CONTROL ROOM HVAC SYSTEM

VALUE IMPACT ASSESSMENT

SEP TOPIC II-1.C, OFFSITE HAZARDS, AND

NUREG-0737, Item III.D.3.4

CONTROL ROOM HABITABILITY

SAN ONOFRE UNIT 1

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I. EXECUTIVE SUMMARY

The objective of this project is to evaluate the cost-benefit of possible upgrades to the San Onofre Nuclear Generating Station Unit 1 Control Room HVAC system as they apply to the resolution of SEP Topic II-1.C, Offsite Hazards and TMI Action Plan Item III D.3.4., Control Room Habitability. This evaluation is performed by calculating the incremental value and impact of successive design enhancing features or requirements on the Control Room HVAC system.

The current design is a single train system. It has no toxic gas monitoring capability at the present time. It is assumed that it does not meet a .67g earthquake level, and it is not specifically designed to meet tornado missile protection requirements. Supplemental capability is currently provided, however, by two possible backups to the existing system. These are:

- o A ventilation path from the Control Room to the Technical Support Center (via one door)
- o A ventilation path from the Control Room to outside environment (proven by operation)

A stepwise (i.e., added one at a time to evaluate individual effectiveness) set of system enhancements to bring the existing system into conformance with the latest requirements has been defined. It is expected that a toxic gas monitoring system would provide the greatest risk reduction per unit cost because of the fact that the hazard from off-site toxic gas is the largest among the possible hazards to control room habitability and the cost of the monitoring system is relatively less expensive compared to other possible enhancements. Similarly, it is reasoned that enhancement of seismic capability and tornado capability would represent the least important option from a cost-benefit perspective. Possible enhancements are shown in Table 1 and include:

- o Addition of a new toxic gas monitoring system
- o Enhancement of the radiation monitoring system
- o Replacement of the existing HVAC with new redundant trains
- o Provision for improved seismic survivability of HVAC
- o Provision for tornado survivability of the existing HVAC system

Each stepwise modification or enhancement has been evaluated in terms of both the cost and the effect on risk to the operators. In order to properly evaluate the risk reduction and cost associated with each stepwise modification, the incremental value is determined. That is, analyses are performed assuming that previous effects or values have already been incorporated.

The analyses conclude that the Control Room HVAC system, including all backup ventilation schemes, is reliable and unlikely to fail during an accident scenario. None of the design changes evaluated have a positive value-impact. It is noted that, of the design changes considered, toxic gas monitoring has the highest risk reduction per unit dollar cost. The other alternative designs have a low risk reduction per unit dollar cost, and should not be implemented. The cost factor is particularly true of the addition of a redundant HVAC train. The addition of another HVAC train requires the addition of a new room to house the new equipment at considerable cost. The study shows this expense to be unwarranted even on a conservative assessment basis.

II. SYSTEM DESCRIPTION

A. Existing Control Room HVAC System

The HVAC System at Unit 1 is a single train system consisting of ducts, dampers, fans, and HVAC unit and filters. Figure 1 is a simplified schematic diagram of the system. During normal operation, air from the normal outside air intake is fed through a usually open damper and compressor/fan unit (A-31) supplying conditioned air into the control room. Upon receipt of containment high pressure or containment isolation signal, the emergency mode of operation is required. Initiation of the emergency mode of operation is a manual action. The HVAC is aligned such that Unit A-31 functions as a recirculation unit; air from the emergency outside air intake is fed through the emergency supply fan and air filter unit (A-33), providing filtered makeup air to the control room. The air filter unit (A-33) contains a pre-filter for normal dust collection, two high efficiency filters for fine radioactive particle collection, and two charcoal filters for radioactive gas adsorption.

B. Existing Backup Capability

1. TSC Connection

In case the control room HVAC System fails, the operator can gain access to the TSC HVAC System by opening a door between the two rooms. Figure 2 depicts a simplified schematic diagram for the TSC HVAC System. During normal operation, filtered and conditioned air is supplied by the TSC air conditioning unit (A-51). A separate filtering system (A-50) is provided for the outside air supply to A-51 through damper FCD/2519B. The emergency outside air intake filter unit A-50 contains a pre-filter for normal dust collection, two high efficiency filters for fine radioactive particle collection, and two charcoal filters for radioactive gas adsorption. Cooling is separate from the normal Control Room HVAC.

2. Outside Air

A second "backup" for the Control Room HVAC System is an option of opening the door connecting the TSC to outside air. A portable fan is used to enhance the ventilation. The TSC HVAC upgrade is relatively new. Prior to its availability, the connection to outside air was used by the operators to maintain reasonable control room conditions during maintenance on the normal control room HVAC unit. These occurrences in the past showed that this is an effective means of maintaining adequate ventilation in the control room in case of the loss of both the control room and TSC HVAC systems.

C. Possible Upgrades

In response to the NRC TMI Action Plan Item III.D.3.4, Control Room Habitability, and SEP Topic II-1.C, Offsite Hazards, a number of possible system upgrades have been identified to meet current design criteria. Table 1 summarizes present features and alternative designs for a series of potential hazards. These are described below.

1. Toxic Gas Monitoring

Unit 2/3 has installed a monitoring system for the detection of Butane, Gasoline, Chlorine, Propane and Anhydrous Ammonia. Although Unit 1 does not have a toxic gas monitoring system, it is expected that an alert from Unit 2/3 (for any substance drifting to Unit 2/3) will warn the operators in Unit 1 to take protective actions.

A possible enhancement is to add a monitoring system to Unit 1 which includes sensors, alarms and isolation devices. The new monitoring system would be able to detect the presence of certain toxic gases and isolate the control room HVAC.

2. Upgraded Radiation Monitoring

The current radiation monitoring system consists of a sensor and an alarm in the control room. Upon receipt of a high radiation signal, a manual switchover to the backup filter is performed by operations personnel. A possible modification is to provide for an earlier indication and automatic switchover system so that manual operator action is not required for control room isolation.

3. Redundant Trains

The existing control room HVAC system has a single train of components. Alternatives rely upon non-HVAC, non-control room equipment. This does not strictly meet the single failure criterion. Redundant upgraded HVAC trains could be provided and would consist of adding fans, filters, and HVAC units. As a result of this enhancement, a new control room HVAC building would need to be constructed to accommodate the new equipment. The new redundant upgraded trains would meet the single failure criterion.

4. Seismic Enhancement

Unit 1 HVAC System is assumed to be designed to withstand earthquake levels up to 0.25g level. A possible enhancement would involve strengthening the structures, components and equipment supports to withstand earthquakes up to the 0.67g level.

5. Tornado Enhancement

The current HVAC system is primarily housed within concrete walls. That is, the air intake is not through a single pipe or duct riser but through a labyrinth of walls leading to a "filter wall". Thus an unknown degree of tornado protection is provided for the normal system. A possible upgrade would involve the redesign to provide assurance of tornado protection. An alternative would involve provision of missile proof air intakes for the new redundant system.

III. ANALYSIS OF VALUE AND IMPACT

In evaluating the desirability of possible system upgrades, it is appropriate to evaluate the "safety" value of possible enhancements and compare this value to the cost or impact of providing the enhancement. In evaluating an older plant such as Unit 1, it is particularly appropriate to evaluate such factors when considering the applicability of new criteria for which the plant was not originally designed. Only those modifications with a significant value-to-impact ratio are considered appropriate. In this context:

- Value is defined as the monetary worth of risk reduction.
- Impact is the cost of the modification, any operations and maintenance costs, outage time (if any), and associated physical plant and personnal impacts (i.e., man-rem exposures associated with the modification)

By evaluating the risk reduction based on probabilistic approaches and estimating the dollar cost associated with each stepwise upgrade, the value-impact is determined. To perform an incremental value-impact assessment, change in value is determined for each of a series of identified alternatives.

A base case is identified as follows:

- Normal system hardware is analyzed as is
- TSC HVAC system and outside air are included as possible backups

For this base case, like other alternative cases, the risk to the control room crew from the following events are evaluated:

- o Excessive temperature
- o Toxic gas
- o Radiation
- o Earthquakes
- o Tornado

It is noted that extensive use is made of published PRA results to facilitate judgment with respect to the risk associated with each hazard.

1. Base Case Analysis

The fault tree for the base case is illustrated in Figure 3. This shows that loss of control room HVAC can occur by five different types of conditions. The first is a normal system failure or malfunction leading to control room high temperature. Other failures require an external hazard to exist. The evaluated hazards include a toxic gas cloud from an accident offsite, radiation release on-site, earthquake, and tornado. The control room HVAC provides air to the control room for a variety of conditions. These evaluated hazards represent the envelope of such conditions. The continuing pages of the fault tree provide the full model of these events. The triangles and the letters in each tree are provided to connect these trees together.

It is seen that loss of control room habitability due to excessive temperature results from the simultaneous occurrence of three events: loss of normal control room HVAC, no air from TSC HVAC System and no outside cooling.

The failure is dominated by loss of Normal Control Room HVAC for an 8 hour period (assumed to be long enough to require action by the operator). The value in the fault tree for this entry is a "per year" frequency. All other entries are for continued operation during the 8 hour period. Electric power is the only dependency between normal and backup systems. The possibility of station blackout leads to other more critical needs than HVAC and is ignored herein. Failure of all power needs coincident with normal HVAC loss is not dominant.

For a toxic gas hazard, the HVAC would not be isolated without either a detection of the presence of toxic gas or notice from outside the unit. The probability of toxic gas entering control room and causing loss of habitability is taken, from a previous study [1], to be 5.5×10^{-6}/year.

Similarly, a typical value for radiation hazards, given no automatic actuation, is 1.8×10^{-7}/year. Seismic risk, using Seismic Safety Margin Research Program [2] methodology and considering different earthquake levels, is 9.3×10^{-8}/year. The tornado hazard is $\sim 10^{-8}$/year[3], which is essentially negligible compared with other hazards. The total probability of loss of control room habitability for the base case is estimated to be 6.0×10^{-6}/year.

In evaluating the value of enhancements it is necessary to first review the base case to determine the most likely cost effective upgrades for first consideration. The upgrades which are to be investigated will consist of the following:

- o Addition of a toxic gas monitoring system (toxic gas hazard is most important contribution to base case risk)

- o Radiation detection enhancement

- o Redundant train addition

- o Seismic upgrade

- o Tornado capability

2. Toxic Gas Monitoring (Step 1 Enhancement)

One possible enhancement of the control room HVAC system is to install a toxic gas monitoring system.

The accidental release of a chemically toxic vapor cloud from the railroad, the highway or fixed installations in the vicinity of the reactor could potentially lead to loss of control room habitability.

The Unit 1 Control Room HVAC System does not have any toxic gas monitoring capability. Possible detection by 2/3 or other site personnel could occur. The hazard associated with toxic gas involves the following steps:

- o Occurrence of the hazard
- o Possible detection
- o Protective action

The nature of the material affects the degree of toxicity and, hence, the time available for the operator to respond. In the analysis, the available time is assumed to be short for the more serious toxic gases (chlorine, ammonia, gasoline, etc.)

The analysis of toxic gas hazards is based upon several assumptions. First, the values for release, transport, and interaction are adopted from analyses performed for the Unit 2/3 FSAR and provided to the NRC in SCE's responses to III.D.3.4. for Unit 1 [4]. A number of potential releases were identified and evaluated.

The monitoring system that is evaluated is taken to be 0.99 reliable for the monitored gases. This is a design value assumption and should be achievable with reasonable technology. Monitored gases include:

- o Propane
- o Gasoline
- o Butane
- o Chlorine
- o Ammonia

For these substances the effect of the monitoring is to reduce the risk of Control Room habitability loss by a factor of 0.01 due to residual failure probability of the monitoring system.

For unmonitored substances, the value from these studies[1] is taken directly with only negligible credit given for notification by Unit 2/3 or the Highway Patrol.

Figure 4 presents the fault tree for toxic gas hazard to the control room. The probability of loss of control room habitability due to toxic gas effects, with the upgrades in place, is estimated to be 1.8 X 10^{-7}/year.

The estimated frequency of loss of control room habitability in the base case is 6 X 10^{-6} /yr. As a result of the enhanced toxic gas monitoring system, the frequency of oss is reduced to 7.2 X 10^{-7} /yr. The reduction is estimated to be 5.3 X 10^{-6}/year. For this study this change is taken as the risk reduction. This is very conservative as other protective features may make the risk of core melt orders of magnitude lower. For example, for a given loss of control room habitability, a transient must occur which requires shutdown and the operator must fail to successfully shutdown from the Auxiliary Shutdown Panel. This is shown in Figure 5.

The cost associated with this enhancement is approximately $500,000.

3. Radiation Detection and Isolation(Step 2 Enhancement)

The evaluation of radiation hazard assumes that a release from any unit on-site could affect control room habitability. The fault tree for this effect is shown in Figure 6. A radiation hazard is evaluated for Unit 2/3 and Unit 1 separately. The likelihood of a rediation hazard event is assumed to be 1 X 10^{-5}/year, a typical value for core damage and serious release.

The existing control room has a radiation monitor but no provision for an automatic isolation. Still, the likelihood of operator action is high as a serious release of radioactivity is very probably an identified accident prior to release.

The factor of .03 for Unit 2/3 causing an effect at Unit 1 is a wind direction factor assuming a uniform wind rose.

This is conservative for the San Onofre site.

The design enhancement consists of automating the isolation of the air intake on high radiation which would enhance the ability to preclude air intake of radioactive material. This reduces the failure of action to be taken by an order of magnitude.

The overall probability of loss of control room habitability due to radiation (in the base case) is estimated to be 2.1×10^{-7}/year. Incorporation of an enhanced system is estimated to reduce this contribution to 1.0×10^{-7}/year. This is a change of 1.1×10^{-7}/year and reduces the total frequency from 7.2×10^{-7}/year to 6.1×10^{-7}/year. Thus a risk reduction of 1.1×10^{-7}/year results from the implementation of a radiation detection and isolation HVAC system.

The cost associated with this enhancement is approximately $300,000.

4. Upgraded Redundant HVAC System (Step 3 Enhancement)

To further improve the control room HVAC system performance, a conceptual control room habitability system shown in Figure 7 is considered.

Figure 8 presents the fault trees for the upgraded HVAC system. It is noted that only events during normal operation are significantly affected by the modification.

The probability for normal loss of control room habitability in the base case is estimated to be 1.8×10^{-7}/year. Incorporation of this enhancement is estimated to reduce this contribution to 2.5×10^{-9}/year. This is a change of approximately 1.8×10^{-7}/year. The overall loss of control room habitability is therefore reduced to 4.3×10^{-7}/year.

Since a new building is installed to accomodate redundant equipment, this enhancement represents a large impact. The estimated cost is approximately $1,300,000.

5. Seismic Upgrade (Step 4 Enhancement)

The current control room HVAC is assumed to be able to withstand a .25g earthquake. A possible enhancement of control room HVAC system is to upgrade it so that the system can withstand a 0.67g level earthquake. The significant effect of this upgrade is only on seismic risk; other hazards remain the same.

The SSMRP[2] study is used as the basis for the evaluation of the seismic risk of San Onofre 1 control room HVAC system.

Assuming that the air handling unit dominates the seismic risk, a bounding analysis using the failure probability of the air handling unit for different earthquake levels indicates that the reduction in frequency of loss of control room habitability is negligible for this upgrade.

For this analysis, no credit was taken for the backup TSC HVAC system. It was further assumed that the response variation of the air handling unit is smaller than the fragility variation of the air handling unit. The failure of the control room HVAC is then approximately independent of the failure of outside cooling.

Figure 9 presents the fault tree assessment for the seismically upgraded HVAC system. The probability of overall loss of control room due to earthquake is reduced from 9.3×10^{-8}/year in the base case to 1.7×10^{-10}/year.

This is a reduction of approximately 9.3×10^{-8}/year and brings the overall loss of habitability to 3.4×10^{-7}/year. The incremental cost for this enhancement is estimated to be approximately $500,000.

6. Tornado Upgrade (Step 5 Enhancement)

A final design enhancement considered is to upgrade the intake to withstand a tornado. San Onofre 1 is located in Tornado Intensity Region II.

In order for a tornado to cause loss of Control Room habitability, it is necessary for the tornado to occur, strike the plant, generate a missile, and destroy the air intake. Other tornado effects are not of concern to this study as only Control Room HVAC upgrades are being evaluated. The current HVAC air intake is behind walls and is generally "protected" by a labyrinth type of air intake flow leading to a filter wall which is protected. Using the J.R. McDonald report, 'Tornado and Straight Wind Hazard Probability for Ten Nuclear Power Reactor Sites', (Reference 3), the frequency of a significant tornado in Region II which generates a hazard to Control Room habitability is assessed to be less than 1×10^{-7}/year.

The risk reduction is estimated to be 1×10^{-8}/year for the analysis. The cost associated with this enhancement is approximately $1,300,000.

IV. SUMMARY OF ANALYSIS AND INCREMENTAL VALUE IMPACT ASSESSMENT

Table 2 summarizes the risk contributors to loss of control room habitability for various stepwise enhancement of the HVAC system.

The results shown in Table 2 indicate that toxic gas is to be the most significant contributor to the loss of control room habitability. Each stepwise enhancement changes only one risk contributor significantly. If all of the identified design alternatives were implemented, the frequency of loss of control room habitability would be reduced from 6.0×10^{-6}/year to 3.3×10^{-7}/year.

It is also possible to evaluate the corresponding risk for each enhancement in terms of the core damage frequency. There is, however, a great deal of uncertainty associated with such an evaluation. Furthermore, it is expected that different conditional core melt probabilities (given loss of control room habitability) are associated with different hazardous events. For example, it is more likely to have a core melt when loss of control room habitability is due to an earthquake than when control room habitability loss is due to toxic gas. Since large uncertainty is associated with the evaluation of the core melt frequency, it is prudent to focus on the risk results in terms of loss of control room habitability.

The cost associated with each enhancement is summarized in Table 3. The cost estimates listed, together with the risk reduction, indicate the incremental effectiveness of each enhancement.

As can be inferred readily from Table 3, Toxic Gas

Monitoring gives the highest incremental risk reduction (value) for the lowest cost (impact), 3.5 X 10^{-11}/year dollar. Tornado represents the lowest incremental value per unit cost expended, i.e. 2.5 X 10^{-14}/year dollar.

Another way to evaluate cost effectiveness is to evaluate both value and impact in terms of dollars and compare using incremental assessment. A variety of algorithms have been postulated for converting from risk reduction to dollars. The NRC safety goal guideline suggests a value of $20,000 per 1.0 X 10^{-5}/year reduction in core melt frequency[5]. It is noted that the core melt frequency is generally very much lower than the frequency of control room habitability loss. Nevertheless,* this value of $20,000 is applied herein to loss of habitability which may be one or more orders of magnitude conservative. For this analysis, conservative estimates based on the above value yield the following results:

PLANT CONFIGURATION	REDUCTION IN FREQUENCY OF CONTROL ROOM HABITABILITY LOSS	MAXIMUM $ VALUE (NO CREDIT FOR BACKUPS)	IMPACT
BASE CASE	-0-	-0-	-0-
TOXIC GAS MONITOR	5.3 X 10^{-6}	$10.6K	$ 500K
RADIATION PROTECTION	1.1 X 10^{-7}	$ 0.2K	$ 300K
REDUNDANCY	3 X 10^{-7}	$ 0.6K	$1,300K
SEISMIC UPGRADE	7 X 10^{-8}	$ .14K	$ 500K
TORNADO PROTECTION	1 X 10^{-8}	$ .02K	$1,300K

* Loss of habitability does not equal core melt. The value of $20,000 is used here for simplicity. This is very conservative.

V. CONCLUSION

The existing San Onofre 1 HVAC system is a single train system and was designed when the current NRC design requirements were not in existence. A number of upgrades have been identified. These include the addition of toxic gas monitoring, enhancement of radiation monitoring, provision of redundant components to meet single failure criterion, upgrade of seismic capability to withstand earthquakes up to 0.67g level and design for tornado resistance. Risk associated with both the current system and its possible enhancement were evaluated using a probabilistic approach and the results assessed in terms of value-impact framework. The risk associated with the control room HVAC system is low. The value-impact assessment indicates that toxic gas monitoring seems to be most cost-effective.

The cost associated with providing a redundant train of HVAC is tremendous, while the value (i.e., risk reduction) is not significant. This suggests that implementing a redundant train of HVAC is not cost-effective.

Based upon these analyses, none of the identified modifications has a positive value-impact ratio. The control room toxic gas monitors have the most favorable ratio, and might be considered.

References

1. E.A. Hughes, A.J. Unione and R.R. Fullwood.
'Analysis of the Probability of a Toxic Gas Hazard for the San Onofre Nuclear Generating Station as a Result of Truck Accidents Near the Plant,' February 28, 1981, submitted by letter from K.P. Baskin of SCE to D.M. Crutchfield of the NRC, Clarification of TMI Action Plan Requirements, April 20, 1981.

2. NUREG/CR-2105, Vol. I - X, 'Seismic Safety Margins Research Program, Phase I Final Report.' 1981.

3. J.R. McDonald.
'Tornado and Straight Wind Hazard Probability for Ten Nuclear Power Reactor Sites.' Institute for Disaster Research, Texas Tech University, Lubbock, Texas, May 1980.

4. R.H. Broadhurst and M.C. Cheok.
'Analysis of Explosive Vapor Cloud Hazards for Rail and Highway Transportation Routes Near the San Onofre Nuclear Generating Station Units 2 and 3 Using a Best Estimate Analysis', NUS3367, Supplement 1, April, 1981.

5. Memorandum from William J. Dircks, U.S. NRC Executive Director for Operations, to NRC Commissioners.
"Action Plan for Implementing the Commission's Proposed Safety Goals," July 6, 1982.

TABLE 1.

CAPABILITY TO WITHSTAND HAZARD AND ALTERNATIVE DESIGNS

CAPABILITY	PRESENT FEATURES	POSSIBLE ENHANCEMENT
Reliable air to Control Room	o 1 train normal HVAC o 1 train backup TSC HVAC plus ouside air o remote shutdown	Add normal redundant fans, filters HVAC unit and dampers, etc.
Toxic gas	o None-rely on-site alert from Unit 2 and 3	Add sensor and alarm or Sensor with Automatic Isolation
Earthquake	o 0.25g design level	Upgrade to 0.67g design level
Tornado	o Primary HVAC within concrete walls - TSC alternate 60' away, light structure o Door opening possible	Add redundant missile proof shields on doors

TABLE 2.

CONTRIBUTORS TO LOSS OF CONTROL ROOM HABITABILITY

DESIGN CAPABILITY	SAFETY LEVEL	NORMAL OPERATION CONTRIBUTION	TOXIC GAS	RADIATION	EARTHQUAKE	TORNADO
Base Case	6.0X10^{-6}/yr*	1.8X10^{-7}/yr	5.5X10^{-6}/yr	2.1X10^{-7}/yr	9.3X10^{-8}/yr	1.0X10^{-8}/yr
Toxic Gas Monitoring	7.2X10^{-7}/yr	1.8X10^{-7}/yr	2.3X10^{-7}/yr	2.1X10^{-7}/yr	9.3X10^{-8}/yr	1.0X10^{-8}/yr
Radiation Detection	6.1X10^{-7}/yr	1.8X10^{-7}/yr	2.3X10^{-7}/yr	1.0X10^{-7}/yr	9.3X10^{-8}/yr	1.0X10^{-8}/yr
Upgraded HVAC System	4.3X10^{-7}/yr	2.5X10^{-9}/yr	2.3X10^{-7}/yr	1.0X10^{-7}/yr	9.3X10^{-8}/yr	1.0X10^{-8}/yr
Seismic Upgrade	3.4X10^{-7}/yr	2.5X10^{-9}/yr	2.3X10^{-7}/yr	1.0X10^{-7}/yr	1.7X10^{-10}/yr	1.0X10^{-8}/yr
Tornado Upgrade	3.3X10^{-7}/yr	2.5X10^{-9}/yr	2.3X10^{-7}/yr	1.0X10^{-7}/yr	1.7X10^{-10}/yr	ϵ

* All numbers are "per reactor year".

TABLE 3.

VALUE-IMPACT RESULTS FOR VARIOUS ENHANCEMENTS:

LOSS OF CONTROL ROOM HABITABILITY

PLANT CONFIGURATION	OVERALL SAFETY	INCREMENTAL COST	RISK REDUCTION
Base Case	6.0×10^{-6}/yr	-0-	-0-
Toxic Gas Monitoring	7.2×10^{-7}/yr	$ 500K	5.3×10^{-6}/yr
Radiation Enhancement	6.1×10^{-7}/yr	$ 300K	1.1×10^{-7}/yr
Redundant Train	4.3×10^{-7}/yr	$1,300K	1.8×10^{-7}/yr
Seismic Upgrade	3.4×10^{-7}/yr	$ 500K	9.3×10^{-8}/yr
Tornado Upgrade	3.3×10^{-7}/yr	$1,300K	1.0×10^{-8}/yr

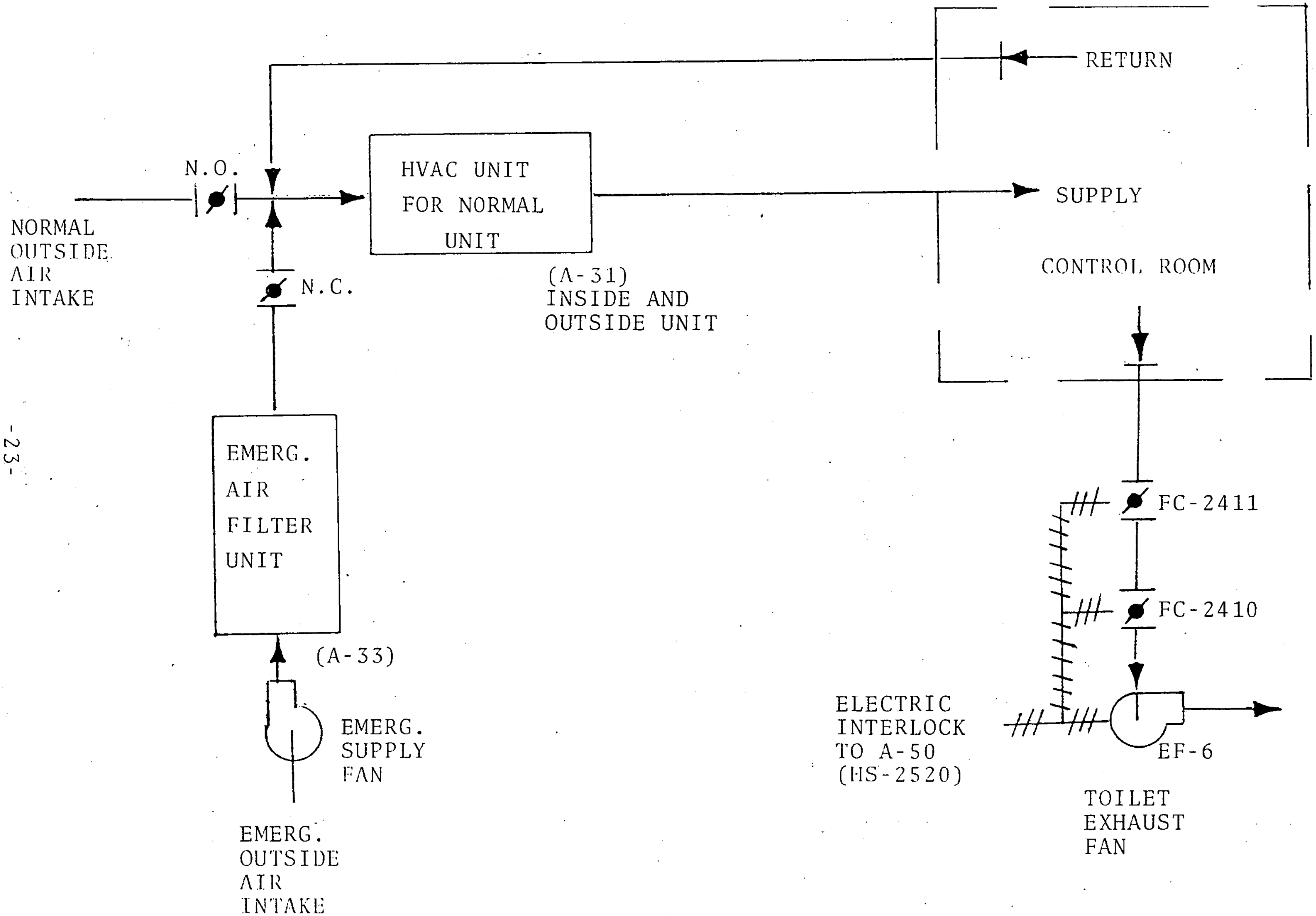


FIGURE 1.

CONTROL ROOM HVAC SYSTEM SCHEMATIC DIAGRAM

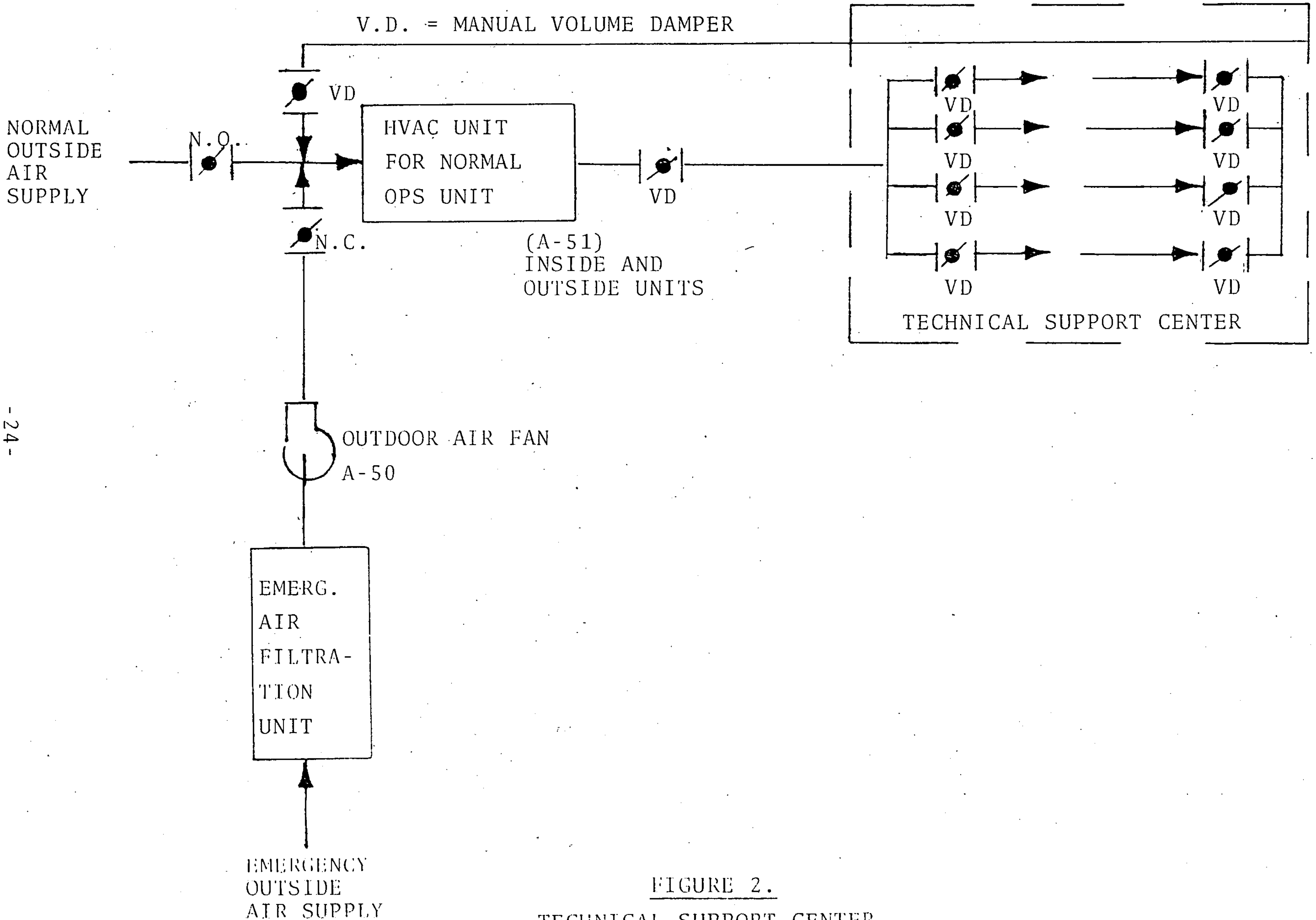


FIGURE 2.

TECHNICAL SUPPORT CENTER

HVAC SYSTEM SCHEMATIC DIAGRAM

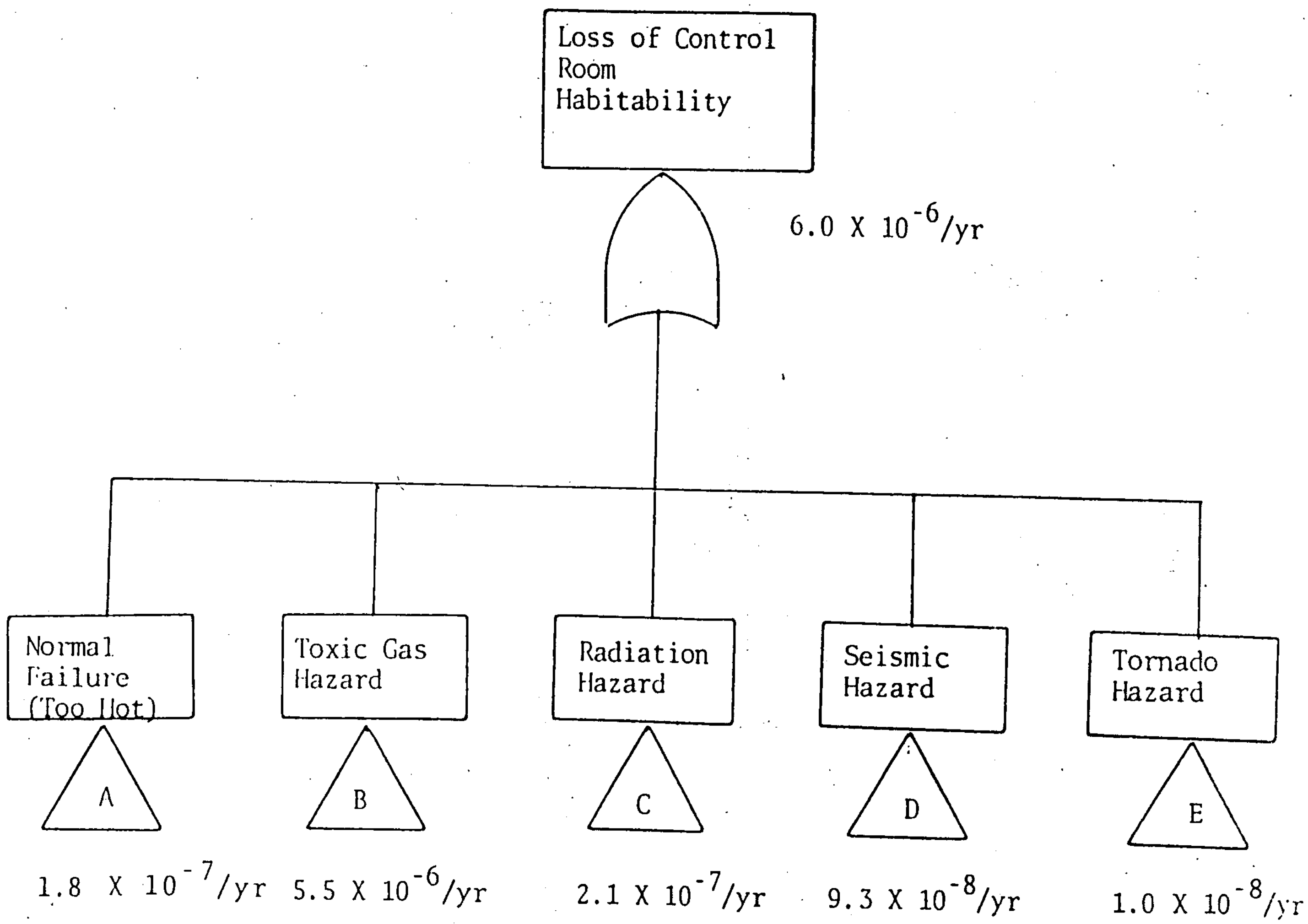
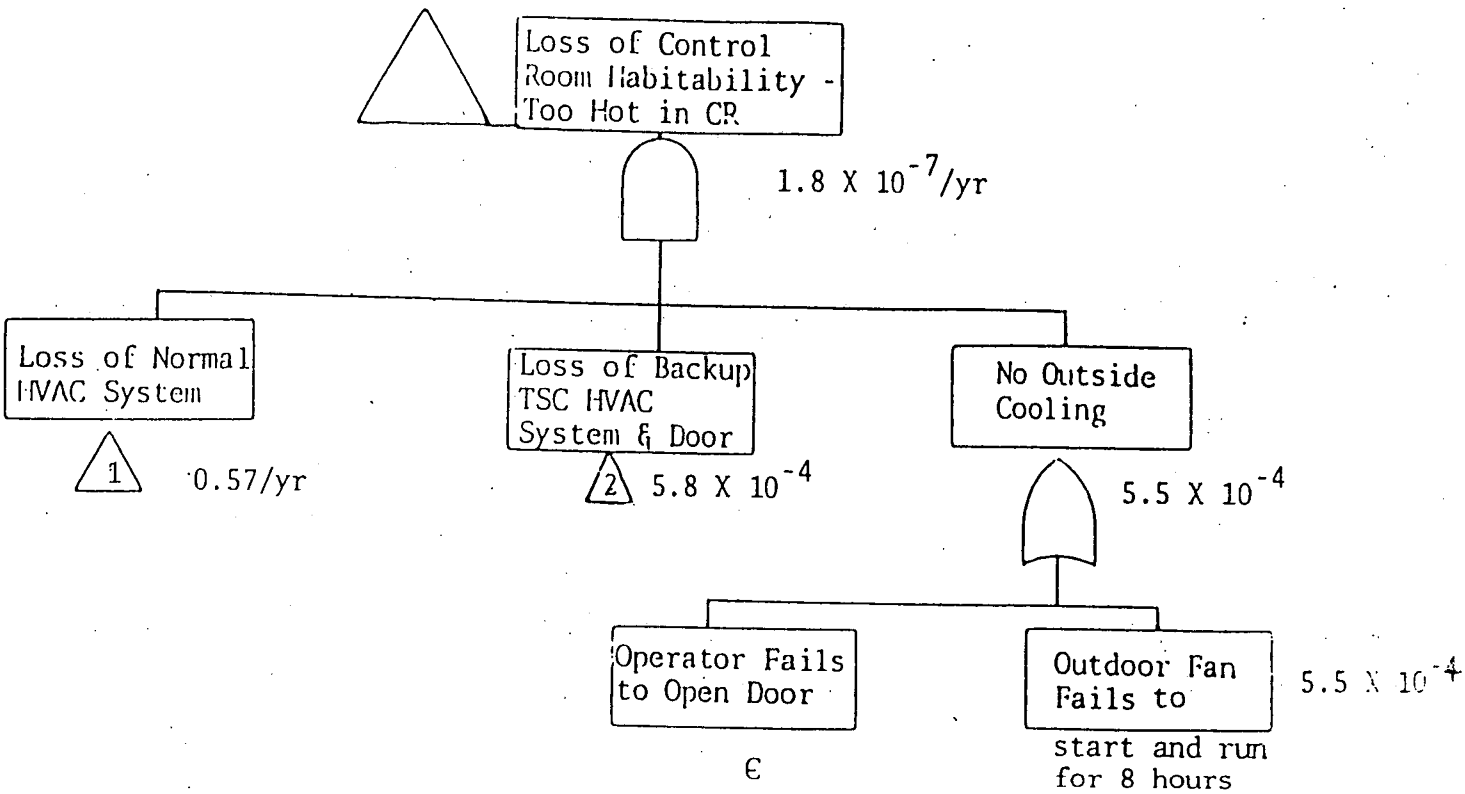


FIGURE 3.

FAULT TREE FOR LOSS OF CONTROL ROOM HABITABILITY: BASE CASE

TOO HOT



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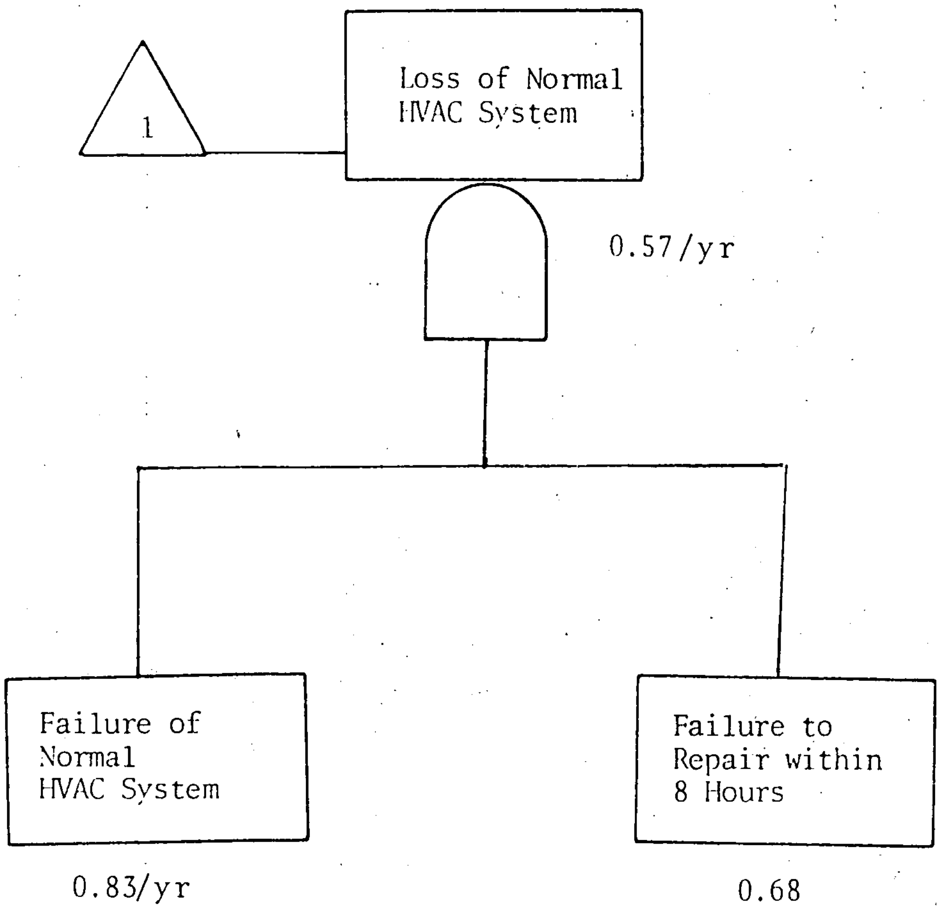

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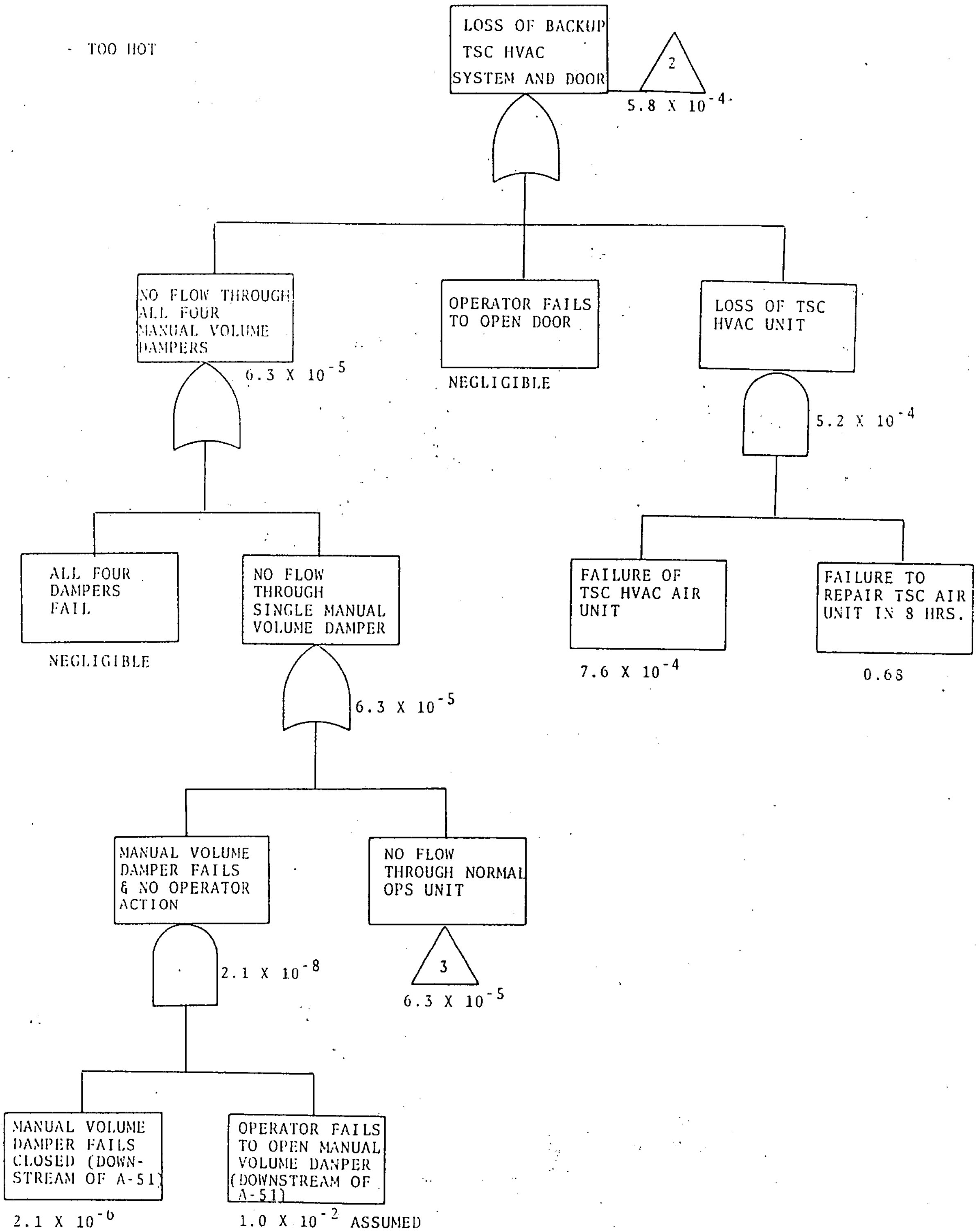

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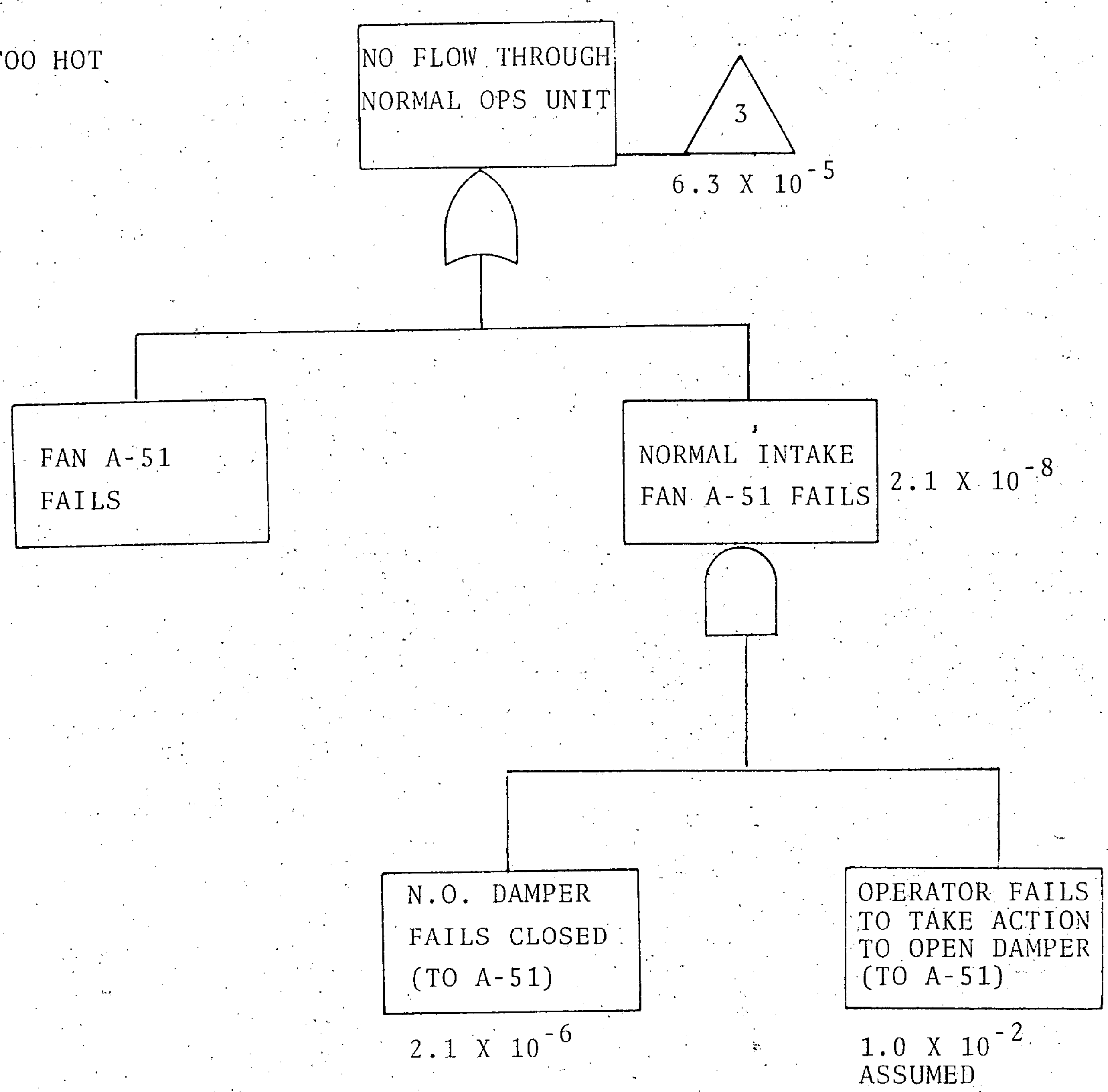
TOO HOT



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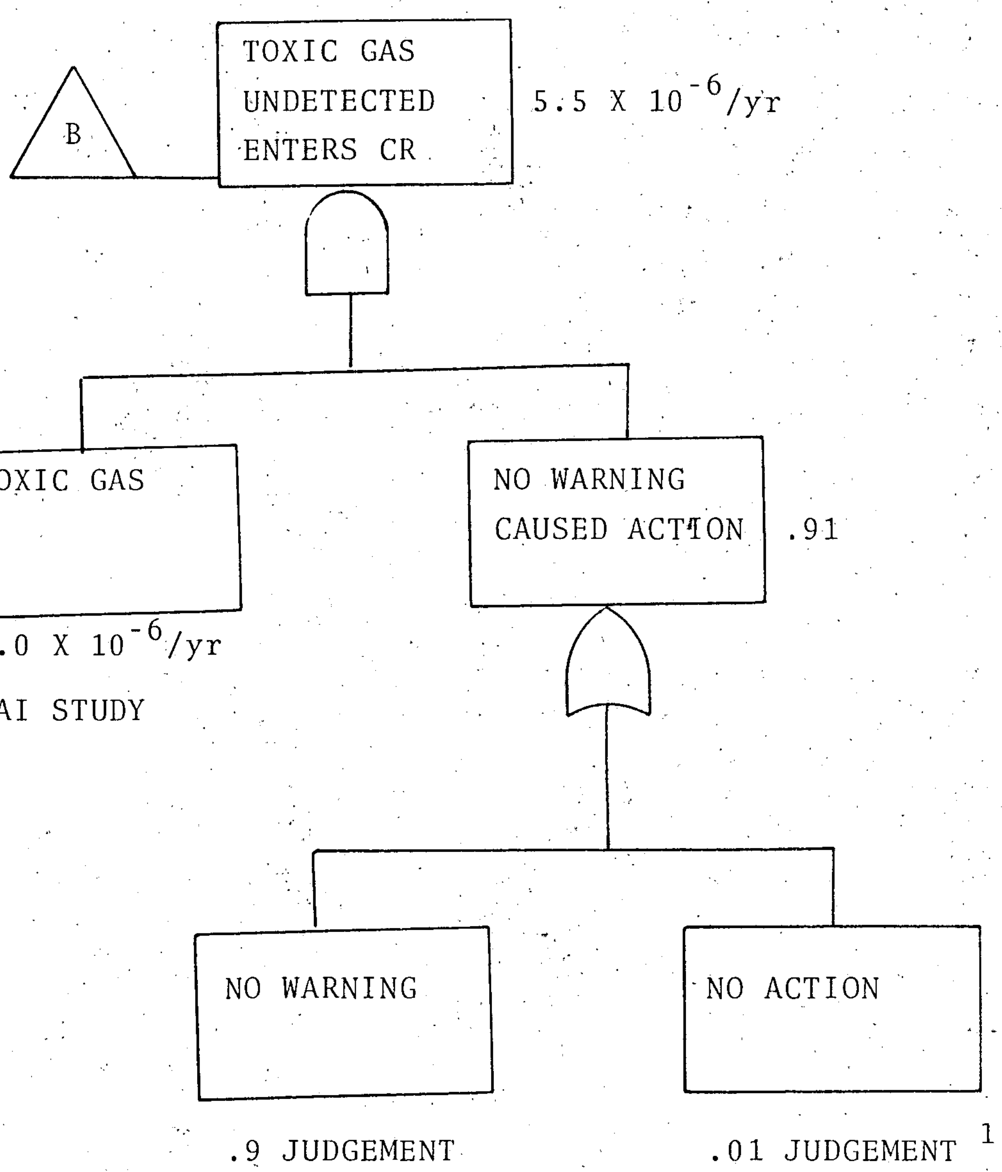
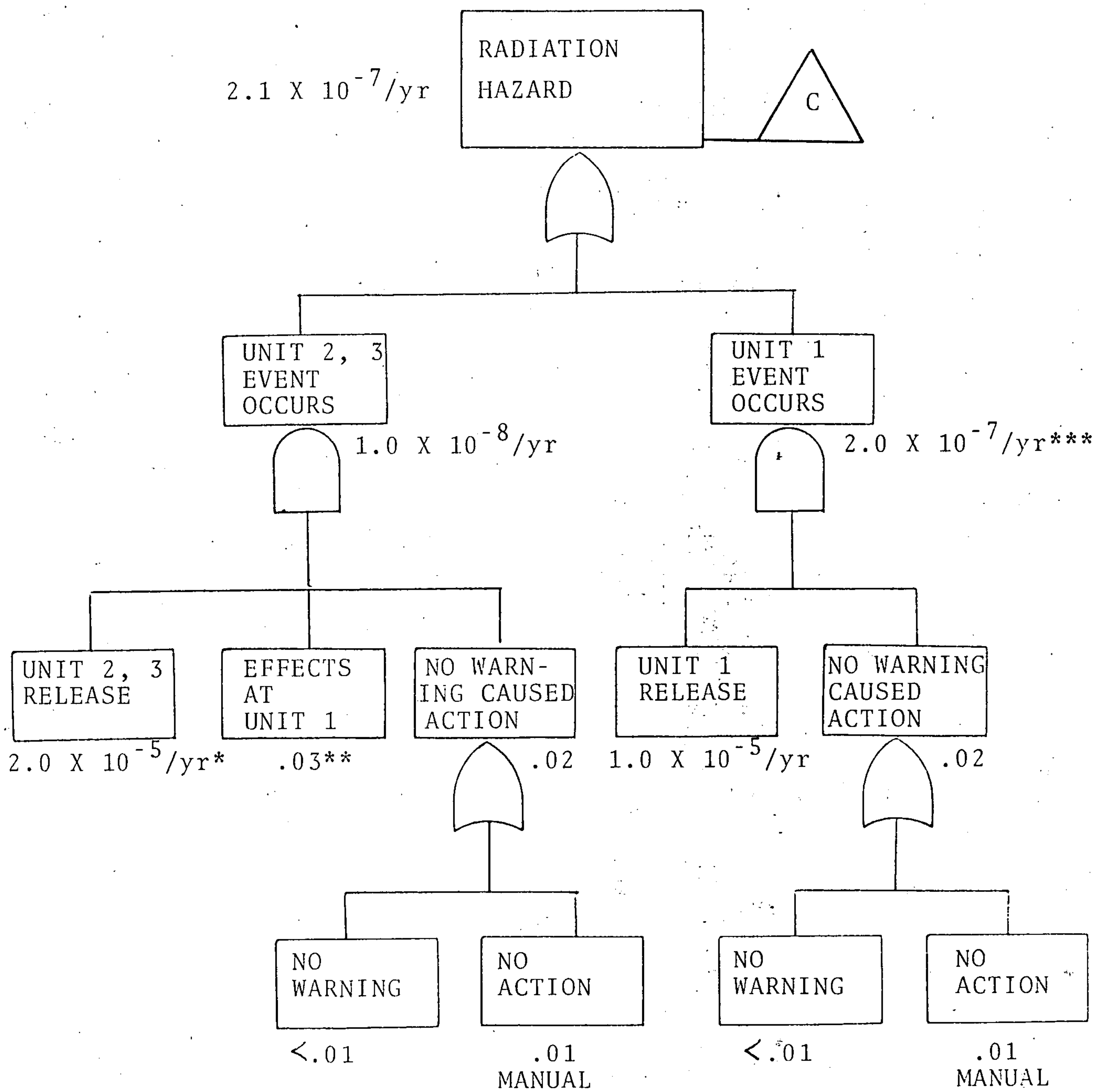


[1] This is believed to be conservative.

FIGURE 3 (continued)

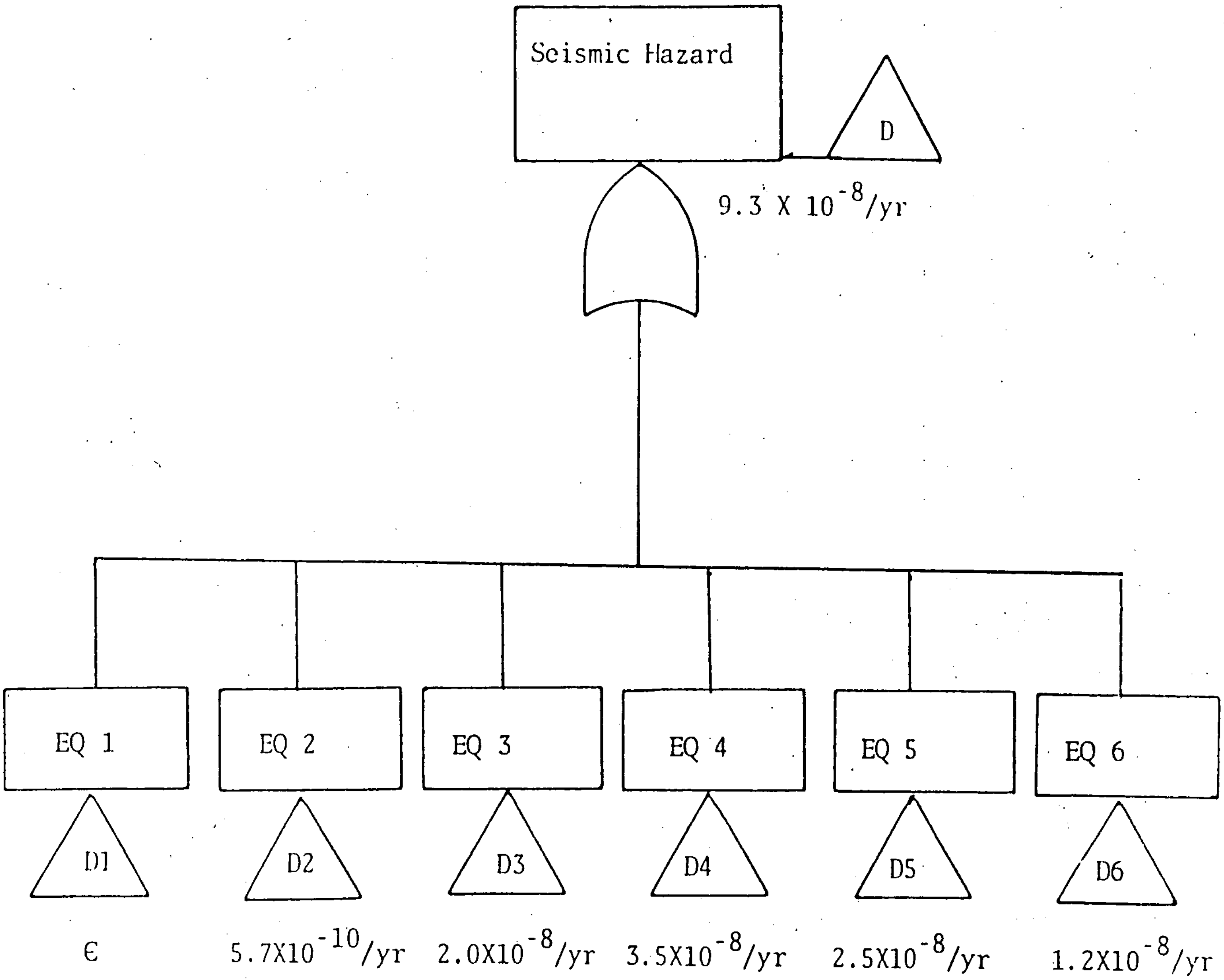


* Assumes "Typical" 1.0×10^{-5}/yr per unit CM

** Assumes uniform dist to 1 sector 1/16 = .06 with arbitrary 50% cance of actual intake effecets = .03

*** Assumed to be dominated by severe release near intake. All less severe sources of rediation appear to be piped to stack

FIGURE 3 (continued)



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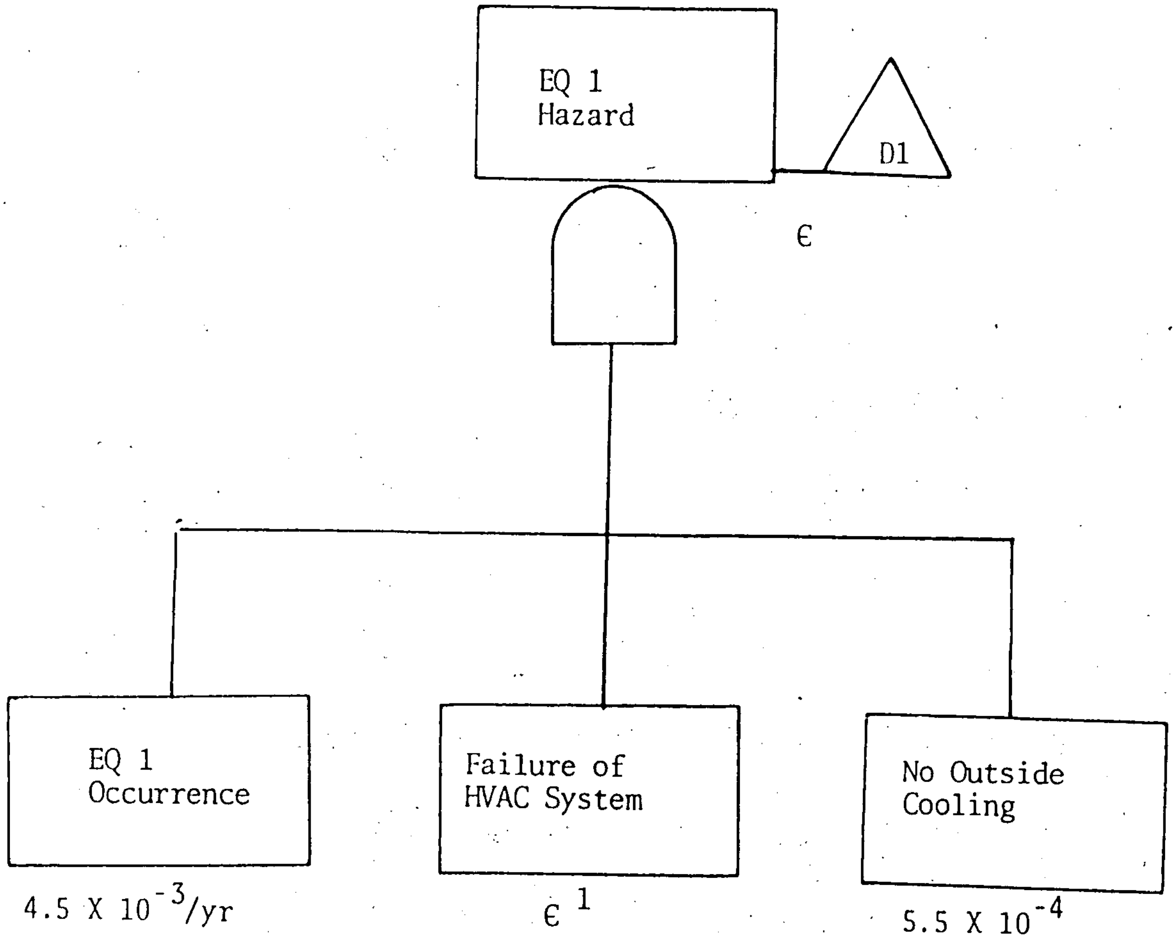


FIGURE 3 (continued)

1 Random failure independent of earthquake treated in "Too Hot" base case

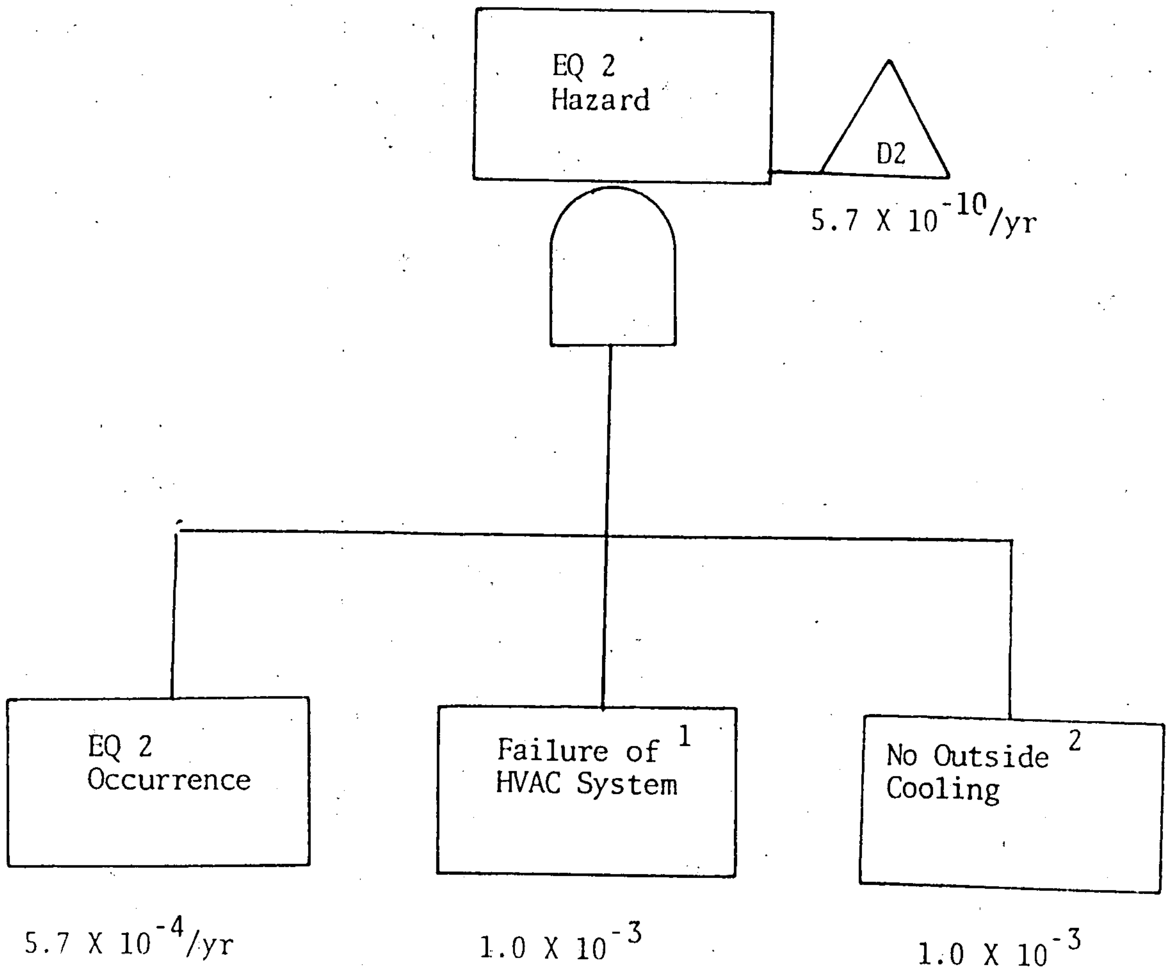


FIGURE 3 (continued)

[1] No credit assumed for TSC HVAC backup

[2] Outside fan assumed to be independent of normal HVAC

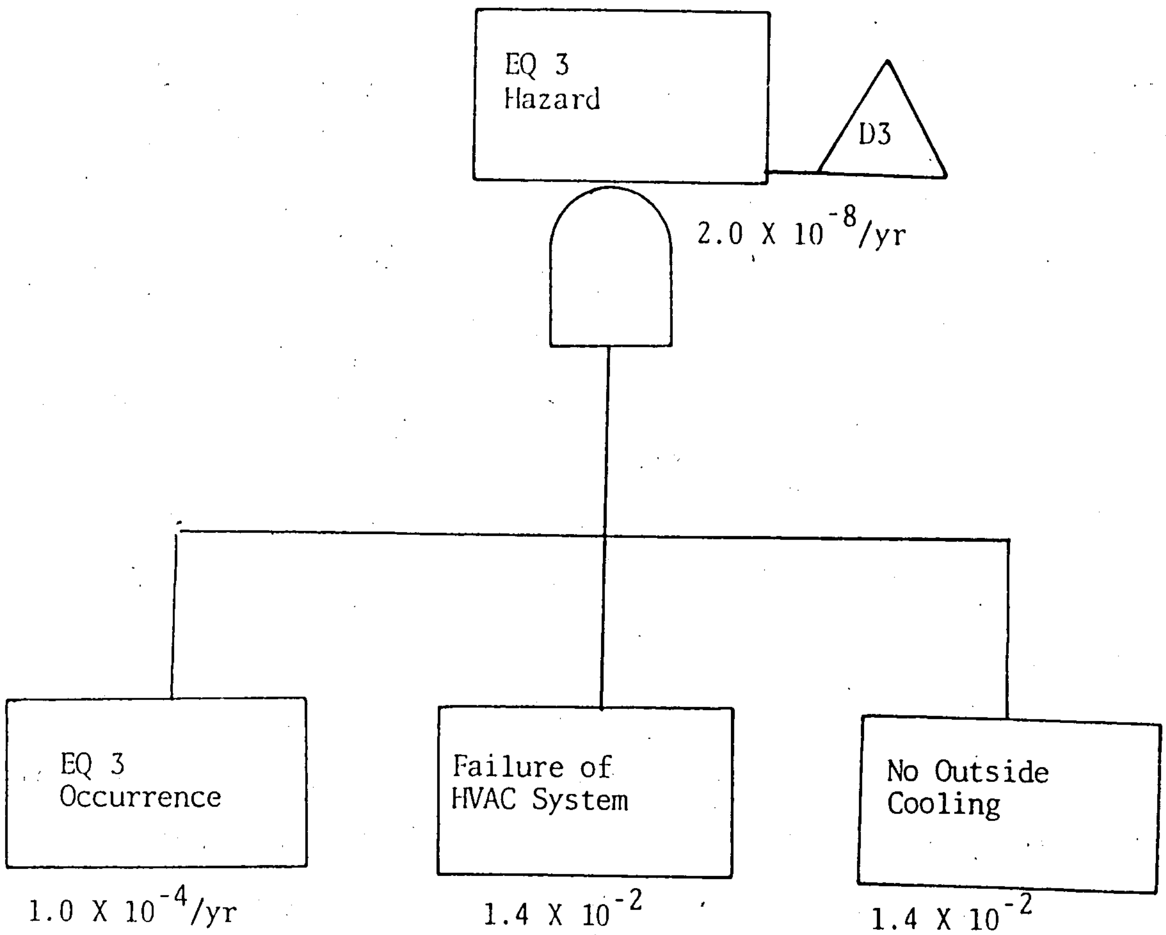


FIGURE 3 (continued)

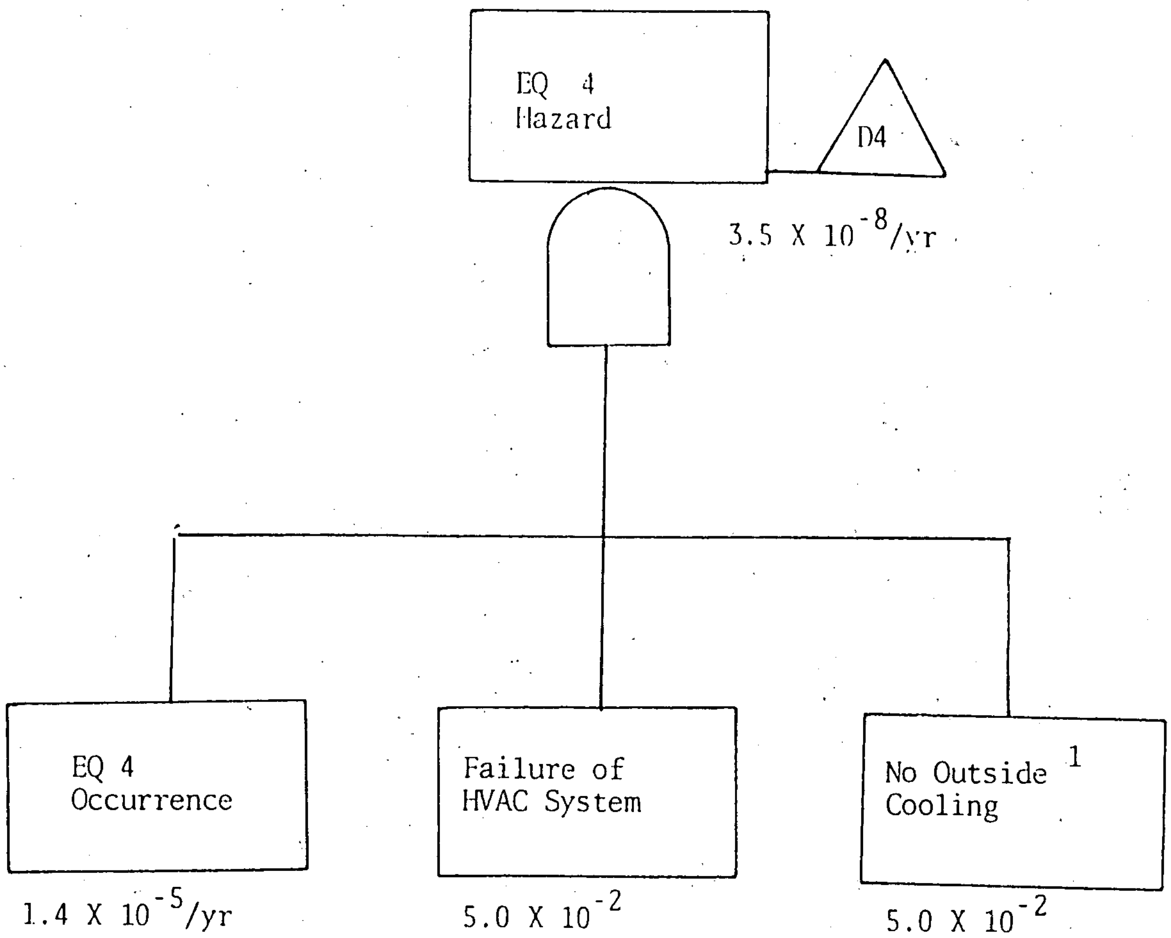


FIGURE 3 (continued)

1 For higher earthquake levels the dependency becomes greater. At this earthquake level, the value of 5×10^{-2} is nearly equal to typical CMF factors (beta) and is assumed to adequately represent the dependency

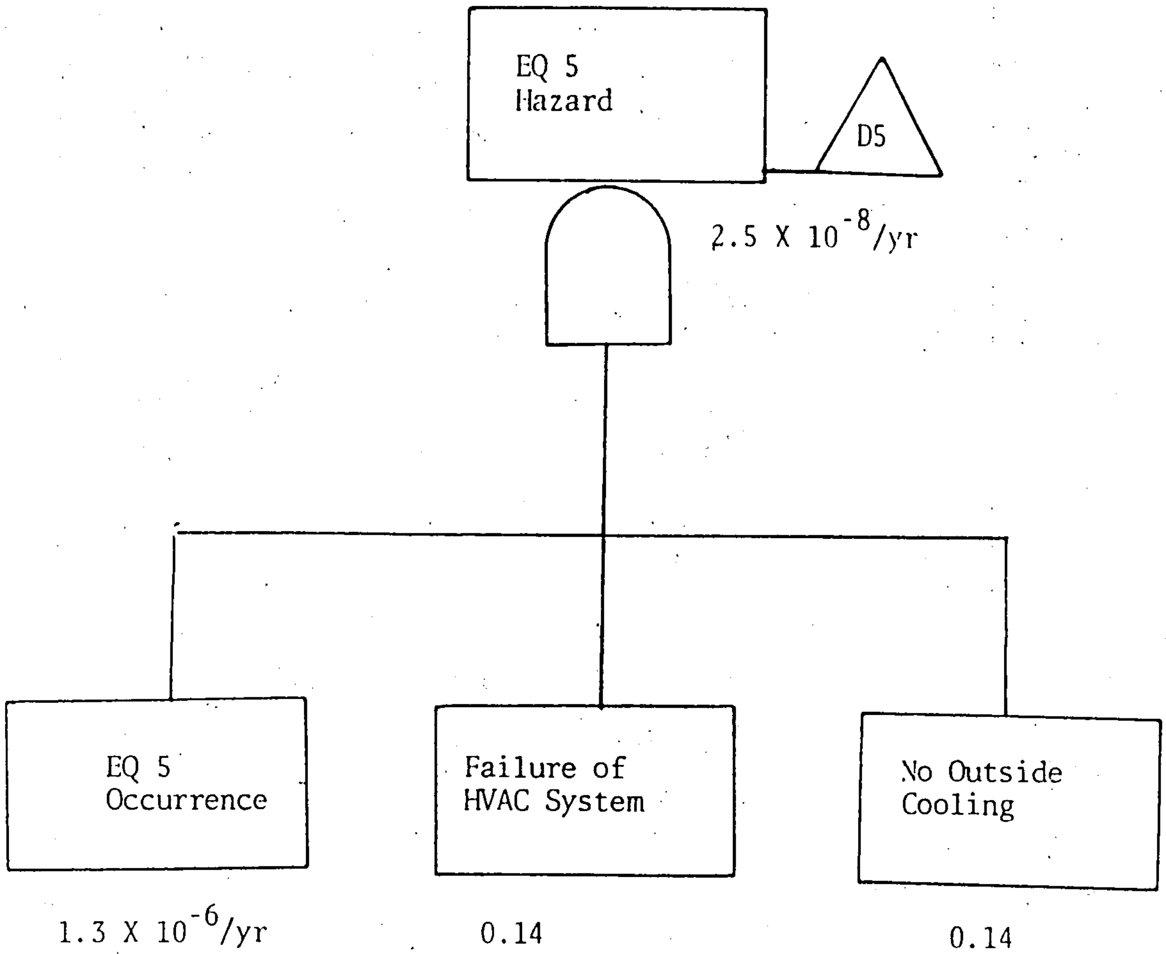


FIGURE 3 (continued)

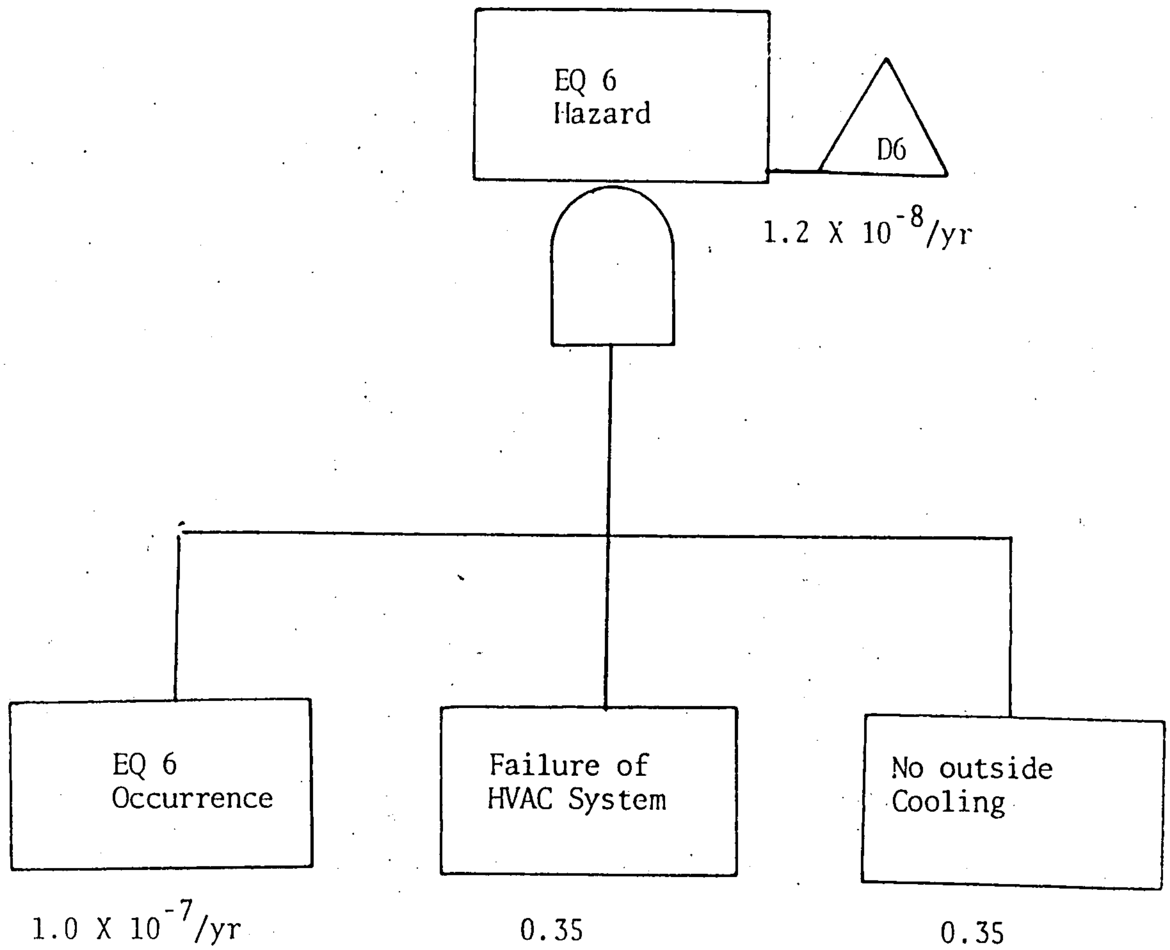


FIGURE 3 (continued)

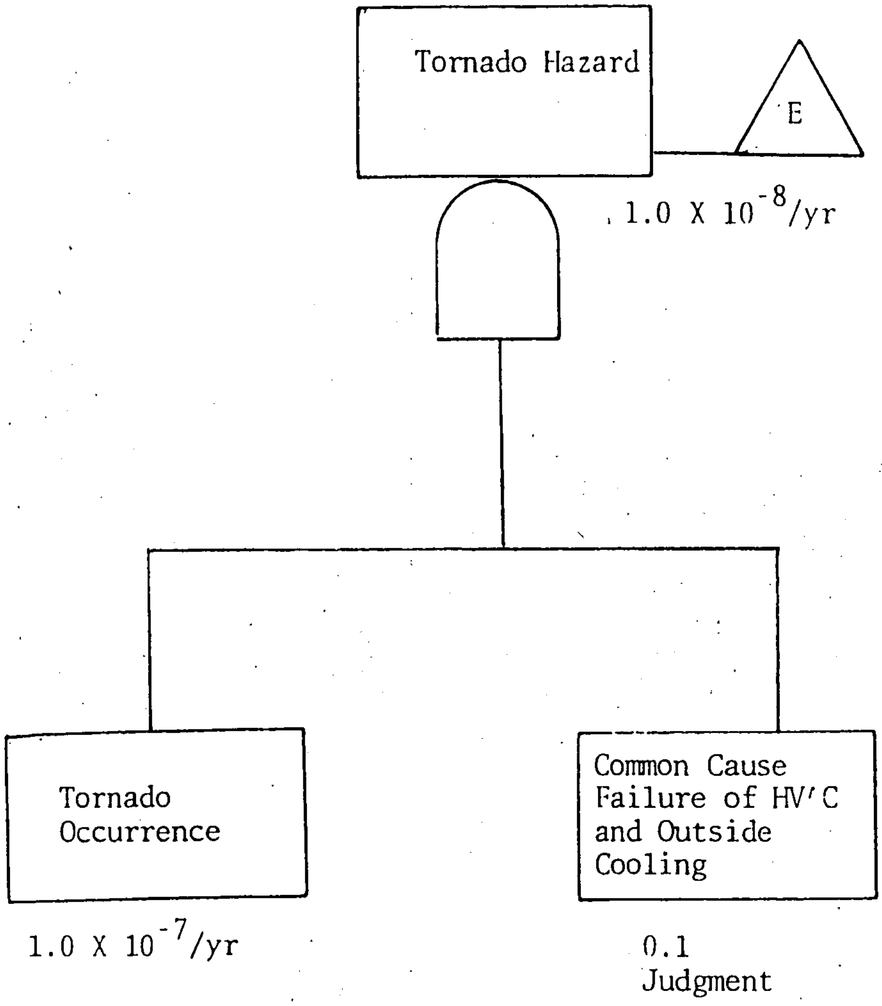


FIGURE 3 (continued)

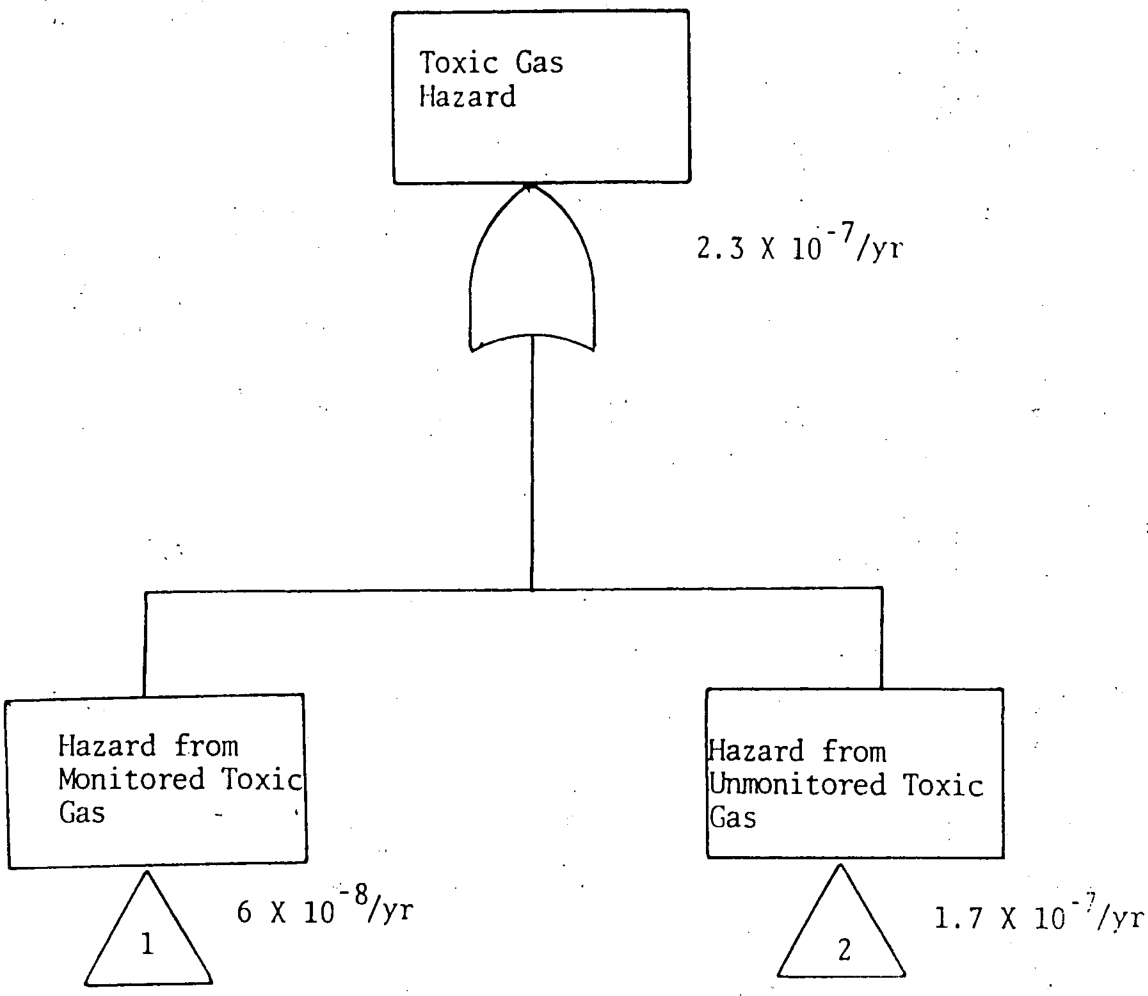


FIGURE 4: FAULT TREE FOR TOXIC GAS HAZARD

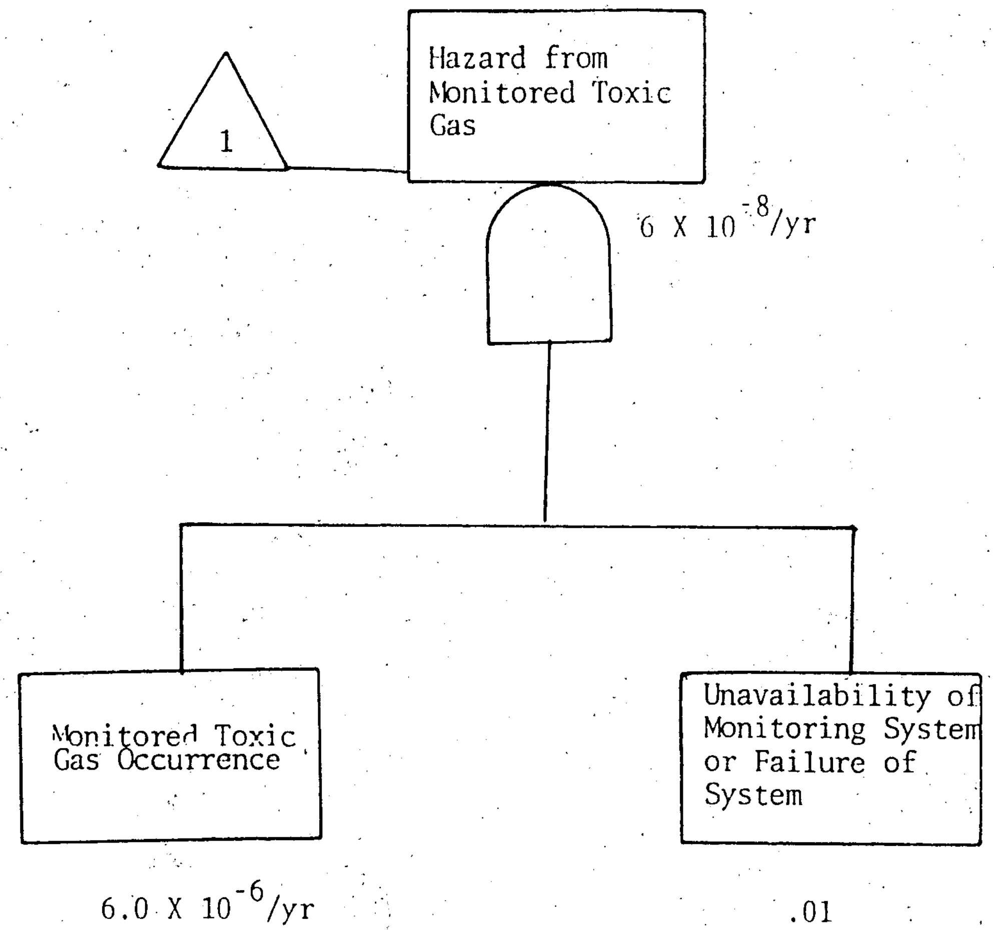


FIGURE 4 (continued)

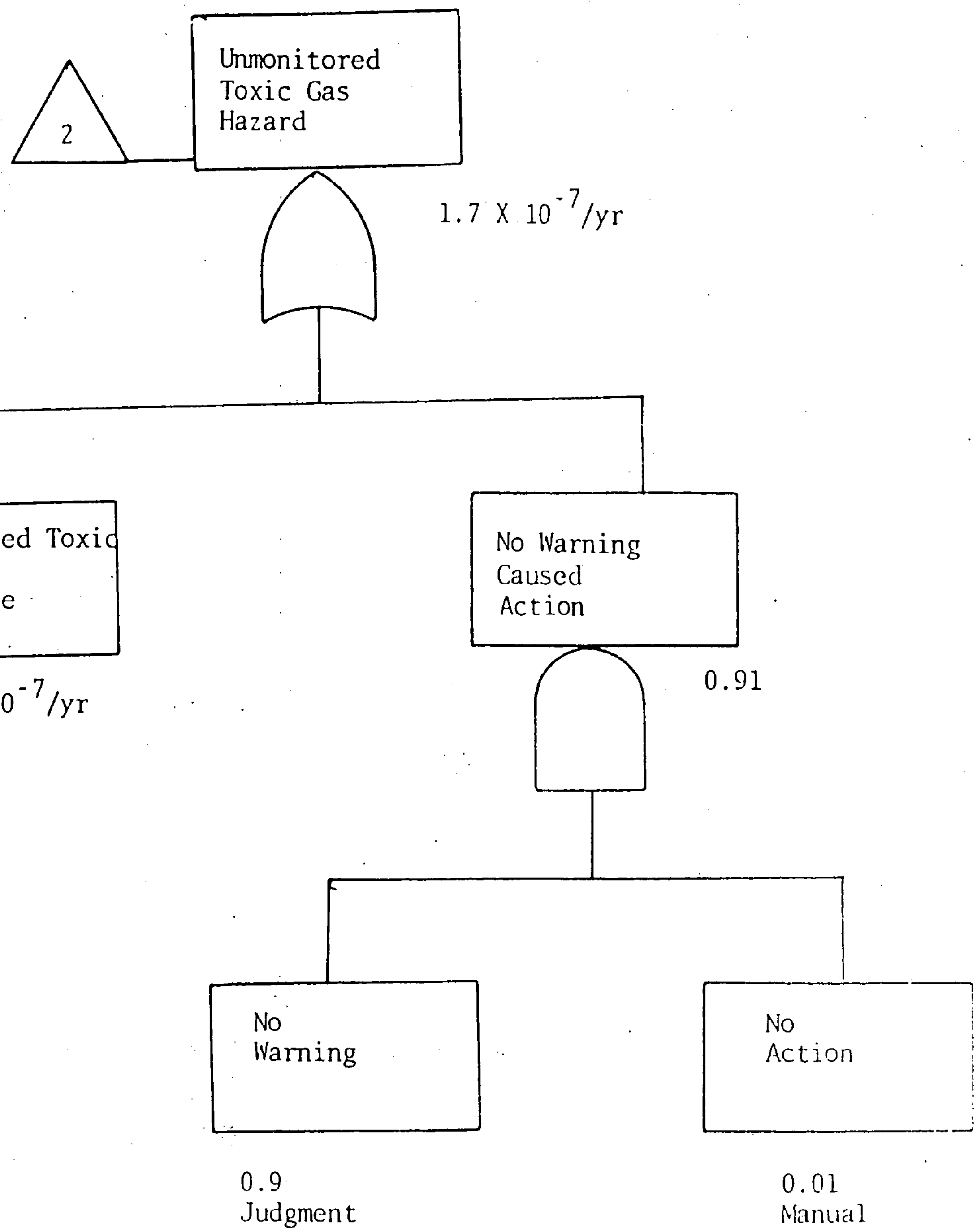


FIGURE 4 (continued)

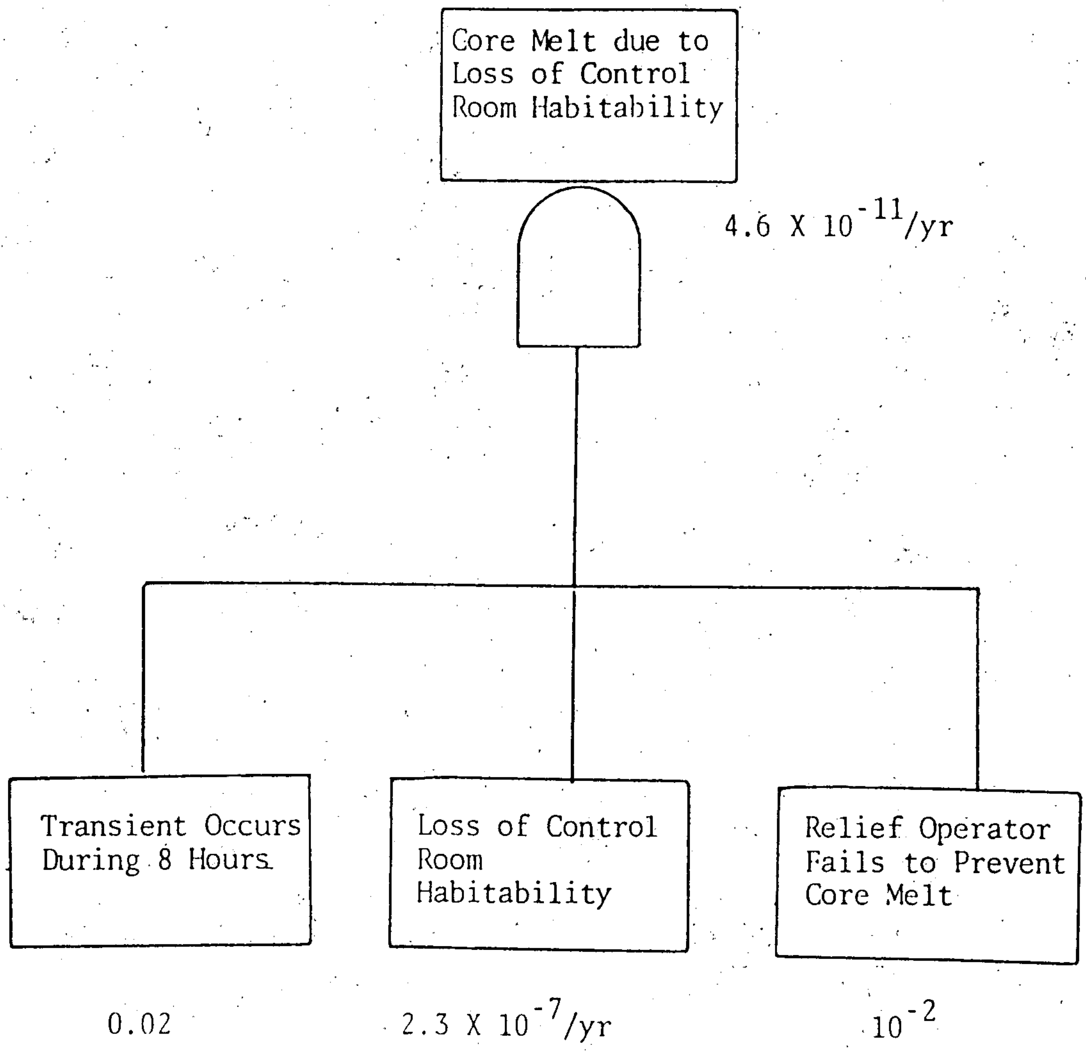
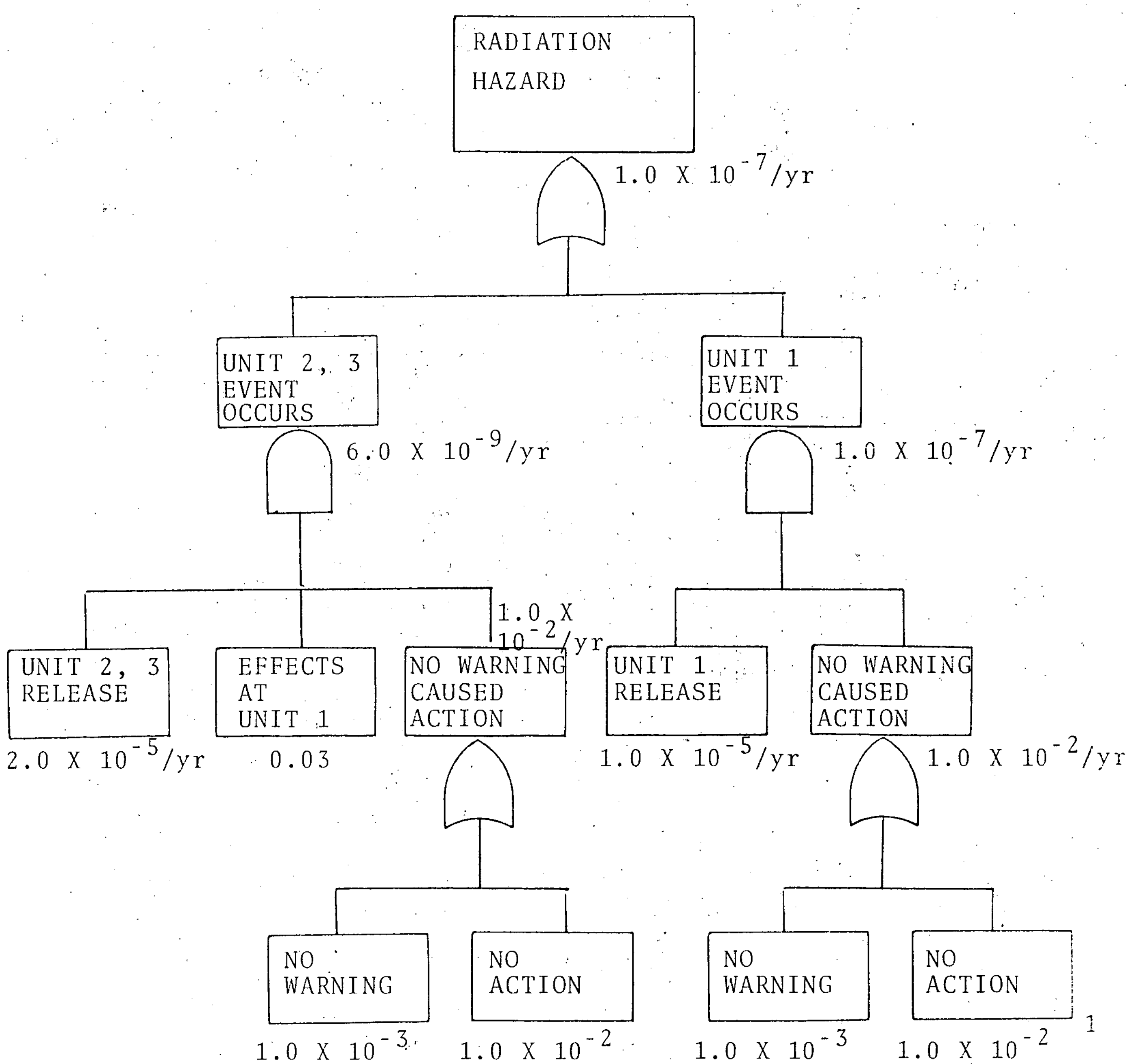


FIGURE 5

CORE MELT FREQUENCY DUE TO LOSS OF CONTROL ROOM HABITABILITY



1 This value is believed to be conservative for this sensitivity study.

FIGURE 6

FAULT TREES FOR RADIATION HAZARD

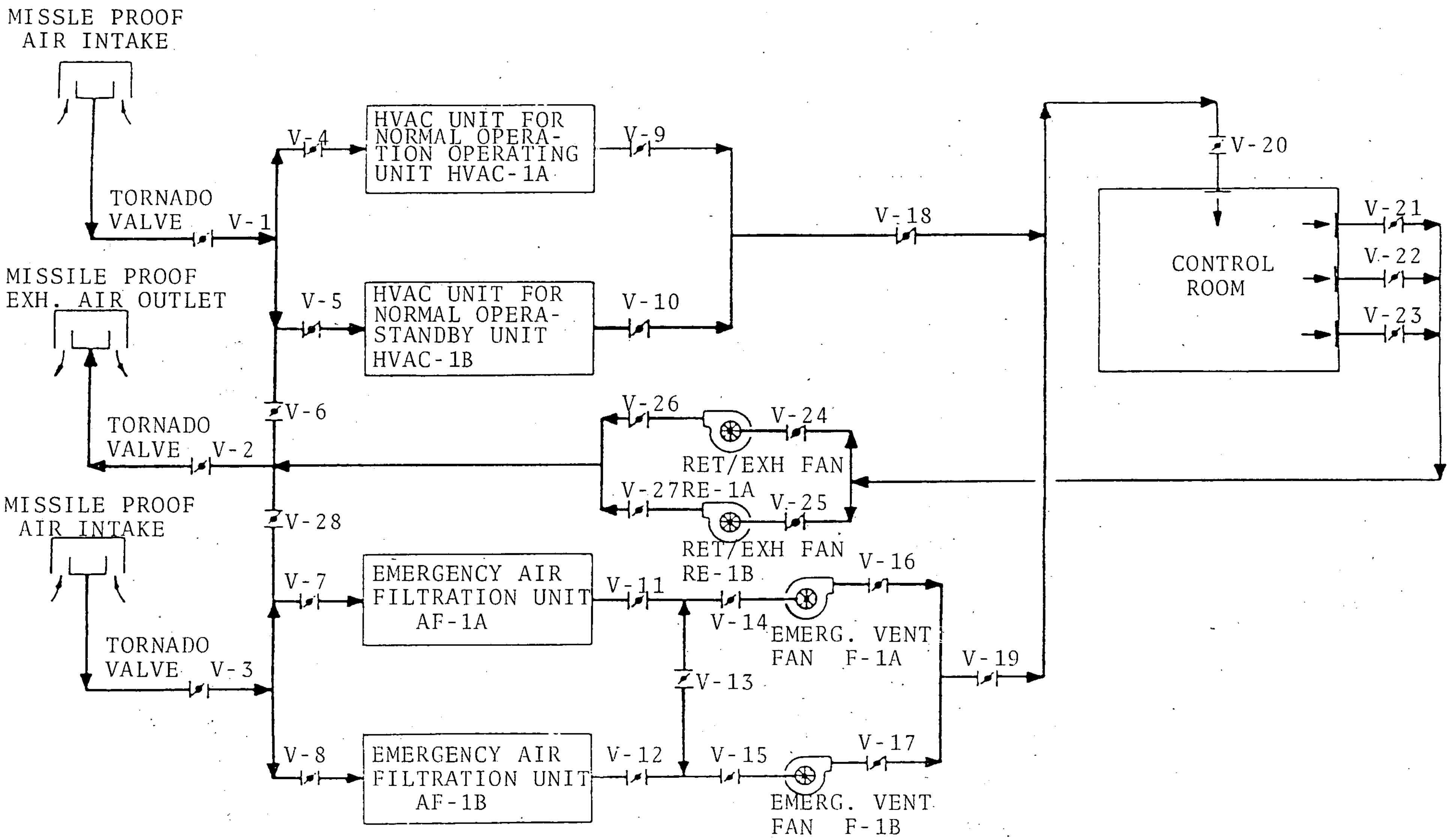


FIGURE 7

CONCEPTUAL UPGRADED CONTROL ROOM HVAC SYSTEM

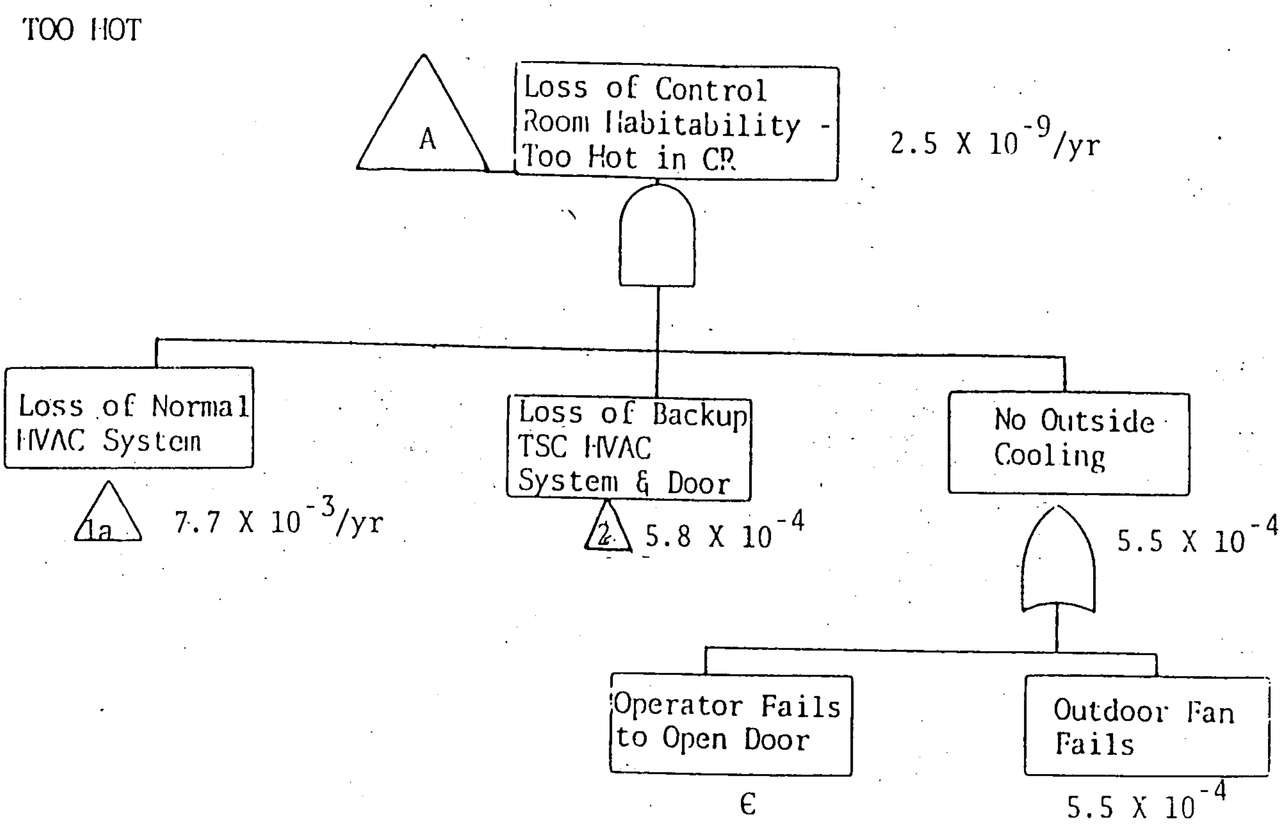


FIGURE 8

FAULT TREE FOR UPGRADED CONTROL GOOM HVAC SYSTEM

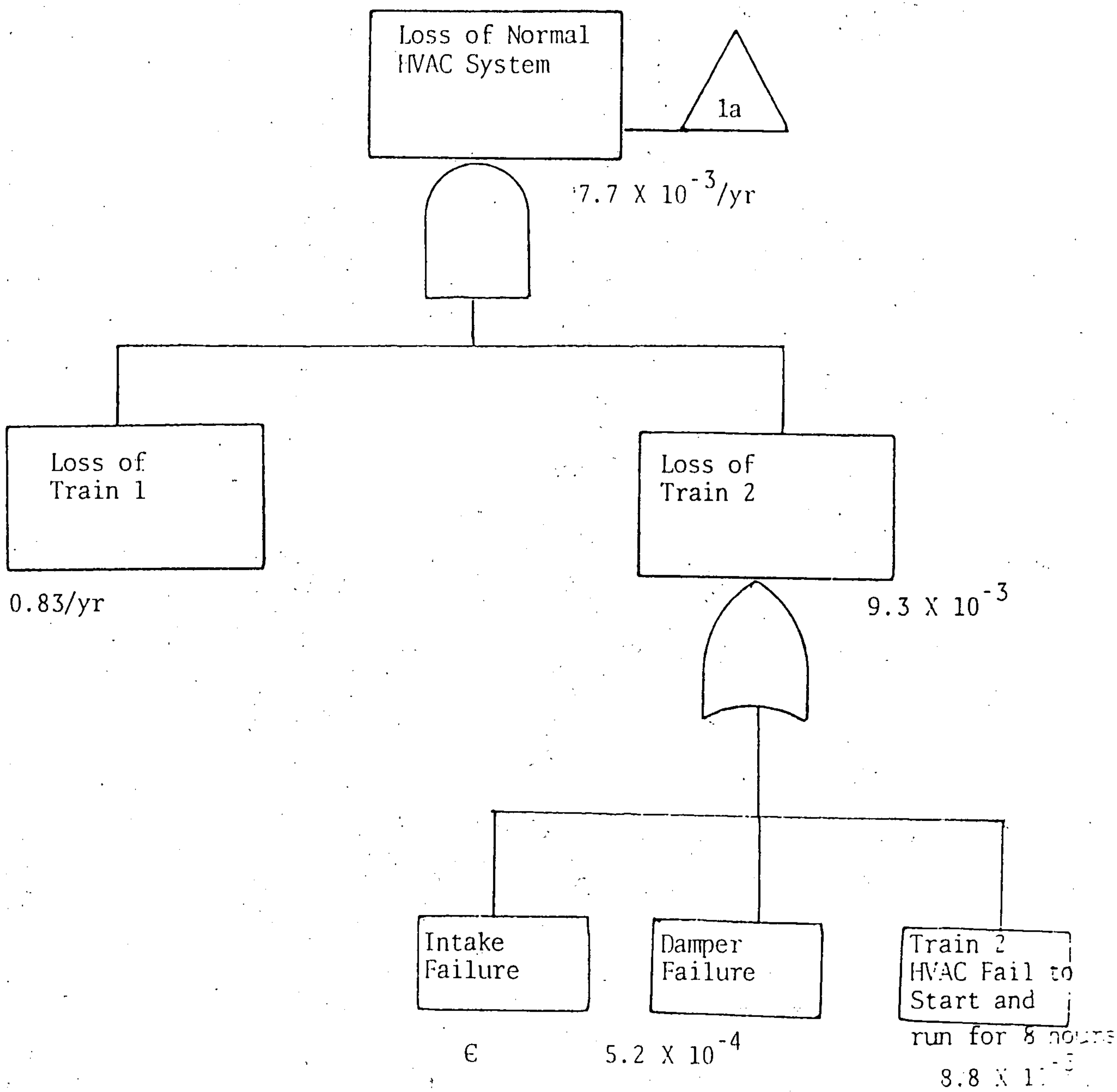


FIGURE 8 (continued)

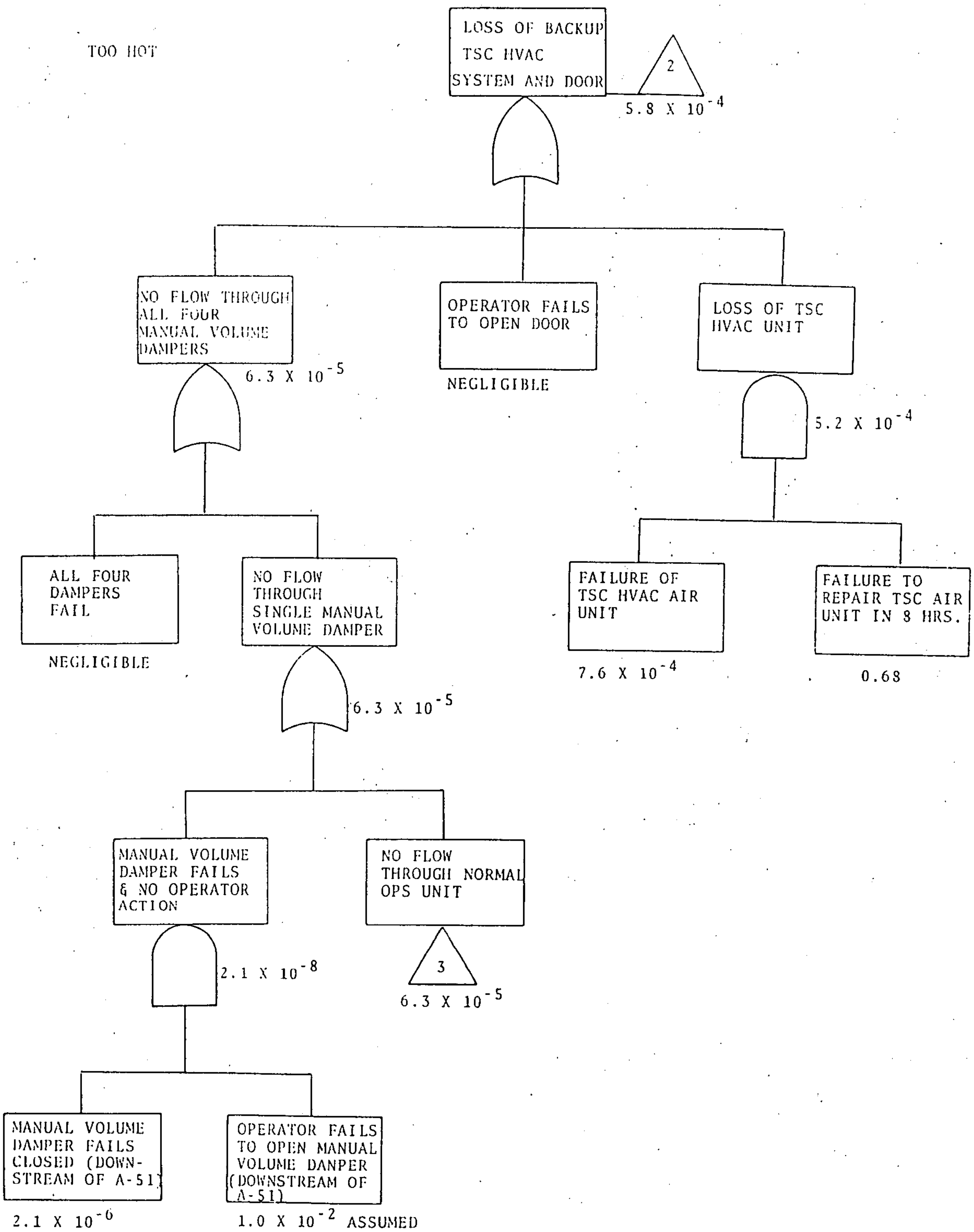


FIGURE 8 (continued)

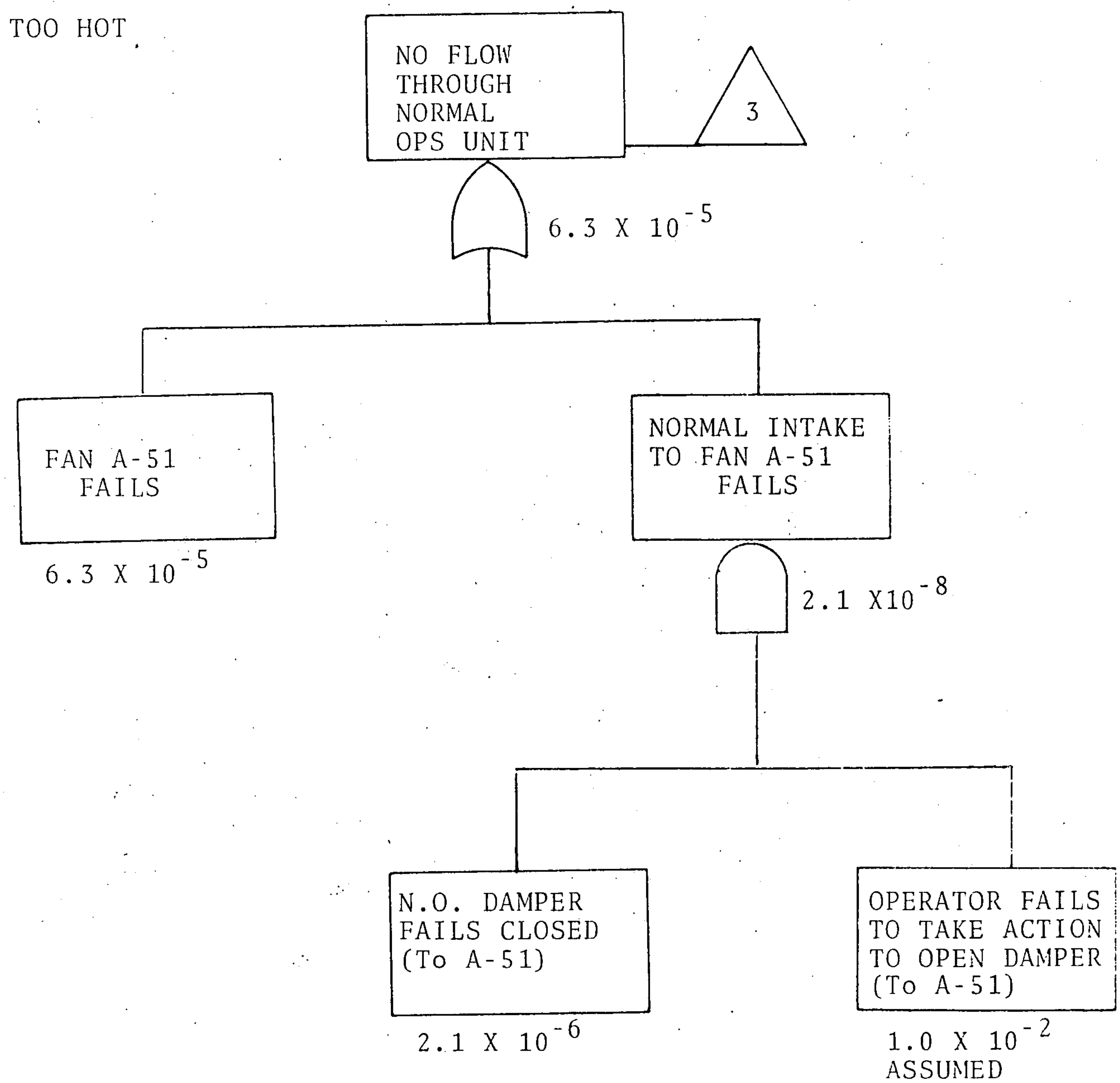


FIGURE 8 (continued)

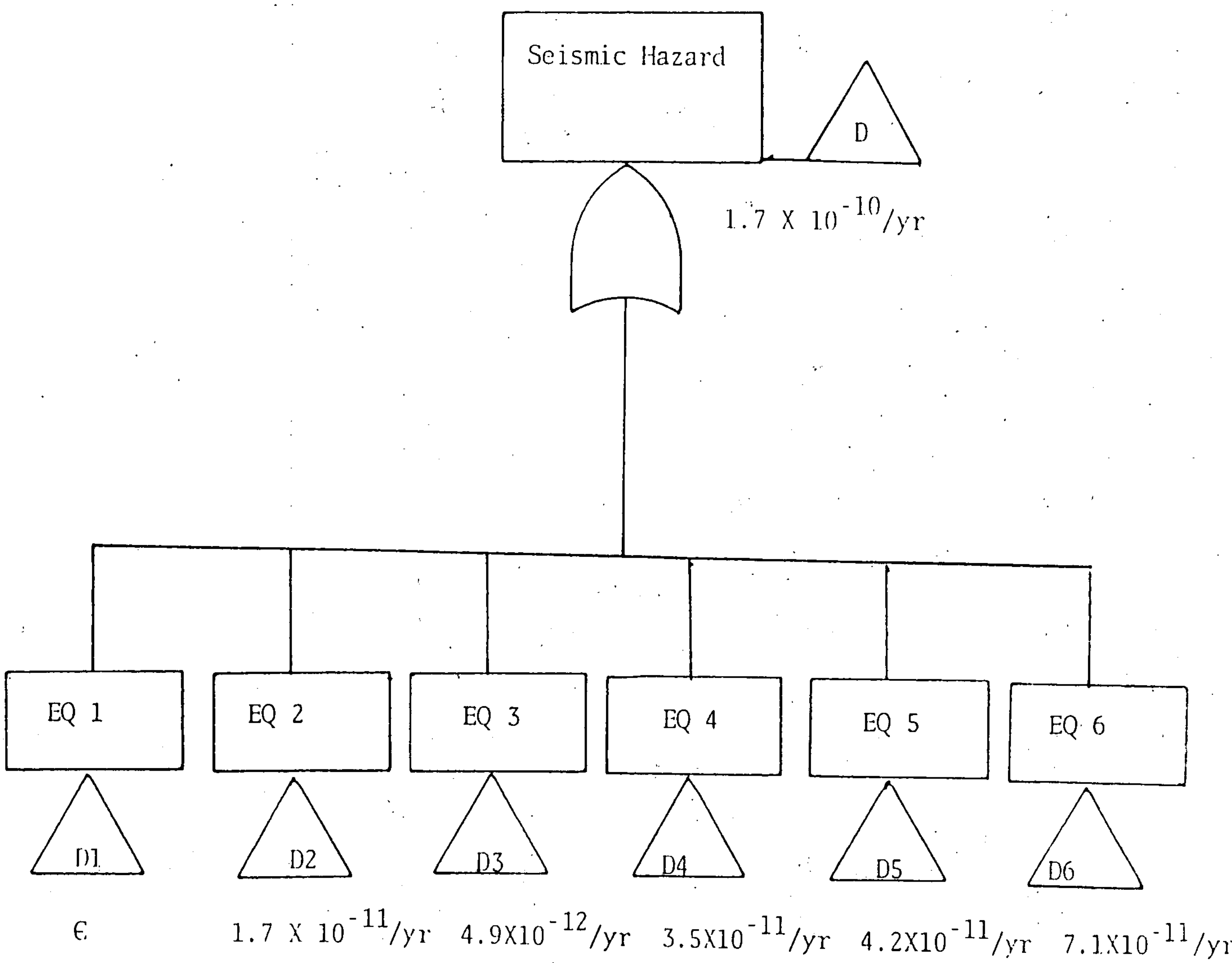


FIGURE 9

FAULT TREE FOR SEISMIC HAZARD

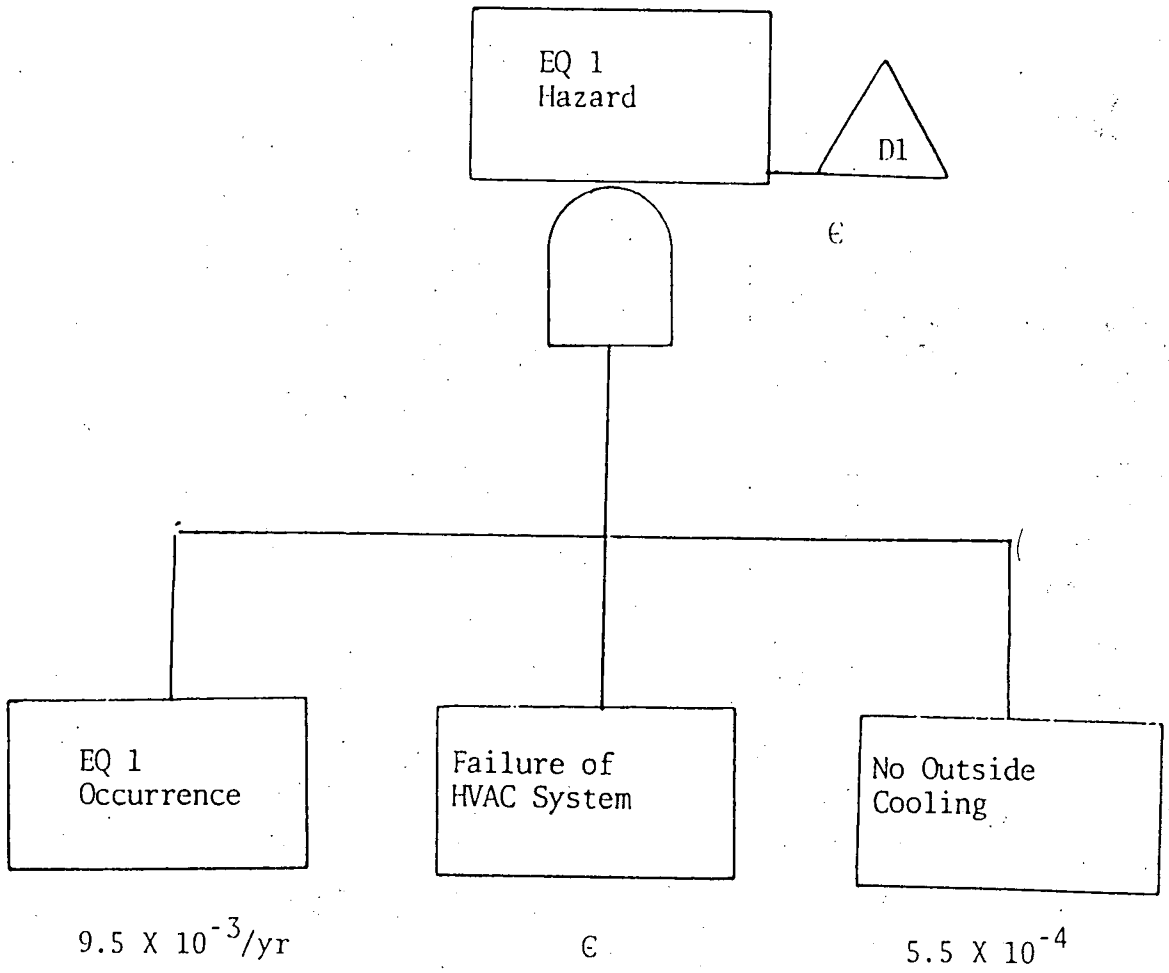


FIGURE 9 (continued)

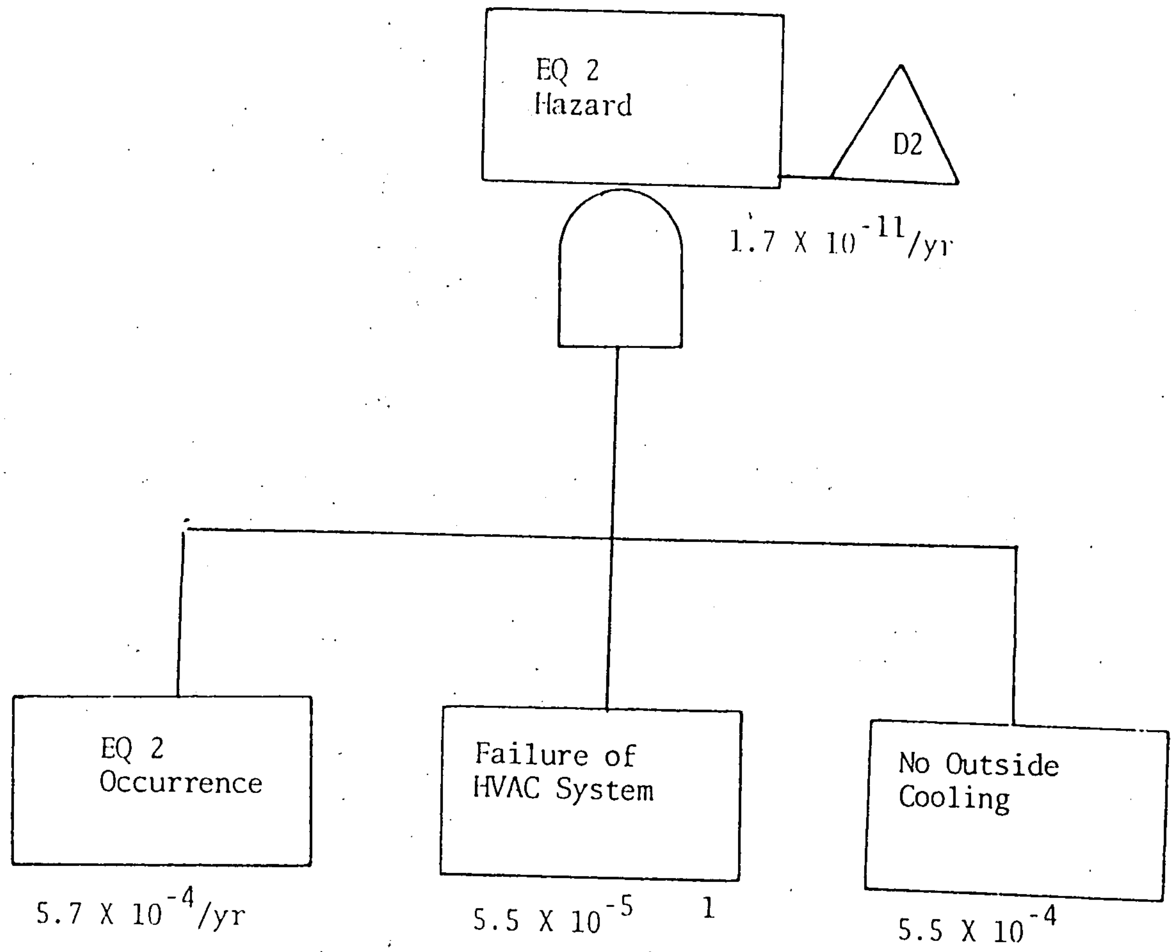


FIGURE 9 (continued)

1 Common Cause failure probability of 0.1 between the redundant HVAC system is assumed.

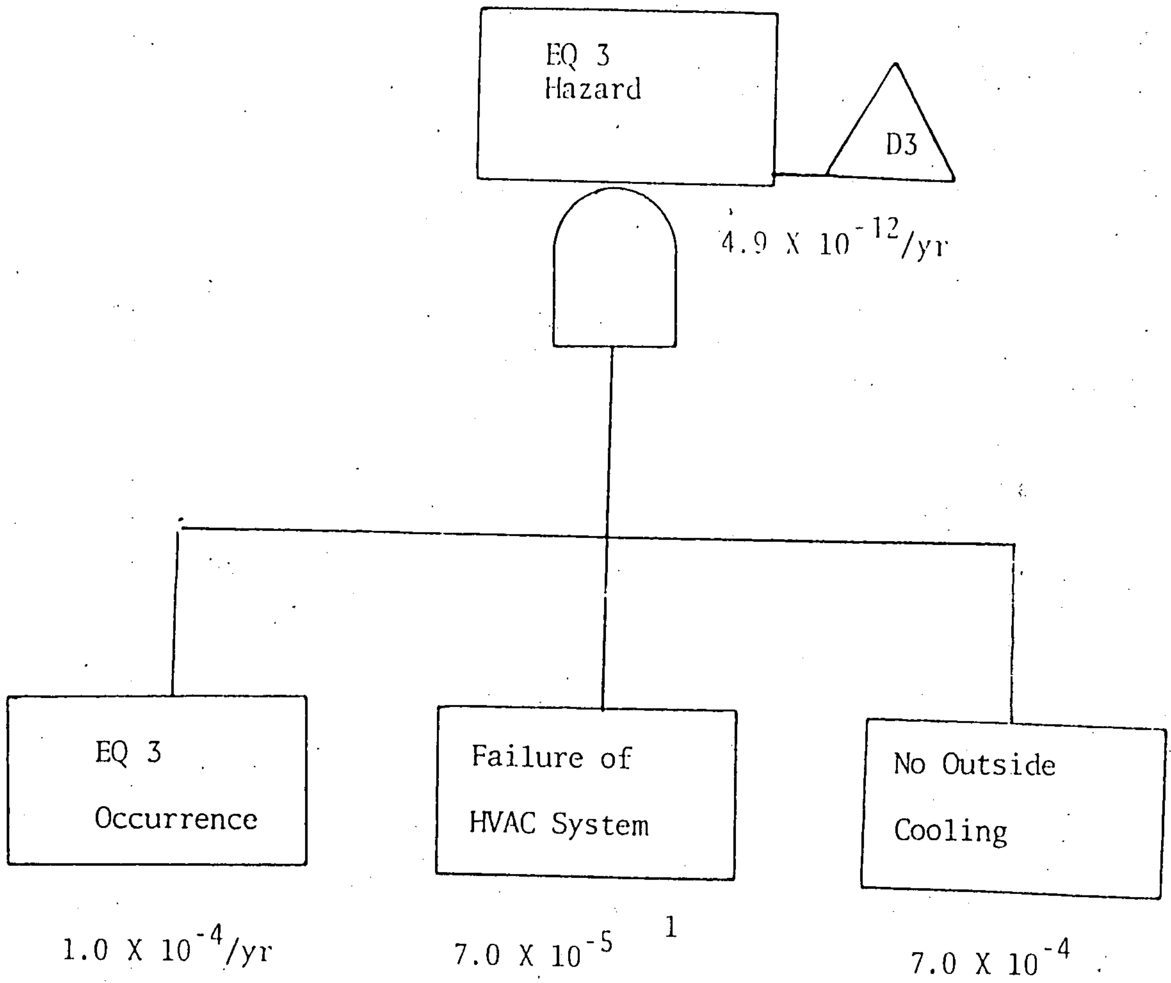


FIGURE 9 (continued)

1 Common Cause failure probability of 0.1 between the redundant HVAC systems is assumed

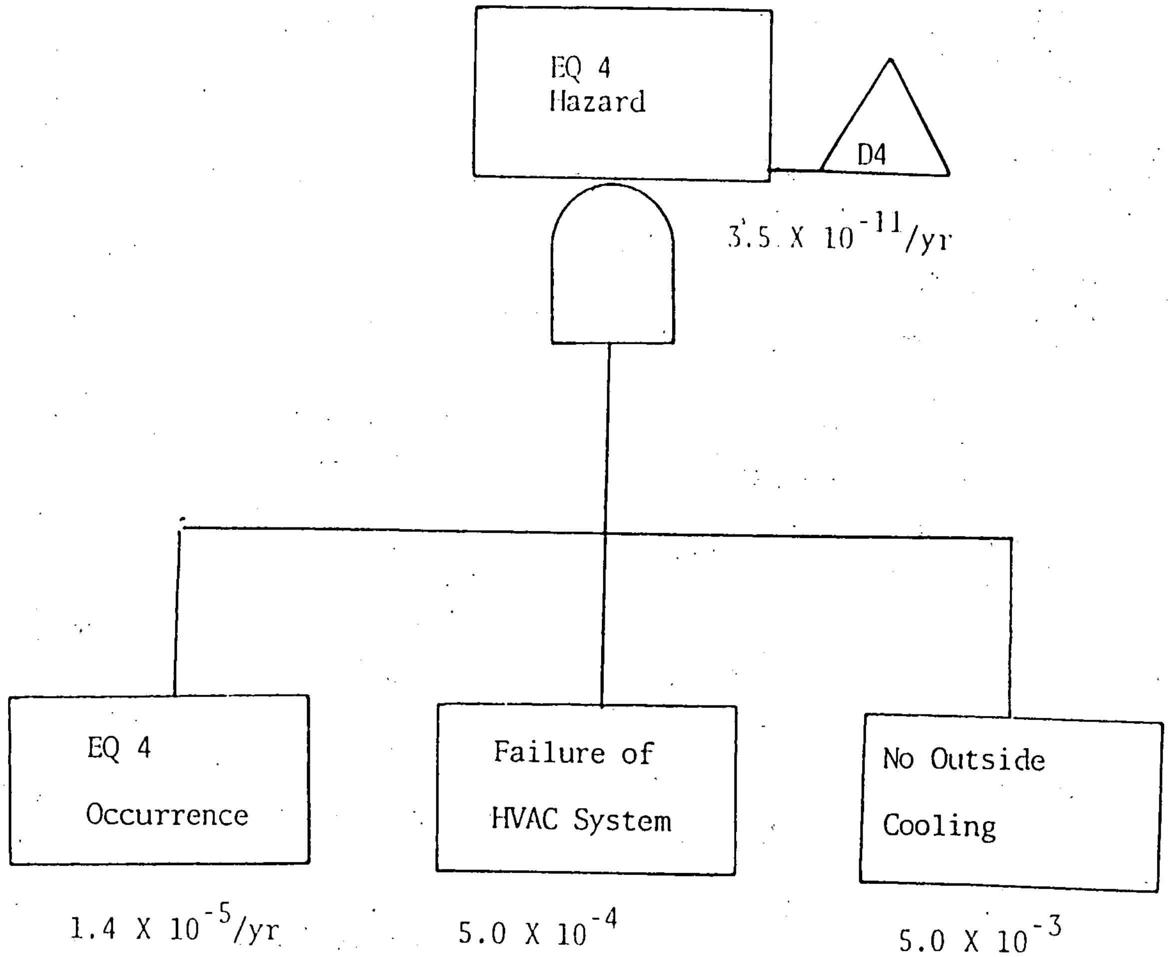


FIGURE 9 (continued)

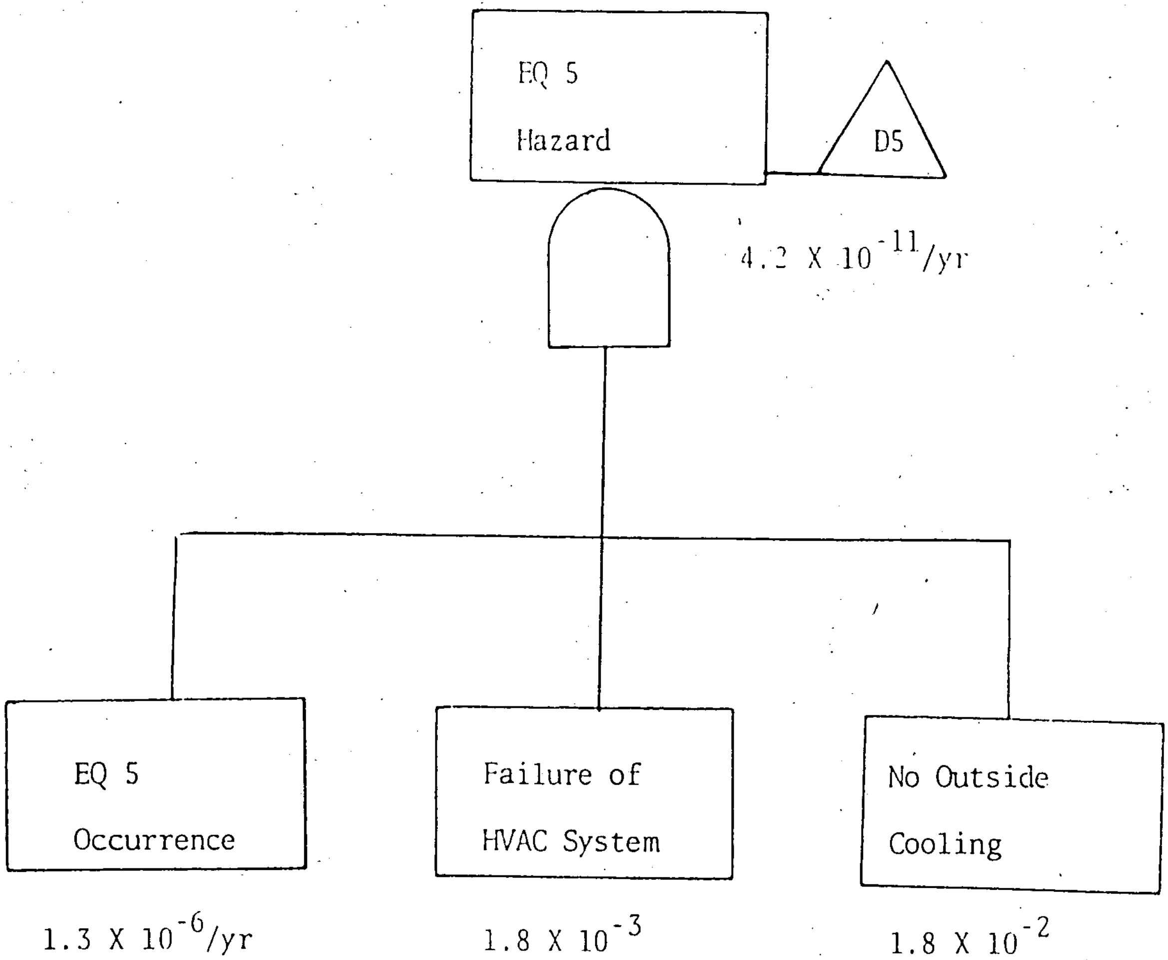


FIGURE 9 (continued)

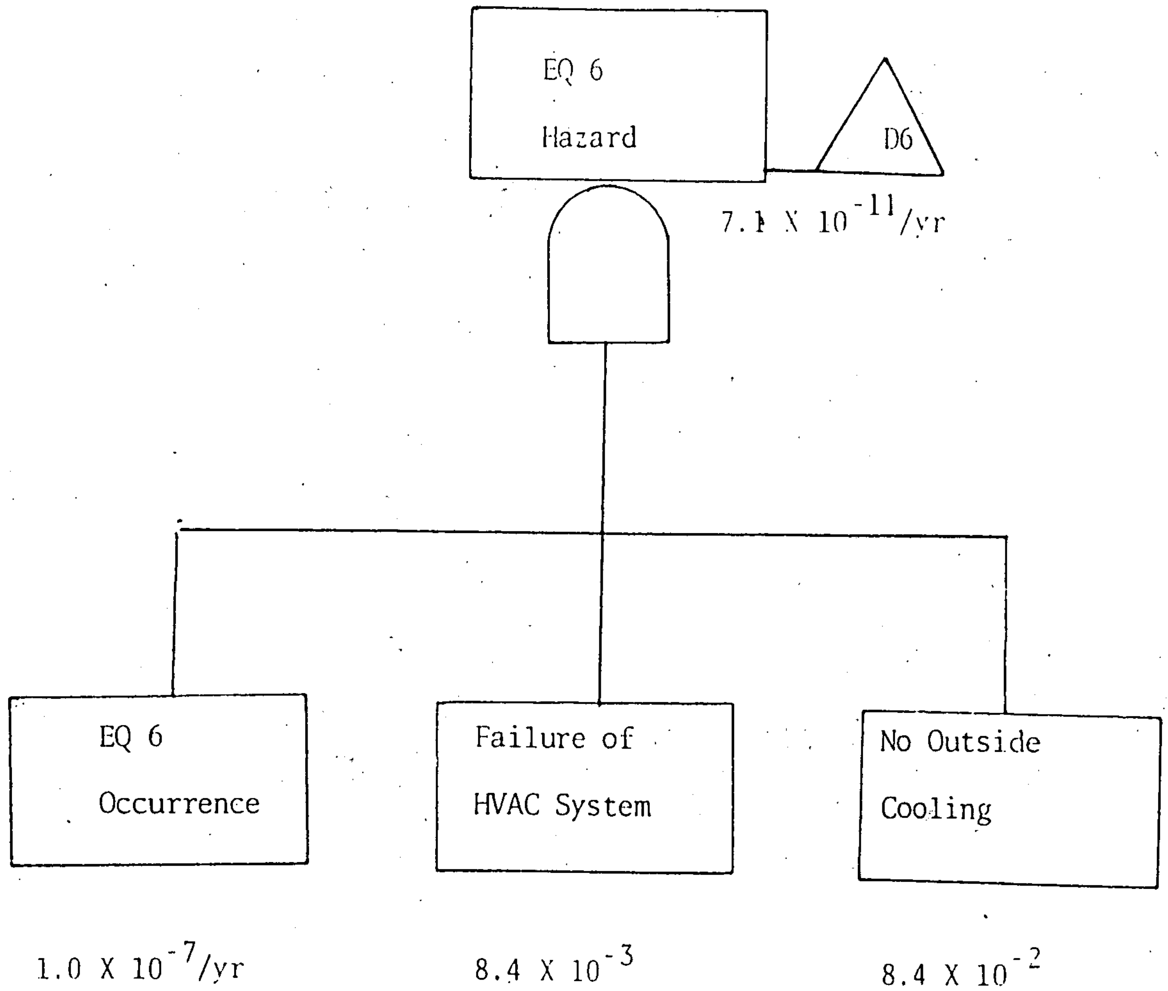


FIGURE 9 (continued)