor line, locate a high pressure switch between shutoff valve XV6815 and the vapor hose, to sound a local alarm (pressure indicator).

3. Rigidly anchor ends of lines at hose connections. (Done)

4. The 3/8" nitrogen fail-safe hose must be lengthened or shortened by the same length as the 10" VCM hose, or it will not work. (Operating procedure)

5. Low pressure switch PSL 6490 on 10" VCM line must have a proper setting to satisfy a valid low pressure condition arising from either low or high pressure loadings. (Done)

27A-10008 (Utility Diagram)

1. Low pressure switch and control room alarm for instrument air. (No switch or alarm)

2. Low pressure switch and control room alarm for nitrogen. (Pressure indicator only)

27A-10009 (Utility Diagram)

1. Check to see if a 6" firewater supply line and 6" ring header around T-1 (or T-2) can furnish adequate water pressure for twelve 2-1/2" Elkhart nozzles, sufficient to cover the tank surface during a fire. (Done)

LEVEL III STUDY RECOMMENDATIONS

A. Improving Reliability of C-4, C-5, and C-6

C-4/C-5 not pumping nitrogen from E-3/E-4 condensers contributes about 65% of the total hazard of VCM vapor release. Since the "normal" trend toward high pressure in T-1/T-2 is quite slow (a 2 or 2.5 PSI increase may take from 1 or 2 days to over 2 or 3 weeks, depending on weather, tank levels, nitrogen content, etc.), almost any situation can be corrected before C-6 emergency compressor must be used to reduce tank pressure which has risen to above, say, 3 PSIG. Of the demands put on C-6 to reduce tank pressure, calculations indicate that most of the demands pass through, that is, C-6 does not get the job done.

To reduce the demands on C-6, the following recommendations are made.

1. Operators frequently check that the valves from E-3 and/or E-4 through to the compressor discharges are lined up correctly, particularly after changing condensers.

2. Both compressors and their support systems (motors, belts, wiring, safeties, etc.) be maintained in top operating shape.

3. Test and check relief valves twice a year.

4. Test and check shutoff valve XV6806 twice a year as well as its solenoid valve XY6806. Possibly a position indicator and alarm on XV6806 would indicate if it had closed.

The above recommendations could reduce demand on C-6 from C-4/C-5 not pumping to about 60% of normal calculated demand.

Upon inspection of the P&ID's, it can be seen that in order for C-6 to perform correctly, the following obstacles must be overcome:

1. High pressure alarms' failures.

2. Operator fails to turn on C-6.

3. C-6 not able to run due to possibly:

   a. Down for maintenance.
   b. E-8 cooler not running.
   c. Broken belts
   d. Motor failure
   e. Safety shutdown
   f. Power failure
   g. P-7 oil pump off
   h. Compressor mechanical failure.

4. C-6 running, but not pumping vapor to the incinerators, due to possibly:

   a. Incinerator is shut down.
   b. Shutoff valve XV6806 is closed.
   c. Control valve FV6005 is closed.
   d. Discharge valve on compressor is closed.
   e. Compressor relief valve is open.
   f. Flow is going through the recycle loop back to the suction tank T-5.

5. Suction valves on C-6 not lined up from T-1/T-2 through to C-6.

To reduce the unavailability of C-6 to reduce tank pressure, the following recommendations are made:

1. All applicable operators should be well instructed in all phases of this unit. The possibility of not turning on C-6 when it should be, would thus be lowered.

2. All mechanical aspects of C-6 should be kept in top shape. Safeties should be tested twice a year.

3. As in #4 above, test and check shutoff valve XV6806 twice a year as well as its solenoid valve XY6806. Possibly a position indicator and alarm on XV6806 would indicate if it had closed.

4. Test and check control valve FV6005 twice a year as well as its solenoid valve FY6005A, transducer FY6005B, and the flow controller in the VCM control room. A remote indication of stem position would also be useful. Use bypass if valve failure is indicated.

5. The compressor relief valve to be checked twice a year.

6. The suction recycle control valve PV 6427 should be checked four times per year, as well as its associated control items, PT6426, PIC 6426B, PT6427, PIC6427, PY6327A, and PY6427B. The control valve fails open, so it is especially important to maintain these loops in top shape.

The above recommendations would reduce the unavailability of C-6 to about 15% of its normal calculated value.

Thus, all recommendations taken together for C-4, C-5 and C-6 could result in the contribution of this part of the high VCM pressure lowering the hazard of VCM release from T-1/T-2 safety valves to about 10% of its normal calculated value.

B. Reducing Backflows from Incinerator Line

Backflow from the incinerator line into the low pressure storage tanks can result from any of several events. The EDC tank vent compressors at the dock storage area have somewhat increased the probability of backflow. Normal backflow would only contain nitrogen and mixed organic vapor. However, with other possible failures xygen, HCl, or water could als be present. These could cause polymerizati n, tank corrosion, contamination, r other serious results.

It is recommended that an anti-backflow device be installed on the incinerator line. This would reduce the probability of backflows by approximately 85%. The device could be installed using an existing valve and flow measurement element.

C. Reducing Liquid Flows into Vapor Lines

Several possibilities exist if condensers, tanks, vent lines, etc. are incorrectly valved of getting liquid VCM into vapor lines. The most serious result of this would be to get liquid into one of the compressors - C-4, C-5, or C-6 - which could cause an explosion and vapor release. The frequency of getting liquid into C-6 or into C-4/C-5 through the knockout drum is very low and no revisions are necessary. However, the frequency of getting liquid into C-4/C-5 through the discharge side is very high, once per 22.1 years. If the discharge valve of the compressor in service has just a slight leak, liquid would get into the cylinder. Subsequent start-up would result in a probable explosion.

To reduce the frequency of getting liquid into C-4/C-5 through the discharge, the following recommendations are made:

1. Install liquid sensors in the vent line from T-7, the non-condensible lines from E-3 and E-4, and the incinerator line and connect these sensors to alarms. OR

2. Revise the discharge piping on C-4 and C-5 such that the piping makes a loop higher than the first pipe budge and then ties into the top of the incineration line. bridge

Failure rate data on the liquid sensors is not available but it is estimated that the hazard rate will be reduced by at least a factor of 10 reducing the hazard frequency to once per 221 years. Revising the discharge piping would reduce the hazard to essentially zero. The liquid sensors are recommended as they provide adequate protection.

CONCLUSIONS

The implementation of the Level III study recommendations will result in the reduction of hazards as follows:

		Rate, Once Per X Years	
		Before	After
1.	VCM Vapor Explosions or Fires	68.8	201
2.	Major VCM Vapor Release	2.8	8.5
3.	VCM Release for T-1/T-2 Safety Valves	3.4	10.3
4.	Backflow from Incinerator Line	9.2	54.0
5.	Liquid to C-4/C-5	20.9	209

APPENDIX

(Fault Trees)

INABILITY TO CORRECT FAULT BEFORE TANK PRESSURE GETS TO 3 PSIG. USE ONCE IN 250 TIMES — .004

5 PAGE A11 — "NORMAL" SOURCE OF HIGH PRESSURE VCM — 54.163/4R — .216 — DEMAND FOR USE OF C-6 COMPRESSOR TO PREVENT BLOWING RELIEF VALVES

ALARMS FAIL — Y θ=.03 — .00308/4R → A

N — .2136/4R

OPERATOR FAILS TO TURN ON C-6 COMPRESSOR — Y .01 — .00214/4R → B

USE .01 — N — .2115/4R → C

Minimum cut set on pressure alarms θ = 2.41x10⁻⁵
use Common Mode θ = .03
$H = \theta(1-e^{-\theta T}) = .00308$
T=1

C — .2115/4R — Y θ=.2801 — .1205/4R → D

C-6 NOT RUNNING θ=.2801 — N — .0910/4R

C-6 NOT RUNNING, DOWN FOR OVERHAUL; E-6 NOT RUNNING; POWER FAILURE; BROKEN BELTS; MOTOR FAILURE; SAFETY SHUTDOWN; P-7 OIL PUMP OFF; COMPRESSOR MECHANICAL BREAKDOWN; FUSE/CIRCUIT BREAKER OUTAGE. TOTAL FAILURE RATE = .2801/4R;
$H = \frac{\theta D}{\theta + D} = .1205$

C-6 NOT PUMPING TO INCINERATOR — Y — .090201/4R

(SEE EXPANDED TREE BELOW) — N — .0008/4R

C-6 NOT PUMPING FROM T-1/T-2 — Y .01 — 8x10⁻⁶/4R

USE .01 — N — SAFE

D, B, A — + — .216/4R — C-6 UNAVAILABLE TO LOWER PRESSURE IN STORAGE TANKS ONCE/4.6 YRS — 6 PAGE A11

DEMAND (SEE ABOVE) — .0910/4R

INCINERATOR SHUTDOWN FDT=.028 — Y .028 — .000255/4R

N — .09074/4R

SHUTOFF VALVE CLOSED XV6806 — Y .036 — .003269/4R

T=1 — N — .08718/4R

CONTROL VALVE CLOSED FV6005 — Y B=.34 — .06958/4R

θ=.072 FDT=.036

θ=.34

ASSUME 4 TRIP/Month LASTING 30 MINUTES
FDT = 4/1440 = .028

LOSS OF INSTR. AIR; SOLENOID VALVE FAILURE; LOSS OF VOLTAGE TO VALVE COIL; BROKEN TUBING

LOSS OF INSTR. AIR; SOLENOID VALVE FAILURE; LOSS OF VOLTAGE TO [redacted] COIL; TRANSDUCER FAILURE; LOSS OF SIGNAL FROM CONTROLLER; LOW SIGNAL FROM CONTROLLER

$H = \frac{\theta D}{\theta + D} = .069577$

.01790/4R — DISCHARGE VALVE CLOSED — Y .01 — .000179/4R

USE .01 — N — .01772/4R

RELIEF VALVE OPEN θ=.08 — Y .04 — .000709/4R

FDT=.04 — N — T=1

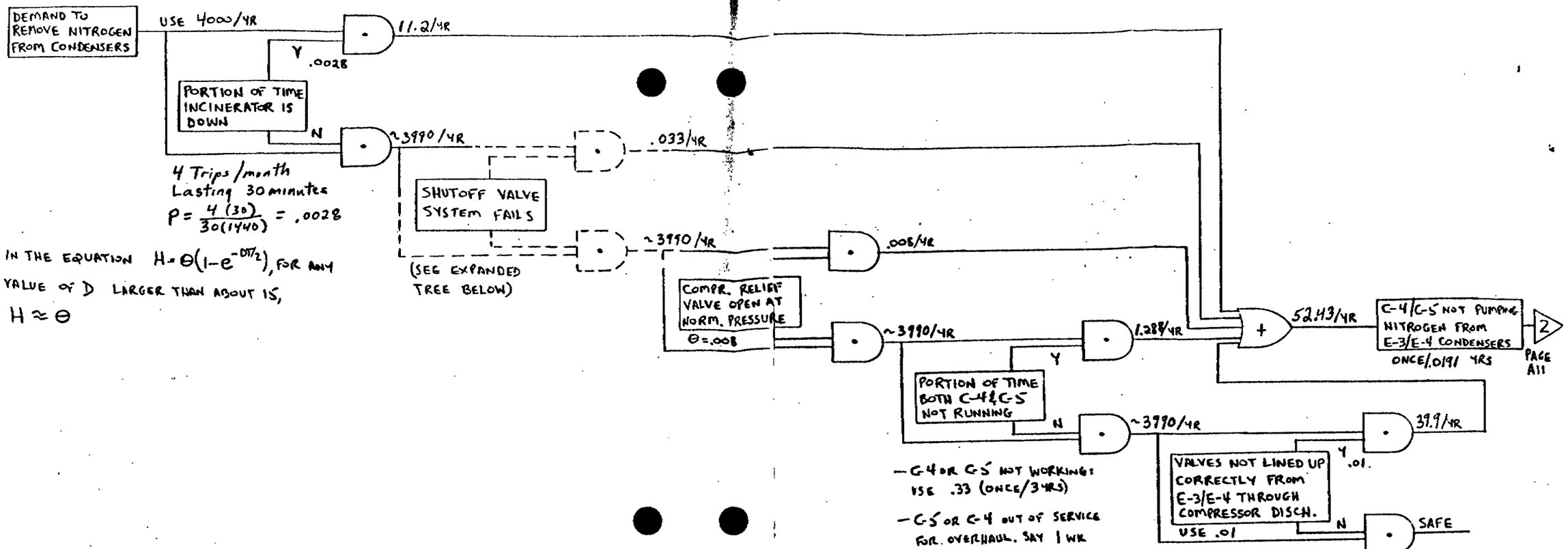
+ — .090201

.016911/4R

.01701/4R — RECYCLE LOOP FLOW θ=.345 — Y

N — .0008/4R

RECYCLE LOOP FLOW MAY BE DUE TO: LOSS OF INSTR. AIR; TRANSDUCER FAILURE; VALVE PV6427 STUCK OPEN; LOW SELECT RELAY FAILS LOW; ACTION REVERSED ON LOW SELECT RELAY; LOW SIGNAL FROM PIC 6427; LOW SIGNAL FROM PIC 6426B
$H = \frac{\theta D}{\theta + D} = .016911$

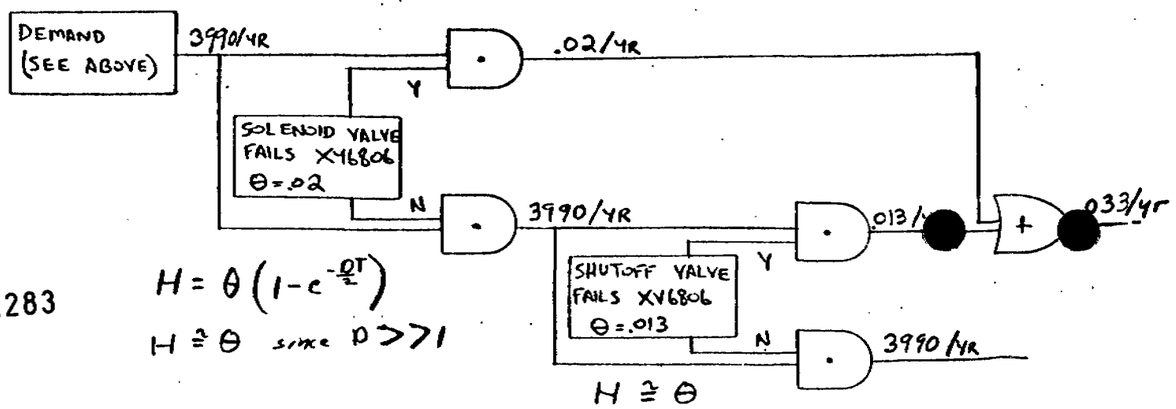


IN THE EQUATION $H = \Theta(1-e^{-DT/2})$, FOR ANY VALUE OF D LARGER THAN ABOUT 15,

$H \approx \Theta$

- C-4 OR C-5 NOT WORKING: USE .33 (ONCE/3 YRS)
- C-5 OR C-4 OUT OF SERVICE FOR OVERHAUL. SAY 1 WK OUT OF EACH YR..

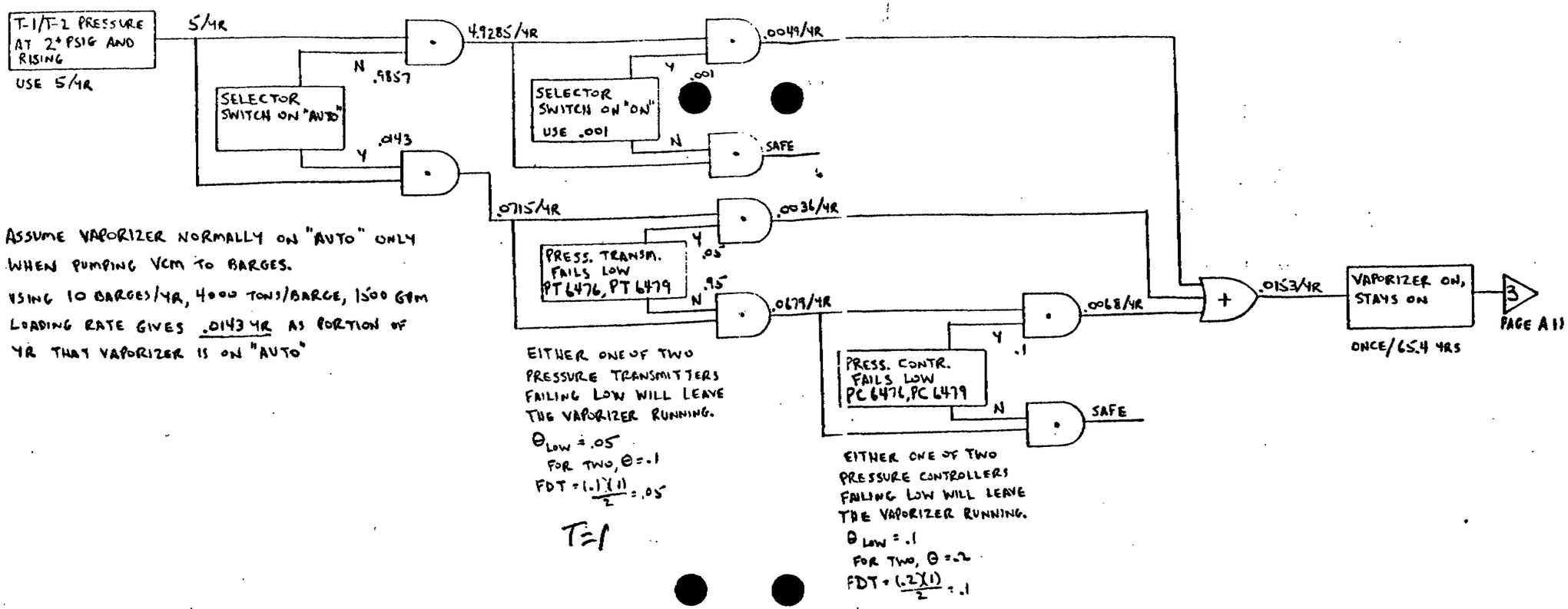
$$f_T = f_A P_B + f_B P_A$$
$$= f_A \Sigma \frac{f_B t_B}{365} + f_B \Sigma \frac{f_A t_A}{365}$$
$$= .66\left(\frac{1.33 \cdot 7}{365}\right) + .66\left(\frac{1.33 \cdot 7}{365}\right)$$
$$= .0337 \text{ times/yr}$$
$$P_x = (.0337)\left(\frac{3.5}{365}\right) = .000323$$
$$H = P \times D = 1.288$$



$H = \Theta\left(1-e^{-\frac{DT}{2}}\right)$

$H \approx \Theta$ since $D > 7!$

$H \approx \Theta$



ASSUME VAPORIZER NORMALLY ON "AUTO" ONLY WHEN PUMPING VCM TO BARGES.

USING 10 BARGES/YR, 4000 TONS/BARGE, 1500 GPM LOADING RATE GIVES .0143 YR AS PORTION OF YR THAT VAPORIZER IS ON "AUTO"

EITHER ONE OF TWO PRESSURE TRANSMITTERS FAILING LOW WILL LEAVE THE VAPORIZER RUNNING.

$\theta_{LOW} = .05$

FOR TWO, $\theta = .1$

$FDT = \frac{.1(1)}{2} = .05$

$T = 1$

EITHER ONE OF TWO PRESSURE CONTROLLERS FAILING LOW WILL LEAVE THE VAPORIZER RUNNING.

$\theta_{LOW} = .1$

FOR TWO, $\theta = .2$

$FDT = \frac{.2(1)}{2} = .1$

PUMP NOT PUMPING

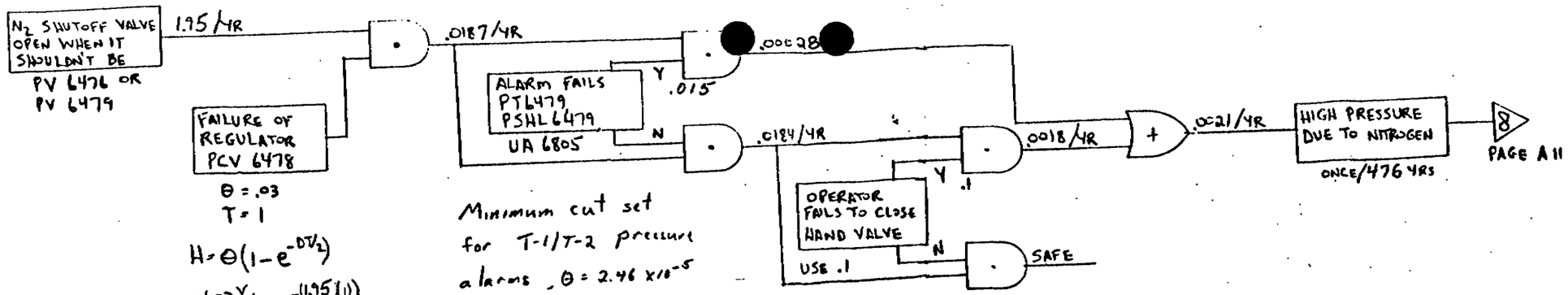
VALVES CLOSED; WRONG PUMP LINED UP; REVERSE ROTATION; SHUT DOWN BEFORE DERIMING COMPLETED; PUMP THERMAL CUTOUT; ETC.

TOTAL: .085/YR

OTHER CAUSES

REFRIGERATION LEFT ON, ICE WON'T MELT; NOT DERIMED LONG ENOUGH; LINED UP TO WRONG UNIT; VCM NOT WARM ENOUGH; MORE ICE THAN USUAL; VALVES NOT LINED UP CORRECTLY; ETC.

TOTAL: .15/YR



$H = \theta(1 - e^{-DT_2})$

$= (.03)\left(1 - e^{-\frac{(1.95)(1)}{2}}\right)$

$= .0187/YR$

Minimum cut set for T-1/T-2 pressure alarms, $\theta = 2.46 \times 10^{-5}$

Use Common Mode $\theta = .03$

FDT = .015

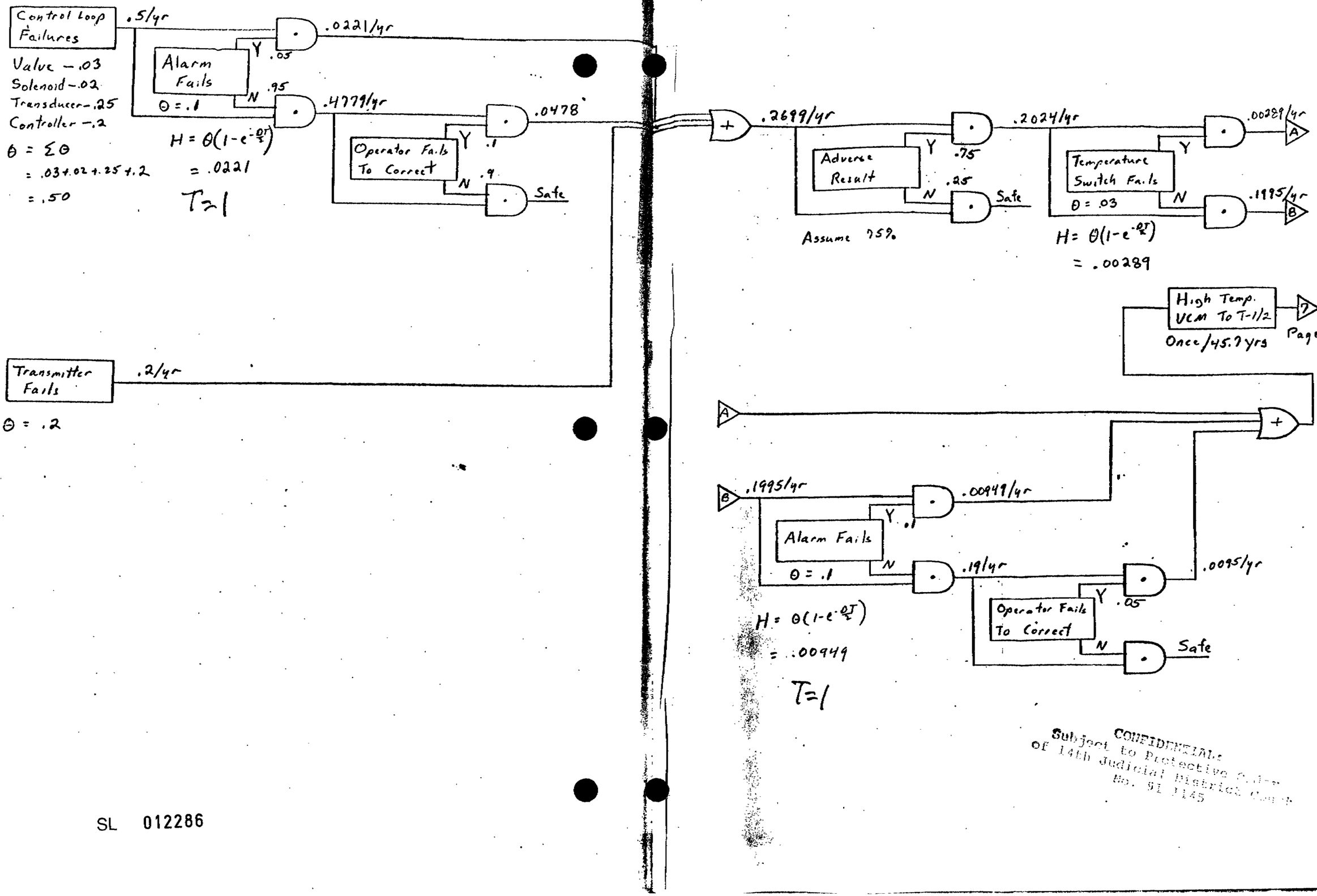
FOR EITHER SHUTOFF VALVE:

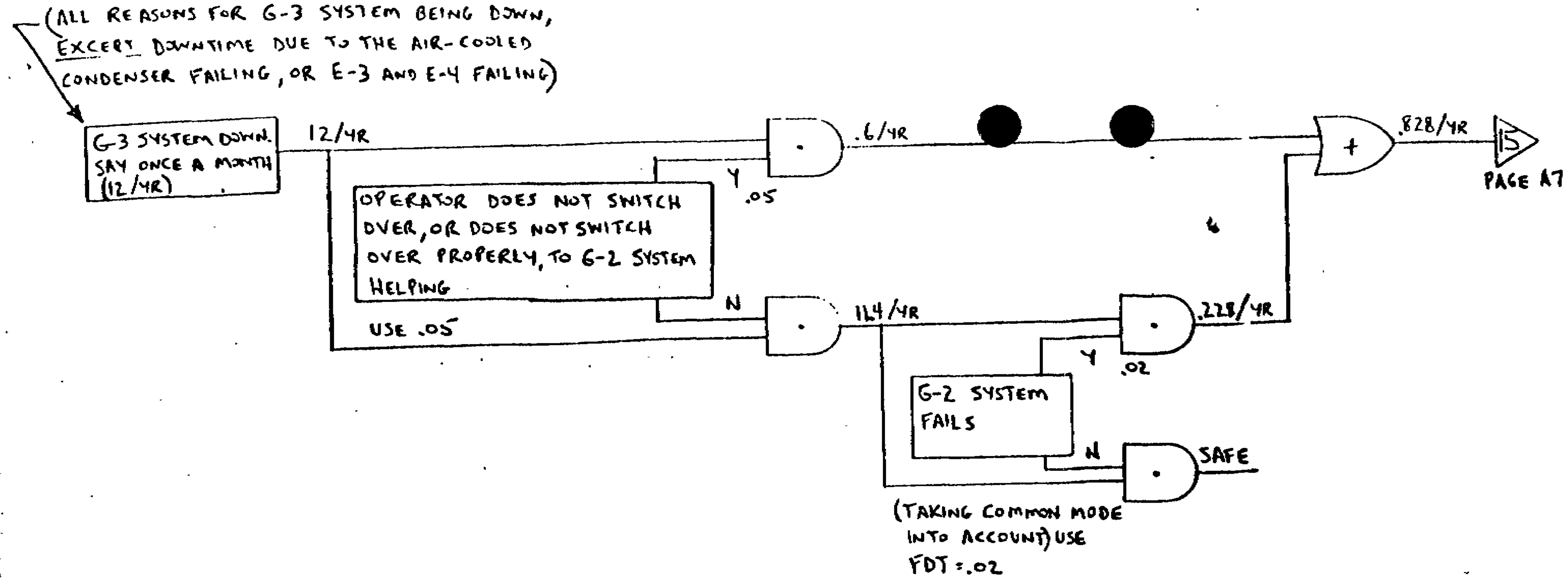
	θ	F-R2
PT FAILS LOW	0.10	0.10 *
PSLLL FAILS LOW	0.03	0.06
LOSS OF VOLTAGE	1.00	1.00 **
LOSS OF INSTR. AIR	0.65	0.75 ***
SOLENOID VALVE FAILS (PY L476, PY 6479)	0.02	0.04
		1.95/HR

* ONE PT FAILED IS A REVEALED FAULT THROUGH PSHL

** GENERAL VOLTAGE LOSS CONSIDERED, RATHER THAN AN INDIVIDUAL WIRE FAULT

*** GENERAL LOSS OF INSTR. AIR CONSIDERED, WITH SOME PARTIAL CREDIT FOR INDIVIDUAL I.A. LOSS





<u>E-3 AND E-4 FAILING</u> CAN BE BY MEANS OF THREE DISTINCT WAYS:

1. SIMULTANEOUS FAILURE WHILE BOTH ARE IN CONDENSING MODE.
2. FAILURE OF ONE IN CONDENSING MODE WHILE THE OTHER IS IN SOME OTHER SERVICE.
3. COMMON MODE FAILURE.

DEVELOPING THE ABOVE:

1. <u>SIMULTANEOUS FAILURE</u>

EVENT	Θ, EVENTS/YR	t DURATION, DAYS	$\Theta \cdot t$
– NH_3 LEVEL CONTROLLER FAILS	0.2	1.0	0.2
– LEVEL VALVE FAILS (INCL. POSITIONER)	0.2	1.0	0.2
– SOLENOID VALVE FAILS	0.001	1.0	0.001
– SELECTOR IN HAND POSITION, SET POINT AT WRONG PLACE	0.04	1.0	0.04
– SLAVE PRESS. TRANSM. FAILS	0.2	1.0	0.2
– SLAVE PRESS. CONTROLLER FAILS	0.1	1.0	0.1
– PRESS. CONTROL VALVE FAILS (INCL. POSITIONER)	0.2	1.0	0.2
	$\Theta_T = 0.941/YR$		$\Theta t_T = 0.941$

$$t_W = \frac{0.941}{0.941} = 1.0 \text{ DAYS}$$

$$f_T = \frac{\Theta_A \cdot \Theta_B}{365}(t_A + t_B) = \frac{(0.941)(0.941)}{365}(1+1) = .0049/YR$$

2. <u>FAILURE WHILE OTHER NOT IN CONDENSING MODE</u>

EVENT	Θ, EVENTS/YR	t DURATION, DAYS	$\Theta \cdot t$
– OUT FOR REPAIRS	1.0	2.0	2.0
– DE[illegible]ING	12.00	0.33	4.0
– HIGH PRESSURE CONDENSING	10.0	0.67	6.7
– OTHER	2.0	2.0	4.0
	$\Theta_T = 25/YR$		$\Theta t_T = 16.7$

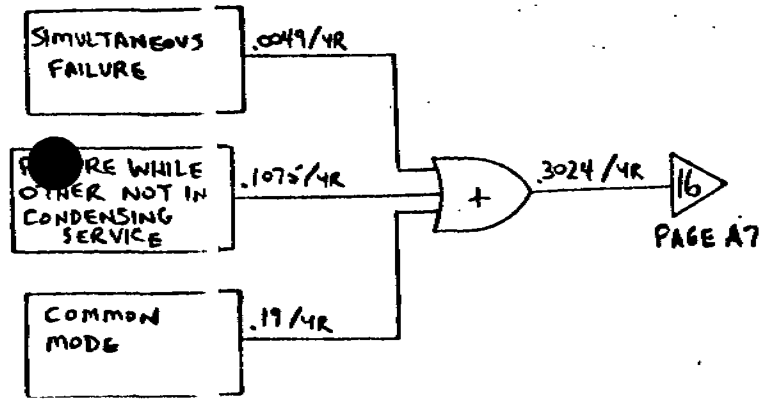
$$t_W = \frac{16.7}{25} = 0.668 \text{ DAYS}$$

$$f_T = \frac{\Theta_A \cdot \Theta_A}{365}(t_A + t_B) = \frac{(0.941)(25)}{365}(1.0 + 0.668) = 0.1075/YR$$

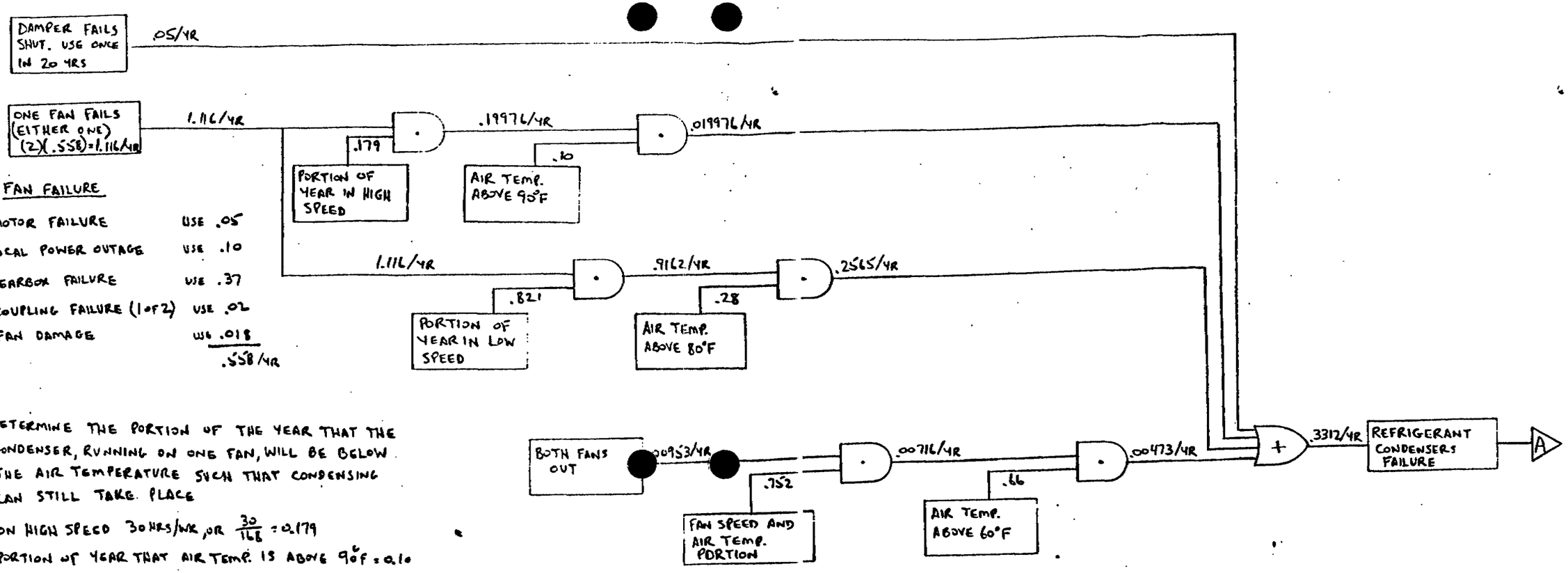
3. <u>COMMON MODE</u>

a. LOSS OF INSTR. AIR — USE .02/YR
b. LOSS OF CONTROL VOLTAGE — USE .02/YR
c. MASTER PRESS. TRANSM. FAILS — USE .10/YR
d. MASTER PRESS. CONTROLLER FAILS — USE .05/YR

COMMON MODE = .19/YR



REFRIGERANT CONDENSERS



FAN FAILURE

MOTOR FAILURE	USE .05
LOCAL POWER OUTAGE	USE .10
GEARBOX FAILURE	USE .37
COUPLING FAILURE (1 OF 2)	USE .02
FAN DAMAGE	USE .018
	.558/YR

DETERMINE THE PORTION OF THE YEAR THAT THE CONDENSER, RUNNING ON ONE FAN, WILL BE BELOW THE AIR TEMPERATURE SUCH THAT CONDENSING CAN STILL TAKE PLACE

- ON HIGH SPEED 30 HRS/MO, OR $\frac{30}{168} = 0.179$
- PORTION OF YEAR THAT AIR TEMP. IS ABOVE 90°F = 0.10
- PORTION OF YEAR ON LOW SPEED = 1.0 − 0.179 = 0.821
- PORTION OF YEAR THAT AIR TEMP. IS ABOVE 80°F = 0.28

(HI SPEED) (BELOW 90°F)
.179 × 90 = .161

(LO SPEED) (BELOW 80°F)
.821 × .72 = .591

.752

NEXT, DETERMINE WHAT LIKELIHOOD THERE IS THAT WITH ONE FAN OFF, THE OTHER WILL ALSO BE OFF.

FAILURE RATE = .558/YR

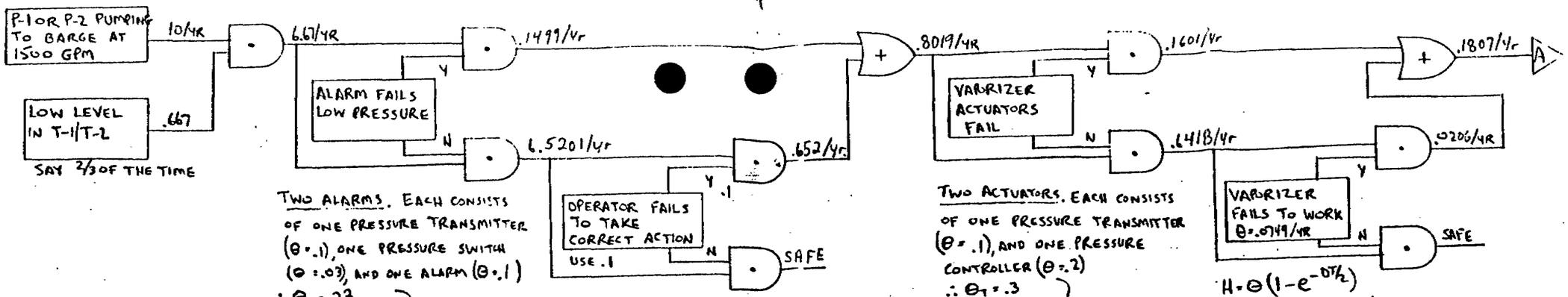
ASSUME 1 MAINTENANCE PERIOD/YR (LASTS 2 DAYS)
FAILURE ALSO TAKES 2 DAYS TO FIX

TOTAL OUTAGE = 1.558/YR

FOR 2 FANS, THIS IS 3.116/YR

(3.116)(2) = 6.332 DAYS/YR OUT

$\frac{6.332}{365} \times .558 = .0953/YR$



TWO ALARMS. EACH CONSISTS OF ONE PRESSURE TRANSMITTER ($\theta = .1$), ONE PRESSURE SWITCH ($\theta = .03$), AND ONE ALARM ($\theta = .1$)

$\therefore \theta_T = .23$, $T = 1/4R$, $D = 6.67/4R$ } $m = 2$

$\theta T = .23$ (Too High)

use $H = \frac{\theta' D}{\theta' + D}$, for $n = 2$, $\theta' = \frac{2}{3}\theta$

$= .1499$

TWO ACTUATORS. EACH CONSISTS OF ONE PRESSURE TRANSMITTER ($\theta = .1$), AND ONE PRESSURE CONTROLLER ($\theta = .2$)

$\therefore \theta_T = .3$, $T = 1/4R$, $D = .6808/4R$ } $m = 2$

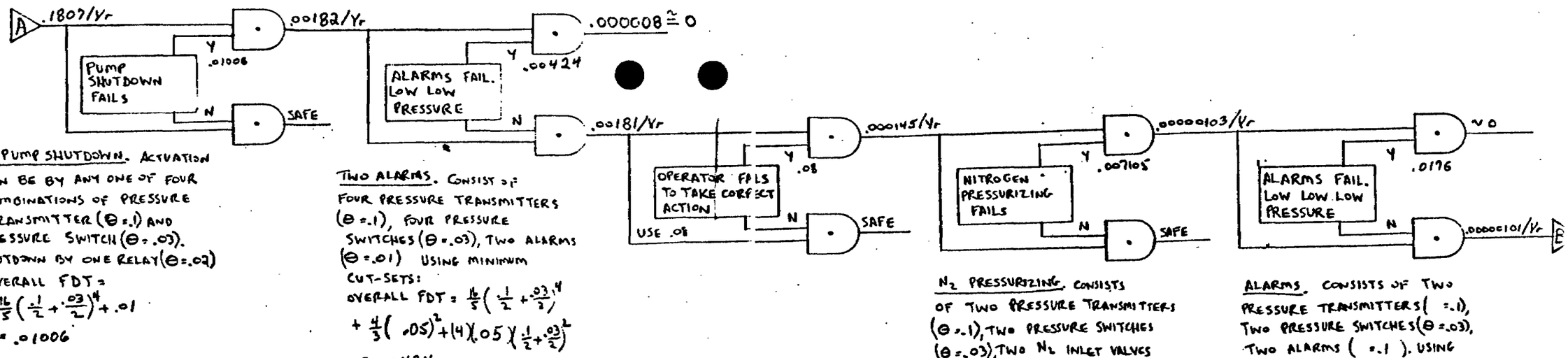
$H = \frac{\theta' D}{\theta' + D}$, $\theta' = \theta\left(\frac{2}{3}\right)$

$= .1601$

$H = \theta\left(1 - e^{-DT/2}\right)$

$= (.0749)\left(1 - e^{-\frac{(.6418)(.1)}{2}}\right)$

$= .0206/4r$



PUMP SHUTDOWN. ACTUATION CAN BE BY ANY ONE OF FOUR COMBINATIONS OF PRESSURE TRANSMITTER ($\theta = .1$) AND PRESSURE SWITCH ($\theta = .03$). SHUTDOWN BY ONE RELAY ($\theta = .02$)

OVERALL FDT =

$\frac{16}{5}\left(\frac{.1}{2} + \frac{.03}{2}\right)^4 + .01$

$= .01006$

TWO ALARMS. CONSIST OF FOUR PRESSURE TRANSMITTERS ($\theta = .1$), FOUR PRESSURE SWITCHES ($\theta = .03$), TWO ALARMS ($\theta = .01$) USING MINIMUM CUT-SETS:

OVERALL FDT = $\frac{16}{5}\left(\frac{.1}{2} + \frac{.03}{2}\right)^4$

$+ \frac{4}{3}(.05)^2 + (4)(.05)\left(\frac{.1}{2} + \frac{.03}{2}\right)^2$

$= .00424$

N_2 PRESSURIZING. CONSISTS OF TWO PRESSURE TRANSMITTERS ($\theta = .1$), TWO PRESSURE SWITCHES ($\theta = .03$), TWO N_2 INLET VALVES ($\theta = .016$). USING MINIMUM CUT-SETS:

OVERALL FDT = $\frac{4}{3}\left(\frac{.1}{2} + \frac{.03}{2}\right)^2$

$+ \frac{4}{3}\left(\frac{.016}{2}\right)^2 + \frac{8}{3}\left(\frac{.1}{2} + \frac{.03}{2}\right)\left(\frac{.016}{2}\right)$

$= .00710S$

ALARMS. CONSISTS OF TWO PRESSURE TRANSMITTERS ($\theta = .1$), TWO PRESSURE SWITCHES ($\theta = .03$), TWO ALARMS ($\theta = .1$). USING MINIMUM CUT-SETS:

OVERALL FDT = $\frac{4}{3}\left(\frac{.1}{2} + \frac{.03}{2}\right)^2$

$+ \frac{4}{3}\left(\frac{.1}{2}\right)^2 + \frac{8}{3}\left(\frac{.1}{2} + \frac{.03}{2}\right)\left(\frac{.1}{2}\right)$

$= .0176$

AS CAN BE SEEN, WITHOUT TAKING INTO ACCOUNT COMMON MODE, THERE IS SO MUCH REDUNDANCY IN THIS SYSTEM, THAT THERE IS *VERY LITTLE CHANCE* OF HAVING A VACUUM IN TANKS T-1/T-2.

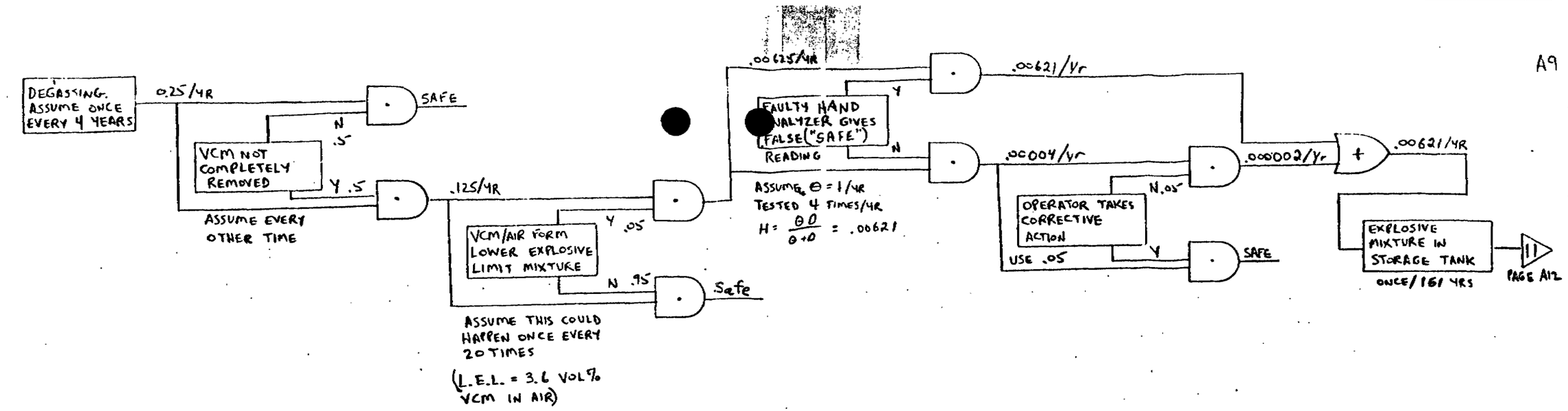
ALSO, THE OTHER WAYS BY WHICH A TENDENCY TOWARD LOW PRESSURE IS E[illegible]CO (C-6 COMPRESSOR ON AND RUNNING, E-3/E-4 CONDENSING AT LOW AMMONIA TEMPERATURES) END UP AT ABOUT ZERO. TOTAL, THEN, IS ZERO.

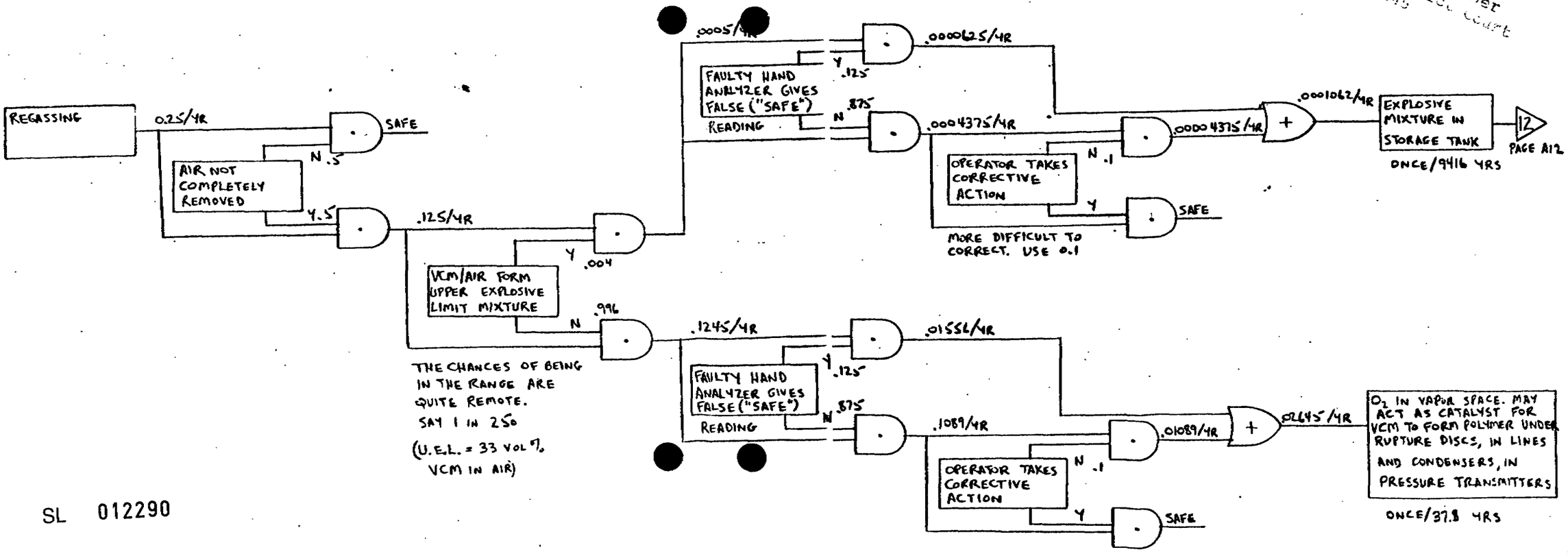
ADD ON COMMON MODE USE $\theta = .03$, SO HAZARD IS ALSO .03/4R (CONSTANT DEMAND)

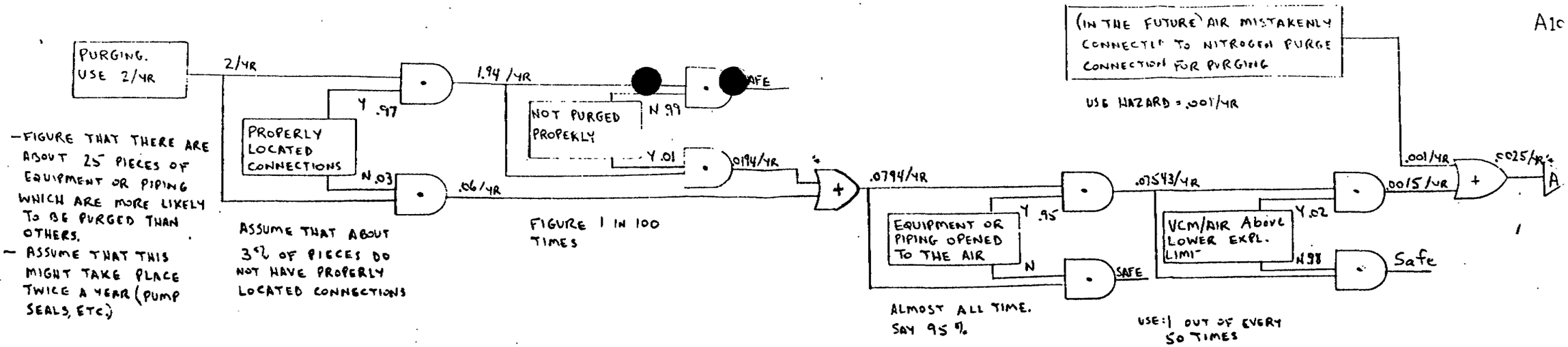
ONCE/333 YRS

SEE PAGE A12

(FROM ICI REF. G8A, PAPER NO. A8, SECTION 6.1, PARAGRAPH 8)







- FIGURE THAT THERE ARE ABOUT 25 PIECES OF EQUIPMENT OR PIPING WHICH ARE MORE LIKELY TO BE PURGED THAN OTHERS.
- ASSUME THAT THIS MIGHT TAKE PLACE TWICE A YEAR (PUMP SEALS, ETC.)

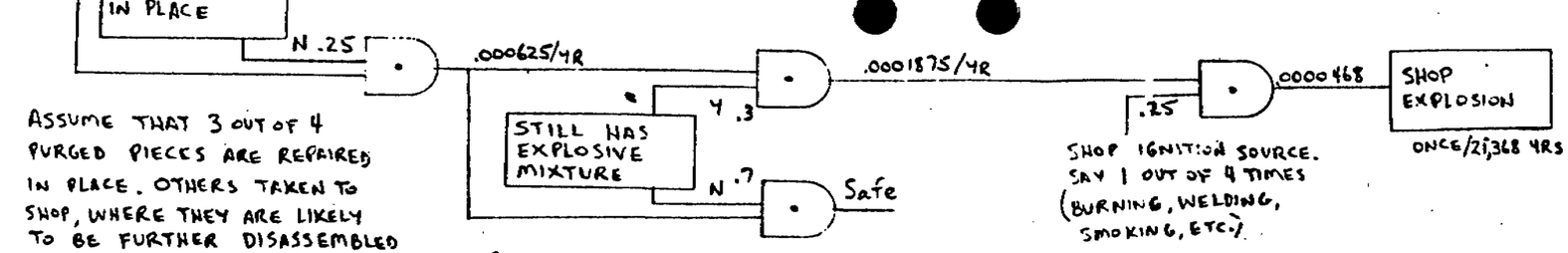
ASSUME THAT ABOUT 3% OF PIECES DO NOT HAVE PROPERLY LOCATED CONNECTIONS

FIGURE 1 IN 100 TIMES

ALMOST ALL TIME. SAY 95 %

USE: 1 OUT OF EVERY 50 TIMES

IGNITION SOURCE. SAY 1 OUT OF 25 TIMES



ASSUME THAT 3 OUT OF 4 PURGED PIECES ARE REPAIRED IN PLACE. OTHERS TAKEN TO SHOP, WHERE THEY ARE LIKELY TO BE FURTHER DISASSEMBLED OR PURGED

SAY 3 OUT OF 10 TIMES

1 → PAGE A3
PERIMING NOT DONE, ICE IN TUBES — .235/YR

2 → PAGE A2
C-4/C-5 NOT PUMPING NITROGEN FROM E-3/E-4 CONDENSERS — 52.43/Yr

+ → 52.664/YR
NO CONDENSING AREA IN E-3/E-4 CONDENSERS

3 → PAGE A3
VAPORIZER ON, STAYS ON — .0153/YR

+ → 54.163/YR
"NORMAL" SOURCE OF HIGH PRESSURE VCM

5 → PAGE A1

4 → PAGE A7
NO CONDENSING OF TANK VAPORS — 1.4616/YR

7 → Page A5
High Temperature VCM To T-1/2 — .0219/Yr

6 → PAGE A1
.216/YR
C-6 UNAVAILABLE TO LOWER PRESSURE IN STORAGE TANKS

VAPORS FROM SHIPS AT RATE FASTER THAN CONTROL SYSTEM CAN HANDLE IT. USE .01 — .01/YR

+ → .286 YR
HIGH VCM PRESSURE → A

Loading VCM Vessel — No Padded — 12/yr

· → .06/Yr

Oper. Opens Wrong Valve — .005
Use .005

· → Safe

A → .286/Yr
Once /3.5yrs

8 → PAGE A4
HIGH NITROGEN PRESSURE — .0021/Yr

EXTERNAL FIRE OR OTHER HIGH ENERGY SOURCE RAPIDLY BOILS OFF VCM. USE .005 — .005/YR

+ → .2931/YR
OVERPRESSURE IN T-1/T-2 — ONCE/3.4 YRS — Major

EQUIPMENT OR PIPING DAMAGE OTHER THAN IN T-1/T-2. USE .001 — .001/YR — Minor

THERMAL EXPANSION OR HIGH N_2 PRESSURE: SAFETY VALVE FAILS

OPEN VALVE, LOOSE PIPE JOINT, FAULTY EQUIPMENT, ETC. USE .0065 — .0065/YR — Minor

- PIPE SPLITS, ETC, USE .0015
- OPEN OR LEAKY VALVE OR FAULTY EQPT. USE .005

+ → .364/Yr
VCM VAPOR RELEASE
ONCE/2.7YRS

.364 − .001 − .0065 = .3565

15 → Page A17
Liquid to Compressors — Major .0479/yr — Once/20.8 yrs

LINE BREAK (FOR 720' of PIPE = .000072/HR) — .000072/HR

OPEN PURGE VALVE USE .01 — .01/HR

+ → ~.01/HR

BLOCK VALVE OPEN. SAY 1/20 OF THE TIME — .05

· → TANK CONTENTS SYPHON OUT THROUGH LINE CONNECTED TO MIXING EDUCTOR — Major .0005/YR

BROKEN DOCK HOSE USE .005 — .005/YR — Major

MISC. PIPE, TANK, OR EQUIPMENT DAMAGE — USE .01 — .01/YR — Major

10 → PAGE A12

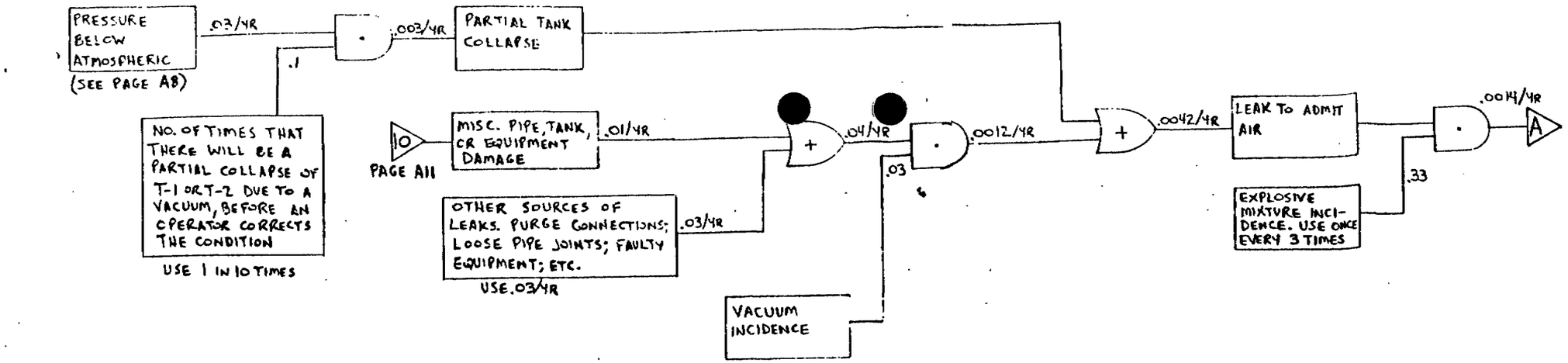
MISC. EXTERNAL FORCES. SEVERE WEATHER; TANK BASE SHIFT; TANK NOZZLE STRAIN; SABOTAGE ETC.

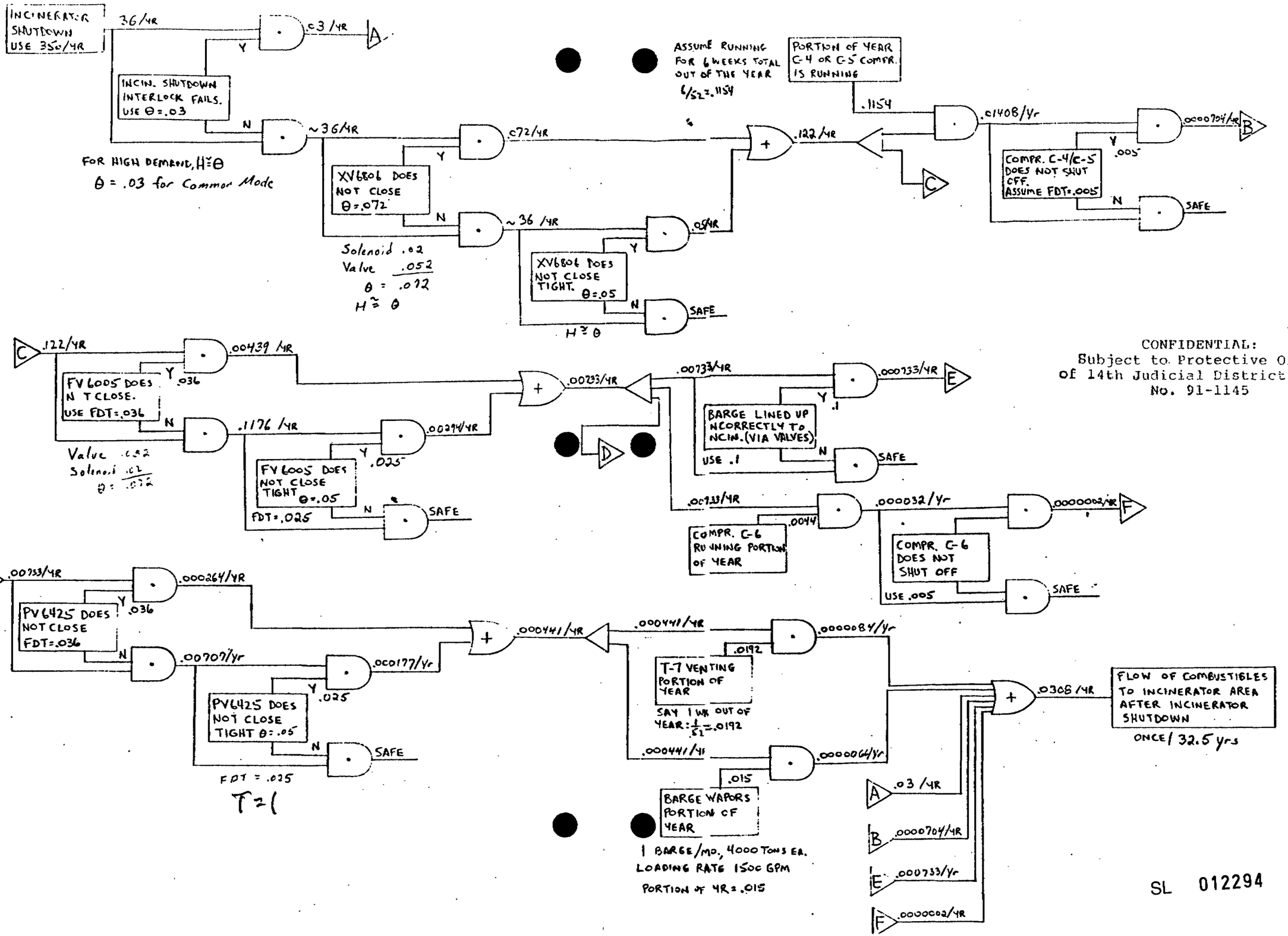
.3565/Yr
Major VCM Vapor Release
Once /2.8 Yrs

Ignition Source — Once per 25 times — .04

· → .01426/Yr
Fire or explosion from vapor release
Once/70.1yrs.

9 → ρ A12





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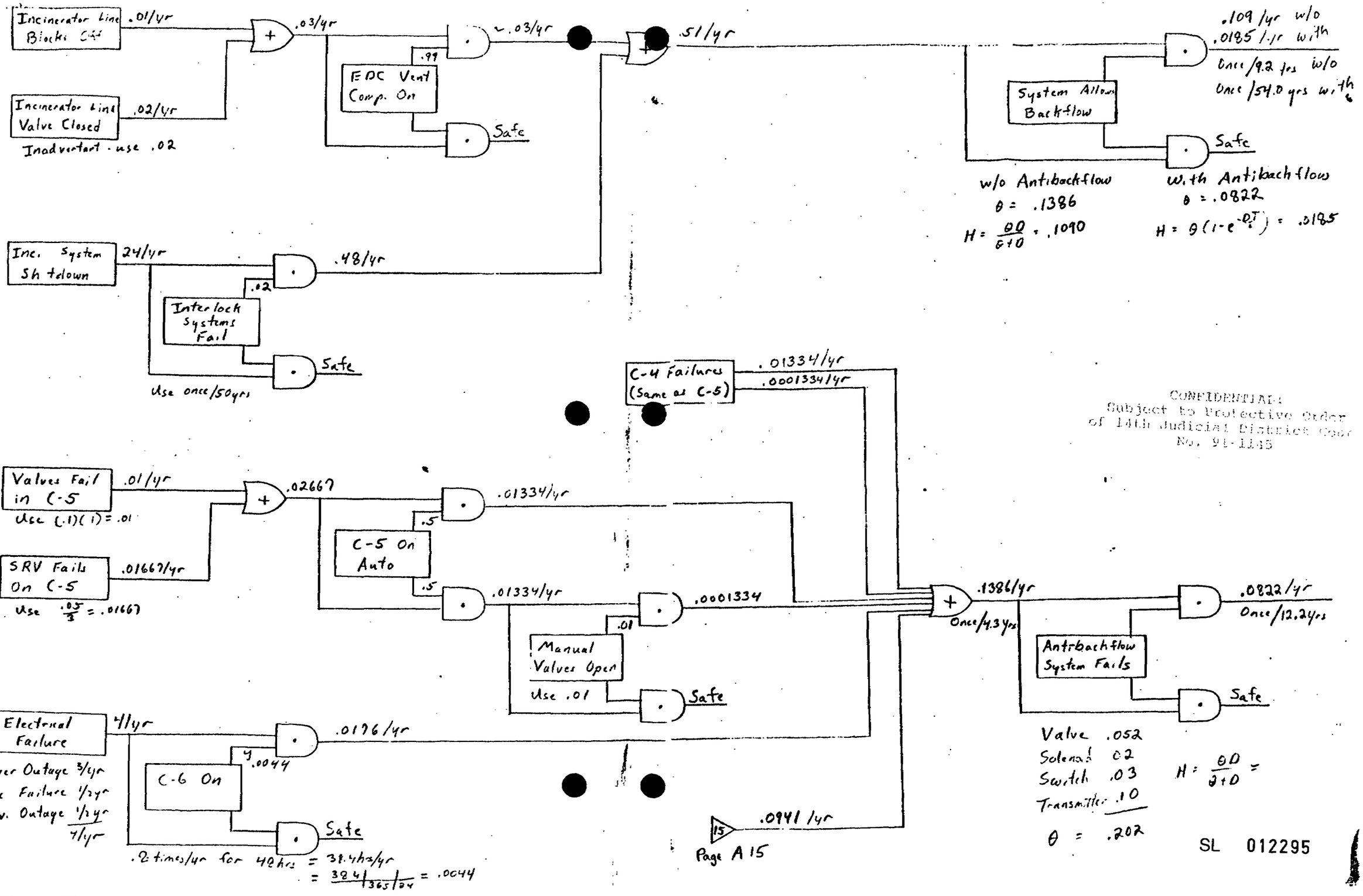
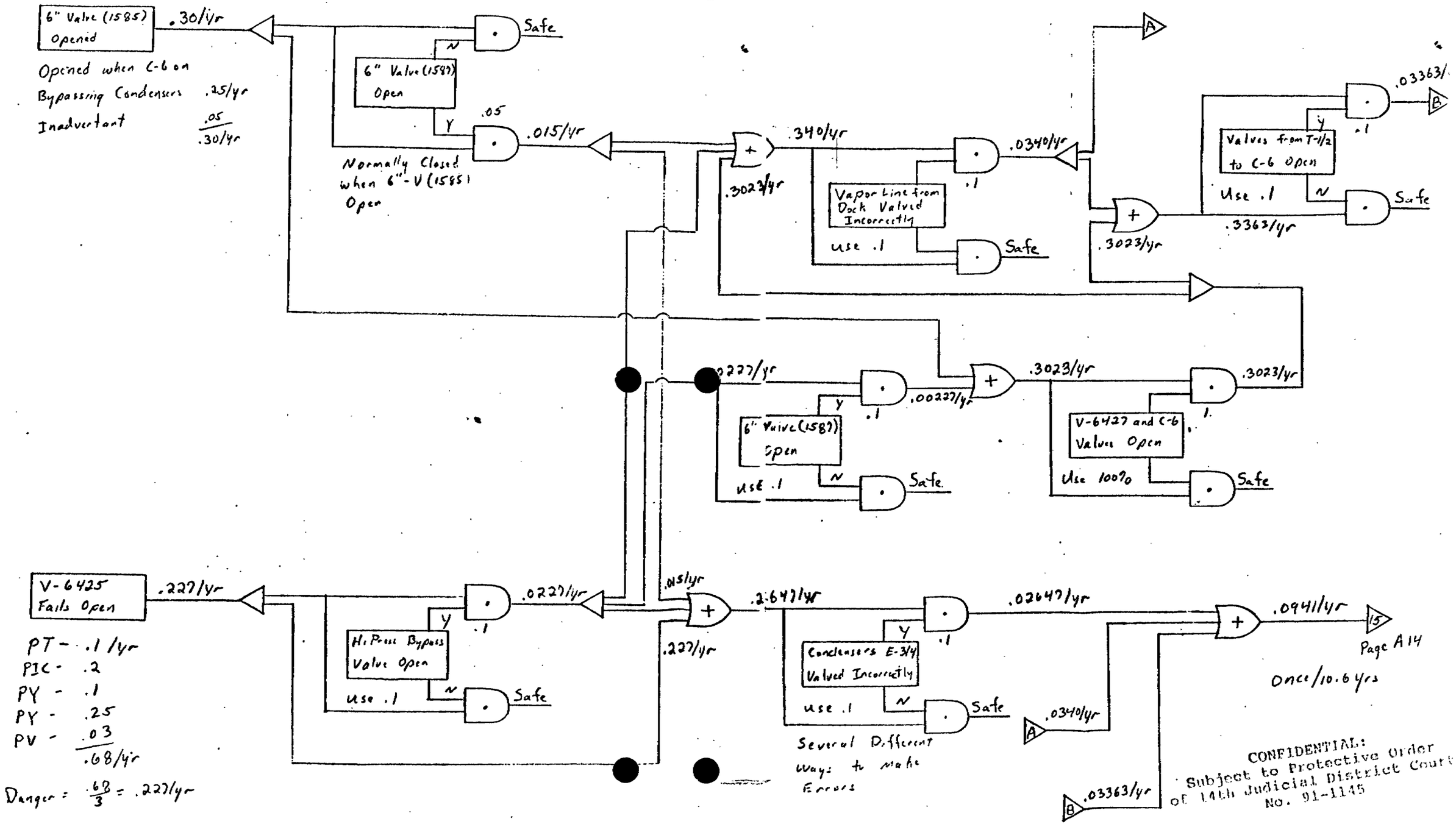
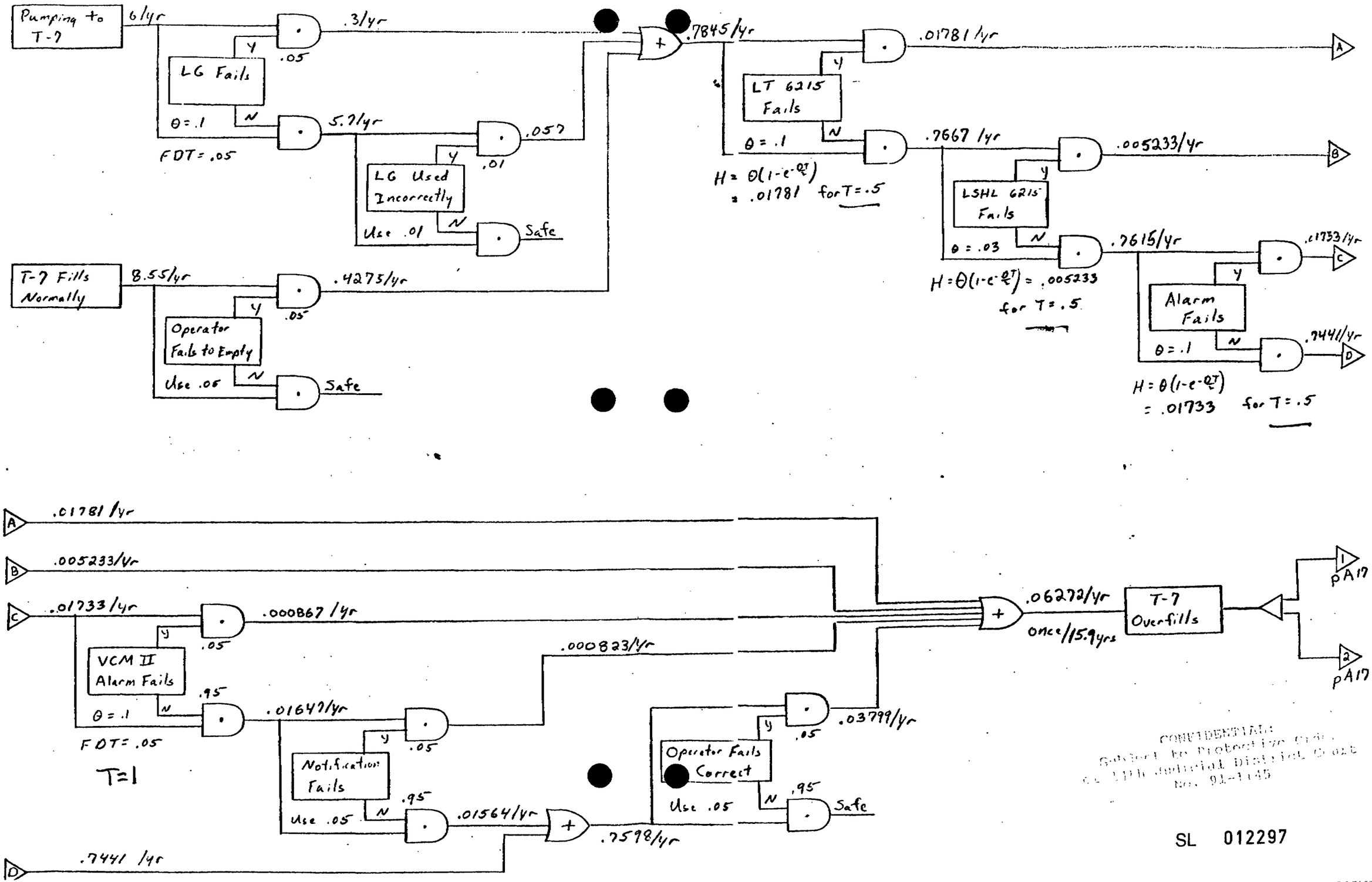
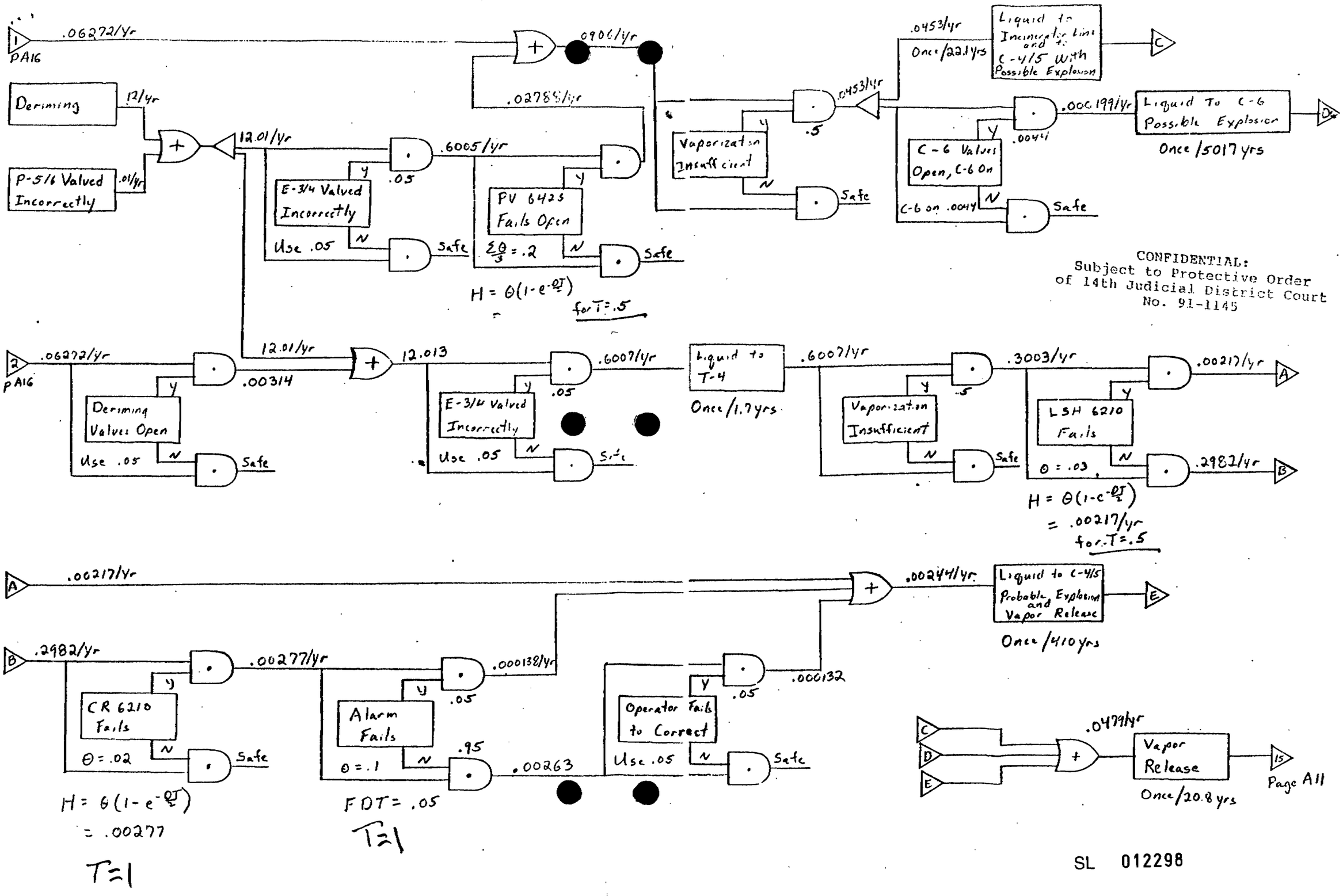
of 14th Judicial District Court
No. 91-1145

SL 012294






Pumping to T-7
6/yr
.3/yr
.05
Y
LG Fails
θ = .1
N
FDT = .05
5.7/yr
.057
.01
LG Used Incorrectly
Use .01
Safe
T-7 Fills Normally
8.55/yr
.4275/yr
.05
Operator Fails to Empty
Use .05
Safe
+
.7845/yr
.01781/yr
LT 6215 Fails
θ = .1
H = θ(1-e^-QT) = .01781 for T = .5
.7667/yr
.005233/yr
LSHL 6215 Fails
θ = .03
H = θ(1-e^-QT) = .005233 for T = .5
.7616/yr
.01733/yr
Alarm Fails
θ = .1
H = θ(1-e^-QT) = .01733 for T = .5
.7441/yr
A
B
C
D
.01781/yr
.005233/yr
.01733/yr
.000867/yr
VCM II Alarm Fails
θ = .1
FDT = .05
T = 1
.95
.01647/yr
.000823/yr
Notification Fails
Use .05
.01564/yr
.7598/yr
Operator Fails Correct
Use .05
.03799/yr
.7441/yr
.06272/yr
once/15.9yrs
T-7 Overfills
1 pA17
2 pA17
CONFIDENTIAL
Subject to Protective Order
In 11th Judicial District Court
No. 91-1145
SL 012297


1
PA16
.06272/yr
Deriming
12/yr
P-5/6 Valved Incorrectly
.01/yr
12.01/yr
E-3/4 Valved Incorrectly
Use .05
.05
Y
N
Safe
.6005/yr
PV 6425 Fails Open
Σθ/3 = .2
Safe
H = θ(1-e^-θT)
for T=.5
.0906/yr
.02788/yr
Vaporization Insufficient
.5
.0453/yr
Safe
.0453/yr
Once/22.1yrs
Liquid to Incinerator Line and C-4/5 with Possible Explosion
C
.000199/yr
C-6 Valves Open, C-6 On
.0044
C-6 on .0044
Safe
Liquid To C-6 Possible Explosion
Once/5017 yrs
D
CONFIDENTIAL:
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of 14th Judicial District Court
No. 91-1145
2
PA16
.06272/yr
.00314
12.01/yr
12.013
Deriming Valves Open
Use .05
Safe
E-3/4 Valved Incorrectly
Use .05
.05
.6007/yr
Liquid to T-4
Once/1.7yrs
.6007/yr
Vaporization Insufficient
.5
.3003/yr
LSH 6210 Fails
θ = .03
.00217/yr
.2982/yr
A
H = θ(1-e^-θT)
= .00217/yr
for T=.5
A
.00217/yr
B
.2982/yr
CR 6210 Fails
θ = .02
.00277/yr
H = θ(1-e^-θT)
= .00277
T=1
Alarm Fails
θ = .1
.95
.00263
.000138/yr
FDT = .05
T=1
Operator Fails to Correct
Use .05
.05
.000132
.00244/yr
Liquid to C-4/5 Probable Explosion and Vapor Release
Once/410 yrs
E
C
D
E
.0479/yr
Vapor Release
Once/20.8 yrs
15
Page A11

SL 012298

INABILITY TO CORRECT FAULT BEFORE TANK PRESSURE GETS TO 3" PSIG. USE ONCE IN 250 TIMES — .004

5 — PAGE A11

"NORMAL" SOURCE OF HIGH PRESSURE VCM — 32.839 /yr

.1354/yr

DEMAND FOR USE OF C-6 COMPRESSOR TO PREVENT BLOWING RELIEF VALVES

ALARMS FAIL — Y θ=.03 — .00194/yr — A

N — .1334/yr

OPERATOR FAILS TO TURN ON C-6 COMPRESSOR — Y .008 — .001067/yr — B

N — .1323/yr — C

USE .008

Minimum cut set on pressure alarms θ = 2.41x10⁻⁵

use Common Mode θ = .03

$H = \theta(1-e^{-\frac{\theta T}{2}}) = .001964$

Change in D only

C — .1323/yr — .00496/yr — D

C-L NOT RUNNING θ=.2801 — Y FDT=.0375

N — .1273/yr

C-L NOT RUNNING. DOWN FOR OVERHAUL; E-B NOT RUNNING; POWER FAILURE; BROKEN BELTS; MOTOR FAILURE; SAFETY SHUTDOWN; P-7 OIL PUMP OFF; COMPRESSOR MECHANICAL BREAKDOWN; FUSE/CIRCUIT BREAKER OUTAGE.

TOTAL FAILURE RATE = .2801/yr

$FDT = \frac{\theta T}{2} = \frac{(.15)(.5)}{2} = .0375$

Assume θ = .15

C-6 NOT PUMPING TO INCINERATOR — Y — .012/ /yr

(SEE EXPANDED TREE BELOW)

N — .1152/yr

C-6 NOT PUMPING FROM T-1/T-2 — Y .002

USE .002 — N — SAFE

Use .002

.00023

A, B, D — + — .0203/yr — C-6 UNAVAILABLE TO LOWER PRESSURE IN STORAGE TANKS ONCE/49.2 YRS — 6 — PAGE A11

DEMAND (SEE ABOVE) — .1273/yr

INCINERATOR SHUTDOWN FDT=.0028 — Y .0028

N — .000355/yr

ASSUME 4 TRIP/Month LASTING 30 MINUTES

FDT = 4/1440 = .0028

No Change

.1269/yr

SHUTOFF VALVE CLOSED XV6806 — Y .018

N — .002285/yr

θ = .072

FDT = .018

LOSS OF INSTR. AIR; SOLENOID VALVE FAILURE; LOSS OF VOLTAGE TO VALVE COIL; BROKEN TUBING

FDT = .018 for T = 0.5

.1247/yr

CONTROL VALVE CLOSED FV6005 — Y .01

N — .001247/yr

θ = .34

Use .01

LOSS OF INSTR. AIR; SOLENOID VALVE FAILURE; LOSS OF VOLTAGE TO VALVE COIL; TRANSDUCER FAILURE; LOSS OF SIGNAL FROM CONTROLLER; LOW SIGNAL FROM CONTROLLER

Assume Open Bypass & Valve Fails

.1234/yr

DISCHARGE VALVE CLOSED — Y .005 — .000617/yr

N — USE .005

Use .005

.1228/yr

RELIEF VALVE OPEN θ=.08 — Y .02 — .002456/yr

N — FDT=.02

FDT = .02 for T = .5

RECYCLE LOOP FLOW MAY BE DUE TO: LOSS OF INSTR. AIR; TRANSDUCER FAILURE; VALVE PV6427 STUCK OPEN; LOW SELECT RELAY FAILS LOW; ACTION REVERSED ON LOW SELECT RELAY; LOW SIGNAL FROM PIC 6427; LOW SIGNAL FROM PIC 6426B

.1203/yr

RECYCLE LOOP FLOW =.345 — Y

N — .1152/yr

T = .25

+ — .0121/yr

.005149/yr

SL 012299

DEMAND TO REMOVE NITROGEN FROM CONDENSERS — USE 4000/YR

AND → 11.2/YR
- Y: .0028 — PORTION OF TIME INCINERATOR IS DOWN
- N: ~3990/YR

4 Trips/month
Lasting 30 minutes
$P = \frac{4(30)}{30(1440)} = .0028$

IN THE EQUATION $H = \theta(1-e^{-DT/2})$, FOR ANY VALUE OF D LARGER THAN ABOUT 15,
$H \approx \theta$

AND → .033/YR — SHUTOFF VALVE SYSTEM FAILS
(SEE EXPANDED TREE BELOW)

AND → ~3990/YR — COMPR. RELIEF VALVE OPEN AT NORM. PRESSURE, $\theta = .005$

$\theta = .005$

AND → .005/YR

AND → ~3990/YR
- Y: PORTION OF TIME BOTH C-4 & C-5 NOT RUNNING
- N: ~3990/YR

AND → .917/YR

- C-4 OR C-5 NOT WORKING: USE .25 (ONCE/4 HRS)
- C-5 OR C-4 OUT OF SERVICE FOR OVERHAUL. SAY 1 WK OUT OF EACH YR.

$f_T = f_A P_B + f_B P_A$
$= f_A \Sigma \frac{f_B t_B}{365} + f_B \Sigma \frac{f_A t_A}{365}$
$= .50\left(\frac{1.25 \cdot 7}{365}\right) + \left(\frac{1.25 \cdot 7}{365}\right)$
$= .02397$ times/yr
$P_2 = (.02397)\left(\frac{3.5}{365}\right) = .0002299$
$H = P \times D = .917$

Reduce C-4/C-5 Not Working to once/4 yrs

OR → 32.10/YR — C-4/C-5 NOT PUMPING NITROGEN FROM E-3/E-4 CONDENSERS ONCE/.03 YRS → (2) PAGE A11

AND → 19.95/YR
- Y: .005 — VALVES NOT LINED UP CORRECTLY FROM E-3/E-4 THROUGH COMPRESSOR DISCH. USE .005
- N: SAFE

P = use .005

DEMAND (SEE ABOVE) — 3990/YR

AND → .02/YR
- Y: SOLENOID VALVE FAILS XV6806, $\theta = .02$
- N: 3990/YR

AND → .013/YR
- Y: SHUTOFF VALVE FAILS XV6806, $\theta = .013$
- N: 3990/YR

OR → .033/YR

$H = \theta\left(1-e^{-\frac{QT}{2}}\right)$
$H \doteq \theta$ since $D \gg 1$
$H \geq \theta$