PROBABILISTIC ASSESSMENT

OF AN

UNCONTROLLED DEBORATION EVENT

WITH A CONTROL ROOM FIRE

FOR THE

PALO VERDE NUCLEAR GENERATING STATION

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I. PURPOSE

The purpose of this report is to present an analysis of the probability of a boron dilution event, leading to dilution of boron concentration below the Technical Specifications (Tech. Spec.) limit, during a control room fire. The analysis was requested by the NRC. It will be used in considering the need for instrumentation changes to the remote shutdown panel.

II. SCOPE

This analysis involves estimating the occurrence frequency of a boron dilution event coupled with a control room fire. Included as part of this analysis is an estimation of the frequency of a control room fire leading to evacuation of the control room, an estimation of the probability of uncontrolled boron dilution event during the time in which the plant is operated from the remote shutdown panel and an estimation of the probability of operator error in detecting and terminating the event. The duration of the deboration is required to be sufficient to reach the Tech. Spec. boron concentration limit (approximately 9 hrs.). The combination of the probabilities of these events gives the total probability of the event of interest.

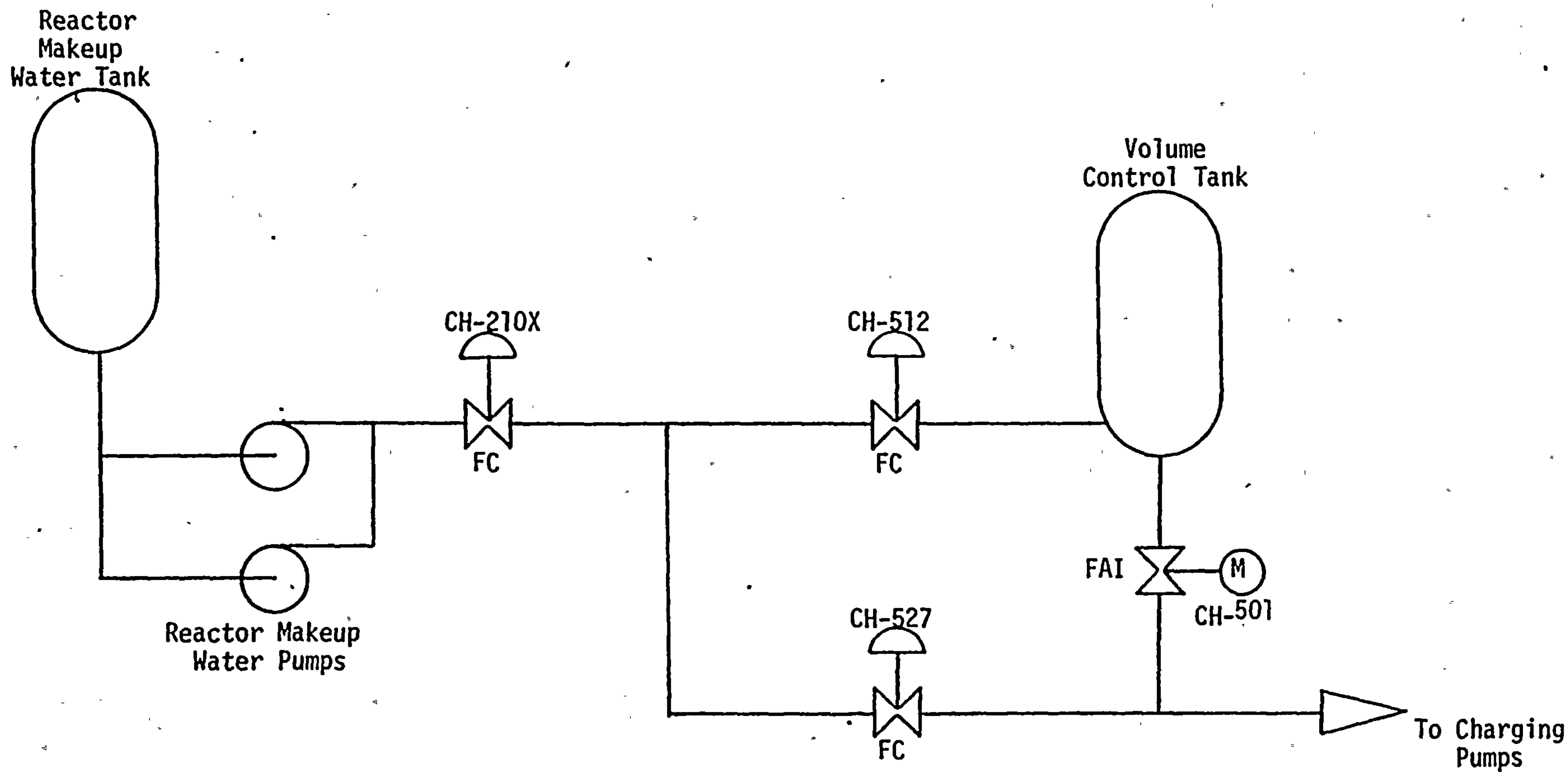
III. ANALYSIS

Figure 1 shows a simple schematic of the valves which must be kept open for a deboration event to occur. Figures 2 and 3 show the fault trees used to evaluate the frequency of the scenario using boron sampling and a source range neutron flux monitor.

The technique for evaluating the required human error probabilities are those suggested by Swain and Guttmann (Ref. 1). The following sections describe the assumptions used and failure probabilities predicted for each element in the fault tree (Fig. 2). The section letter (a through - f) corresponds to the specific element indicated on the fault trees.

FIGURE 1

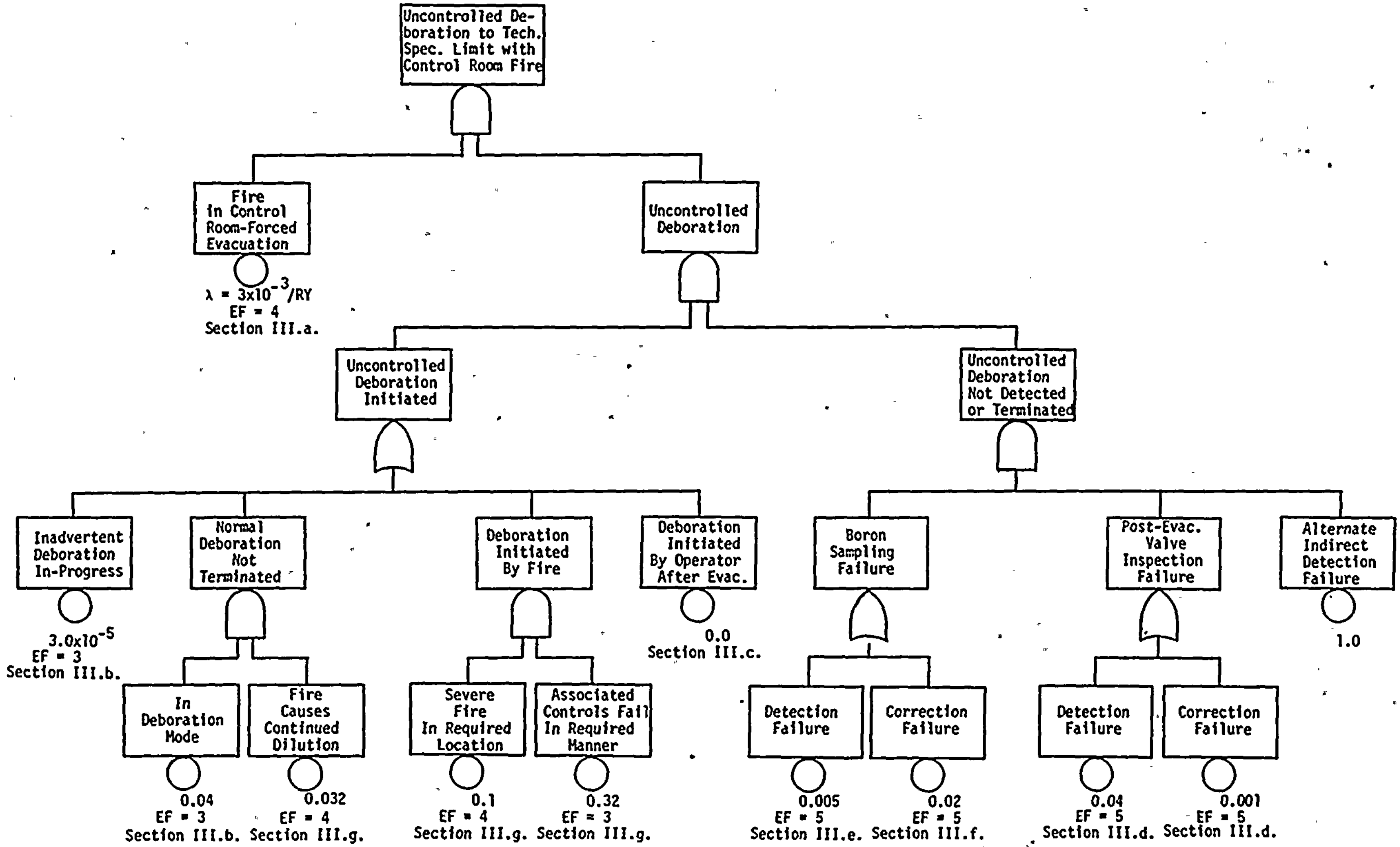
VALVE ARRANGEMENT
FOR BORON DILUTION*



*From CESSAR Figure 9.3-1

FIGURE 2

FAULT TREE FOR BORON DILUTION AND CONTROL ROOM FIRE WITH BORON SAMPLING



a) Frequency of Control Room Fire

G. Apostolakis (Ref. 2) published a study on the frequency of fires in various locations at a nuclear reactor site and concluded that the median probability for a control room fire during commercial operation is 3.0×10^{-3}/RY (Error Factor, EF = 4). Different probabilities apply during construction. Frequencies from Reference 2 were used in the Zion PRA Study (Ref. 3). The Apostolakis results are consistent with a similar study by Hockenbery (Ref. 4). In the Oconee PRA (Ref. 5), a separate analysis of the probability of fires in the electrical equipment room yielded a frequency of 3.7×10^{-3}. This result is close to that obtained by Apostolakis. The control room fire frequency from Reference 2, i.e., 3.0×10^{-3}/RY (EF = 4), was used in this work.

Apostolakis predicted the frequency of fires of any severity. Most fires at reactor sites have been very minor. Fleming (Ref. 6) reviewed industry-wide experience and concluded that 40% of the fires at reactor sites are extinguished within five minutes and that 90% are extinguished within 30 minutes. The Oconee PRA Study presents the data from Fleming and concluded that all fires would be extinguished within an hour (Ref. 7). Sideris (Ref. 8) reviewed 214 fire incidents and gave a table of fire severity in terms of cost in direct fire loss. Most fires (46%) did less than $5,000 in damage. Four fires (1.9%) did damage in excess of one million dollars. If you considered a severe fire as one resulting in over $100,000 in damage, then 12% of the fires would qualify. The Sideris Study included fires during construction and testing as well as operation. These studies were general studies and do not take into account the fact that the control room is occupied at all times, contains no flammable liquids, and has both fire extinguishers and access to fire hoses. Special air filtering equipment and air packs are also available in the control room. A fire severe enough to lead to the control room being uninhabitable for sufficient time to have an extended boron dilution transient is very unlikely. For this study, the conservative assumption is made that all control room fires are severe enough to require abandoning the control room for an extended time. Thus,

the frequency of having a control room fire requiring evacuation is 3.0×10^{-3}/RY (EF = 4).

b) Deboration In-Progress

The coincident occurrence of a deboration event with a control room evacuation can be considered to develop in the following four ways:

1. A normal deboration is in progress, the fire occurs and causes the normally automatic termination of the deboration to fail

2. An inadvertent deboration event happens to be in progress at the time of the fire and continues independently of the fire

3. An extended deboration event is initiated by the fire

4. A deboration event is inadvertently initiated by an operator following evacuation of the control room.

Scenarios 1 and 2 are discussed in this section. Scenario 3 is discussed in Section III.g and Scenario 4 in Section III.c.

Normal Deboration In-Progress

Deboration equipment is used during startup, power changes and normal operation to offset fuel use and fission product inventory increase. During the time that the plant is at full power, the deboration equipment is being used about 10 minutes per shift or 2.1% of the time. The average number of shutdowns in a PWR is 12.3/RY (Ref.9). If in the assent to power, the deboration equipment was run an average of 16 hrs, this would be an additional 2% of the time. The probability of being in a normal deboration was assumed in this study to be .04.

Inadvertent Deboration Event in-Progress

An evaluation of the industry-wide operating experience (Ref. 10) concluded that over the past 8 years the frequency of RCS boron dilution events was 0.05/RY. Eighty percent of these events were caused by human error. Most incidents occurred during refueling (56%) or hot shutdown/standby (28%) with only 16% occurring during critical operation. No boron dilution incident resulted in a reactivity excursion or transient, scram of a unit or a challenge to the reactor protection systems. For each event, the operator had sufficient time to diagnose and correct the cause of the inadvertent dilution before the shutdown margin was challenged.

This frequency is consistent with the frequency reported in the NREP data base (Ref. 11) which suggests 0.04/RY, EF = 3. In the Oconee PRA Study (Ref. 12) boron dilution transients were not considered because

> "credible dilutions would result in reactivity effects judged to be insignificant with respect to mitigation. Dilutions resulting in substantial reactivity were judged to be of small probability due to the time required and the amount of non-borated water required. Core melt due to a dilution accident was judged to be dominated by more frequent transients."

In the Zion PRA Study (Ref. 3), the mean frequency for all overpower transients was 0.023/RY. The overpower transients included control rod withdrawal, and cold water addition as well as boron dilution.

For this study occurrence frequency of Reference 10 was used. The probability was adjusted to eliminate deborations during refueling outages reducing the frequency to 0.022/RY. The Tech. Specs. call for performing boron concentration measurements every 12 hours when at power. Conservatively assuming that deboration transients start right after the last sample, the probability of being in an inadvertent deboration transient at any given time is 3.0×10^{-5}, EF = 3. This is based on multiplying 0.022/RY times 12 hr./event and dividing by the number of hours per year. The error factor from Reference 11 is used.

c) Misalignment of Valves after Control Room Fire

A local valve alignment check is required in the procedures following control room evacuation. Emphasis of the check would be on shutting down the plant and stabilizing the plant. Considering the control room fire and the control room uninhabitable, there would be no intent of a rapid return to power or power operation. Therefore, there would be no intentional action to dilute the boron. To accidently initiate a boron dilution, a minimum of two valves would have to be opened and a third valve closed. A second deboration path requires that three valves be opened and a fourth closed. Valve realignment would not be going on in this area and position indicators are available on all of the relevant valves. It is assumed to be unlikely that a boron dilution accident would be initiated after the control room is evacuated. As a result, the probability at point III.c. of the fault tree was put equal to zero.

d) Detection of Boron Dilution During Valve Inspection

Given that a boron dilution event is in progress at the time of the fire and control room evacuation, it can be discovered and terminated either during the mandated local valve alignment check, during one of the samples taken at regular intervals or through some indirect observation.

The failure of the operators to discover and terminate the deboration during the valve check is discussed in this section. Failures to discover it during sampling and to terminate it following the discovery are discussed in Sections III.e. and III.f respectively. The probability of discovering it as a result of some indirect observation was not considered. This is a conservatism.

After the reactor scram and control room evacuation, a local check of the valve alignments is performed. It is conservatively assumed that the inspection is performed only once. Because of the unusual nature of the event and the fact that the fire could have changed valve status; the inspection is assumed to be more rigorous than a normal daily walk-down.

A check list is used. The Human Error Probability (HEP) in this inspection is based on failure to use the valve restoration list and failure to recognize the incorrect valve alignment. The combined HEP for this event is 0.02 (EF = 5). All four valves indicated in Figure 1 have position indicators on them and only valve (CH 210) needs to be correctly assigned to terminate the deboration. Since the valve checking is not done immediately after a control room fire, it was assumed that the auxiliary operator was under moderately high stress when doing the valve check (a step-by-step task). This factor increases the HEP for failing to discover the deboration to 0.04. No credit was taken for any redundant checks by other personnel at the site. Once the operator has identified the valve as being misaligned, the probability of not correcting it is small, i.e., 0.001.

e) Detection of Boron Dilution Using Boron Sampling

Beginning two hours after the control room has been abandoned, boron concentration will be verified on an hourly basis. An HEP value based on manual sampling is calculated below. However, it should be noted that boron concentrations could also be and probably would be read directly from a boronometer located on the CVCS train.

It was estimated that the time from initiating the deboration transient until reaching the Tech. Spec. limit is approximately nine hours. Two additional hours would be required to reach criticality. This estimate neglects the Xenon buildup which would peak at nine hours and further delay a return to criticality. Xenon poisoning would burn off after forty hours. Also neglected are the fuel burnup effects. The time to return to criticality from a boron dilution accident would lengthen during the fuel cycle until a return to criticality would not be possible. These times are also conservatively based on the assumption that three charging pumps are adding unborated water and the plant is cooling down at 60°F/hr. The nine hour time to Tech. Spec. limit is used in this analysis.

Seven samples would be performed assuming a nine hour duration and starting the samples two hours into the incident. The first failure mode is failing to perform the samples at all. This error of omission assumes the use of a long procedure with multiple entries for check-off and recording of the boron concentration results.

The sampling procedure consists of selecting the correct train, flushing the sample line, and reading the sample results correctly. Failure of the boronometer itself was also considered in assembling the HEP, but the human error dominates. The total HEP for the first boron concentration test is 0.015, EF = 4.

The sampling is performed seven times. Each succeeding sample is conservatively assumed to be dependent on the first sample. No credit was taken for the fact that the seven samples would most likely extend over more than one shift and that different personnel would perform the test. The HEP for the second test was assumed to be moderately dependent on the first test (HEP = 0.15). The third test has a high dependency on the previous tests (HEP = 0.5). No credit is taken for the next four (4) tests (HEP = 1.0). The total HEP for boron sampling is 0.0011, EF = 4.

The above HEP calculation is based on single individuals performing the task, at normal stress levels, without reminders or assistance from others. During the event, the operator would be joined by the second operator, shift supervisor and shift technical advisor. These three additional people would help to identify errors. The effect of the additional personnel would be expected to reduce the total HEP by a factor of 0.1. However, this effect was conservatively neglected.

At the initial start of the incident the operators are at a very high level of stress. As the event continues, stress is reduced but to a moderately high level. The HEP were increased by a factor of 5 to account for the stress levels. The final HEP used for boron sampling is 0.005, EF = 4.

f) Correction of Valve Alignment Given Boron Sampling

After the boron dilution is discovered, an auxiliary operator (AO) would be sent to close the valve, CH210X, to terminate the boron dilution (see Fig. 1). The HEP for correcting the valve alignment is based on two oral instructions to close the valve (technician to operator to A.O.), coupled with failure to close the correct valves (HEP = 0.008). The failure to close the correct valves and terminate the deboration would be discovered in later boron samples or possibly from other instrumentation, and a recovery factor of 0.5 (high dependency on first attempt) was assumed. The total HEP for the valve correction is 0.004, EF = 4. As in the previous analysis, the effects of a moderately high stress were included. This effect increases the HEP by a factor of five. In this analysis the HEP for correction of the valve alignment is 0.02, EF = 5.

g) Fire Initiating or Continuing Boron Dilution

A complete evaluation of the probability that the control room fire initiates the boron dilution accident would be a major task. A conservative estimate for this number was made based on an analysis in the Oconee PRA Study (Reference 13) of the probability that a fire initiates the opening of a motor operated valve.

The analysis assumes the control cable is directly exposed to a fire and the authors calculated the probability of hot shorting some of the nine wires presumed in one cable. A mean value of 0.32, EF = 3, was calculated although they state that experienced engineers from their design staff felt that this estimate was too high.

The initiation of a boron dilution transient would require opening two pneumatic actuated valves in one path or two pneumatic actuated and one motor operated valve in a second path. All of the pneumatic valves would fail closed if power were lost. The fire would have to either open at least two valves or cause the controller to fail in a specific mode. It

was assumed that given a fire in the CVCS controller or CVCS cable area, the failure rate was the same as for a cable for one motor operated valve. This failure rate is based on the assumption that the cable is in an area where the fire is located. Given the size of the control room and the number of cabinets, we assigned a 10% chance that the cables are in the fire. The combined probability that the cables or controls are exposed to the fire and initiate the boron dilution was 0.032, EF=3. This number was also used for the probability that the fire prevents termination of a normal dilution.

h) Source Range Neutron Flux Monitor at Remote Shutdown Panel

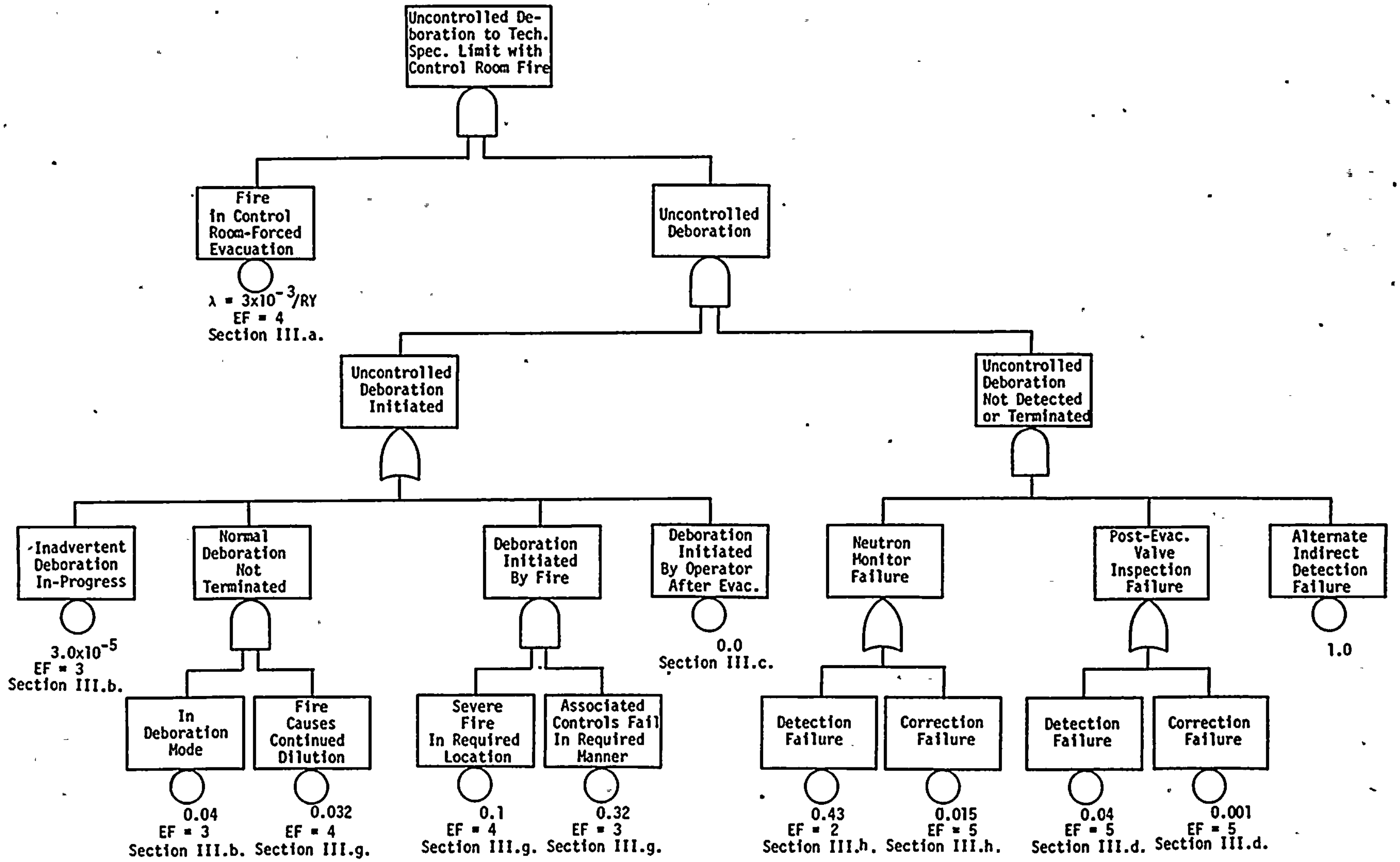
Figure 2 and sections e and f are based on the detection of the uncontrolled boron dilution using boron sampling. Another possibility is the use of a source range neutron flux monitor at the remote shutdown panel. Figure 3 shows the fault tree for the use of a source level neutron flux monitor instead of boron sampling. This section will describe the analysis that generated the failure frequencies for using a neutron flux monitor and terminating the boron dilution.

The source range neutron flux meter will be off-scale for the first half hour. It will be on-scale and decreasing during the next 12 to 24 hours. The exact rate of count will depend on the degree of core burnup and sub-criticality. For the first initial audit the meter will show no deviation. Deviation in readings will only occur after the Tech. Spec. limit for shutdown margin is reached and 15 minutes to 30 minutes before recriticality. For this analysis it was assumed that the meter would show an approach to recriticality for 20 minutes. The operator is assumed to scan the panel every 30 minutes for deviant meters. Therefore, there is a 33% chance that criticality could occur between meter readings. The probability that the operator will scan the panel while the meter is effective is 0.67.

When the operator scans the panel, the HEP for noticing the deviant meter is 0.15 (EF = 2). This is based on an initial audit of the panel and the meter is assumed to be an analog meter without an audio alarm or limit

FIGURE 3

FAULT TREE FOR BORON DILUTION AND CONTROL ROOM FIRE WITH SOURCE RANGE NEUTRON FLUX MONITOR



marks. The total HEP when considering the fact that the meter is only effective for a short period is HEP = 0.43, EF = 2.

In previous analyses, a moderately high stress was used which increases the HEPs. Such an assumption would double this HEP but was not used because of the large value of the HEP. The HEP used was based on an initial audit where the operator more closely monitors the panel. In later audits the performance might deteriorate. This effect was not considered. Both these assumptions tend to decrease the error rate associated with using the neutron flux monitor and therefore increases its advantage in risk reduction. Even with these optimistic assumptions, the total failure probability associated with use of the neutron flux monitor is 0.43, or almost half the time the meter will not be effective.

Given that the operator correctly reads the neutron monitor, he then gives an oral instruction for an auxiliary operator (A.O.) to terminate the dilution by closing valve CH-210X (Figure 1). The A.O. may fail to follow this explicit instruction or close the wrong valve. The total HEP for this is 0.006, EF = 5. If the operator fails, it is assumed he tries again but has a high dependency on his first attempt (HEP = 0.5). As in the previous analysis, no credit is given for other personnel assisting the operator who is at a moderate high stress level for a dynamic activity (MF = 5). The final HEP for correcting the valve alignment is 0.015, EF = 5.

IV. RESULTS AND CONCLUSIONS

The probability of a control room fire and concurrent extended boron dilution is calculated by evaluating the tree to obtain the cutsets and combining the basic failure probabilities of Section III. This was done using the SAMPLE code (Reference 14). A log normal distribution was assumed for modeling the basic failure probabilities. The frequency of an extended boron dilution event with a control room fire and boron sampling was found to have a median value of 1.3×10^{-7}/Reactor Year (RY) and an error factor* of 17. This value is very small compared to the NRC proposed safety goal (1×10^{-4}/RY).

* Error Factor times median value gives the 95% confidence value.

If a source range neutron flux monitor were to be used to detect a boron dilution (rather than using hourly boron sampling), the frequency of an extended boron dilution event with control room fire would be increased to 2.1×10^{-6}/RY, EF = 13. This increase over boron sampling is because the neutron flux monitor is only effective during the 15 to 30 minutes immediately preceding recriticality and has a high probability of not being interpreted properly. If operator stress and repetitive scanning effects were considered, the error rate could even be higher than the 0.43 value discussed in Section III-h.

Using both the low level neutron monitor at the remote shutdown panel and boron sampling reduces the frequency to a median value of 6.25×10^{-8}/RY, EF = 17. This reduces the risk of the transient by 6.7×10^{-8}/RY, a very small reduction.

V. REFERENCES

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