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Review of the Byron/Braidwood Units 1 and 2 Auxiliary Feedwater System Reliability Analysis

Prepared by R. Youngblood, I. A. Papazoglou

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ABSTRACT

This report presents the results of a review of the Auxiliary Feedwater System Reliability Analysis for Byron Units 1 and 2/Braidwood Units 1 and 2. The objective of this report is to estimate the probability that the Auxiliary Feedwater System will fail to perform its mission for each of three different initiators: (1) loss of main feedwater with offsite power available, (2) loss of offsite power, (3) loss of all 460 VAC power. The scope, methodology, and failure data are prescribed by NUREG-0611, Appendix III. The results are compared with those obtained in NUREG-0611 for other Westinghouse plants.

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SUMMARY AND CONCLUSIONS

After the accident at Three Mile Island, a study was performed of the reliability of the auxiliary Feedwater System (AFWS) of each then-operating Westinghouse plant. The results of this study were presented in NUREG-0611. Commonwealth Edison has provided NRC with a study of the Byron and Braidwood AFWS, performed using NUREG-0611 as a guideline. BNL has reviewed this study. The BNL conclusions are as follows ("High", "Medium", and "Low" refer to the NUREG-0611 reliability scale).

1. For an accident initiated by loss of main feedwater with offsite power available:
   The reliability of the Byron/Braidwood Auxiliary Feedwater System plus startup train is in the "High" range (Unavailability = 1.2×10^{-5}/demand).

2. For an accident initiated by loss of main feedwater coupled with loss of offsite power:
   The reliability of the Byron/Braidwood Auxiliary Feedwater System is at the high end of the "Medium" range, provided that the inter-unit bus tie is utilized (Unavailability = 2.6×10^{-4}/demand).

3. For an accident initiated by Loss of all AC power:
   The reliability of the Byron/Braidwood Auxiliary Feedwater System is in the "Medium" range (Unavailability = 2.2×10^{-2}/demand).

These results are summarized and compared with Commonwealth Edison's results on the following table. Refer to Table 4.3 of the B/B report and Appendices C and D of this report for explanation of the Commonwealth Edison results.

Byron/Braidwood AFWS

Unavailability per demand

	BNL	Commonwealth Edison
LMFW	1.2×10^{-5}	7.1×10^{-6}
LOOP	2.6×10^{-4}*	9.4×10^{-5}*
LOAC	2.2×10^{-2}	1.7×10^{-2}

* These numbers are calculated assuming an inter-unit bus tie. See Appendices C and D.

1. INTRODUCTION

The purpose of this study is to review and evaluate the "Byron Units 1 & 2 and Braidwood Units 1 & 2 Auxiliary Feedwater System Reliability Analysis"[2] (hereafter "the B/B report") and perform an independent simplified AFWS reliability analysis using methodology and data put forth in NUREG-0611[1]. The objective of the simplified reliability analysis is to assess the probability of failure of the AFWS on demand under different loss of main feedwater conditions, namely,

(a) Loss of Main Feedwater without Loss of Offsite Power (LMFW),
(b) Loss of Main Feedwater associated with Loss of Offsite Power (LOOP),
(c) Loss of Main Feedwater associated with Loss of Offsite and Onsite AC (LOAC).

After the accident at Three Mile Island, a study was performed of the Auxiliary Feedwater Systems (AFWS) of all then-operating plants. The results obtained for operating Westinghouse-designed plants were presented in NUREG-0611[1]. At that time, the objective was to compare AFWS designs; accordingly, generic failure probabilities were used in the analysis, rather than plant-specific data. Some of these generic data were presented in NUREG-0611. The probability that the AFWS would fail to perform its mission on demand was estimated for three initiating events: LMFW, LOOP, and LOAC. The results of this study are depicted in Figure 1.1.

Since then, each applicant for an operating license has been required[3] to submit a reliability analysis of the plant's AFWS, carried out in a manner similar to that employed in the NUREG-0611 study. Recently, a quantitative criterion for AFWS reliability has been defined by NRC[4] in the New Standard Review Plan (SRP).

> "...An acceptable AFWS should have an unreliability in the range of 10^{-4} to 10^{-5} per demand based on an analysis using methods and data presented in NUREG-0611 and NUREG-0635. Compensating factors such as other methods of accomplishing the safety functions of the AFWS or other reliable methods for cooling the reactor core during abnormal conditions may be considered to justify a larger unavailability of the AFWS."

One goal of this study is to compare the B/B AFWS to the plants studied in NUREG-0611. For this purpose, it is important to follow the NUREG-0611 methodology as closely as possible. Another goal is to evaluate the B/B AFWS with respect to the reliability goal set forth in the new SRP[4], namely, that the AFWS should have an unreliability in the range of 10^{-4} to 10^{-5} per demand.

The B/B AFWS design has two trains, but some additional redundancy is available in the startup feedwater system, if offsite power is available. For

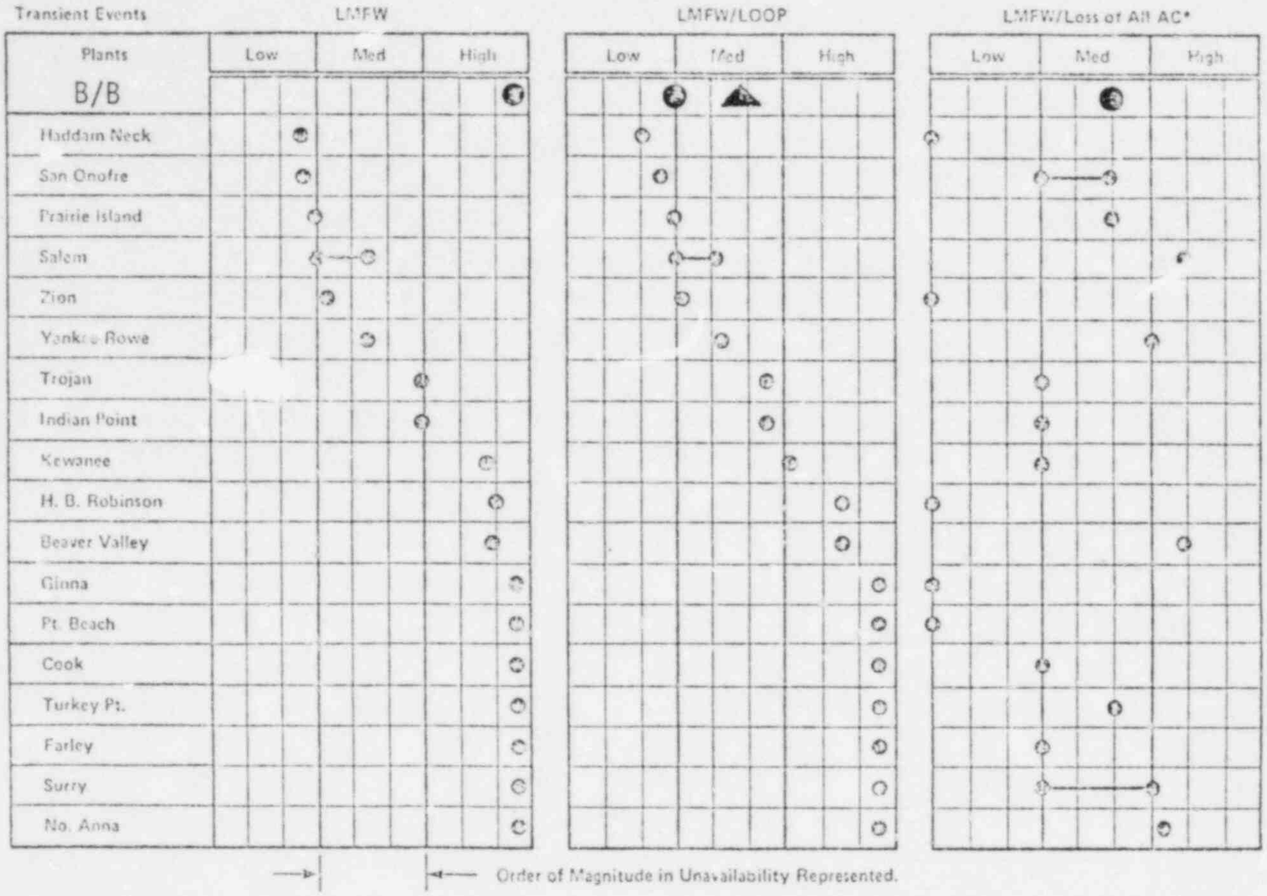
the LMFW initiator, then, the B/B AFWS design + startup train compares well with three-train designs. For LOAC, the AFWS is typical in having a single AC-independent train. For LOOP, however, the B/B AFWS is not as reliable as most three-train systems. The primary focus of this review is to elucidate this point.

In Section 2, the mission of the AFWS is described, and the B/B AFWS is presented. Salient features of the B/B design are noted and compared to NRC recommendations.

In Section 3, the reliability analysis is presented. The dominant contributors to unavailability are identified. The unavailability of the AFWS for each of the three initiators (LMFW, LOOP, LOAC) is given. The sensitivity of the results to certain assumptions is explained. Differences between BNL's analysis and the B/B report are noted.

In Section 4, BNL's conclusions are presented. The unavailabilities of B/B's AFWS are compared to those of other Westinghouse plants.

Appendix A discusses the frequency of LOOP. Appendix B summarizes the logical implications of giving credit for feed-and-bleed. Appendix C discusses the effect of adding an optional link between 4160VAC buses of Units 1 and 2.



*Note: The scale for this event is not the same as that for the LMFW and LMFW/LOOP.

Reliability Characterizations for AFWS Designs in Plants Using the Westinghouse NSSS.

Adapted From NUREG-0611

● Assessment based on original report

▲ Assessment based on proposed modification (Refer to Appendix C)

FIGURE 1.1

2. SYSTEM MISSION AND DESCRIPTION

2.1 System Mission

The mission of the AFWS is to provide feedwater to the steam generators in the event of LMFW. Core damage will result if decay heat is not removed in sufficient quantity, either by producing steam in the steam generators or by allowing hot primary coolant to escape via the pressurizer while replenishing it with high-pressure injection("feed-and-bleed"). LOOP and LOAC cause LMFW, and therefore also challenge the AFWS.

At B/B, AFWS mission success is defined as delivery of 160 gpm to each of three steam generators or 240 gpm to each of two steam generators before they boil dry (20 to 30 minutes). Ordinarily, the AFWS is required to operate for about 5 hours to cool the unit down to 350°F, below which temperature the low pressure residual heat removal system operates.

2.2 Description of the B/B AFWS

2.2.1 General Description

The B/B AFWS is sketched in Figure 2.1 of this report (Figure 3-1 of the B/B report). The AFWS consists of two trains, one electric-motor-driven (EMD) and one diesel-engine-driven. In addition, there is the startup train, which is part of the main feedwater system but is available to supply feedwater during some transients. The AFWS is initiated by either a low-low steam generator signal, a safety injection signal, or a loss of offsite power. The startup train requires operator initiation. The following paragraphs outline the most important attributes of the AFWS. The startup train is not analyzed here; its most relevant attributes are summarized in section 3.4.1.1.

2.2.2 Pumps

Both AFWS pumps are 1165 brake horsepower units. The diesel driven AFWS pump is capable of providing 840 gpm at 3350 feet head, which is nearly twice the capacity required for mission success. This pump is capable of supplying its own cooling and lubrication independently of AC, but when AC is available, backup pumps are provided for oil pressure, water jacket cooling, and room air cooling.

The EMD AFWS pump is capable of providing 890 gpm at 3350 feet of head, which is nearly twice the capacity required for mission success. It requires AC; therefore, its unavailability given LOOP is dominated by the unavailability of the associated emergency diesel generator.

2.2.3 Suction

The primary suction source is the condensate storage tank. Redundant flow paths begin at the CST and meet at a header which supplies both pumps (see

Figure 2.1). No single valve can block the flow. In the event of low suction pressure, there is automatic switchover to service water. There are startup suction filters which are further discussed in Section 3.8, on common cause failures.

2.2.4 Discharge Paths and Recirculation Flow

Flow from each pump goes to all four steam generators through independent paths (refer to Figure 2.1). Flow is controlled by manually controlled air operated normally open control valves which fail open on loss of air. Upstream of the header from which the four discharge paths emerge, there is a valve which is temporarily closed during testing. In the event of a system demand, this valve opens automatically. During the first phase of a pump test, closure of this valve directs flow to recirculation; at the conclusion of a test, the test valve opens, and flow is tested all the way into the steam generators. Thus, no portion of this system stays untested between challenges or shutdowns. There are flow restricting orifices in each path, so that depressurization of a steam generator does not result in excessive diversion of AFW to the faulted steam generator.

The normal recirculation path is back to the CST; if suction switches over to service water, recirculation also switches over.

2.2.5 Support Systems

The diesel driven pump is capable of supplying all of its own cooling and lubrication, so that it can operate completely independently of AC. When AC is available, there are external sources of cooling and lubrication which improve the reliability of the unit. The EMD pump requires essential service water for cooling. Here, this has been assumed to be available if emergency AC is available.

2.2.6 Testing and Maintenance Policy

Monthly, or after any maintenance act, a full flow test is conducted. During a test, a discharge valve is first closed to direct flow to recirculation (see Figure 2.1). An actual system demand during this period causes this valve to open to permit flow to the steam generators. At the conclusion of the first phase of the test, this valve is opened to permit testing of full flow to the steam generators. If this test is carried out, a significant class of failures is substantially reduced in probability. For example, the analog of leaving a discharge valve closed in another plant corresponds here to leaving a discharge valve closed and disabled and failing to carry out plant policy re testing. This testing policy significantly improves the reliability of the system.

2.3 Qualitative Assessment

The B/B report deals with the B/B AFWS plus the startup train. The at-

tributes of the startup train are quite different from those of the AFWS. The two-train AFWS has the following important strengths, which correspond to NRC recommendations made in NUREG-0611:

1. Automatic initiation of Trains A and B, even during test (recommendation GL-1);
2. Redundant flowpaths from the condensate storage tank (CST) to the pumps, so that no single valve can block the flow (recommedation GL-2);
3. The ability of Train B to function independently of AC (recommendation GL-3);
4. Automatic switchover from the CST source to the Essential Service Water, in the event that low pump suction pressure is sensed (recommendation GL-4);
5. Monthly staggered testing of the entire flowpath from the CST to the steam generators (recommendation GS-6):

On the other hand, the AFWS has only two trains, which for LOOP seriously degrades its reliability. For LMFW, the startup train can be made available, but the NRC recommendations with respect to automatic initiation, etc., are not met, since the startup train must be manually initiated.

If even modest credit is given for the startup train, the strengths of the AFWS are such that the reliability of the combination is high for LMFW initiator. Given LOOP, the redundancy is minimal (2 trains). Given LOAC, B/B is typical in that it has a single AC-independent train; but the train is of a relatively new type, and its reliability is correspondingly uncertain.

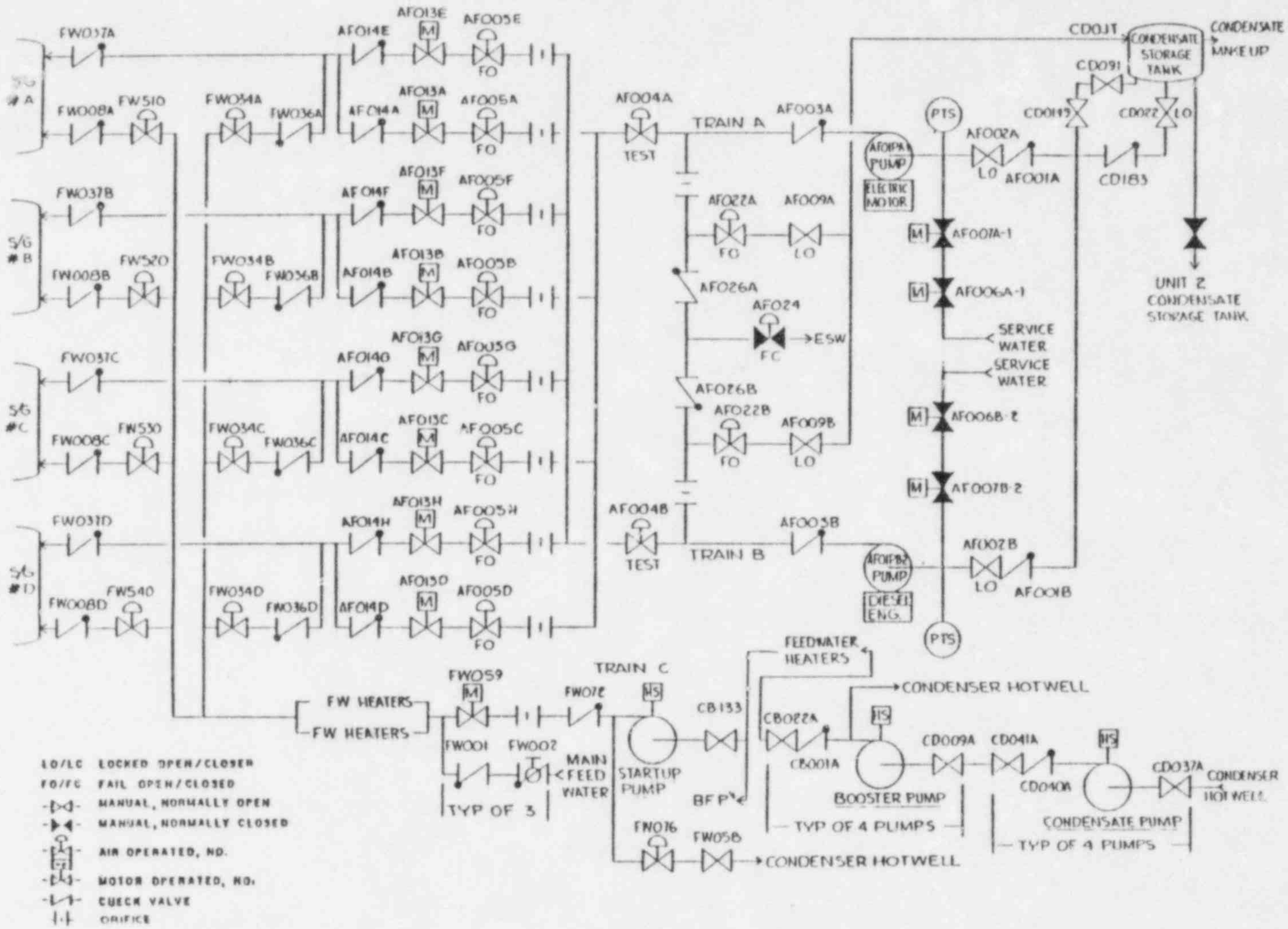


Figure 2.1 Simplified Diagram of AFWS for Byron/Braidwood Units

3. RELIABILITY ANALYSIS

3.1 Scope of the Reliability Analysis

The values given here are point estimates of the unavailability. The following points should be borne in mind concerning these results.

1. Uncertainty analysis has not been performed. As noted in NUREG-0611, such analysis typically indicates that the median unavailability is somewhat higher than the point estimate(*) (by a factor of two or less), which, for the purposes of NUREG-0611, did not matter.

2. Depending on the error factors assigned to individual failure rates, the error factor multiplying the median unavailability can easily be around three for analyses such as this.

3. A detailed modelling of common cause failures has not been attempted in this review but it is clear that the estimate would increase somewhat as a result of such a study. (A qualitative discussion of common cause failures is provide in Section 3.8.)

3.2 Approach of the B/B Report vs. Approach of BNL Review

The B/B report identified many contributors to the top event "Failure to remove heat from the SG's". It also provided considerable material on common cause failures. As originally written, the report's conclusions did not lend themselves to simple comparison with NUREG-0611 guidelines; revised conclusions were submitted in a letter(*). However, owing to misunderstanding concerning NRC guidelines, these were calculated using unrealistic assumptions. Finally, at a meeting in Bethesda, these misunderstandings were largely sorted out. A third set of numbers is warranted. These numbers are calculated by relying on the system description in the B/B report to identify dominant contributors, and quantifying them according to NRC guidelines.

After the review was essentially complete, the utility proposed a link between 4160 VAC buses of units 1 and 2 to improve the availability of AC to the EMD AFWS pump given LOOP. The effect of this is discussed in Appendices C and D, and included in Tables 3.1 and 3.4 (results calculated with and without crosstie option).

3.3 Assumptions

1. Maintenance on more than one AFWS train at a time is not permitted.
2. It is assumed here that the B/B assessment of 3×10^{-2} is a realistic estimate of the probability of the operator failing to supply feedwater from the startup train given LMFW.

(*) Point estimate: unavailability calculated using the medians of the input variables.

3. Although the B/B report states that an AFWS train can be down for 7 days, the maintenance unavailabilities assessed here are those tabulated in NUREG-0611 as mean maintenance act durations for trains which are allowed to be down for 72 hours.
4. In the case of the diesel-driven pump, the services are provided by the pump itself. In the case of the EMD pump, Essential Service Water is required for cooling. Here, we have assumed that the Essential Service Water availability is the same as that of emergency AC. This may be incorrect given a LOOP affecting both units; this is discussed in Appendix C. Failures associated with lubrication are assumed to be included in the EMD pump failure probability.

3.4 Dominant Failure Modes

Let V_{ij} = unavailability of the dischange path from pump i's test valve to steam generator j,

P_i = unavailability of all components upstream of the test valve of pump i (including the test valve itself).

(Refer to Figure 2.1). Then the event "failure to provide flow from one AFWS pump to at least two steam generators" may be written

$$P_AP_B + P_A(V_{BA}V_{BB}V_{BC} + V_{BB}V_{BC}V_{BD} + V_{BA}V_{BC}V_{BD} + V_{BA}V_{BB}V_{BD}) + P_B(V_{AA}V_{AB}V_{AC} + V_{AB}V_{AC}V_{AD} + V_{AA}V_{AC}V_{AD} + V_{AA}V_{AB}V_{AD}) + \text{higher order terms.}$$

Barring substantial common cause failures involving multiple-V events, it is easily seen that the dominant contributors are contained in P_AP_B.

Valve maintenance on a flow control valve (e.g., AF005E) would effectively incapacitate an entire train, because it would be necessary to isolate an entire discharge header from its pump. This would be a substantial contribution to maintenance unavailability. Here, it has been assumed that such maintenance acts either will not be performed with the reactor at power or can be combined with pump maintenance.

For present purposes, then, the dominant contributions to the

AFWS unavailability can be written

Unavailability = AH•BH•CH + AH•BM•CH• + AH•BH•CM

Where AH = Train A Hardware failures,
AM = Train A Maintenance,
BH = Train B Hardware failures,
BM = Train B Maintenance,
CH = Startup Train Hardware failures + Human Error,
CM = Startup Train Maintenance,

and each quantity must be re-evaluated for each initiator. This expression is so constructed that no two trains are simultaneously out for maintenance.

Figures 3.1-3.3 show simplified fault trees for each of the three initiators considered. These reflect the considerations leading up to the above formula.

Following are descriptions of the important contributors to the unavailability of each train.

3.4.1 Data

Ideally, all of the data would be prescribed by NUREG-0611, but there are important contributors whose values were not given in NUREG-0611. Two instances are diesel generator unavailability and diesel pump unavailability. Here, the WASH-1400 value for diesel generator failure to start, and NUREG-0611 prescribed data for diesel maintenance are employed. Diesel pumps were not contemplated in NUREG-0611; we have adopted the B/B report's value of 1 X 10^{-2} for the failure to start, and the NUREG-0611 prescription for maintenance unavailability. The B/B report's value is based on data obtained from Trojan, whose diesel-driven pump was initially much worse than this but appears to have been improved to this level.

3.4.2 Dominant Contributors to Unavailability Given LMFW

Train A: The dominant contributors are described below and given in Table 3.1. They are:

1. Maintenance and failure of the EMD pump, including control circuitry;

2. Failure of automatic initiation would be a large contributor except that failures of manual backup initiation within the available time has a fairly low probability.

Train B: The dominant contributors are described below and given in Table 3.2. They are:

1. Maintenance and failure of the diesel-driven pump, including control circuitry;

2. Failure of automatic initiation would be a large contributor except that failure of manual backup initiation within the available time has a fairly low probability.

Startup Train: The dominant contributors are given in Table 3.3. They are:

1. Probability of operator failing to initiate flow (several steps are necessary);

2. Probability that the cause of the initiating event (LMFW) will render the startup train unavailable;

3. Maintenance or failure of the startup train. (It is doubtful that maintenance would be performed on this train during operation, but it has been assessed.)

3.4.2.1 Startup Train Unavailability

The startup train is assessed in the B/B report to have an unavailability of 3.7×10^{-2} per demand for LMFW initiators and is unavailable when offsite power is unavailable.

The source of water for this train is the condenser hotwell; it is required that at least one of the four condensate/condensate booster pumps be functioning, and that the startup pump be functioning. This train also requires that several manual actions be taken before it can supply feedwater following a LMFW. The failure of these manual actions dominates the B/B report's 3.7×10^{-2} estimate (10^{-2} failure probability for each of three manual acts). Hardware failures were deemed much less important; indeed, if the human error contribution and the maintenance contribution are subtracted from this figure, the availability of the startup train following LMFW is comparable to that of the EMD train of the AFWS. This conclusion has to do with the fact that the startup train components are in general already running, and need not be started.

However, the B/B report assessed the unavailability of the startup train under normal conditions; the quantity of interest is the unavailability of this train given that a LMFW has just occurred. Some LMFW events cause violation of the requirements listed above; of the 80 LMFW events surveyed in NUREG-0611, 5 would render this train unavailable, or at least come very close to doing so. In one case, a low level in the hotwell caused cavitation of the condensate pumps; in three cases, suction strainers in several pumps were clogged by an upwelling of debris in the hotwell; and one case simply refers to "the loss of the condensate pumps." From the descriptions given in some of these cases, it is not completely clear that all flow paths are completely blocked; but it is clear that there are contributions to the unavailability of this train following LMFW that are comparable to the dominant human error probabilities assessed in the study, and which completely dwarf the hardware failures assessed therein. Pending further study of these events, let us assume that half of the above mentioned 5 events correspond to unavailability of the startup train; then we must add $\frac{2.5}{80} \sim 3 \times 10^{-2}$ to the unavailability previously calculated, giving 7×10^{-2} as the unavailability of the startup train following LMFW.

3.4.3 Dominant Contributors for LOOP

Train A. Train A depends on emergency AC, so its unavailability is essentially the unavailability of the diesel generator. This is the dominant

contributor given LOOP. Note that the crosstie option changes this conclusion (Appendix C).

Train B. The dominant contributor is still the diesel-driven pump; the unavailability given LOOP changes only because backup cooling and lubrication pumps are no longer available.

Startup Train. The startup train is unavailable.

3.4.4 Dominant Contributors for LOAC

Train A. Train A is unavailable.

Train B. The unavailability is still dominated by the diesel-driven pump unavailability.

Startup Train. The startup train is unavailable.

3.5 Summary of Results

3.5.1 Results

The AFWS unavailabilities are calculated in Table 3.4 and plotted in Figure 1.1.

For LMFW, the unavailability of the AFWS plus startup train is $1.2X10^{-5}$/demand, which is "High" reliability. For LOOP, the unavailability of the AFWS is $2.6x10^{-4}$/demand, assuming an inter unit crosstie and assuming that LOOP affects only one unit (see Appendix C). For LOOP, the reliability is "Medium". For LOAC, the unavailability is $2.1X10^{-2}$/demand, which is "Medium".

3.5.2 Comparison with a Typical Three-Train System

LMFW. The B/B AFWS and startup train reliability is relatively high for the LMFW transient. This is because credit is given for the startup train, and because the design accords with NRC guidelines which minimize the potential for single-point failures. Given the startup train, B/B essentially has a three-train system. The AFWS alone has a failure probability of $1.8X10^{-4}$ given LMFW.

LOOP: The reliability is reduced from the LMFW result by a factor of 60 for the LOOP initiator. This arises from a multiplicative combination of the following:

a. The startup train is unavailable, giving a factor of 14;

b. The unavailability of Train A goes up by a factor of 4.

Recently, the utility has proposed an inter unit connection (see Appendix C) to improve the availability of AC to the EMD pump. This significantly improves the reliability, placing the system at the high end of the "medium" range.

LOAC: The B/B AFWS is typical in having a single AC-independent train, whose unavailability is the AFWS unavailability.

3.5.3 Sensitivities

1. Failure rate of the diesel pump (Train B). It is argued in the report that while Trojan initially appeared to have a fairly unreliable diesel pump, many of its problems have now been solved. The failure probability used in the report is based on experience at this one plant after corrective action. The value thus obtained is not unreasonable, but it is clear that a value based on the edited experience of one plant is highly uncertain relative to most of the other parameters. One also wonders whether the newness of these devices will lead to relatively lengthy maintenance outages.

2. The conclusion is also somewhat sensitive to the value used for diesel generator unavailability. The values presented here are calculated using the WASH-1400 value for failure to start. In any case, the Train A unavailability given LOOP is dominated by this number.

3.6 Comments on Maintenance

The B/B AFWS partially depends on emergency AC power in the event of LOOP, but it does not take advantage of the redundancy of the emergency AC source. Like many plants, B/B has one AFWS train which is operable without emergency AC; but while many plants have two separate electric-motor-driven (EMD) pump trains, each connected to a single emergency AC bus, B/B has a single EMD pump connected to one of the emergency AC buses. Thus, in the event of a LOOP, there is a significant class of double failures which incapacitate the B/B AFWS, and which would not incapacitate a typical three-train design.

Some of these double failures involve maintenance. Note that in the event of LOOP, both AFWS trains are ultimately diesel-powered: Train A by a diesel generator, Train B by direct diesel drive. Diesel maintenance can be time-consuming, but the Limiting Conditions of Operation appear not to reflect the vulnerabilities of this particular AFWS. For example, if the Train A DG is out for maintenance, the Train B diesel generator must be demonstrated to be operable; but this is no help to the AFWS, which does not use the Train B DG. Under these circumstances, it would be logically consistent to require that Train B of the AFWS be demonstrated to be operable, and similarly, that the Train A DG be demonstrated operable whenever the Train B AFWS diesel is out for maintenance.

3.7 Differences Between BNL Assessment and Commonwealth Edison Assessment

At this point, there is no single document or collection of documents which describes B/B's position as BNL presently understands it. The original report, while useful in itself, was generally considered not to have followed NRC guidelines closely enough in its calculation. The report was followed by a letter (Ref. 5), in which revised estimates of unavailability were given without supporting details. Ultimately, there was clarification of a number of points concerning both the guidelines and the analysis. Thus, a third set of numbers is called for. This is provided in the present work.

Where the guidelines are clear, there is little scope for disagreement. Where the analysis goes beyond the NUREG-0611 guidelines, there are substantive questions. Following are areas in which BNL differs with the utility on points which were covered in the original report in a way which has not been obsoleted by subsequent events.

1. Assessment of the startup train. The B/B report analyzes this train as if hardware failures were negligible compared to human error. The analysis is conducted assuming that LMFW events have negligible impact on the hardware in this train. BNL considers that since this train is part of the main feedwater system, extreme caution is necessary in taking credit for its ability to mitigate failures of the main feedwater system. This is due to the fact that there is a relatively high likelihood that failures that cause Loss of Main Feedwater will also cause failure of the startup train. Given this interdependence of the accident initiator (LMFW) and the mitigating system, BNL assesses the hardware unavailability given LMFW at a much higher value than does the report. (See Section 3.2).

2. Frequency of loss of offsite power. This was nominally beyond the scope of the review, but some discussion of it is warranted because this initiator frequency varies significantly from one plant to another. Commonwealth Edison has suggested a figure of 0.017/yr for Loop frequency, without providing full details. This seems overly optimistic; on the other hand, there are grounds for expecting B/B's LOOP frequency to be lower than average. This is discussed in Appendix A.

3.8 Common Cause

The B/B report mentions several possibilities for common cause failures: the steam generators themselves, the automatic start logic, and failure to isolate the blowdown lines, to mention a few. These are beyond the scope of NUREG-0611. Additionally, the B/B report treats hypothetical potential commonalities parametrically, using the "beta-factor" method. This, too, is beyond the scope of NUREG-0611.

One potential area of commonality is that of the valves regulating flow to the steam generators. There are four paths from each pump, so losing flow from one pump to two SG's due to control valve failures requires three valve

failures. These are normally open, and fail open, so that prevention of feedwater flow by this mechanism is a relatively insignificant contributor.

The three trains have significantly different character; one of the two AFWS trains is powered by emergency-backed AC, and the other is direct-diesel-driven, while the startup train depends upon offsite power. Given a loss of offsite power, the EMD AFWS pump depends on a diesel generator while the redundant train depends on direct diesel drive. This raises the question of possible coupling (e.g. coupled maintenance errors) between the two diesels.

For LMFW, it could be argued that the system is highly diverse, and therefore relatively immune to common-cause failures. However, there is one methodological point to be raised which is conceptually related to "common cause" failures: the startup train failure probability must be properly conditioned on the event that a LMFW has occurred. It is inappropriate to calculate the startup train's <u>average</u> undependability, as is done in the B/B report. This is explained in the section on Startup Train Unavailability (Section 3.4.2.1).

At some plants, suction is a major potential source of failure of all AFWS trains. At B/B there is some redundancy in the flowpath from the CST to the pumps; and additionally, there is automatic switchover to a backup source in the event of low suction pressure. For LMFW, when the startup train is potentially available, the suction source is the hotwell, which is independent.

Suction strainers do not show up on the simplified system diagram supplied with the B/B report, but it is stated on page F-2 that the AFWS pumps have startup suction filters. These have been a source of common cause failures at other plants. Part of the problem has been failure to remove them on schedule. Since they do not belong in the system after startup, there is an argument against including them in a comparative study of different AFWS designs. On the other hand, the record shows that a realistic assessment of AFWS failure probability cannot ignore suction strainers. AFWS failure from this cause is roughly a 10^{-4} event. This has not been included in the results presented here. The startup train is "diverse" in this sense (it is unlikely to be affected by plugging of AFWS strainers); on the other hand, automatic switchover of suction does not recover the AFWS, so the startup train is the only hope, and it is available only if offsite power is available.

Figure 3.1 Simplified Fault Tree: Loss of Main Feedwater

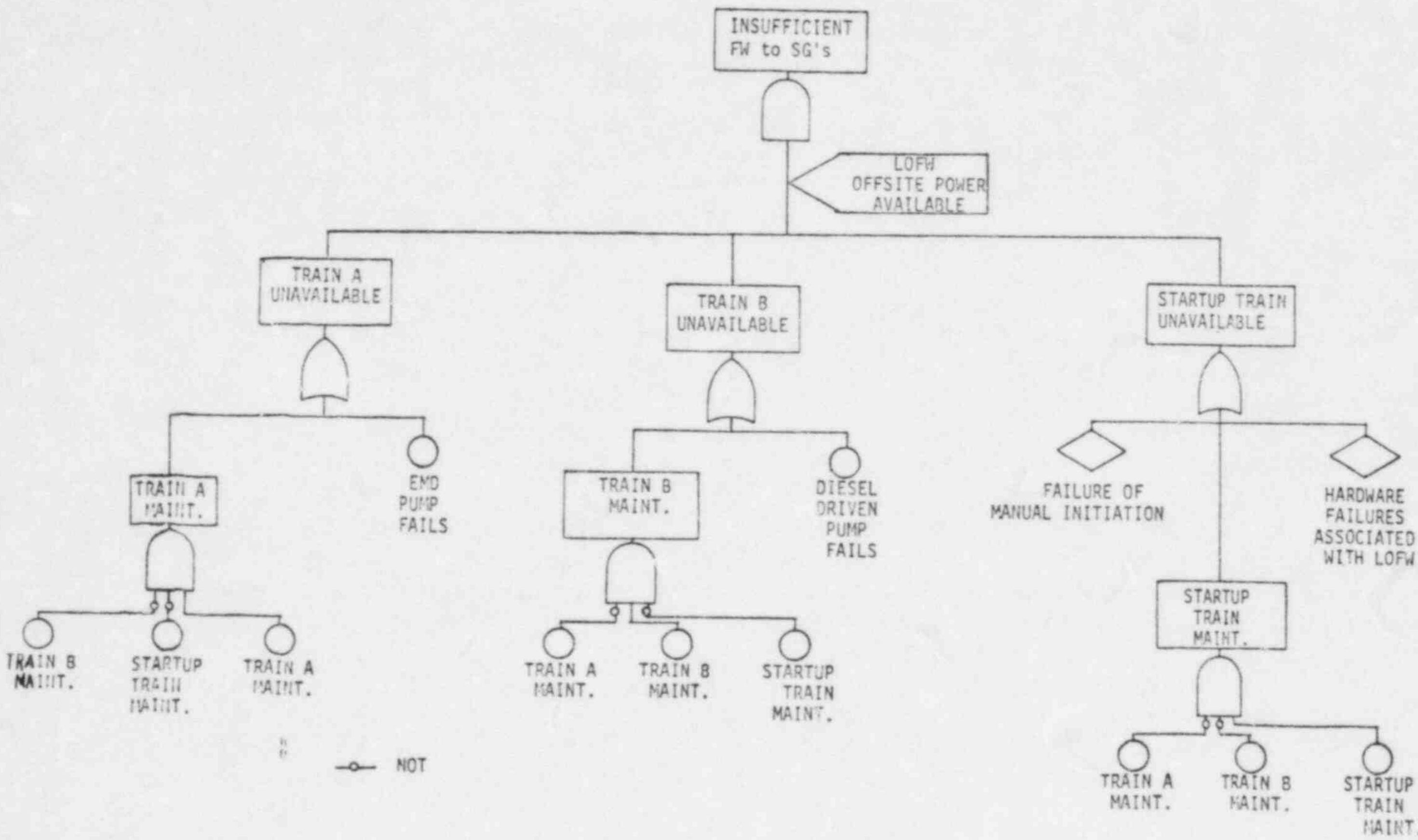


Figure 3.2: Simplified Fault Tree: Loss of Offsite Power

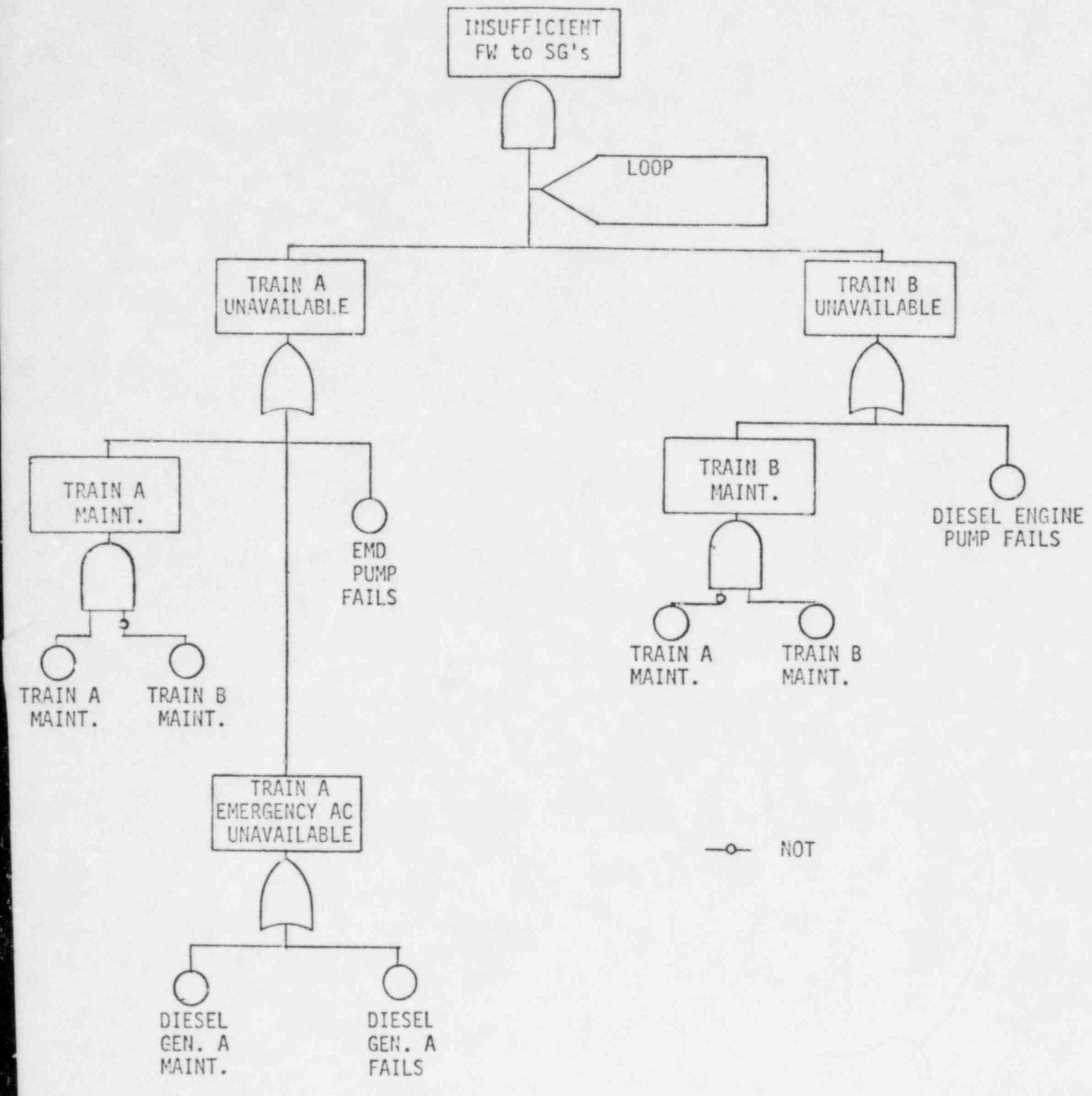


Figure 3.3: Simplified Fault Tree: Loss of All AC

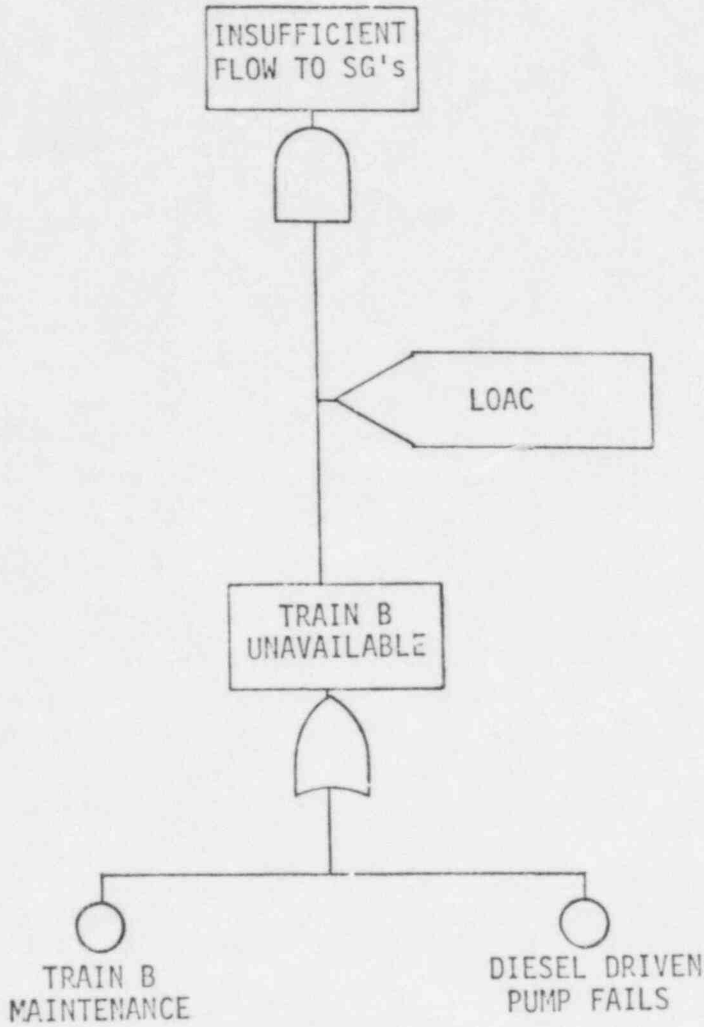


Table 3.1

Dominant Contributors to Train A Unavailability

Contributors for LMFW

Value (source is NUREG-0611, unless otherwise noted)	Comments
5×10^{-3}	Pump failure to start: 1×10^{-3} pump, 4×10^{-3} control circuit, monthly testing.
3×10^{-4}	Plugging of any of 2 suction valves & 1 discharge valve (10^{-4} each)
7×10^{-5}	Failure of actuation logic (7×10^{-3}) and failure of operator backup within 20 minutes (10^{-2})
$\sum = 5.37 \times 10^{-3}$ = AH (LMFW)	
5.8×10^{-3}	Pump maintenance 19 hr. x 0.22/720
2.1×10^{-3}	Valve maintenance 7 hr. x 0.22/720 (Discharge valve)
$\sum = 7.9 \times 10^{-3}$ = AM (LMFW)	
	ADDITIONAL CONTRIBUTORS FOR LOOP WITHOUT CROSSTIE OPTION
3.6×10^{-2}	Failure of Diesel Generator to start or Diesel Generator maintenance (WASH-1400)
$\sum = 4.14 \times 10^{-2}$ = AH (LOOP)	
7.9×10^{-3} = AM (LOOP)	

ADDITIONAL CONTRIBUTORS FOR LOAC
THIS TRAIN IS UNAVAILABLE GIVEN LOAC
AH (LOAC) = 1.
AM (LOAC) = 0.

Table 3.1 (Cont.)

Value	Comments
	ADDITIONAL CONTRIBUTOR GIVEN LOOP AND CROSSTIE OPTION
1.72×10^{-3}	$3.6 \times 10^{-2} \times (1 \times 10^{-2} + 2 \times 10^{-3} + 3.6 \times 10^{-2})$ Probability of Diesel Generator failure and (operator failure or breaker failure or failure of other unit's diesel)

$\sum = 7.1 \times 10^{-3}$ = AH (LOOP W/CROSSTIE)

7.9×10^{-3} = AM (LOOP W/CROSSTIE)

Table 3.2

DOMINANT CONTRIBUTORS TO TRAIN B UNAVAILABILITY

CONTRIBUTORS FOR LMFW

Value	Comments
(source is NUREG-0611, unless otherwise noted)	
1×10^{-2}	Failure probability assessed in B/B report for Diesel-driven pump, reduced from 3×10^{-2} failure probability observed at Trojan. This value (1×10^{-2}) was achieved <u>after</u> a period of "burn-in".
3×10^{-4}	Plugging of any of 2 suction valves or 1 discharge valve (10^{-4} each)
7×10^{-5}	Failure of actuation logic (7×10^{-3}) and failure of operator backup within 20 minutes (10^{-2})

$\sum = 1.04 \times 10^{-2}$ = BH (LMFW)

6.4×10^{-3}	Diesel maintenance 21 hr. x 0.22/720
2.1×10^{-3}	Discharge valve maintenance 7 hr. x 0.22/720

$\sum = 8.5 \times 10^{-3}$ = BM (LMFW)

ADDITIONAL CONTRIBUTORS FOR LOOP

3×10^{3}	Additional contribution to unreliability of diesel-driven pump due to loss of AC - powered services (B/B report)

$\sum = 1.34 \times 10^{-2}$ = BH (LOOP)

8.5×10^{-3} = BM (LOOP)

Table 3.2 (Cont.)

Value	Comments
	ADDITIONAL CONTRIBUTORS FOR LOAC
	NONE
BH (LOAC) = 1.34×10^{-2}	
BM (LOAC) = 8.5×10^{-3}	

Table 3.3

DOMINANT CONTRIBUTORS TO STARTUP TRAIN UNAVAILABILITY

CONTRIBUTORS FOR LMFW

Value	Comments
3×10^{-2}	Human failure to initiate (B/B report)
2×10^{-3}	B/B assessment of random hardware failures
3×10^{-2}	Additional contribution ot hardware failure probability <u>given that a LMFW has occurred</u> (see text)
$\sum = 6.2 \times 10^{-2}$ = CH (LMFW)	
5.8×10^{-3}	Pump maintenance, assessed in B/B report as a "conservatism," it being doubtful that this train can be maintained during operation.
$\sum = 5.8 \times 10^{-3}$ = CM (LMFW)	

THIS TRAIN IS UNAVAILABLE GIVEN LOOP OR LOAC
CH (LOOP) = 1 = CH (LOAC)
CM (LOOP) = 0 = CM (LOAC)

Table 3.4

AFWS UNAVAILABILITIES

AH = Hardware & Human Error contributors to Train A unavailability.
BH = Hardware & Human Error contributors to Train B unavailability.
CH = Hardware & Human Error contributors to Startup Train unavailability.
AM = Maintenance contributions to Train A unavailability.
BM = Maintenance contributions to Train B unavailability.
CM = Maintenance contributions to Startup Train unavailability.

	AH	AM	BH	BM	CH	CM
LMFW	$5.4x10^{-3}$	$7.9x10^{-3}$	$1.04x10^{-2}$	$8.5x10^{-3}$	$6.2x10^{-2}$	$5.8x10^{-3}$
LOOP, NO CROSSTIE	$4.14x10^{-2}$	$7.9x10^{-3}$	$1.34x10^{-2}$	$8.5x10^{-3}$	1	0
LOOP, CROSSTIE	$7.1x10^{-3}$	$7.9x10^{-3}$	$1.34x10^{-2}$	$8.5x10^{-3}$	1	0
LOAC	1	0	$1.34x10^{-2}$	$8.5x10^{-3}$	1	0

Unavailability = AH·BH·CH + AM·BH·CH + AH·BM·CH + AH·BH·CM

LMFW	$1.2x10^{-5}$
LOOP, NO CROSSTIE	$1x10^{-3}$
LOOP(one unit) with CROSSTIE	$2.6x10^{-4}$
LOAC	$2.2x10^{-2}$

4. CONCLUSIONS

The conclusions are plotted in Fig. 1.1, and tabulated together with Commonwealth Edison's results in the "Summary" at the beginning of this report. Below is a brief discussion of the result obtained for each initiator.

LMFW: Given offsite power, three trains are potentially available to mitigate a loss of main feedwater: the two trains of the AFWS plus the startup train. There are substantial disadvantages associated with the startup train, namely that several operator actions are necessary to initiate it, and it is not truly independent of the main feedwater system. However, it is independent of the AFWS, and therefore enhances the reliability of the combined system. The B/B AFWS plus startup train therefore has "High" reliability (unavailability 1.2×10^{-5}/D), which is typical of many three-train systems.

LOOP: As originally designed, B/B is assessed at the boundary between "Low" and "Medium" reliability (see Fig. 1.1); the redundancy is only that of two trains, because the startup train is not available given LOOP, and the electric-motor-driven pump requires emergency AC. The utility proposes to back up emergency AC with an inter-unit bus tie. This has the effect of substantially reducing the unavailability of emergency AC, so that the system unavailability is essentially that of a two-train system with AC available. The reliability is at the high end of the "Medium" range (2.6×10^{-4}).

There is some argument for expecting a lower than average frequency of loss of offsite power at B/B. This is discussed in Appendix A. Formally, this does not enter the probability per demand of AFWS failure given LOOP, but LOOP frequency does enter any discussion of expected number of failures.

LOAC: Only the diesel-driven pump train is potentially available to mitigate a loss of all AC. No dependencies which would render this train unavailable given LOAC were identified. Its hardware and maintenance unavailabilities place it in the "Medium" range of system reliability for this initiator (2.2×10^{-2}/D), which is typical of single-train systems.

REFERENCES

1. Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Westinghouse-Designed Operating Plants, NUREG-0611 (January 1980).

2. "Byron Units 1 & 2, Braidwood Units 1 & 2 Auxiliary Feedwater System Reliability Analysis", GA-C16444, W. Hannaman, D. Ligon, T. Taniguchi, L. Bowen, and T. Weis, (August 1981).

3. Letter from D. F. Ross, Jr. to "All Pending Operating License Applicants of Nuclear Steam Supply Systems designed by Westinghouse and Combustion Engineering", dated March 10, 1980.

4. USNRC Standard Review Plan, Auxiliary Feedwater System, NUREG-0800, Revised July 1981.

5. Letter from T. R. Tramm to H. R. Denton, October 27, 1981.

6. Letter from T. R. Tramm (Commonwealth Edison) to H. R. Denton (NRC) on "Byron Units 1 and 2 Braidwood Units 1 and 2 Auxiliary Feedwater System Reliability", dated December 15, 1981.

7. "A Critique of the Offshore Power Systems Risk Study for the Zion Nuclear Plant," A. J. Buslik and R. A. Bari, BNL Report #28750, (December 1980).

8. Loss of Offsite Power Survey Status Report, prepared by Raymond F. Scholl, Jr. (USNRC).

APPENDIX A

LOOP FREQUENCY

Although the demand unavailability is of primary interest here, the frequency of LOOP affects the conclusions which are to be drawn. The B/B study presents information concerning LOOP; we offer the following additional information.

A survey of nuclear experience with LOOP has been conducted[7]. From this survey, the following emerged:

1. The average LOOP rate is 0.27/reactor yr.

2. The mean time to partial recovery from LOOP is 2 hours; the probability that a given LOOP will last longer than 20 minutes is 1/2 or more (the study is ambiguous).

3. Most LOOP events are caused by such things as circuit break trip during relay testing, improper yard switching operations, improperly set relays, maintenance errors, etc., rather than fortuitous independent multiple outages.

4. Some plants have many more outages than others.

The B/B study states that apart from transformer failures (0.064 per year) LOOP events are double line outages, which are "expected to be 0.017 per year with an average outage duration of approximately seven hours" (page A-6). Thus, the B/B study is claiming a much lower LOOP rate than the average.

The figure of 0.017 is not derived in the report, and we cannot therefore comment on the derivation. A proper calculation of multiple line outages should take due account of the simultaneity of climatic assaults on all the lines (e.g., a tornado or lightning storm in the area threatens all the lines at once); a realistic appraisal of LOOP frequency (which is a more general event) should try to take into account the circuit breaker/yard switching/relay setting events mentioned above. (An event which was apparently of this general type resulted in a loss of standby power at Zion 1 in 1979). It is not clear whether any of this has been considered; the study simply attributes the predicted reliability of B/B's power supply to the generally high reliability of the midwestern grid, even though nearby Palisades, Point Beach, Kewaunee and LaCrosse apparently have somewhat higher than average LOOP rates.

Although we are unable to check the B/B claim of 0.017/yr., it may be inappropriate to assume the NUREG-0611 figure of 0.2/yr., if one wishes to be realistic. There is some empirical basis for giving Commonwealth Edison credit for a better LOOP frequency. Noting that Zion had never had a LOOP in its seven years of operation, Buslik and Bari remarked[8] for Zion that "at a 50% confidence level, one can say that the probability of loss of offsite

power event ... is ... 0.1/reactor/yr." Apart from a tornado at Dresden, we know of no other LOOP events at Commonwealth Edison sites (Dresden, Zion, Quad Cities). Thus, this utility can claim some success in this area, and an estimate in the range of 0.1 is not unreasonable.

In summary: on the basis of what we have been given, the B/B estimate of 0.017/yr. is optimistic. On the other hand, there is evidence that B/B can anticipate a lower than average LOOP frequency. BNL considers 0.1 to be a reasonable guess.

APPENDIX B

Comments on "Feed-and-Bleed"

According to the SRP, the AFWS unavailability is to be considered in light of the possibility of other methods of core cooling. One such possibility is "feed-and-bleed," in which primary coolant is permitted to escape through a pressurizer relief valve ("bleed"), and is replenished by the high pressure injection system ("feed"). The present discussion is intended to show how credit for feed-and-bleed can qualitatively alter the conclusion that would be drawn from a survey of the AFWS unavailability alone. It is not intended as a comment on the feasibility of feed-and-bleed in general.

It has been emphasized in this review that the two-train B/B AFWS does not take advantage of the redundancy of emergency AC power. Thus, after a LOOP, the reliability of the B/B AFWS is relatively low, being dominate by double failures, some of which involve the unavailability of emergency AC Train A. The fault tree shown in Fig. B-1 shows how to feed-and-bleed changes the picture. For purposes of this discussion, we have separated out the double event "failure of all emergency AC given LOOP (which fails "feed") from other events which fail high pressure injection. It is seen that given LOOP, the dominant cut set is failure of Diesel Generators A and B and Train B of the AFWS. This triple event is characteristic of the dominant contributors to unavailability of a typical three-train AFWS, in which failure of both DG's fails the two EMD trains, and the third event is the failure of the AC-independent train.

Thus, by using DGB for feed-and-bleed, B/B could argue that their dominant cut sets for core damage given LOOP are the same as those at plants having three-train AFWS's. Such a conclusion is, of course, based on the assumption that failure of emergency AC is the dominant failure mode of feed-and-bleed. Scrutiny of this assumption is beyond the scope of this review.

Figure b-1a: Simplified Fault Tree Core Damage Following Extended Loss of Offsite Power

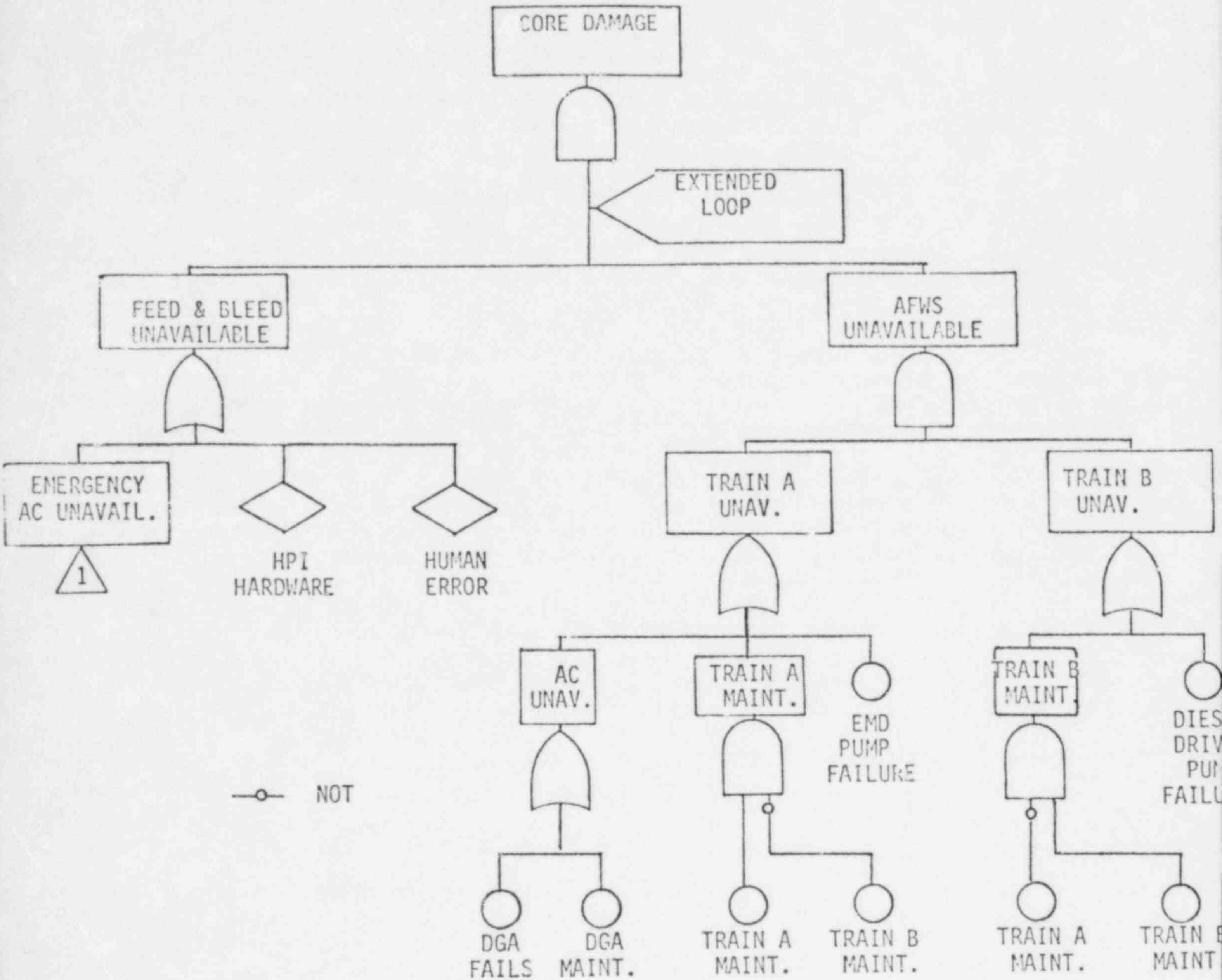
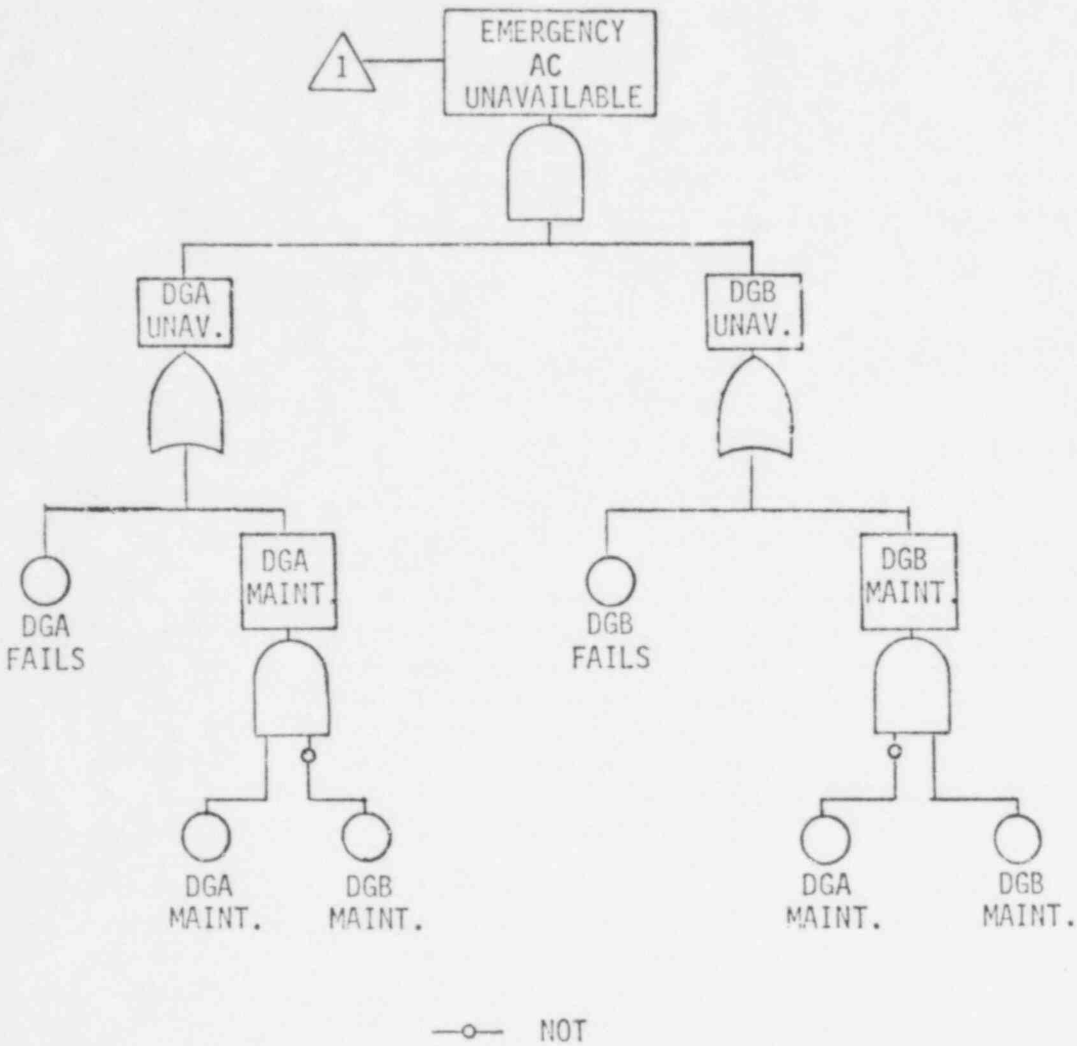


Figure B-1b: Simplified Fault Tree Core Damage Following Extended Loss of Offsite Power (Cont.)



APPENDIX C

INTER-UNIT BUS TIE

A major factor in AFWS unavailability given LOOP is the unavailability of emergency AC power on Train A. Because of this, in a very recent memorandum (attached as Appendix D), the utility has suggested that given a LOOP at Unit 1, say, there should be the option of connecting the 4160 V Bus 141 (Unit 1) to the comparable bus in Unit 2 (the Station Auxiliary Transformer on Unit 2 is sized to handle both buses, and in the event of LOOP on Unit 2 as well, it is possible to shed some loads from both buses in order to carry Unit 1's AFW pump on Unit 2's diesel generator).

This raises questions about possible new problems, which are beyond the scope of the present analysis.

Given the feasibility of such an interconnection, the improvement in AFWS reliability is substantial. The unavailability of emergency AC at Train A was formerly "unavailability of diesel generator A" (3.6×10^{-2}); given the bus tie, the unavailability of emergency AC is "unavailability of diesel generator A and unavailability of emergency AC from Unit 2." If we assume no LOOP at Unit 2, the unavailability of AC from Unit 2 is essentially due to human error (10^{-2}) and circuit breakers (2×10^{-3}). If we assume a LOOP on Unit 2, the unavailability of Unit 2's diesel now contributes as well, so that the total contribution is $3.6 \times 10^{-2} \times (1 \times 10^{-2} + 2 \times 10^{-3} + 3.6 \times 10^{-2})$ $= 1.7 \times 10^{-3}$ (see Table 3.1).

This assumes that service water is not among the loads shed to permit Unit 2's DG to carry both buses. If service water is not available to the EMD pump, then the benefit of the crosstie is not clear for the case in which LOOP affects both units.

For a LOOP affecting only one unit, the variable AH is now 7.1×10^{-3}, and one calculates a system unavailability of 2.6×10^{-4}.

In performing this calculation, the utility obtains 9×10^{-5}, which is a factor of 3 lower than the result given above. This discrepancy arises chiefly because the Train B diesel-driven pump unavailability is taken by the utility in the new calculation to be 5×10^{-3} rather than 1×10^{-2} as used in Table 3.4. Originally, the utility assessed the pump at 10^{-2}; now, the utility argues that 5×10^{-3} corresponds more nearly to the NRC mandate (knowing nothing about the pump, one could infer 5×10^{-3} from a table given in NUREG-0611, which does not explicitly cover pumps of this type). A more natural adaptation of the NRC prescribed data base would be to use diesel generator data, which would lie closer to the 10^{-2} figure.

APPENDIX D

Letter from T. T. Tramm (Commonwealth Edison) to H. R. Denton (NRC) with memorandum.

Commonwealth Edison
One First National Plaza, Chicago, Illinois
Address Reply to: Post Office Box 767
Chicago, Illinois 60690

December 15, 1981

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Byron Station Units 1 and 2
Braidwood Station Units 1 and 2
Auxiliary Feedwater System
Reliability
NRC Docket Nos. 50-454/455/456/457

References (a): September 18, 1981, letter from T. R. Tramm to H. R. Denton.

(b): October 27, 1981, letter from T. R. Tramm to H. R. Denton.

(c): October 30, 1981, letter from D. G. Eisenhut to L. O. DelGeorge.

(d): November 10, 1981, letter from T. R. Tramm to H. R. Denton.

Dear Mr. Denton:

This is to provide additional information regarding the reliability of the Byron/Braidwood Auxiliary Feedwater System (AFWS).

References (a), (b) and (d) provided the results of analyses of AFWS reliability for Byron and Braidwood. During the review of these analyses with the NRC staff, certain recalculations were requested. The recalculations have been completed and are summarized in the enclosure to this letter. The reanalysis conforms to SRP 10.4.9 by taking credit for a second auxiliary power supply to the feedwater pump. An unavailability of 9.4×10^{-5} per demand has been demonstrated.

Upon receipt of staff concurrence with this approach, the response to FSAR Question 10.53 will be revised to include the results of this reanalysis.

Please address questions regarding this matter to this office.

One (1) signed original and fifty-nine (59) copies of this letter and the enclosure are provided for your review and approval.

Very truly yours,

T. R. Tramm

T. R. Tramm
Nuclear Licensing Administrator

Enclosure: "Byron/Braidwood Stations, Auxiliary Feedwater System Reliability Analysis, Second Recalculation," December 14, 1981.

cc: I. Papazoglou, Brookhaven Nt'l Lab

TRT/lm

3053N

December 14, 1981

Subject: Byron/Braidwood Stations
Auxiliary Feedwater System Reliability Analysis
Second Recalculation

Summary of Results

Unavailability per Demand

Initiating Event	Report (1)	First Recalculation (2)	Second Recalculation
LOOP	6.4×10^{-4}	8.9×10^{-5}	9.4×10^{-5}

Assumptions

1. LMFW coincident with LOOP (3)
2. LOOP considered on the unit under study only
3. Credit taken for manual breaker closure to BUS 141 from Bus 241
4. Other assumptions per NUREG-0611

Discussion

ESF Bus 141, the bus that supplies the 1A motor driven auxiliary feedwater pump, is capable of being supplied from one of three sources: The system aux transformer (SAT 142-1); the diesel generator (DG 1A); or the Unit 2 ESF Bus 241. (See Figure 1).

In the event of a LOOP event, Bus 141 automatically transfers to DG 1A. If DG 1A fails to start, the operator is able to close two breakers from the control room to feed Bus 141 from Bus 241, which still has power from the system aux transformer associated with that bus or from diesel generator 2A. The operator is capable of closing these breakers within the 20 minute steam generator boil dry time assumed in this analysis.

The capability of supplying the Unit 1 ESF busses from the Unit 2 ESF busses is not a new feature and has existed in the B/B design since its beginning. In fact these crossties are the alternate source of offsite power to the ESF busses required by our Technical Specifications. The NRC Staff has reviewed this system and has found it to be acceptable.

The crosstie between Bus 141 and Bus 241 is capable of feeding all the safety loads of Bus 141. The SAT on Unit 2 is more than adequately sized to handle the safety loads of both Bus 141 and Bus 241, hence the use of the crosstie does not compromise the safety of Unit 2.

The assumption of loss of offsite power to only one unit is supported by the results presented in Table 1. The total frequency of loss of offsite power to a single unit is 0.605 events/year. The major contribution to the frequency is failure of the SAT's, which is 0.3 per transformer with a total of 0.6 for the two transformers supplying a single unit. The second contributor to the LOOP per unit is a fault associated with the line supplying the ring bus section that feeds the SAT's of a unit. This contribution is 0.005 events/year.

As can be seen from Table 1, the events that cause loss of offsite power to both units is 3.6×10^{-4}, the major contributor being tornado damage (Attachment A). This is a small number compared to the overall estimated frequency of LOOP to the unit, and hence, we have concluded that the LOOP initiating event is applicable to only one unit.

However, under the condition of LOOP to both units, Bus 141 my still be fed from Bus 241 when Bus 241 is being supplied from diesel/generator 2A. There are no breaker interlocks to prevent this operation.

The crosstie operation will be conducted under a specific set of circumstances and controlled by a well defined emergency operating procedure. The procedure will cover the following conditions:

(1) LOOP has occurred on Unit 1 and there is no auxiliary feedwater being supplied to the Unit 1 steam generators because the 1A diesel/generator fails to start and the 1B Auxiliary Feedwater pump fails to start.

(2) a) LOOP has not occurred on Unit 2. The crosstie breakers may be closed to Bus 141 to pick up AFW pump 1A.

or

b) LOOP has occurred on Unit 2. Unit 2 AFWS is operating normally and only normal shutdown loads are present. Both of the Unit 2 emergency diesels have started and are carrying their respective ESF busses. The crosstie breakers may be closed to pick up Bus 141 and the 1A AFW pump. Nonessential loads on Bus 241 may be stripped in order to accomodate the 1A AFW pump load. Diesel generator 2A operation must be monitored closely to ensure that the generator is not overloaded.

The above operations can be completed within 20 minutes of the initiating event, which is the steam generator boil dry time assumed in this analysis.

We wish to emphasize that LOOP to both units is not an event that we consider to be credible. Nevertheless the capability exists to ensure sufficient auxiliary feedwater flow to the faulted unit.

The number associated with remote manual closure of the two breakers required to supply Bus 141 from Bus 241 is 1.2×10^{-2} per demand. There are two components to this unavailability number: 1×10^{-2} per manual action (this is considered to be one manual action) and 1×10^{-3} unavailability per demand for each of the two breakers. The unavailability per demand of diesel generator 1A was chosen to be 3×10^{-2}. [3]

Conclusion[4]

Credit for use of two auxiliary power supplies to Bus 141 leaves us with an AFWS unavailability per demand of 9.4×10^{-5}, which meets the requirements of SRP 10.4.9.

LAB:mnh
0984b*

Notes

(1) Table 4.3, under "Automatic Startup with Manual Backup" p 4-14, Byron Units 1 and 2, Braidwood Units 1 and 2, Auxiliary Feedwater System Reliability Analysis, Final Report, dated August, 1981.

(2) October 27, 1981 letter from T.R. Tramm to H.R. Denton.

(3) NUREG-0611 assumed a diesel generator unreliability number of $1X10^{-2}$. We have not recalculated our system unavailability using the lower diesel generator unreliability, however it stands to reason that the system unavailability would yet be lower than the $9.4X10^{-5}$ presented in the results section.

(4) Other approaches to solving our dilemma of adequate AFWS reliability without a second motor driven pump supplied from the other ESF bus were considered. They are discussed in Attachment 2.

LAB:mph
0984b*

PRELIMINARY

Table 1

SYSTEM PLANNING
DEPARTMENT

November 23, 1981

Byron Station
Loss of System Aux. Power Supply

	Frequency (Events/Year)	Approx. Duration (Hours)
Grid Collapse or Islanding	$< 10^{-8}$	
345 kV Switchyard destroyed by tornado	3.6×10^{-4}	
4-345 kV lines outaged due to independent and/or common mode outages	2.5×10^{-7} (1)	
Subtotal - events isolating the entire station from the interconnected system	3.6×10^{-4}	
Cherry Valley line outage causes LBB isolating SAT (Figure 2)	0.005	1
Subtotal - 345 kV supply to SAT	0.0054	
SAT outage (2)	0.6	110
Subtotal - events outaging one SAT	0.605	
Total - all events outaging SAT	0.605	

(1) Frequency increases during line maintenance outages which average less than 1 day per line per year.

(2) Duration of outage on the faulted transformer. The other transformer can generally be retained to service by switching within 1 hour. Frequency is twice that for single full-sized transformer.
Outage frequency based on Commonwealth Edison data, which is available upon request.

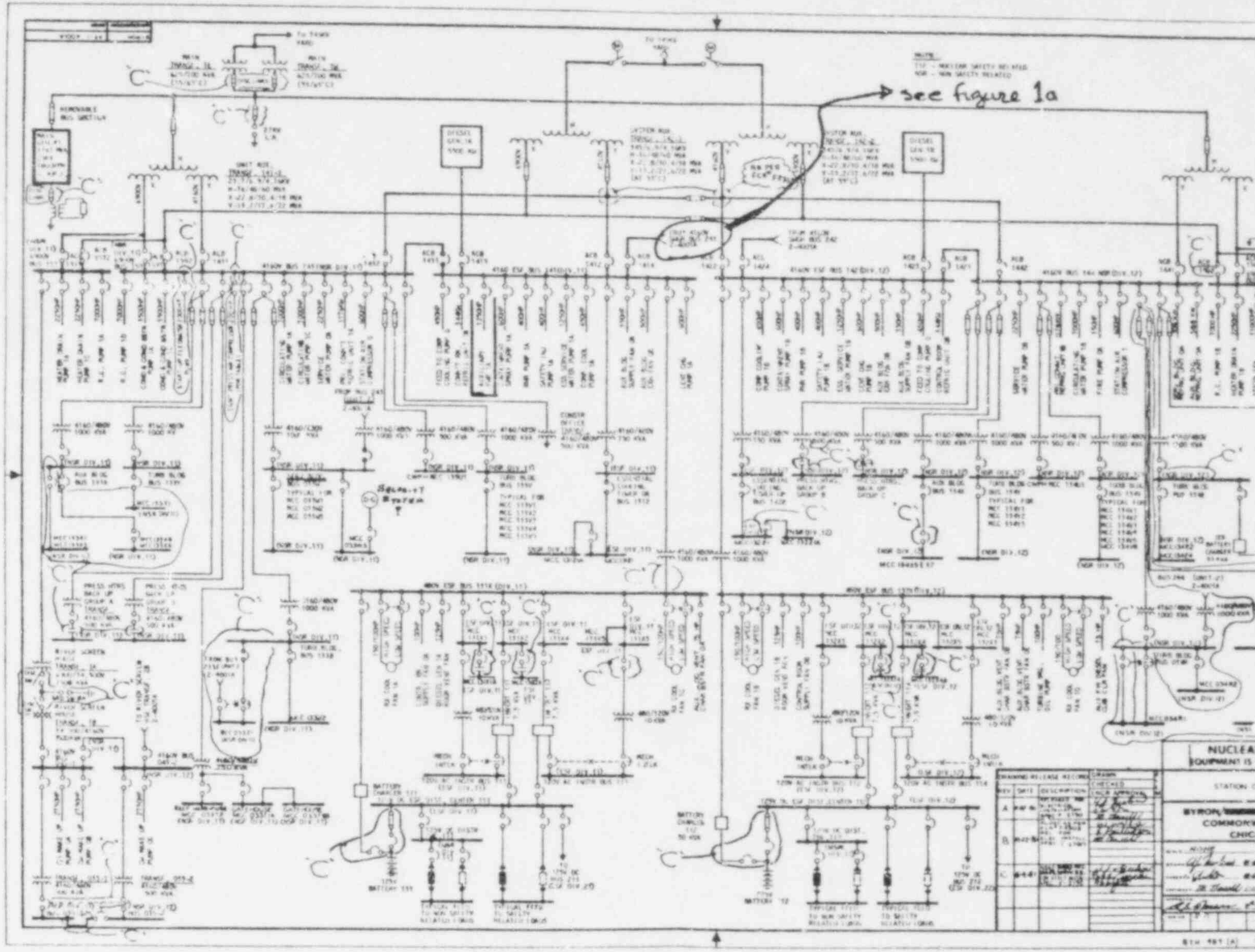
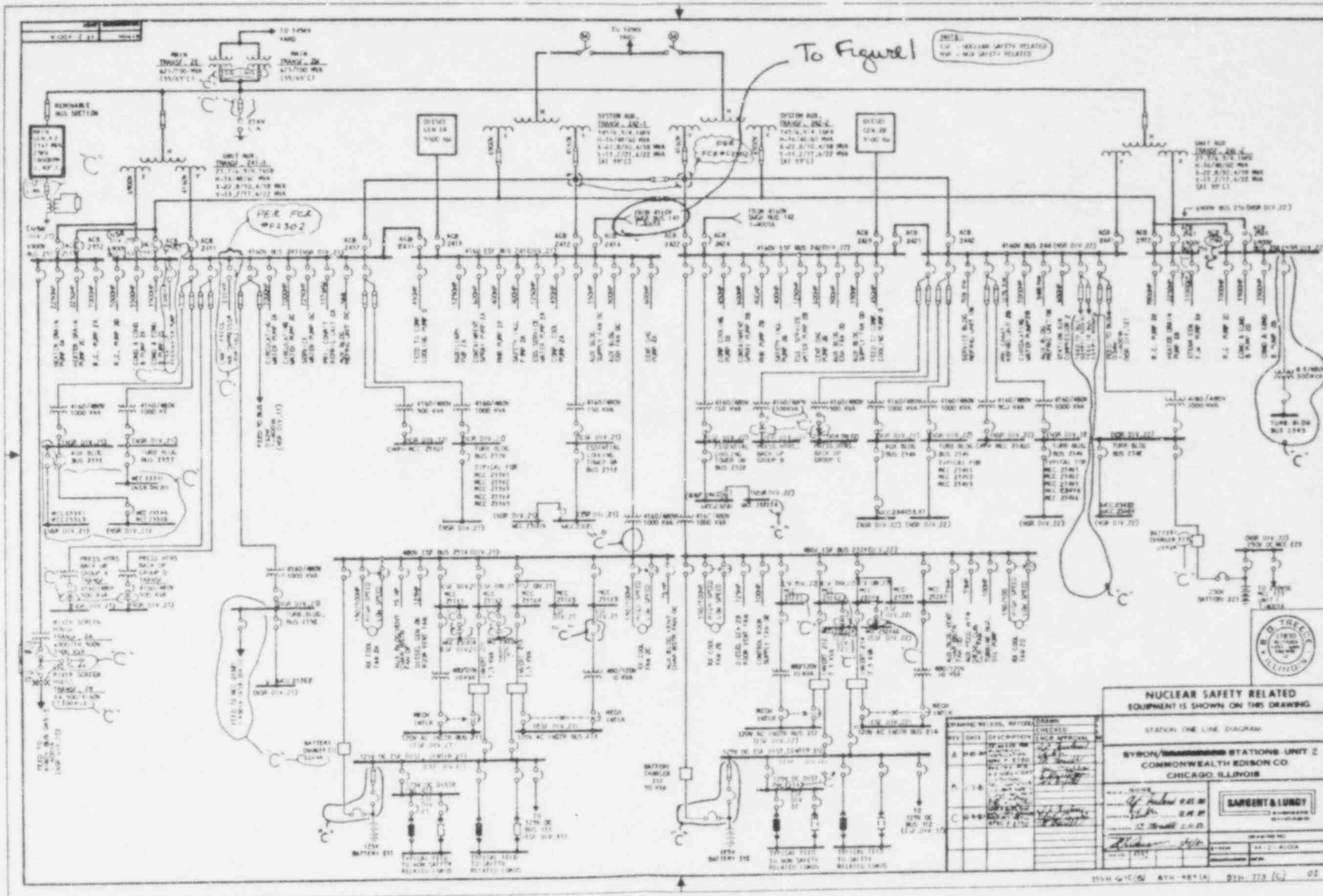

see figure 1a
NUCLEAR SAFETY RELATED
EQUIPMENT IS SHOWN ON THIS DRAWING
STATION ONE LINE DIAGRAM
COMMONWEALTH EDISON CO.
CHICAGO, ILLINOIS
SARGENT & LUNDY

Figure 1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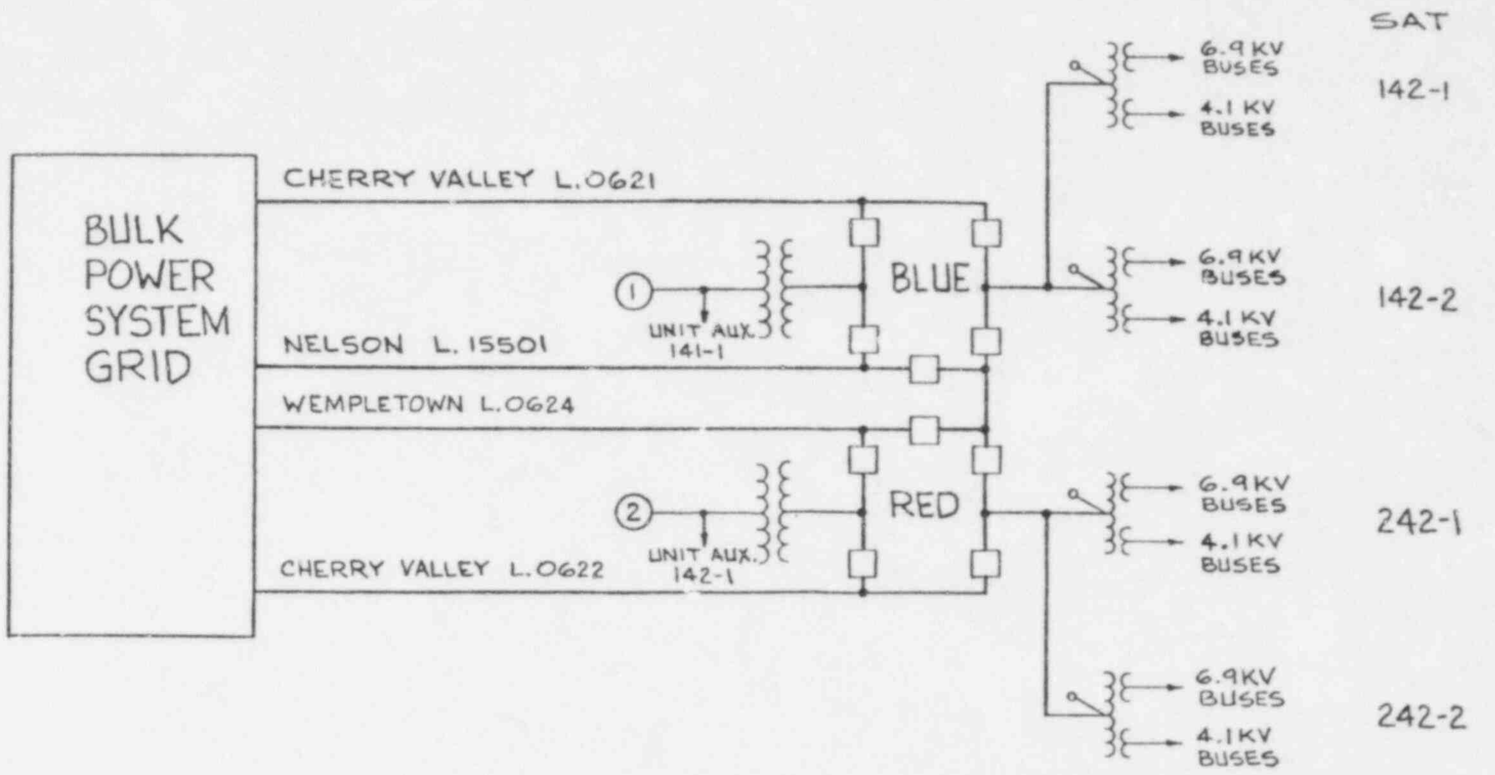
NUCLEAR SAFETY RELATED
EQUIPMENT IS SHOWN ON THIS DRAWING
STATION ONE LINE DIAGRAM
BYRON/[redacted] STATIONS - UNIT 2
COMMONWEALTH EDISON CO.
CHICAGO, ILLINOIS
SARGENT & LUNDY

Figure 1a



BYRON STATION

345KV BUS CONFIGURATION

SYSTEM PLANNING DEPARTMENT

NOVEMBER 20, 1981

Figure 2

ATTACHMENT 1

PRELIMINARY

November 18, 1981

SYSTEM PLANNING DEPARTMENT

Complete Outage of
Byron Station Off-Site
Power Due to Tornadoes

The frequency of tornadoes outaging all sources of offsite power to Byron Station has beeen estimated. Such outage could occur either from a tornado damaging each of the rights-of-way leading to the station, or from a tornado hitting the switchyard at the station.

The present Byron transmission plan utilizes 3 rights-of-way leaving the station site in different directions: to Cherry Valley (21 miles northeast; lines leave site in an easterly direction); Nelson (33 miles southwest; line leaves site in a southerly direction); and Wempletown (30 miles north); line leaves site in a northwesterly direction). A reasonably straight tornado path cannot intersect all three rights-of-way except by hitting the relatively small area of the station switchyard. The frequency of this event is estimated as once in 2800 years.

If the Wempletown right-of-way were eliminated, tornadoes heading in the prevailing northeasterly direction and passing within five or six miles of the station could outage both of the remaining rights-of-way. We estimate the frequency of this occurrence as once in 350 years, or eight times as frequent. In this case the lines were modelled to the points where they intersect the present Nelson-Cherry Valley right-of-way, as there is a negligible risk of a tornado intersecting two rights-of-way on the same line but separated by several miles.

The results are based on 102 tornado path lengths and compass headings observed in the Chicago area (the "Centennial" data) whose summary statistics are as follows:

	Mean	Standard Deviation	Range
Path Length (miles)	6.34	10.45	0.52 - 68.4
Compass Heading (degrees) (0° = North, 90° = East)	64.5	19.1	19 - 135

The station switchyard was assumed to present a 900 foot wide "target" to any tornado heading, allowing for the tornado path width.

The analysis method is an improved computerized version of that presented by Mr. John Teles at the 1980 American Power Conference, with certain analytical refinements relating to the path lengths and compass headings of tornadoes.

A W Schneider Jr.

A. W. Schneider, Jr.
System Planning Department

Approved: R. L. Lundgren

Attachment 2

ther Approaches

e attempted to show that restoring offsite power to Unit 1 within the team generator boil dry time, or even within the core uncovery time, is credible event. Though we certainly have good feelings that following ne transformer failure, the most likely event, the operator can restore he other system aux transformer within a sufficiently short time eriod. Similarly, if a Cherry Valley Line outage occurs, we are easonably certain that station personnel can isolate the fault and estore power to the system aux transformers.

nfortunately we have not compiled sufficient data to support our claim. e are continuing to search out data that will provide reasonable eliability numbers for operator action following either a transformer ailure or a line outage. Until such time we cannot assume that offsite ower is restored.

nnh
984b*

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This report presents the results of a review of the Auxiliary Feedwater System Reliability Analysis for Byron Units 1 and 2/Braidwood Units 1 and 2. The objective of this report is to estimate the probability that the Auxiliary Feedwater System will fail to perform its mission for each of three different initiators: (1) loss of main feedwater with offsite power available, (2) loss of offsite power, (3) loss of all 460 VAC power. The scope, methodology, and failure data are prescribed by NUREG-0611, Appendix III. The results are compared with those obtained in NUREG-0611 for other Westinghouse plants.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Reliability
Availability
Auxiliary Feedwater System
Byron Units 1 & 2
Braidwood Units 1 & 2
PWR
Loss of main feedwater
Loss of offsite power
Loss of all 460V AC power
NUREG-0611

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