

STUDY ON  
EFFECTS OF REMOVING THE  
TURBINE REDUNDANT OVERSPEED TRIP SYSTEM

&

EVALUATION OF SURVEILLANCE TESTING  
AND IMPACT ON DESTRUCTIVE OVERSPEED PROBABILITY

CAROLINA POWER & LIGHT  
ROBINSON UNIT NO. 2  
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EFFECTS OF REMOVING THE  
TURBINE REDUNDANT OVERSPEED TRIP SYSTEM  
AT H. B. ROBINSON UNIT 2  
(Revised June 1989)

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## A. Purpose of Study

A probabilistic review and analysis of the effects of removing the Turbine Redundant Overspeed Trip System (TROTS) was conducted by Westinghouse Electric Corporation at the request of Carolina Power and Light Company who may wish to remove the system from the H. B. Robinson turbine in the future. The purpose of the analysis was to evaluate the turbine reliability with TROTS removed and to determine whether the resultant risk of turbine missile ejection was low enough to meet the current NRC acceptance criteria.

## B. Summary and Conclusions

A new probabilistic analysis was performed to evaluate the removal of the TROTS system. The current analysis supports the following conclusions with respect to removal of TROTS.

1. The probabilities of turbine missile ejection from the Robinson fully-integral rotors are far below the NRC acceptance criteria without any benefit of TROTS. Therefore, the protective benefits of TROTS are not needed to assure sufficiently low probabilities of destructive overspeed and missile ejection.
2. From the basis of probabilistic analysis, the removal of TROTS from the Robinson turbine leaves sufficient redundancy and diversity of trip and overspeed protection for safe turbine operation. Independent failures of the mechanical overspeed trip mechanism, overspeed protection controller, or electrical solenoid trip have a minimal or insignificant effect on the probability of destructive overspeed as long as this redundancy and diversity is maintained.
3. Testing the existing turbine trip and overspeed protection systems (without TROTS) in accordance with current Robinson procedures (OST-551 Rev. 11, OST-553 Rev. 4, and GP-005 Rev. 27) results in an annual frequency of destructive overspeed and missile ejection that is

well below the criterion of  $10^{-5}$  per year. Therefore, a probabilistic basis is established which supports the current Robinson test intervals of the mechanical overspeed trip mechanism, overspeed protection controller, electrical solenoid trip mechanism, and turbine valves.

4. Current surveillance testing of turbine trip and overspeed protection systems (without TROTS) in conjunction with testing of turbine valves at intervals longer than the current monthly interval required by Robinson procedure OST-551 results in an annual frequency of destructive overspeed and missile ejection that is below the criterion of  $10^{-5}$  per year. Therefore, a probabilistic basis exists which supports the current surveillance frequency of turbine trip and overspeed protection simultaneous with extended test intervals of the turbine valves at Robinson Unit 2.

#### C. Background and Description of TROTS

TROTS, also called the Independent Emergency Overspeed Protection System or IEOPS in Westinghouse documentation, was designed approximately twenty years ago as a system that could be added to the turbine to provide additional redundant protection against overspeed. At that time, physical model simulations of the impact and penetration of LP turbine disc fragments through the turbine casing indicated that inadvertent acceleration of the turbine to runaway destructive overspeed was certain to result in the ejection of turbine disc fragments with sufficient energy to damage plant safety components.

IEOPS was proposed in the late 60's as an "additional" overspeed protection system which could be added to operating turbines to increase the diversity of overspeed detection and trip and thereby decrease the probability of destructive overspeed. All Westinghouse nuclear steam turbines in operation at that time were supplied with a standard mechanical overspeed trip system plus one or more other systems for controlling overspeed or for tripping the turbine upon loss of load. However, when the industry began to confront the

issue of turbine missile damage, the design of a new trip system that would meet the most stringent criteria for nuclear protection systems was judged to be a prudent and satisfactory solution.

IEOPS was developed in accordance with IEEE 279 as a safety or protection-grade system that was redundant to the other trip systems on the turbine and which was testable during normal operation. As such, the first probabilistic analysis of this system, performed for the Point Beach plant (Reference 1), was later modified for other plants and incorporated into the licensing basis of the few plants that had the system. Reference 2 is the probabilistic study of the TROTS system that was made for the Robinson turbine.

Over the approximate period of 1974 to 1988, Westinghouse has collected reliability data on its nuclear and fossil steam turbines. The Westinghouse studies that have utilized these data (References 3, 4, and 5) have shown that there is enough redundancy in these systems from the probabilistic risk analysis perspective such that the failures of these systems generally do not show up in the top minimal cutsets that are most responsible for the overspeed probability. In general, the mechanical trip device and other overspeed protection and protective components that are actuated with overspeed or loss of load have been found to be very reliable when maintained in accordance with Westinghouse recommendations.

The TROTS system installed on the Robinson turbine has a total of 28 solenoid-actuated dump valves which open on overspeed to dump the high pressure oil from the actuators of the steam valves, thereby closing the valves. There are two dump valves attached to each turbine valve (4 governor valves, 2 stop valves, 4 interceptor valves, and 4 reheat stop valves). Each dump valve is normally deenergized and opens upon receipt of actuation power from one of two separate DC power sources. Only one dump valve must open to close the turbine valve. Although the purpose of TROTS is to protect against destructive overspeed, the reheat stop and interceptor valves are also included in the IEOPS scheme even though the failures of these valves alone cannot cause a destructive overspeed event.

TROTS has three speed detectors at the generator end of the turbine that send speed signals to three separate conditioning and logic circuits. The conditioning and logic sections of the system send a continuous output signal to the coils of six hermetically sealed overspeed detection relays as long as the turbine speed is less than 111 percent. In the event that the TROTS overspeed setpoint of 111 percent is reached, the signal to the coils of the overspeed detection relays is terminated which opens the contacts of the relays. This, in turn, terminates the voltage to the coils of four control relays. The deenergization of the control relays results in the closing of contacts which apply DC control power to the solenoid dump valves, thereby opening the dump valves, thereby closing the turbine valves through their springs.

#### D. Analysis and Methodology

The analysis and calculation of the effects of TROTS removal utilized three fault trees of turbine design, intermediate, and destructive overspeed, and utilized component failure data, all of which came from the study performed in 1987 for the special Westinghouse Owners Group (Reference 5). Robinson Unit 2 was a part of the 1987 study. The fault trees include failures of the standard protective and trip components but do not include failures of the IEOPS system. IEOPS was installed on five of nineteen units in the 1987 study, and the Robinson turbine was grouped for purposes of analysis with three other nearly-identical turbines that did not have an IEOPS or TROTS.

The failure criteria or sequence of events that define the overspeeds are given in Table 1. These failure criteria are applicable to Robinson, and the fault trees incorporate failure logic that is consistent with the definitions in this table. For information, the design overspeed sequence results in turbine speed that approaches but does not exceed the design overspeed of the turbine which is 120 percent of rated speed. The intermediate overspeed sequence results in a maximum overspeed of approximately 130 percent, while the destructive overspeed sequence is defined as causing the turbine to accelerate freely to a runaway speed of approximately 180 percent. At this approximate speed, the physical model simulations of the late 1960s showed that sections of shrunk-on LP turbines discs would penetrate a steel plate

simulating the outer casing of the LP turbine. The ejection of disc fragments from fully-integral LP rotors at runaway speed has not been simulated in physical model tests. However, analysis indicates that runaway speeds of FI rotors could cause the generation of a missile. It was assumed in the risk analysis that fully-integral LP rotors behaved the same as built-up rotors at destructive overspeed.

All three overspeed events involve a system separation in which it is assumed that all or practically all of the load on the turbine-generator is lost quickly and not restored. This loss of load is necessary in order to provide the conditions which are favorable for rapid turbine acceleration. In the current analysis, a mean frequency of system separation of 0.5 per year, determined for all PWRs, was used.

Information supplied by the Robinson plant on the turbine steam system and on the turbine control and trip system was reviewed and compared with the fault trees. A list of the design information that was reviewed is given in Table 2. The review confirmed that the Reference 5 fault trees of design and intermediate overspeed correctly modeled the existing turbine valve and turbine control system at Robinson. The destructive overspeed fault tree from Reference 5 was modified to produce a more accurate model of the blockage of fluid paths that return the EH fluid to the reservoir. Other changes were made in the modeling of overspeed protection and trip systems which resulted in a more accurate model and an improved presentation of the destructive overspeed tree. This new destructive overspeed fault tree has been included in Addendum 1 of this report.

A brief augmented list of the trip systems at Robinson is given for information in Table 3. In summary, the fault trees of design and intermediate overspeed contain failures of the main speed detection system, the overspeed protection control system, and the electrical solenoid trip valve which opens with loss of load. The destructive overspeed fault tree contains failures of all of the protective systems included in the design and intermediate trees plus the failure of the mechanical overspeed trip valve.



The Robinson plant has surveillance test procedures for turbine components such as inlet valves, turbine trip systems, and the overspeed protection controller system. At the request of Carolina Power and Light, the test procedures and specific test frequencies were reviewed and the fault tree analysis models were constructed to accurately incorporate the effects of testing. The analyses and calculations of design, intermediate, and destructive overspeed probability all incorporate the effect of the test frequency of turbine valves.

The calculation of destructive overspeed probability was reviewed and updated to accurately reflect the testing of the mechanical overspeed trip system, the overspeed protection controller system, and the electrical solenoid trip. A review of test procedures and control system operation was made to identify faults related to the overspeed trip and overspeed protection function whose probabilities were affected by testing. After the components were identified, the failure probabilities of the affected components were quantified in accordance with the basic calculation model and used in the quantification of the probability of destructive overspeed. The calculation model is based on probabilities or unavailabilities of tested standby components being directly proportional to the time interval between tests, with the component failure rate serving as a constant of proportionality.

Table 4 lists the turbine components that affect the destructive overspeed analysis and the test intervals of the components. Test intervals from the Robinson surveillance test procedures are shown in the table along with recommended test intervals from Westinghouse instruction leaflet I.L. 1250 5240.10 (Reference 7). Final calculations of destructive overspeed probability were made using the Robinson test intervals. Since the test intervals of some components such as OPC and trip components are longer than the intervals recommended by Westinghouse, a short evaluation of the relative effects of extending these test intervals on the probability of destructive overspeed is given in Addendum 1 of this report. This addendum gives the detailed results that were obtained to assess the impact of the longer Robinson test intervals.

Plant information on the steam extraction lines from the turbines was also reviewed and compared to the fault tree of extraction nonreturn valve failure in Reference 5. In Reference 5, a failure to block reverse steam flow in any two of the extraction lines to the turbine following a loss of load and turbine trip results in design overspeed. The Robinson plant has six LP extraction lines for feedwater heating which originate at locations on the LP turbines where sufficient blading exists downstream of the extraction points to drive the unit to overspeed. These six extraction lines combine into four lines, each of which has an extraction nonreturn valve. The HP turbine has two extraction lines with double valving in each. The general fault tree of the system in Reference 5 is representative of the system at Robinson with the exception that the lines with double valving are not modeled. However, probability of reverse steam flow would be significantly less in the lines with double nonreturn valves, and this additional probability would not have a significant effect on the system failure probability.

The component failure data used in the quantification of overspeed was obtained from the previous Reference 5 study. Surveys of turbine valve reliability were first made in 1974 and were followed by more detailed surveys in 1982 and 1987. The Robinson experience since the date of the last questionnaire survey has been as good as or better than the industry average. In summary, the failure data used in the analysis is believed to be representative of the current conditions at the plant.

Probabilities of turbine missile ejection were calculated using the methodology developed in Reference 5. This methodology involves the calculation of a total missile probability that results from design, intermediate, and destructive overspeed. The overspeed probabilities, designated  $P(A)$ ,  $P(B)$ , and  $P(C)$ , were obtained from Reference 5. The general equation used to calculate the probability of turbine missile ejection is given in Table 5.

The conditional probabilities of missile ejection,  $P(M/A)$ , and  $P(M/B)$ , indicate the probability of missile ejection once the turbine reaches overspeed. Conditional probabilities have been calculated by Westinghouse based on the specific properties of many LP rotors at operating plants. In the current study, the fully-integral (FI) rotors installed at the plant were considered. The source of conditional probability data for the FI rotors is Reference 5.

Turbine missile probabilities were calculated during the last year of operation of the LP rotors before their scheduled inspections. For the FI rotors, this inspection interval is 10 years. The last year of operation is used in the analysis because the conditional probabilities  $P(M/A)$  and  $P(M/B)$  are higher at this time than during any preceding year. The calculation of turbine missile probabilities assumed that the LP rotors had accumulated 10 years of operating time just prior to inspection. This assumption results in more conservative values of  $P(M/A)$  and  $P(M/B)$  than if 10 years of calendar time was used. The results of the calculations and the probability data used to obtain the results are given in Table 6. Since turbine valve test intervals at Robinson may increase in the future, the results have been reported for turbine valve test intervals of 1 month, 6 months, and 12 months.

#### E. Discussion of Results

Calculations of the total annual probability of turbine missile ejection due to overspeed were made for the Robinson plant through the use of detailed fault trees and component failure data. The analysis assumed that TROTS was removed from the turbine, and the fault trees modeled the actual overspeed protection controls and remaining overspeed trip components that are currently installed on the turbine.

The total probability of turbine missile ejection from the Robinson turbine with the FI rotors in service, TROTS removed, and testing in accordance with the Robinson intervals in Table 4 was determined to be approximately  $7.5 \times 10^{-8}$  per year. This probability is far below the current acceptance

criteria of the NRC. Table 6 gives probabilities of turbine missile ejection for the current monthly testing of turbine valves and for extended test intervals. All other turbine components are assumed to be tested in accordance with the Robinson intervals given in Table 4. Destructive overspeed accounts for almost all of the total turbine missile probability in Table 6 because fully integral L.P. rotors are very unlikely to eject missiles at design and intermediate overspeed.

The turbine missile probabilities in Table 6 meet the general NRC acceptance criteria of  $1 \times 10^{-5}$  per year.

For information, the NRC acceptance criteria, stated in Reference 6 for unfavorably oriented turbines, is summarized below :

<u>Probability Per Year</u>	<u>Licensee Action</u>
A. $P(1) < 10^{-5}$	Start up and operate plant
B. $10^{-5} < P(1) < 10^{-4}$	Plant may operate until next scheduled outage at which time action must be taken to reduce $P(1)$ to A above.

#### F. References

1. "Likelihood and Consequences of Turbine Overspeed at the Point Beach Nuclear Plant," WCAP-7525, Westinghouse Nuclear Energy Systems, June, 1970.
2. "H. B. Robinson Unit No. 2, Likelihood and Consequences of Turbine Overspeed," Docket-50261-34.
3. "Evaluation of the Impact of Reduced Testing of Turbine Valves," WCAP-10161, Westinghouse Nuclear Energy Systems, September 1982 [PROPRIETARY].

4. "Analysis of the Probability of a Nuclear Turbine Reaching Destructive Overspeed," WSTG-3-P-A, Westinghouse Steam Turbine Generator Division, May 1981 (Revised July 1, 1987) [PROPRIETARY].
5. "Probabilistic Evaluation of Reduction in Turbine Valve Test Frequency," WCAP-11525, Westinghouse Electric Corporation, June 1987 [PROPRIETARY].
6. U.S. Nuclear Regulatory Commission Letter and Enclosure from C. E. Rossi to J. A. Martin of Westinghouse Electric Corporation, dated February 2, 1987.
7. "Periodic Functional Tests," Westinghouse Instruction Leaflet I.L. 1250 5240.10, dated 3/86.

TABLE 1  
GENERAL TURBINE FAILURE SEQUENCES RESULTING IN OVERSPEED  
ROBINSON UNIT 2

A. Design Overspeed Failure Sequence:

1. System separation occurs.
2. One or more governor valves or two or more interceptor valves stick open, or the initial protective action of dumping the governor valve emergency trip fluid header fails.
3. The stop and reheat stop valves close successfully after receipt of the overspeed trip signal.

B. Intermediate Overspeed Failure Sequence:

1. System separation occurs.
2. One or more combinations of reheat stop and interceptor valves fail to close and block the flow of steam, or one or more combinations of stop valve bypass and governor valves fail to block the flow of steam.
3. The stop valves close successfully after receipt of the overspeed trip signal.

C. Destructive Overspeed Failure Sequence:

1. System separation occurs.
2. One or more combinations of governor and stop valves in the same steam path stick open, or the protective action associated with overspeed protection control, overspeed trip, and loss of load trip fail to dump the high pressure fluid from the governor and stop valve actuators.

TABLE 2  
LIST OF DESIGN INFORMATION AND SURVEILLANCE  
TEST PROCEDURE DOCUMENTS  
H. B. ROBINSON UNIT 2

- o Electro-Hydraulic High Pressure Oil System Flow Diagrams:  
HBR2-8699 Sheet 1, Rev. 0  
HBR2-8699 Sheet 2, Rev. 4  
HBR2-8699 Sheet 3, Rev. 1
- o Electro-Hydraulic Control and Lubrication System Diagrams:  
CP&L 5379-3291, Rev.0  
W 717J068  
W 718J049, CP&L 5379-6206, Rev. 0
- o Logic Diagram: Turbine Trip Signal, 5379-3695, Rev. 7
- o Main and Extraction Steam System Flow Diagrams:  
  

G-190196, Sh. 1, Rev. 29	G-190196, Sh. 3, Rev. 16
G-190196, Sh. 2, Rev. 19	G-190196, Sh. 4, Rev. 2
- o System Description Procedure SD-033, Rev.4, Turbine and Controls
- o HBR 2 Updated FSAR Section 10.2, Turbine Generator
- o HBR 2 Updated FSAR Section 3.5, Missile Protection
- o Operations Surveillance Test Procedures:  
  

OST-551 Rev. 11, Turbine Valve and Trip Functional Test, dated 11-16-88
OST-553 Rev. 4, Turbine Mechanical Overspeed Trip Test, dated 1-24-89
OST-554 Rev. 3, Turbine Bearing Oil System and E.H, Control System Hydraulic Components Test, dated 9-22-88
- o General Procedure GP-005 Rev. 27, Power Operation, dated 4-25-89

TABLE 3  
DESCRIPTION OF TURBINE TRIP AND  
OVERSPEED PROTECTION SYSTEMS AT ROBINSON UNIT 2

Mechanical Overspeed Trip Valve: This mechanism consists of an eccentric weight mounted in the shaft of the turbine at the governor end plus a normally-closed cup valve which is opened by a lever and trigger in the event that the overspeed trip setpoint of 110 percent is reached. The opening of the cup valve dumps the autostop oil which, in turn, results in the dumping of the high pressure fluid from all of the turbine valves through each valve's dump valve, thus causing the turbine valves to close by their spring action.

20/AST Electrical Solenoid Trip Valve: This normally-closed valve will open in the event that a generator trip signal occurs as a result of a complete loss of load or opening of the generator breaker. Actuation of the solenoid opens a plunger valve that dumps the autostop oil in a separate and redundant manner from the overspeed trip valve.

Overspeed Protection Controller: This system has two solenoid-operated valves, labeled 20-1/AG and 20-2/AG, which will dump the governor valve emergency trip fluid at an overspeed setpoint of 103 percent. This action causes the governor and interceptor valves to close and remain closed as long as the overspeed condition exists. The system has a separate speed detector mounted at the governor end of the turbine.

TROTS: Described previously in Section C of this report. This system was not included in the overspeed fault trees. TROTS provides a means of dumping the high pressure fluid from the turbine valve actuators through a separate path from the governor and stop valve emergency trip fluid headers. TROTS has a separate speed detector mounted at the generator end of the turbine.

Additional Note:

There are four redundant means of dumping the governor and stop emergency trip headers. The mechanical overspeed trip and electrical solenoid trip are separate and redundant systems for dumping autostop oil. The dumping of the autostop oil results in the opening of the hydraulically-operated interface valve which dumps the governor and stop valve emergency trip fluid headers. The emergency trip valve, labeled 20/ET, is a redundant valve for dumping the emergency trip fluid lines which opens upon receipt of a low pressure signal in the autostop oil header. The two solenoid valves of the overspeed protection control system are a third and fourth means of dumping the governor emergency trip fluid header.



TABLE 4  
COMPARISON OF TEST INTERVALS OF TURBINE COMPONENTS  
INVOLVED IN ANALYSIS OF DESTRUCTIVE OVERSPEED PROBABILITY

<u>Turbine Component or System</u>	<u>Test Interval Recommended by Westinghouse</u>	<u>Test Interval in Robinson 2 Procedures</u>	
		<u>Procedure</u>	<u>Interval</u>
Stop Valves	Weekly	OST-551	Monthly
Governor Valves	Weekly	OST-551	Monthly
Overspeed Protection Controller	Semi-annually	OST-553	18 mo. [refueling <sup>(1)</sup> ]
Mechanical Overspeed Trip Weight	Monthly	OST-551 <sup>(2)</sup>	Monthly
Mechanical Overspeed Trip Mechanism	Semi-annually	OST-553 <sup>(3)</sup>	18 mo. [refueling <sup>(1)</sup> ]
Remote Electrical Solenoid Trip Valve	Semi-annually	GP-005	18 mo. [startup <sup>(4)</sup> ]

NOTES:

- (1) Test is performed during power reduction for refueling or during power escalation following refueling. Refueling frequency is once per 18 months.
- (2) Oil pressure test, conducted while turbine is on-line.
- (3) Overspeed test, conducted while turbine is off-line.
- (4) Test is required following refueling. Test is not required if the startup is a recovery from a reactor trip.

TABLE 5  
GENERAL METHODOLOGY OF PROBABILISTIC CALCULATIONS  
OF TURBINE MISSILE EJECTION

The general equation for evaluating the total annual probability of missile ejection due to overspeed is:

$$P(1) = P(A) \times P(M/A) + P(B) \times P(M/B) + P(C)$$

Where:

P(1) = Annual probability of turbine missile ejection

P(A) = Annual probability of design overspeed of turbine

P(B) = Annual probability of intermediate overspeed of turbine

P(C) = Annual probability of destructive overspeed of turbine

P(M/A) = Conditional probability of missile ejection given that design overspeed occurs

P(M/B) = Conditional probability of missile ejection given that intermediate overspeed occurs

P(A), P(B), and P(C) are mean probabilities calculated through fault tree analysis of the turbine valve and related control and trip systems.

P(M/A) and P(M/B) are determined specifically for the LP fully-integral and built-up rotors at Robinson 2.

TABLE 6  
RESULTS OF TURBINE MISSILE PROBABILITY CALCULATIONS  
ROBINSON UNIT 2 WITH TROTS REMOVED

A. CONDITIONAL PROBABILITIES OF MISSILE EJECTION DURING LAST YEAR

Rotor Type	First Quarter		End of Year	
	P(M/A)	P(M/B)	P(M/A)	P(M/B)
Fully Integral (FI)	5.0E-7	7.5E-6	1.0E-6	1.6E-5

B. PROBABILITIES OF TURBINE OVERSPEED [YR<sup>-1</sup>]

Turbine Valve Test Interval	P(A) Design Osp.	P(B) Interm. Osp.	P(C) Destr. Osp.
1-MO.	4.20E-4	1.19E-5	7.50E-8
6-MO.	5.98E-4	1.39E-5	3.86E-7
12-MO.	8.54E-4	1.80E-5	9.80E-7

C. PROBABILITIES OF TURBINE MISSILE EJECTION [YR<sup>-1</sup>]

Turbine Valve Test Interval	Fully Integral Rotor	
	First Quarter P(1)	End of Year P(1)
1-MO.	7.5E-8	7.6E-8
6-MO.	3.9E-7	3.9E-7
12-MO.	9.8E-7	9.8E-7

Note: The probabilities listed under letters B and C above are based on an assumed system separation frequency of 0.5 per year. P(A), P(B), and P(C) can be corrected for any other system separation frequency by dividing by 0.5 and multiplying by the actual separation frequency to be considered.

ADDENDUM 1  
EVALUATION OF SURVEILLANCE TESTING AT ROBINSON UNIT 2  
AND IMPACT ON DESTRUCTIVE OVERSPEED PROBABILITY

Addendum to Report:

"Effects of Removing the Turbine Redundant Overspeed Trip System,"  
Dated June 1989.

The purpose of this addendum is to provide additional details and destructive overspeed probability results which show the relative effects of changing the test frequencies of various turbine components. The probability results in the main report (Table 6) indicated that destructive overspeed probability increased by approximately one order of magnitude if the test intervals of the stop valves and governor valves were changed from one month to one year. However, the Table 6 results did not consider the relative increase in the probability that might result if the test intervals of other turbine components were changed.

The Robinson Unit 2 surveillance test procedures require testing of the overspeed protection controller, the electrical solenoid trip valve, and the complete mechanical overspeed trip mechanism every 18 months, as indicated in Table 4. This differs from the 6 month test interval recommendation given by Westinghouse in Instruction Leaflet I.L. 1250 5240.10 (Reference 7). The six month test interval was recommended many years ago based on conservative engineering judgement. The effects of extending the 6 month test interval to 18 months was evaluated. This evaluation was made in conjunction with extending the test intervals of the stop and governor valves.

The Robinson 2 surveillance test procedures were reviewed in order to gain an understanding of how each test was performed and how each component's operability was verified. After this review, an identification was made of basic faults in the fault tree that were affected either directly or indirectly by testing. The faults in Table 7 were determined to fit the

basic unavailability calculation model in which failure probability or unavailability of the fault is directly proportional to the time interval between tests. The table contains several faults outside of the boundary of the component or system being tested because the test outcomes in the procedures are defined in terms of a turbine trip or in terms of closure of the turbine valves. For example, a fault such as clogging of the autostop oil header would be detected in the overspeed trip test of the mechanical overspeed trip mechanism since the control and stop valves would not close or would close in a delayed manner if the autostop oil header did not depressurize rapidly as soon as the overspeed trip speed was reached.

The destructive overspeed probabilities calculated for the investigation of extending the test intervals of the mechanical overspeed trip device, the overspeed protection controller, and the electrical solenoid trip are given in tabular form in Table 8. The extension of the test interval from 6 months to 18 doubles the destructive overspeed probability for turbine valve test intervals up to about 3 months and has a lesser impact for the longer turbine valve test intervals of 6 months and 12 months. This effect of doubling the probability is considerably less than the approximate ten-fold increase in destructive overspeed probability that results from increasing the turbine valve test interval from one month to 12 months. Assuming a frequency of system separation of 1 per year, the probability or annual frequency of turbine missile ejection due to destructive overspeed (the only significant event) is well below the criteria of  $1.0 \times 10^{-5}$  for all test intervals evaluated in Table 8.

Table 9 gives the top four faults having the largest importance factors for each case analyzed. Only two faults related to testing of the mechanical overspeed trip device, overspeed protection controller, and the electrical solenoid trip appear in Table 9. These faults are failure of the emergency trip fluid header common to the stop valves due to clogging (D12B), and failure of the stop valve to close promptly due to mechanical damage (D47SV\*). The latter fault is included in the list because mechanical

damage is assumed to be a fault that slows the rate of closure of the valve and is assumed to be detectable only during turbine trip when the high pressure oil is suddenly dumped.

The detailed results on component importance indicate that faults of the OPC solenoid valves, the mechanical overspeed trip mechanism, and the electrical solenoid trip valve contribute very little to the probability of destructive overspeed. Each of these components have importance factors of less than 5 for all of the test interval cases considered and are relatively unimportant contributors to destructive overspeed probability in comparison to the component faults listed in Table 9. These protective devices are relatively ~~unimportant~~ contributors because they function as a diverse and redundant system.

The results presented are based on the assumption that the diversity and redundancy associated with the dumping of the EH emergency trip fluid is maintained through surveillance testing or inspection at 18 month intervals. This redundancy consists of the two 20/OPC solenoid dump valves which operate in response to a signal from the overspeed protection controller, and the redundant combination consisting of the hydraulic-operated interface dump valve and the solenoid-operated 20/ET dump valve.

E 7  
DETAILED LIST OF FAULTS AFFECTED BY TESTING AND BASIS FOR  
EVALUATING EXTENDED TEST INTERVALS

Fault Identification Code <sup>(1)</sup>	Description of Fault	Failure Rate <sup>(2)</sup> [hr <sup>-1</sup> ]	Applicable Robinson Unit Test Procedure <sup>(3)</sup>	Test Intervals Evaluated <sup>(4)</sup>
D01	Failure of Mechanical Overspeed Trip Weight	3.87E-8	B,C	F
D02	Failure of Mechanical Overspeed Trip Valve	6.55E-9	C	H
D03	20/AST Solenoid or Plunger Valve Fails	4.51E-8	E	H
D04	20/AST Actuation Train Fails	2.59E-8	E	H
D06	Oil-Operated Interface Valve Fails to Open	4.90E-7	C,E	H
D07	Return Line for EH Trip Fluid is Clogged	5.19E-9	C,E	H
D11CV*	Control Valve (CV) Dump Valve Fails to Open	5.67E-9	C,E	H
D11SV*	Stop Valve (SV) Dump Valve Fails to Open	5.67E-9	A	G
D12A	Emergency Trip Fluid (ETF) Header for CV is Clogged	6.97E-8	C,D,E	H
D12B	ETF Header for SV is Clogged	6.97E-8	C,E	H
D13	Auto stop Oil Line is Clogged	6.56E-9	C,E	H
D14CV*	Drain Line Through Top of CV Cylinder is Clogged	5.76E-9	A	G
D14SV*	Drain Line Through Top of SV Cylinder is Clogged	5.76E-9	A	G
D16SV*	Stop Valve Sticks Open	2.33E-7	A	G
D17CV*	CV Servovalve Fails to Connect Cylinder to Drain	2.61E-8	A	G
D18CV*	CV Servovalve Circuitry Fails	1.12E-7	A	G
D19CV*	Control Valve Sticks Open	2.95E-8	A	G
D20CV*	Check Valve in CV Trip Fluid Line Fails to Open	2.57E-9	C,D,E	H
D20SV*	Check Valve in SV Trip Fluid Line Fails to Open	2.57E-9	C,E	H
D23	Failure of Overspeed Protection Controller (OPC) Actuation Train	1.02E-7	D	H
D24A/B	20/OPC Solenoid Valve Fails to Open	4.37E-7	D	H
D27SV*	SV Dump Valve Drain Line Fails to Open	8.78E-9	C,E	H
D28SV*	Check Valve on SV Dump Valve Drain Line Fails to Open	2.57E-9	C,E	H
D32CV*	CV Actuator Piston Sticks Open	5.67E-9	A	G
D32SV*	SV Actuator Piston Sticks Open	5.67E-9	A	G
D41	Check Valve Between ETF Headers Fails to Open	2.57E-9	C,E	H
D47SV*	Mechanical Damage of SV Inhibits Closing	7.05E-8	C,E	H
D08	20/ET Solenoid Valve Fails to Open	2.10E-7	C,E	I
D09	63/AST Pressure Switch Which Actuates 20/ET Fails	6.02E-7	C,E	I

NOTES: (1) These codes identify the basic faults in the destructive overspeed fault tree, where "\*" is replaced by a number to indicate the particular control valve or stop valve.

(2) The failure rates are based on Westinghouse data as given in WCAP-11525 (Reference 5).

(3) Test procedure number followed by the procedure section number in parentheses are given below for letters A through E. The procedure either directly tests the component or can be assumed to test the component as a result of the component being exercised during a turbine trip or during closure of the turbine valves.

A = OST-551 (7.3)	C = OST-553 (7.5)
B = OST-551 (7.6)	D = OST-553 (7.8)
	E = GP-005 (5.2.21)

(4) The letters F through I correspond to the following test intervals that were considered in quantifications of destructive overspeed probability:

F = 1 MO	H = 6 MO, 12 MO, 18 MO
G = 1 MO, 3 MO, 6 MO, 12 MO	I = 18 MO

TABLE 8  
PROBABILITY OF TURBINE DESTRUCTIVE OVERSPEED<sup>(1)</sup>  
BASED ON VARYING THE INTERVALS OF SURVEILLANCE TESTING

Test Interval of Turbine Valves	Test Interval of Other Protective Components <sup>(2)</sup>		
	6 MO	12 MO	18 Mo
1 MO	7.36E-8	1.11E-7	1.50E-7
3 MO	1.81E-7	2.67E-7	3.57E-7
6 MO	4.51E-7	6.10E-7	7.71E-7
12 MO	1.36E-6	1.66E-6	1.96E-6

NOTES:

- (1) Probability of destructive overspeed given system separation, or annual frequency of destructive overspeed based on an assumed system separation frequency of 1.0 per year. The probabilities given above can be corrected for any other separation frequency by multiplying by the actual separation frequency to be considered.
- (2) Includes all components in Table 7 with applicable test procedures OST-553 (Section 7.5), OST-553 (Section 7.8), and GP-005 (Section 5.2.21).



TABLE 9  
IMPORTANCE OF TOP FOUR DOMINANT FAULTS  
CONTRIBUTING TO DESTRUCTIVE OVERSPEED PROBABILITY

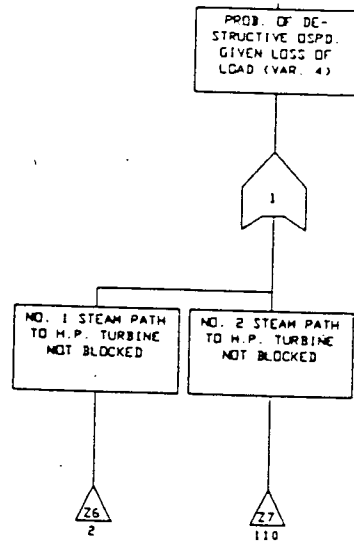
Test Interval of Turbine Valves	Importance Factors <sup>(1)</sup> for Various Test Intervals Test Interval of Other Protective Components:		
	6 MO	12 MO	18 MO
1 MO	A <sup>(2)</sup> (27.5)	A (32.2)	A (34.6)
	C (19.9)	C (26.0)	C (28.9)
	D (19.6)	D (25.7)	D (28.6)
	E (34.7)	E (22.8)	F (20.4)
3 MO	A (48.8)	A (51.0)	A (52.0)
	B (31.7)	B (21.1)	B (15.7)
	C (19.3)	C (25.6)	C (28.6)
	D (19.0)	D (25.2)	D (28.3)
12 MO	A (65.8)	A (65.2)	A (64.9)
	B (66.5)	B (52.7)	B (43.6)
	G (12.7)	C (15.9)	C (19.8)
	H (12.7)	D (15.7)	D (19.6)

NOTES:

(1) Importance factors are given in parentheses. The factors are determined by summing the importances of all cutsets in which the fault appears.

(2) The letters A through H correspond to the following basic faults:

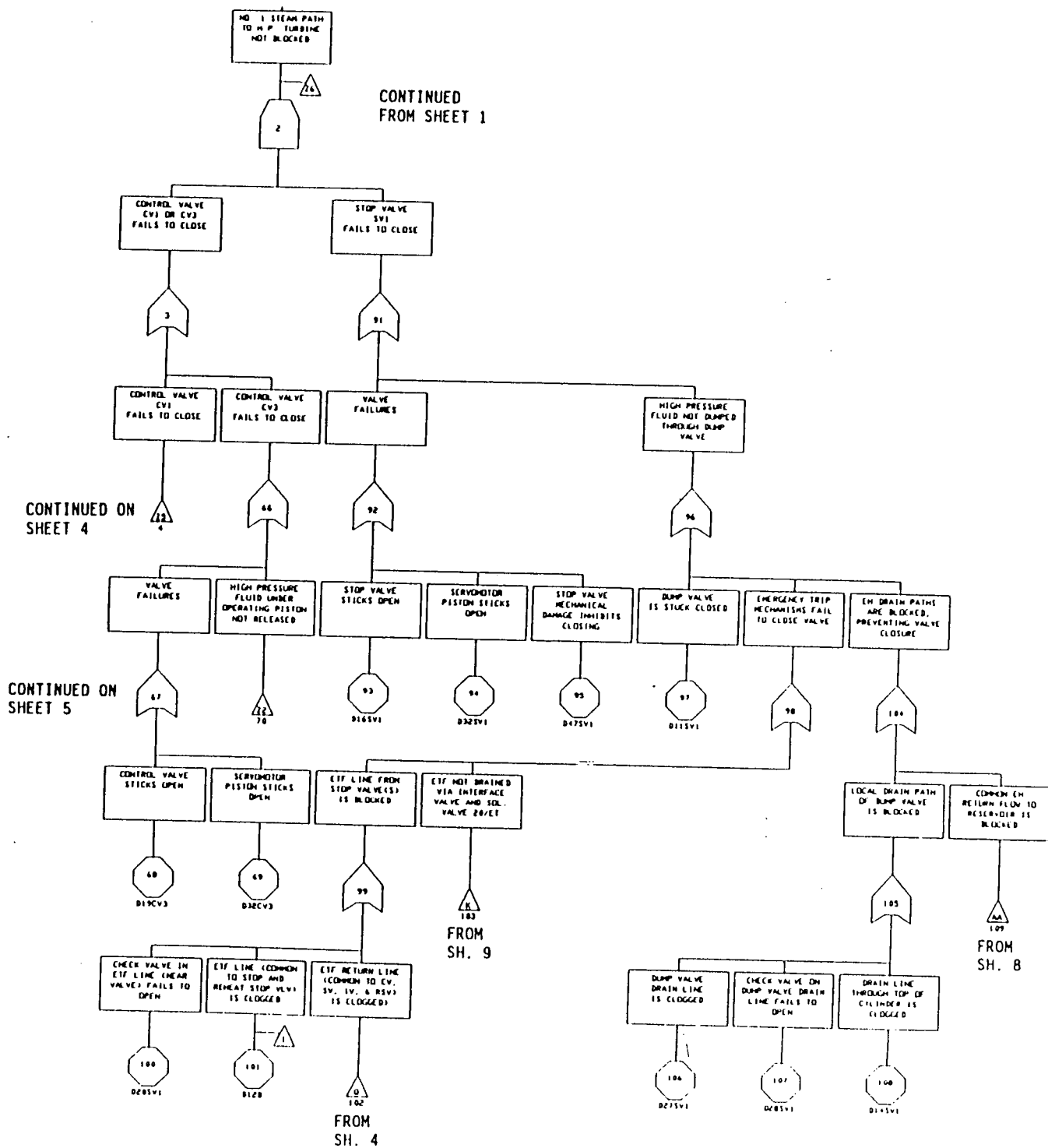
- A = Control valve (CV) sticks open
- B = Stop valve (SV) sticks open
- C = Mechanical damage of SV inhibits closing
- D = Emergency trip fluid header for SVs is clogged
- E = Return lines to EH reservoir are blocked due to common cause.
- F = CV servo/dump valve drain line fails to open
- G = Drain line through top of CV cylinder is clogged
- H = CV actuator piston sticks open



CONTINUED ON  
SHEETS 2 & 3

Figure 1: Destructive Overspeed Fault tree (Sheet 1 of 10)

Figure 1: Destructive Overspeed Fault tree (Sheet 2 of 10)



CONTINUED  
FROM SHEET 1

CONTINUED ON  
SHEETS 6 & 7

FROM  
SH. 9

FROM  
SH. 2

FROM  
SH. 4

FROM  
SH. 8

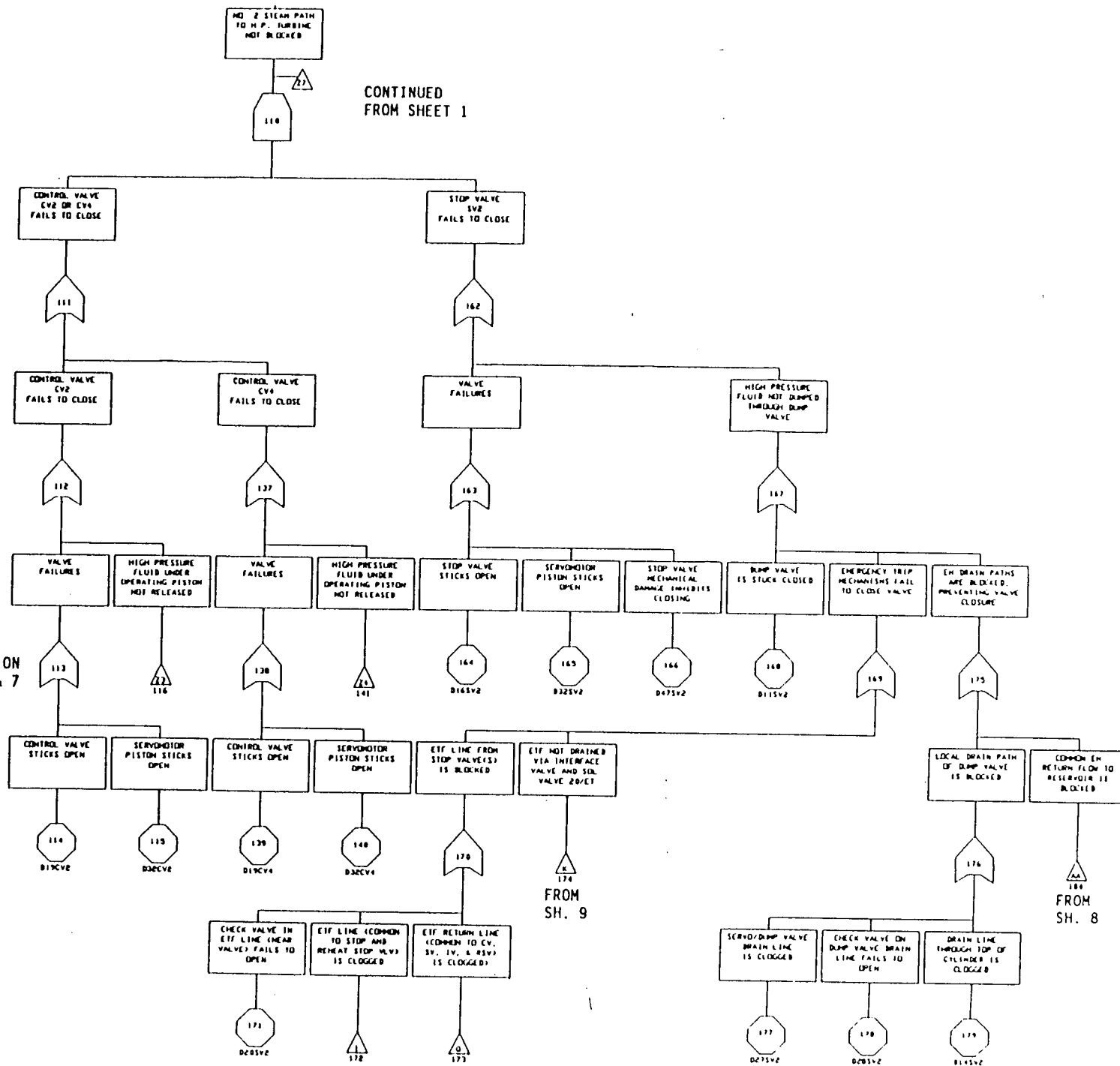


Figure 1: Destructive Overspeed Fault tree (Sheet 3 of 10)

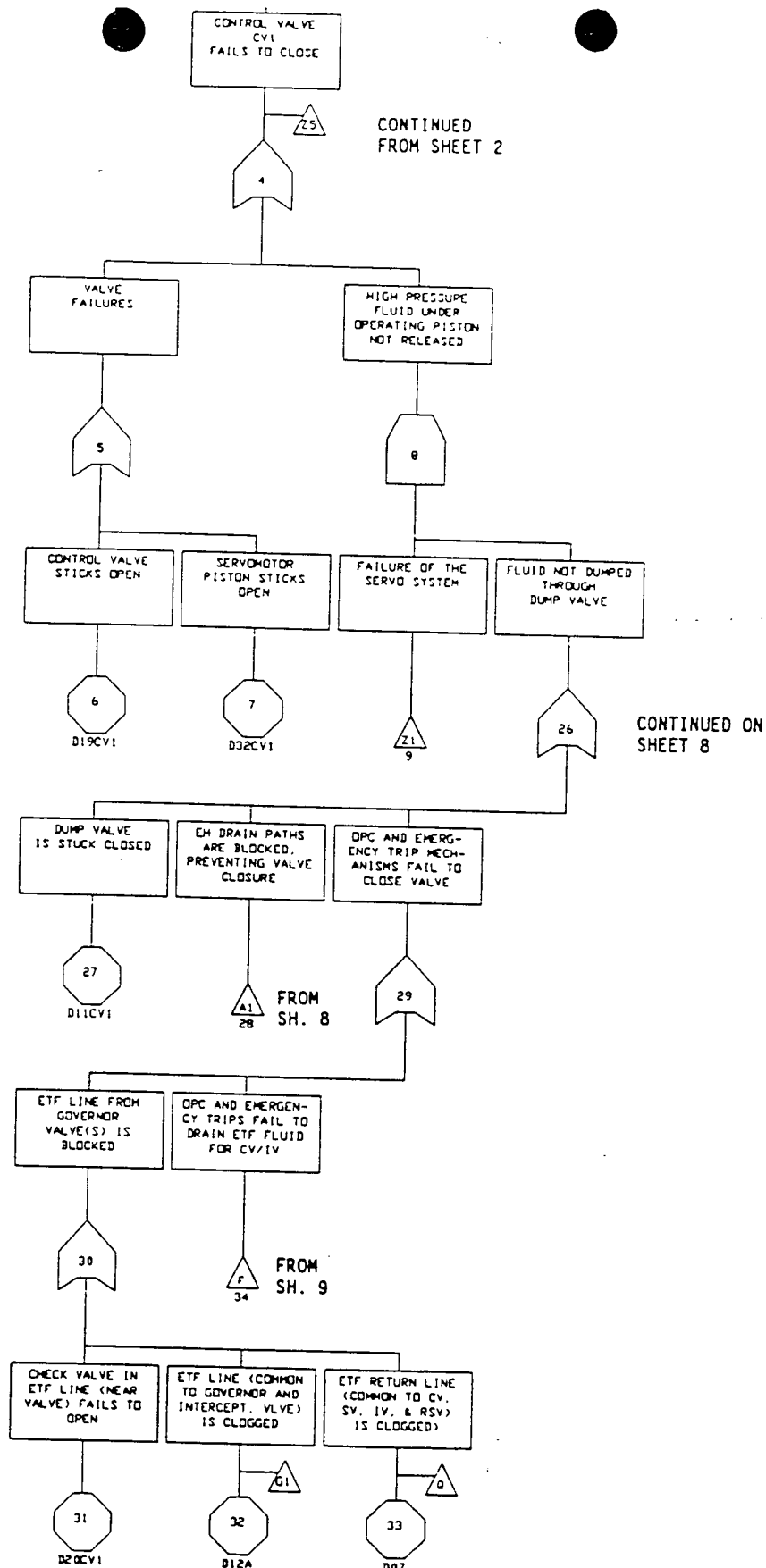


Figure 1: Destructive Overspeed Fault tree (Sheet 4 of 10)

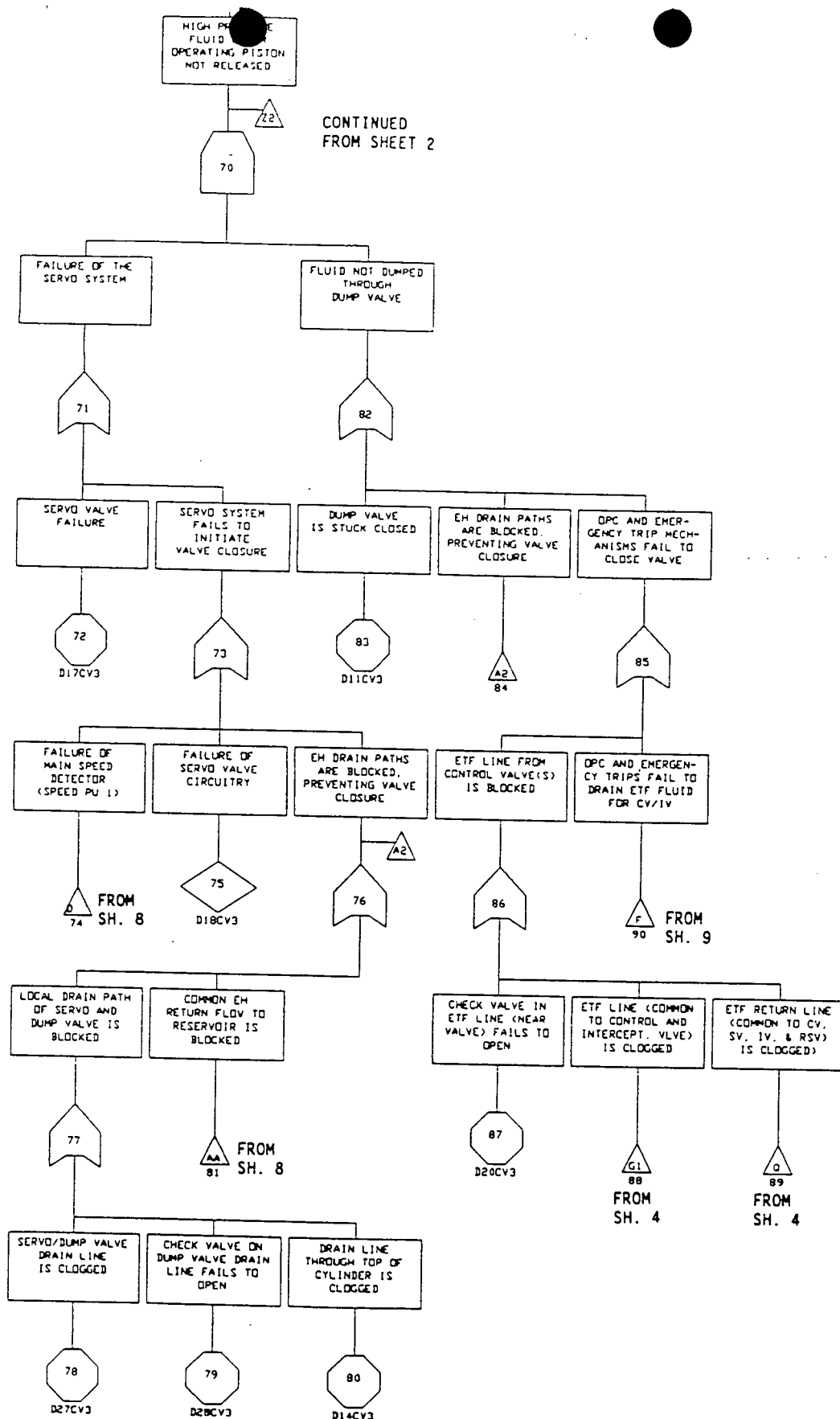


Figure 1: Destructive Overspeed Fault tree (Sheet 5 of 10)

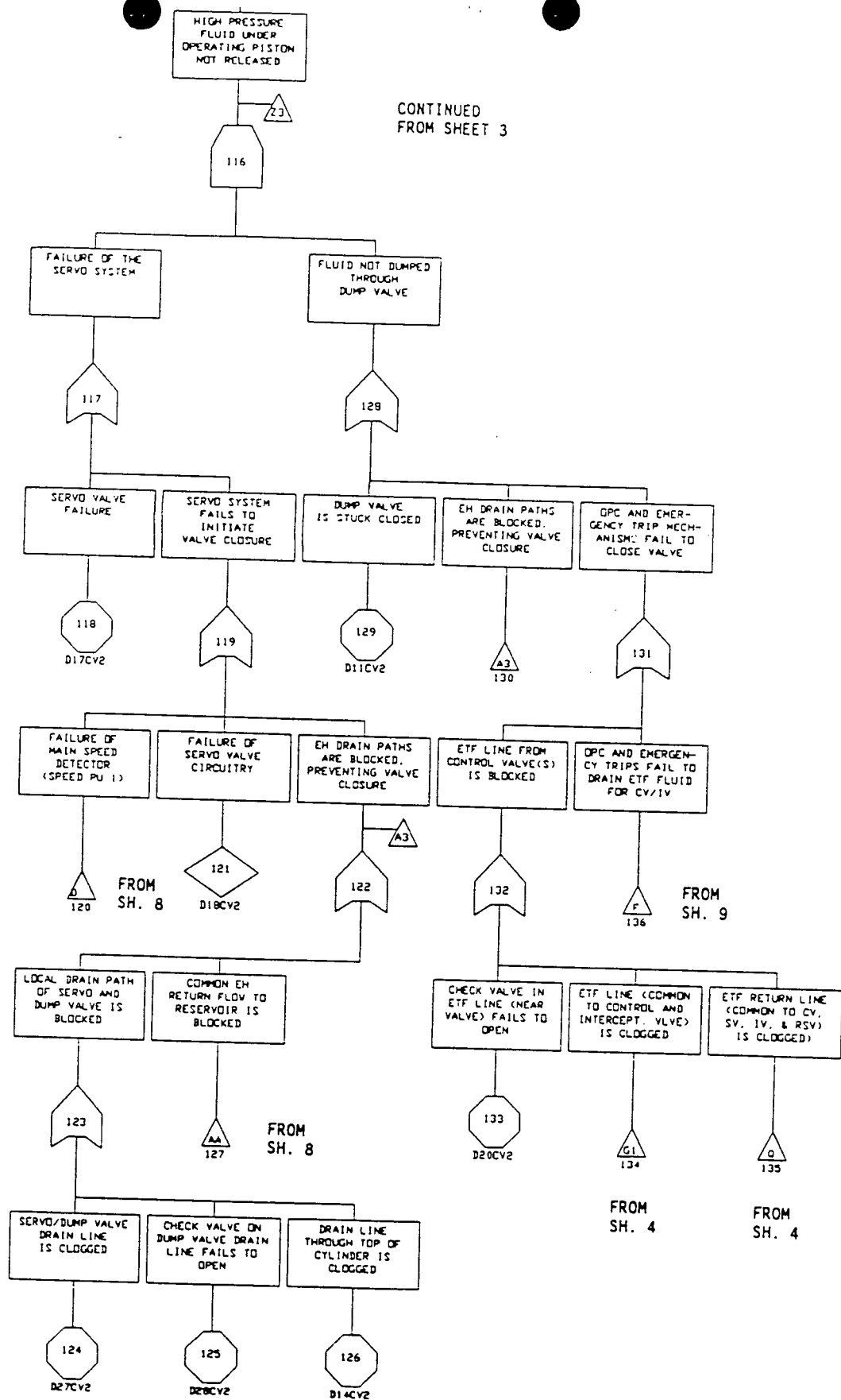


Figure 1: Destructive Overspeed Fault tree (Sheet 6 of 10)

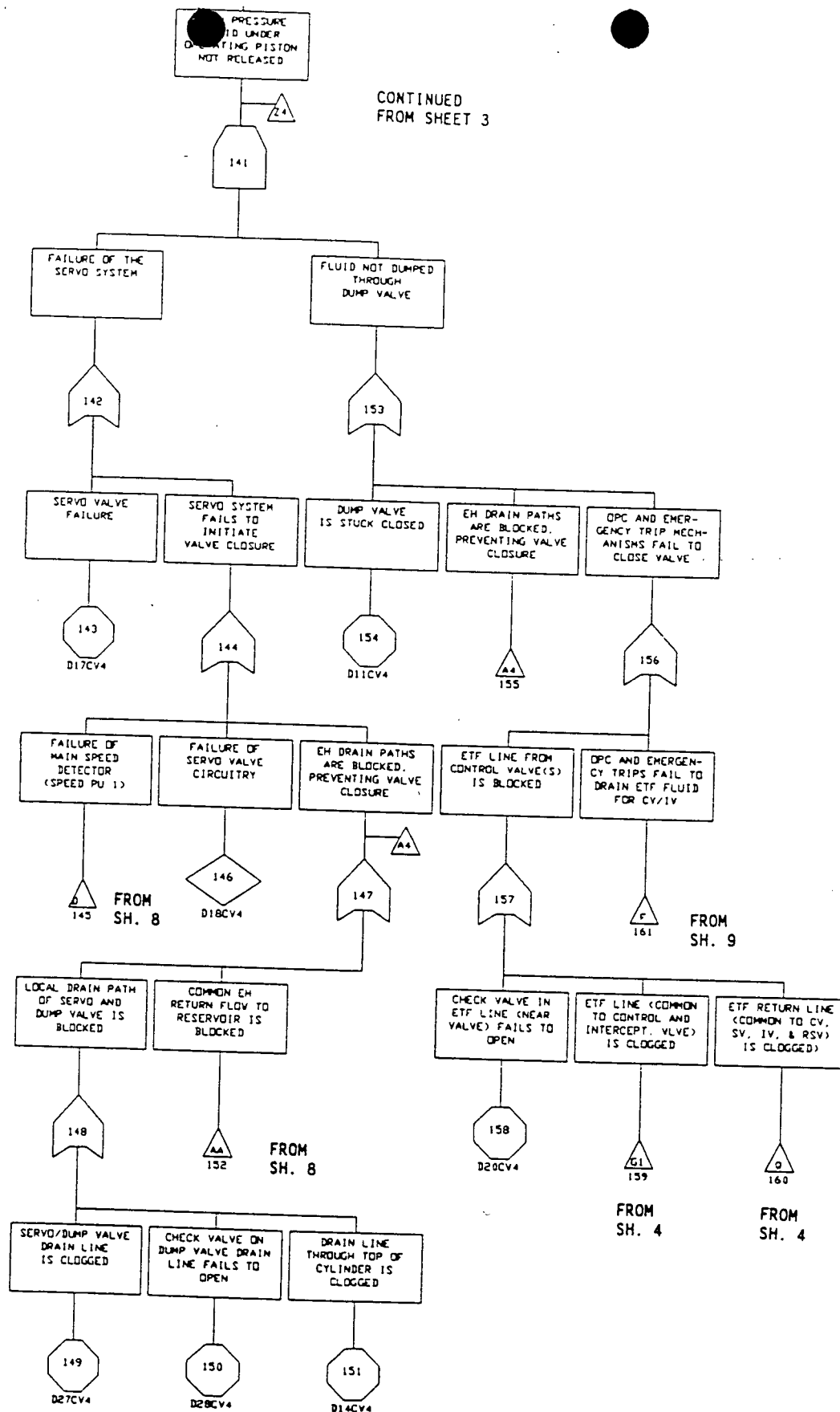


Figure 1: Destructive Overspeed Fault tree (Sheet 7 of 10)



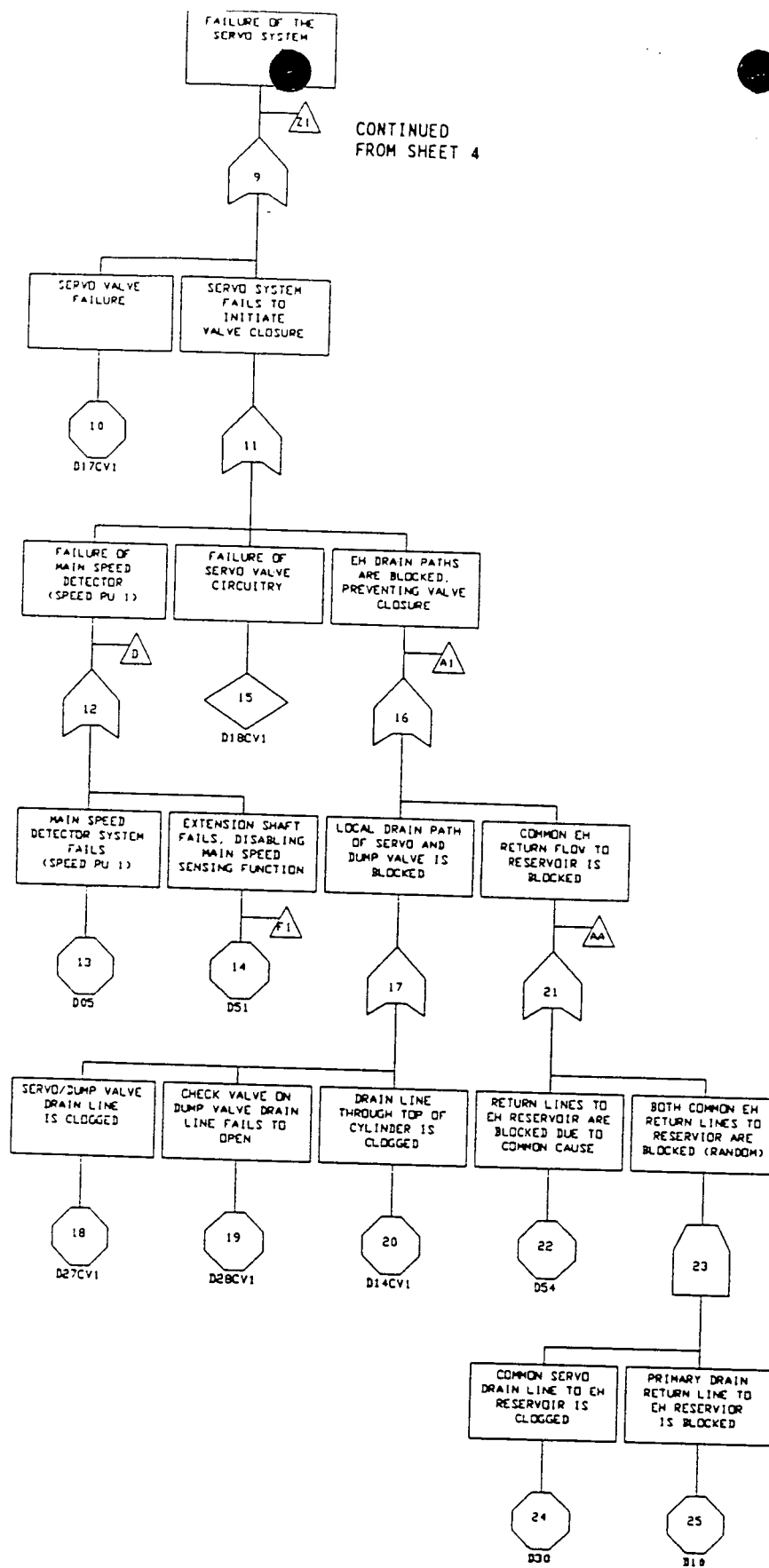


Figure 1: Destructive Overspeed Fault tree (Sheet 8 of 10)

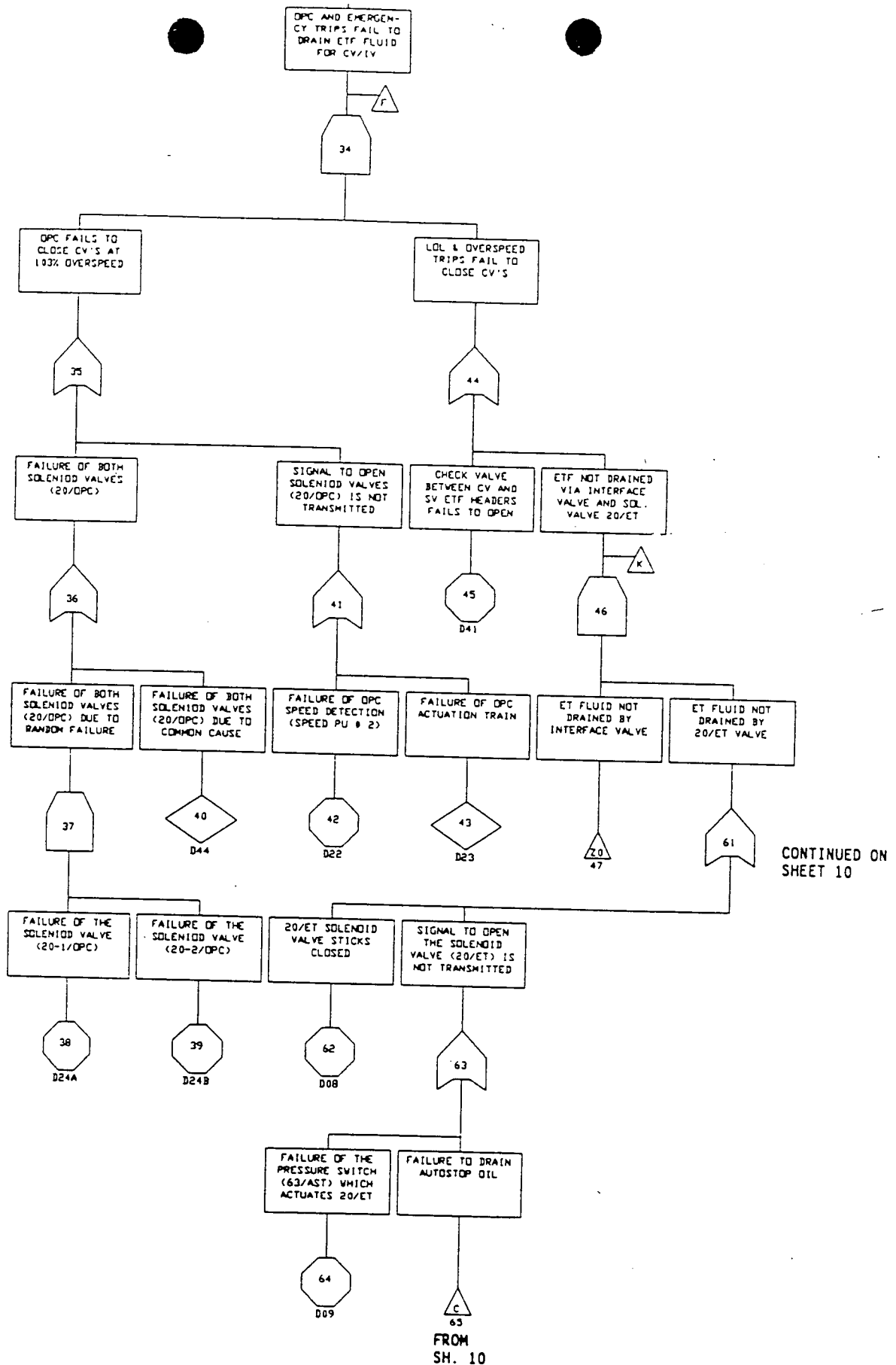


Figure 1: Destructive Overspeed Fault tree (Sheet 9 of 10)

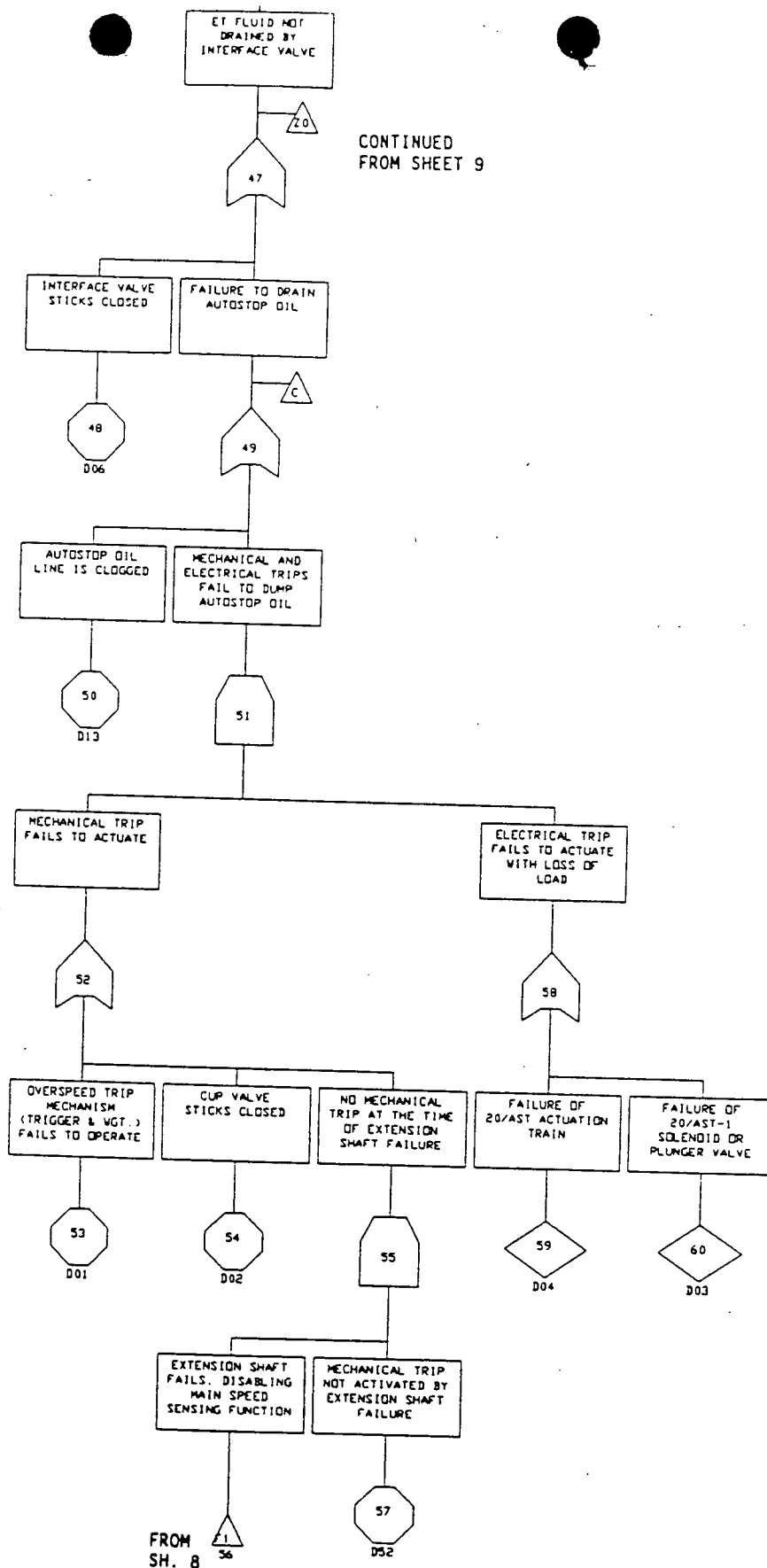


Figure 1: Destructive Overspeed Fault tree (Sheet 10 of 10)