ENCLOSURE 4

A REVIEW OF THE DIABLO CANYON POWER PLANT DIESEL GENERATOR ALLOWED OUTAGE TIME STUDY

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I. INTRODUCTION

I.1 Scope and Objectives

The scope of the present study is to support the NRC's effort to respond to a request by the Pacific Gas and Electric Co. (PG&E) to modify the Technical Specifications for Allowed Outage Time (AOT) for the Diesel Generators (DGs) presently operating and an additional one to be installed at its Diablo Canyon Nuclear Power Plant.

The direct objectives of this report are:

- To review the approaches applied in a supporting study, attached to the request, which analyzes the impact of the system and AOT modifications to the core damage frequency (CDF).
- To provide and to compare the results of auditing or validating calculations performed at BNL with those obtained in the PG&E study and to comment on them.

I.2 Background

The PG&E request is supported by detailed analysis of the unavailabilities of system configurations consisting of five and six DGs under various redundancy and AOT conditions as well as an evaluation of the impacts of the modified system and AOT conditions to the CDF.

The document entitled, "Diablo Canyon Power Plant, Diesel Generator Allowed Outage Time Study,"[1] contains the description of the approaches used and the results of the calculations. The study extensively uses, "The Diablo Canyon Probabilistic Risk Assessment (DCPRA)"[2] presently under review at BNL. Additional information on the AOT study was provided by PG&E in a presentation at the NRC (June 1989) and in two letters[3,4] sent to BNL in regard to various review questions.

I.3 Organization of the Report

The first part (Part 1) of the present report summarizes the results obtained by BNL in reviewing the methodology and calculations described in the AOT study.[1] The second part (Part 2) contains the detailed descriptions of the Diablo Canyon diesel generator, the diesel fuel transfer systems, and their PRA unavailability models.[2] This latter part also contains the results of a comprehensive review of the models performed recently at BNL and targeted to AOT-related aspects of the system's analysis.

Part 1 is organized as follows: Section 1 presents the proposed relaxation of Technical Specifications and briefly discusses PG&E's methodology and the results of the justification analyses. Section 2 comments on PG&E's approaches and maintenance data used. It compares the results of BNL's calculations on diesel unavailabilities (top event split fractions) obtained under various AOT conditions for both seismic and nonseismic accident sequences with those given in the AOT study. Section 3 describes the results of BNL's audit and sensitivity calculations performed by scrutinizing the CDF impact and risk ratio analyses of the AOT study. Section 4 summarizes the findings and the main conclusions of the BNL review. Appendix I contains the prior maintenance duration distribution used in the AOT study and maintenance duration and failure rate data for various diesel generator subsystems and components.

Part 2 is essentially represented by "Letter Report-07" on the DCPRA review which is entitled, "A Review of System Analysis in the DCPRA: Diesel Generator and Diesel Fuel Transfer Systems." The description of its organization can be found in its introductory Section I.2. We note that some of the review findings include open issues at this time, however, we do not believe the resolution of these items will have an appreciable effect upon the overall PRA results and conclusions.

PART 1

REVIEW RESULTS OF THE DG AOT STUDY

1. JUSTIFICATION ANALYSES FOR RELAXED TECHNICAL SPECIFICATIONS FOR DIESEL GENERATORS

For the sake of clear understanding and reader convenience, this section reiterates the Technical Specification relaxation issues requested by PG&E and provides a brief summary of the methodology and results of their justification analyses.

1.1 Proposed Relaxation of Technical Specifications for Diesel Generators

Currently, five DGs constitute the emergency DG system at the DCPP Units 1 and 2: two DGs dedicated to Unit 1, two DGs dedicated to Unit 2, and one, a "swing diesel" is shared between the two units. The swing diesel is physically located in Unit 1.

In order to increase the flexibility of plant operation and diesel maintenance scheduling efficiency, PG&E committed itself to install a sixth DG by the fourth refueling outage of Unit 2 (scheduled for October 1991). The sixth DG will also be an ALCO type DG like the five existing ones. With the sixth diesel installed and operable, each Diablo Canyon unit will have three dedicated DGs which will simplify the operation of the plant.

The present DCPP Technical Specifications provide a 72-hour AOT when a given unit DG is inoperable with that unit in Modes 1 through 4. When a DG becomes inoperable, the operability of the ac offsite sources must be demonstrated by performing surveillance tests within one hour and at least once per eight hours thereafter. If the DG became inoperable due to causes other than preventive maintenance or testing, the operability of the remaining DGs must be demonstrated within 24 hours (regardless of when the inoperable DG is restored to operable status). The inoperable DG must be restored to operable status within the 72-hour AOT or action must be initiated to place the unit to cold shutdown (Mode 5), where the subject limiting condition for operation (LCO) is no longer applicable.

The relaxation of the Technical Specifications (No.3.8.1.1 Action Statement b) proposed by PG&E is the following: Increase the AOT from the current three days (72-hours) to seven days (168 hours), so that corrective (non-scheduled) maintenance, inspection and post-maintenance operability testing appropriately and conveniently could be performed.

The proposal relates to both diesel configurations, the current five, as well as the planned six diesel configuration. Preventive (scheduled) maintenance (overhauls) of the dedicated DGs would be performed, as in the past, during the unit's refueling periods.

1.2 Methodology of the Justification Analyses

PG&E claims that the above proposed AOT relaxation is fully supported by plant experience, training of personnel on advanced diesel maintenance, recent improvements of the DGs and by the results of justification analyses described in Reference 1.

The justification analyses were directed to the assessments of two main issues:

a. the appropriateness of a seven-day AOT for the purposes of unscheduled maintenance of the present and planned DG configurations and
b. the safety impact of performing required scheduled maintenance of the swing diesel given a seven-day AOT.

Two approaches were used for these assessments. The first was based on the DCPRA,[2] thus Reference 1 and consequently the present report refer to it as the "risk analysis approach." The second was based on stand-alone fault-tree models of the current and planned DG configurations. Reference 1 as well as the present report refer to this as the "reliability analysis" approach.

The annual and relative risks were evaluated by both of the approaches. Relative risk was defined[5] by the ratio of the risk during the AOT to the risk during the time interval when no DG is in maintenance or test. This "risk ratio" (RR) constrains the duration of the AOT by requiring that the ratio should be less than unity. In general, "risk" may refer to system unavailability, core damage frequency or health risks, depending on the "level" where the effect of the AOT is evaluated. The PG&E AOT study evaluated "risk" at the core damage frequency level.

The application of the reliability analysis approach by PG&E was intended to complement the risk analysis approach. A PRA usually calculates time averaged risk values; time-dependent effects (like testing) on the availability of the remaining diesels when one DG is in maintenance or staggered testing are not taken into account. In addition, the unavailability modelling of the DGs in a PRA does not usually go "deep" enough, so that failure modes of the diesel subsystems or support systems are not explicitly indicated in the model.

The time-dependent unavailability analysis was performed by PG&E on the fault tree models of the diesel systems by using the FRANTIC-ABC PC computer code.

1.3 Results of the Justification Analyses

Both of the approaches, risk and reliability analyses, were used to calculate the following cases:

- Base Case -- 5DG configuration, three-day AOT on all DGs to perform unscheduled maintenance. The risk analysis approach addressed also performing scheduled maintenance on the swing diesel during power operation of one unit with the other unit in refueling. Total scheduled outage was assumed to be ten days (i.e., several three-day AOT periods) during a refueling period of 1.5 years. Table 2.1 contains the definitions of the calculations performed by the risk analysis approach, these calculations are denoted by 1A and 2.

- Second Case -- 5DG configuration, seven-day AOT on all DGs to perform unscheduled maintenance. The risk analysis approach also addressed performing scheduled maintenance on the swing diesel. Total scheduled outage was seven days (no multiple outages) during a refueling period of 1.5 years. In Table 2.1, these calculations are denoted by 1B and 3.

- Third Case -- 6DG configuration, seven-day AOT on all DGs to perform unscheduled maintenance. Since there is no swing diesel, scheduled maintenance can now be performed without affecting the other unit. In Table 2.1 this calculation is denoted by 4.

In order to determine the relative risk, several support calculations were carried out. Those associated with the risk analysis approach are denoted by 5 and 6 in Table 2.1. Calculation 5 analyzed the condition when no maintenance (scheduled or unscheduled) is allowed on any of the 5DGs. Calculation 6 provided the risk (5DG configuration) if the swing diesel were unavailable for the entire year (i.e., calculated the conditional core damage frequency). This calculation assumed seven-day AOT for unscheduled maintenance on other DGs.

For completeness, the results of both of the analyses, risk and reliability, are reproduced in Table 1.1 from Table 6.1 of Reference 1. Based on the data presented, PG&E concluded that:

- The risk ratio criterion is satisfied for all cases by both methods of analysis.
- The effect on risk of changing from a three-day to a seven-day AOT is insignificant; on the order of 1 to 3 percent of the CDF.
- The effect on risk of adding the sixth DG is greater than the effect of changing to a seven-day AOT with an overall decrease of the order of 5 to 15 percent in CDF. Both of the analysis approaches confirmed the appropriateness of a seven-day AOT for the purpose of performing unscheduled maintenance for both the five and six DG configurations.

- According to the results of the risk analysis approach, 1) there is a negligible increase in risk associated with a seven-day AOT over a three-day AOT with regard to performing scheduled maintenance on the swing diesel and 2) the resulting quantitative benefits of a single seven-day AOT far outweighs the risk associated with multiple three-day AOTs.

Table 1.1
Analytical Results[1] for Unplanned and Planned Maintenance Activities

	PRA Analysis			Reliability Analysis (Unplanned)	
	Unplanned & Planned[2]	Unplanned			
	Frequency	Frequency	Relative Ratio[3]	Frequency	Relative Ratio[3]
Base Case					
3-Day AOT/5 DGs (10 day Outage)[2]	2.12E-04	2.08E-04	0.05	LOOP 2.29E-04	0.06
				LOCA/ LOOP 1.10E-09	0.08
Case 2					
7-Day AOT/5 DGs (7 day Outage)[2]	2.15E-04	2.12E-04	0.08	LOOP 2.35E-04	0.08
				LOCA/ LOOP 1.10E-09	0.10
Case 3					
7-Day AOT/6 DGs (0 day)[2]	2.02E-04	2.02E-04	0.08	LOOP 2.00E-04	0.05
				LOCA/ LOOP 7.43E-10	0.13

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[1] PRA reflects frequency for Unit 1 only, whereas reliability considers frequency for both units

[2] Duration of outage for planned maintenance.

[3] AOT Risk Level/Non-AOT Risk Level.

2. REVIEW OF THE RISK ANALYSIS RESULTS

2.1 General

After having invested some preliminary efforts to review the AOT study, BNL selected the risk analysis approach and its associated calculations and results to be the focus of our review efforts.

There were several reasons to choose this particular focused approach. These are as follows:

1. As was mentioned in the introduction, the unavailability modelling of the DG and diesel fuel transfer systems of the DCPRA were already under review by BNL (see Part 2) and therefore relevant computer software was already available for further calculations to be carried out in a timely fashion. A substantial in-depth review of the results obtained by the reliability analysis would have required audit calculations of the diesel fault trees practically starting from scratch.

2. The reliability analysis assumes four-hour mission times for the 5DG configuration (the PRA model assumes six hours for nonseismic and 24 hours for seismic events) and two hour mission times for the 6DG configuration. The use of different mission times prevents the direct comparison of the results obtained for 5DG and 6DG configurations.

3. The reliability analysis did not address seismic effects.

4. The reliability analysis approach did not address or evaluate the risk impact of the scheduled maintenance on the swing diesel.

5. The results of the reliability analysis, although numerically different from the risk analysis, supports the same conclusions as the risk analysis.

2.2 The Review Approach

As a first phase, the adequacy of the unavailability modelling of the DGs and diesel fuel transfer system in the DCPRA was reviewed. This was done partly in the framework of the general review of the DCPRA. The detailed results are described in Part 2 of this report. Two main observations which have to be kept in mind, however are reiterated here:

1. The diesel system analysis in the DCPRA seems to be weak in adequately representing the potential failure contributions of diesel subsystems. (The reliability analysis used a much more detailed diesel model.)

2. The unavailability contributions due to the overhauls of the other unit diesels and the swing diesel when one unit is at power were not taken into account. •(In the case of the swing diesel, that is precisely the cause that additional risk calculations had to be performed in the AOT study.)

As a second phase (Part 1 of this report), the adequacy of the risk (core damage frequency) impact calculations due to changes in AOT and system redundancy were scrutinized taking into account comments 1 and 2 above.

This phase consisted of the following steps:

a. A review of the quantities which determine the total unavailability of DGs (average total unavailability of DGs due to maintenance duration and maintenance frequency).
b. Review and sensitivity calculations on non-seismic and seismic top event split fractions characterizing the unavailabilities of DGs under various boundary and AOT conditions. These top events appear in the support system event tree of the plant core damage frequency model.
c. Audit and sensitivity calculations on the core damage frequencies. These were performed by propagating the audited or newly generated top

events through the dominant sequence PRA model. Table 2.1 lists the definitions of various core damage frequency calculations. New calculations made to study sensitivity or consistency are denoted by "BNL's sensitivity calculation." They will be explained later.

d. Audit of the risk ratio results.

The subsequent subsections and Section 3 describe these steps in detail.

2.3 Maintenance Unavailability of the DGs

In the DCPRA the AOT dependency of the diesel top events appears through a quantity called total diesel maintenance unavailability, P_T. The quantity reflects the conditions that due to Technical Specification limitations only one diesel or one Level Control Valve (LCV) of the Fuel Oil Day Tank may be in maintenance at a time (see also Part II).

Thus, $P_T = P_{DG} + P_{LCV} - P_{DG} * P_{LCV}$, where P_{DG} is the maintenance unavailability of the diesel itself and P_{LCV} is the maintenance unavailability of the LCV. Furthermore, P_{DG} is defined as: P_{DG} = ZMDGSD*ZMDGSF, where ZMDGSD = 10.1 hours is the mean duration of the diesel maintenance; and ZMDGSF = 7.74-4 hr^{-1} is the mean frequency of diesel maintenance.

Similarly, P_{LCV} = ZMDGN3D*ZMGNDF, where ZMGN3D = 18.9 hours is the mean duration of the LCV maintenance; and ZMGNDF = 2.03-5 hr^{-1} is the mean frequency of LCV maintenance. With these values P_{DG} = 7.817-3 and P_{LCV} = 3.837-4, and P_T = 8.201-3.

The above mean maintenance duration and frequency data are AOT-dependent values. They were obtained by updating generic maintenance duration and frequency values using plant-specific data. These data were used in the "Base Case" calculations in the AOT study.

If one compares this data with those used in the reliability approach, one can observe some inconsistencies. From Table 5.7 of the AOT study[1] one can easily obtain, by assuming a lognormal distribution, the following data (without updating any priors):

ZMDGSD' Median = 11.63 hours, Mean = 11.90 hours

ZMDGSF' Median = 1.04-3 hr^{-1}, Mean = 1.06-3 hr^{-1}

P'_{DG} Median = 1.21-2, Mean = 1.26-2

By using the previous value for P_{LCV}, one obtains a new value for the mean total maintenance unavailability:

$P'_T = P_{LCV} + P'_{DG} = 1.198\text{-}2$

The main cause of the inconsistency is the diesel maintenance frequency and in a lesser measure the mean maintenance duration.

Consider now the generic mean priors:

ZMDGSD^P = 17 hours

ZMDGSF^P = 1.03-3 hr^{-1}

ZMGN3D^P = 13 hours

ZMGNDF^P = 2.7-5 hr^{-1}

One can observe that the generic mean prior maintenance frequency almost exactly coincides with the plant-specific value (w/o update). Its not clear how the DCPRA arrived at the updated value: ZMDGSF = 7.74-4 hr^{-1}. However, the essential problem here is that P'_T seems to be the correct total unavailability and this should have been used in the "Base Case" calculations.

BNL requested additional information from PG&E about the generic prior diesel maintenance duration distribution (ZMDGSD). The distribution and its characteristic parameters are reproduced in Table I.1 of Appendix I from PG&E's answer.[3] The mean value of that prior is: ZMDGSD^P = 10.5 hours, in apparent variance with the value given in the DCPRA (see above).

In the "Second" and "Third Case" calculations, i.e., when a 7-day AOT is considered, PG&E increased only the mean maintenance duration of the diesels. The mean maintenance frequency of the diesel was taken to be the same, as for the 3-day AOT. For the increased value of the mean maintenance duration, PG&E took ZMDGSD = 16 hours. The selection of this value was supported by several qualitative arguments. Among others the expert opinions of the maintenance personnel. The arguments were also repeated in Reference 3. The Palisades diesel outage data were quoted as experience values. There was no reference to any other experience data source.

Also from Table 5.7 of the AOT study, one can easily obtain the Palisades values (AOT is 7-days):

$ZMDGSD_{Pal}$ Mean = 11.55 hours, Mean = 11.90 hours
$ZMDGSF_{Pal}$ Median = 1.33-3 hr^{-1}, Mean 1.36-3 hr^{-1}
P_{DG}^{Pal} Median = 1.54-2, Mean 1.62-2

Thus, the mean total maintenance unavailability:

$$P_T^{Pal} = P_{LCV} + P_{DG}^{Pal} = 1.66\text{-}2$$

The AOT study uses for the 7-day AOT (ZMDGSD = 16 hours): $P_T = 1.277\text{-}2$, an underestimation of about 30% relative to the value determined based on the Palisades data. In order to obtain an independent assessment for a generic mean diesel maintenance duration, BNL used the diesel subsystem downtimes and failure rates collected in a recent EPRI study.[7] These downtimes are given in Table I.2 of Appendix I ranked in [illegible]creasing order. Based on these data and by assuming a lognormal maintenance duration distribution, an overall mean maintenance duration value was determined (see Appendix I). The value obtained by BNL is:

$\overline{ZMDGSG} = 20.6$ hours.

Since it is considerably higher than 16 hours, one can infer that the above value of P_T, $P_T = 1.277\text{-}2$ indeed may underestimate the expected mean maintenance unavailability for a 7-day AOT.

Because of the above ambiguities in the correct values of the mean maintenance duration and frequencies, it was decided that besides auditing the risk calculations of the AOT stud additional sensitivity calculations would be performed with a bounding mean diesel maintenance duration of 24 hours and the original mean maintenance frequency of 7.74-4 hr^{-1}. The corresponding range of total maintenance unavailability, P_T, extends from quite low values up to 2.10^{-2}. The exact values are given in Table 2.2. The table also shows that this P_T range covers a mean maintenance duration range from 0 hours to 17.5 hours, if for the mean maintenance frequency, the reliability analysis value, ZMDGSF' = 1.06-3 hr^{-1} is taken. In Table 2.1 these calculations are denoted by 1C, 3A, 4C, and 6B.

The sensitivity calculations allowed BNL to determine an unambiguous functional relationship between the total maintenance unavailability and the diesel top event split fractions, i.e., through them the core damage frequency.

2.4 Review of Top Event Split Fractions

The DCPRA defines six top events in the electric part of the support system event tree associated with the unavailability of the diesel generators. The top event definitions, boundary conditions, success criteria, their quantified values for seismic and non-seismic accident sequences, the top event split fractions, and the main contributors to the top event split fractions are thoroughly described and discussed in Part 2. For better understanding and convenience, however, the designators of the top events and their relationships with the diesels are also given here:

- Top Event GF - Diesel Generator 13 ("Swing diesel')
- Top Event GG - Diesel Generator 12
- Top Event GH - Diesel Generator 11
- Top Event 2G - Diesel Generator 21
- Top Event 2H - Diesel Generator 22
- Top Event SW - Units alignment of swing diesel, 13.

For the audit calculations of the AOT modified top events and for BNL's own sensitivity calculations, the same SETS-code[a] models and locally generated PC software were used which had been developed for auditing the DCPRA results. Tables 2.5 and 2.7 of Part 2 show the detailed comparison of the results of the audit calculations with those of the DCPRA and the AOT study in the "Base Case" for (3-day AOT, 10.1 hours mean maintenance duration) non-seismic and seismic split fractions.

The final results of these calculations are also listed in Tables 2.3.A and 2.3.B of this section for non-seismic and seismic split fractions, respectively. These tables also contain the results of the audit calculations for the "Second Case" (7-day AOT, 16 hour mean maintenance duration) and of the BNL's sensitivity calculation (7-day AOT, 24 hour mean maintenance duration). For comparison, the tables conveniently also list the values given by PG&E in Table 4.3 of the AOT study.[1]

In order to check the internal consistency of the results obtained, the various split fractions can be plotted against the Total Maintenance Unavailability, P_T. This functional representation is convenient because it allows us to interpret the results when one considers a mean diesel maintenance frequency other than the 7.74-4 hr^{-1} offered by PG&E.

Figure 2.1 shows such a functional representation for the non-seismic top event split fractions GF1, GG3, GH6, 2GA, 2HG. The graph of these split fractions appears to be a straight line. Its extrapolation to $P_T = 0$ provides a quite accurate graphical checking of the corresponding PG&E value given for "Zero Diesel Maintenance" calculations in Table 4.3 of the AOT study.[1] (Similar "graphical" spot checking "validated" other "zero maintenance" split fractions as well.)

The split fractions shown in Figure 2.1 essentially represent the unavailability of the individual diesel units in the DCPRA, when all the support systems are available (see Part II).

For comparison, the unavailabilities of DG11 and DG13 determined by the "more detailed" reliability analysis calculations are also plotted as a function of the maintenance duration. Its not clear why the PRA unavailabilities are larger (about a factor of 2) than those obtained with the reliability model, where the support system unavailabilities were not taken to be zero.[2]

The results of BNL's audit calculation on those top event split fractions (non-seismic and seismic) which had to be completely requantified to account for the condition when the swing diesel is unavailable, are shown in Table 2.4. (More specifically, the unscheduled maintenance duration of the other diesels given the swing diesel is inoperable is set equal to eight hours. This is based on Technical Specification 3.8.1.1 Action Statement f.) For comparison, Table 2.4 also indicates the original PG&E values. One can observe that there is a general agreement between the two calculations.

Summarizing, (disregarding the discrepancies previously identified between the results of the risk and reliability approaches in Section 2.1 and the factor of two from just above) one can say that there is an overall agreement between the BNL audit results and PG&E split fraction data. The small inconsistencies appearing here or there are presumably the consequences of the fact that BNL used point estimates, while PG&E used a Monte-Carlo approach in the split fraction quantification.

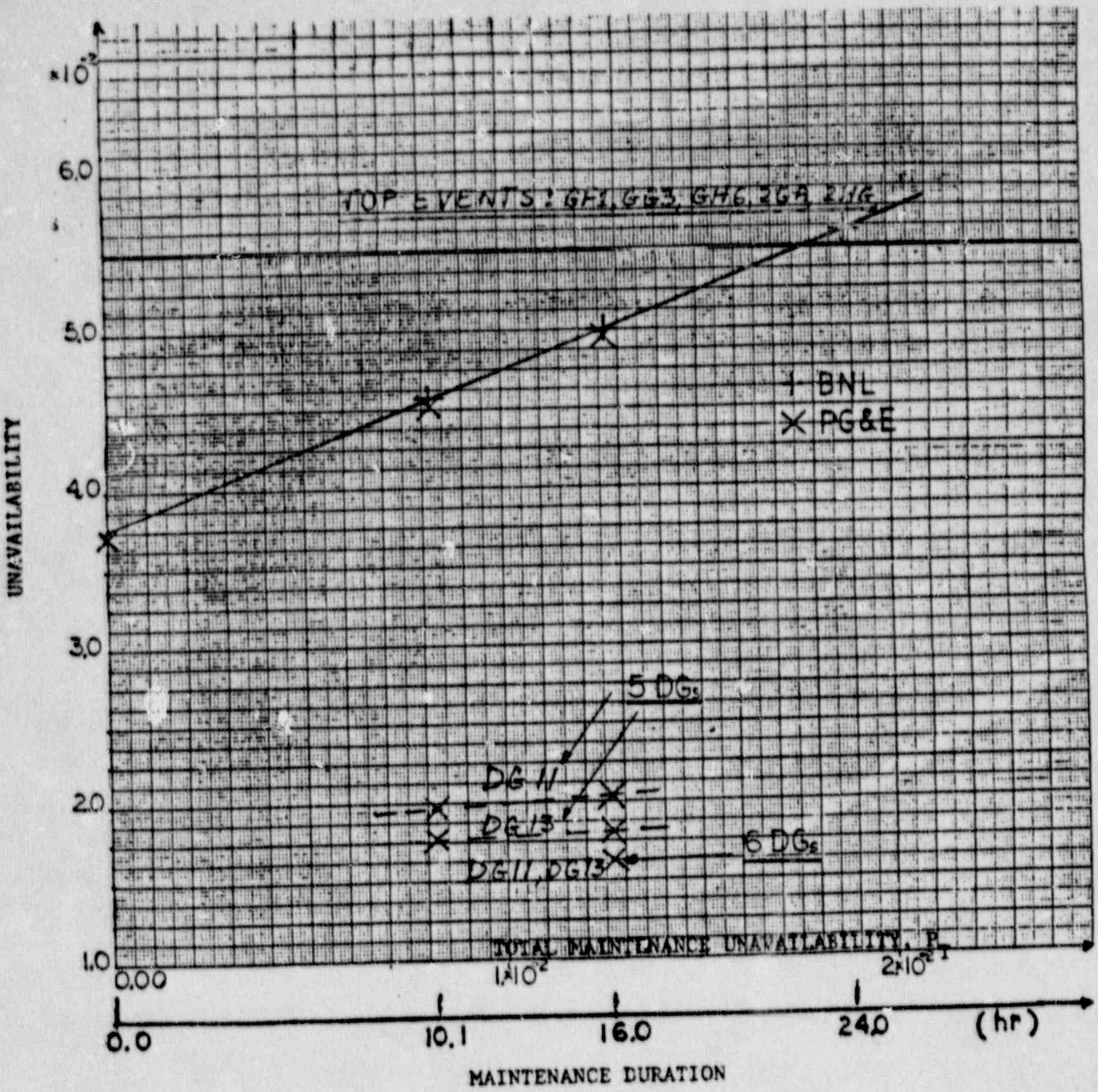


Figure 2.3 Diesel generator unavailability (Top Event Split Fractions: GF1, GG3, GH6, 2GA, 2HG in DCPRA) as a function of Total Maintenance Unavailability. The dashed lines (DG11 and DG13) at the bottom of the figure and the data point (DG11, DG13) represent the results obtained from the diesel generator reliability study for the present (5 DGs) and the planned (6 DGs) diesel configurations, respectively.

Table 2.1
Definition of Calculations - Risk Analysis Approach

				With One Unit at Power		
Number of Calculation	Number of DGs	Allowed Outage Time, AOT (Days)	Mean DG Maintenance Duration, MMD (Hrs)	Overhaul Period of Swing Diesel (Days)	Overhaul Period of DGs of the Other Unit (Days)	Notes
5	5	**	0	0	0	Audited by BNL.
1A*	5	3	10.1	0	0	Audited by BNL.
1B	5	7	16	0	0	Audited by BNL.
1C	5	7	24	0	0	BNL's sensitivity calculation.
2	5	3	10.1	10	0	Audited by BNL.
3	5	7	16	7	0	Audited by BNL.
3A	5	7	24	7	0	BNL's sensitivity calculation.
4A	6	**	0	0	0	BNL's sensitivity calculation.
4B	6	3	10.1	0	0	BNL's sensitivity calculation.
4	6	7	16	0	0	Audited by BNL.
4C	6	7	24	0	0	BNL's sensitivity calculation.
6A	5	3	10.1	1 year	0	BNL's sensitivity calculation.
6	5	7	16	1 year	0	Audited by BNL.
6B	5	7	24	1 year	0	BNL's sensitivity calculation.

*DCPRA assumptions.
**No DG maintenance.

Table 2.2
Total Maintenance Unavailability, P_T

Mean DG Maintenance Duration, ZMDGSD, hr	P_T, With DG Maintenance Frequency, ZMDGSF = 7.74-4 hr^{-1}	Mean DG Maintenance Duration, ZMDGSD' hr	P_T', With DG Maintenance Frequency, ZMDGSF' = 1.06-3 hr^{-1}
0	3.837-4	0	3.837-4
10.1	8.201-3	-	-
16	1.277-2	11.9	1.298-2
24	1.896-2	17.5	1.896-2

Table 2.3.A
Nonseismic Conditional Split Fractions for the Diesel Generators

Top Event	Split Fraction	10.1 Hours MMD for all Diesels		16 Hours MMD for all Diesels		24 Hours MMD for all Diesels	
		PG&E	BNL	PG&E	BNL	PG&E	BNL
GF	GF1	4.523-2	4.571-2	4.946-2	5.010-2	---	5.606-2
GG	GG1	4.477-2	4.527-2	4.909-2	4.976-2	---	5.592-2
	GG2	5.561-2	5.474-2	5.682-2	5.649-2	---	5.843-2
	GG3	4.523-2	4.571-2	4.946-2	5.010-2	---	5.606-2
GH	GH1	4.436-2	4.490-2	4.878-2	4.948-2	---	5.583-2
	GH2	5.408-2	5.322-2	5.545-2	5.516-2	---	5.732-2
	GH3	8.265-2	8.097-2	8.063-2	7.873-2	---	7.641-2
	GH4	4.477-2	4.527-2	4.909-2	4.976-2	---	5.592-2
	GH5	5.561-2	5.474-2	5.682-2	5.649-2	---	5.843-2
	GH6	4.523-2	4.571-2	4.946-2	5.010-2	---	5.606-2
2G	2G1	4.396-2	4.453-2	4.847-2	4.921-2	---	5.576-2
	2G2	5.364-2	5.271-2	5.507-2	5.475-2	---	5.702-2
	2G3	6.250-2	6.246-2	6.254-2	6.229-2	---	6.211-2
	2G4	2.898-1	2.910-1	2.726-1	2.711-1	---	2.493-1
	2G5	4.436-2	4.490-2	4.878-2	4.948-2	---	5.583-2
	2G6	5.408-2	5.322-2	5.545-2	5.516-2	---	5.732-2
	2G7	8.265-2	8.097-2	8.063-2	7.873-2	---	7.641-2
	2G8	4.477-2	4.527-2	4.909-2	4.976-2	---	5.592-2
	2G9	5.561-2	5.474-2	5.682-2	5.649-2	---	5.843-2
	2GA	4.523-2	4.571-2	4.946-2	5.010-2	---	5.606-2
2H	2H1	4.356-2	4.417-2	4.817-2	4.894-2	---	5.571-2
	2H2	5.320-2	5.219-2	5.470-2	5.434-2	---	5.675-2
	2H3	6.206-2	6.196-2	6.205-2	6.177-2	---	6.157-2
	2H4	6.922-2	7.003-2	6.996-2	7.017-2	---	7.031-2
	2H5	7.729-1	8.294-1	7.521-1	8.114-1	---	7.883-1
	2H6	4.396-2	4.453-2	4.847-2	4.921-2	---	5.576-2
	2H7	5.364-2	5.271-2	5.507-2	5.475-2	---	5.702-2
	2H8	6.250-2	6.246-2	6.254-2	6.229-2	---	6.211-2
	2H9	2.898-1	2.910-1	2.726-1	2.711-1	---	2.493-1
	2HA	4.436-2	4.490-2	4.878-2	4.948-2	---	5.583-2
	2HB	5.408-2	5.322-2	5.545-2	5.516-2	---	5.732-2
	2HC	8.265-2	8.097-2	8.063-2	7.873-2	---	7.641-2
	2HD	4.477-2	4.527-2	4.909-2	4.976-2	---	5.592-2
	2HE	5.561-2	5.474-2	5.682-2	5.649-2	---	5.843-2
	2HG	4.523-2	4.571-2	4.946-2	5.010-2	---	5.606-2

Table 2.3.B
Seismic Conditional Split Fractions for the Diesel Generators

Top Event	Split Fraction	10.1 Hours MMD for all Diesels		16 Hours MMD for all Diesels		24 Hours MMD for all Diesels	
		PG&E	BNL	PG&E	BNL	PG&E	BNL
GF	GF1	8.510-2	8.389-2	8.721-2	8.810-2	---	9.382-2
GG	GG1	8.417-2	8.325-2	8.654-2	8.756-2	---	9.347-2
	GG2	9.502-2	9.085-2	9.428-2	9.375-2	---	9.726-2
	GG3	8.510-2	8.389-2	8.721-2	8.810-2	---	9.382-2
GH	GH1	8.334-2	8.272-2	8.595-2	8.712-2	---	9.322-2
	GH2	9.329-2	8.913-2	9.275-2	9.219-2	---	9.591-2
	GH3	1.115-1	1.080-1	1.090-1	1.088-1	---	1.098-1
	GH4	8.417-2	8.325-2	8.654-2	8.756-2	---	9.347-2
	GH5	9.502-2	9.085-2	9.428-2	9.375-2	---	9.726-2
	GH6	8.510-2	8.389-2	8.721-2	8.810-2	---	9.382-2
2G	2G1	8.251-2	8.221-2	8.537-2	8.670-2	---	9.300-2
	2G2	9.244-2	8.827-2	9.205-2	9.144-2	---	9.532-2
	2G3	1.016-1	1.794-2	9.964-2	9.956-2	---	1.014-1
	2G4	1.903-1	1.908-1	1.851-1	1.846-1	---	1.777-1
	2G5	8.334-2	8.272-2	8.595-2	8.712-2	---	9.322-2
	2G6	9.329-2	8.913-2	9.275-2	9.219-2	---	9.591-2
	2G7	1.115-1	1.080-1	1.090-1	1.088-1	---	1.098-1
	2G8	8.417-2	8.325-2	8.654-2	8.756-2	---	9.347-2
	2G9	9.502-2	9.085-2	9.428-2	9.375-2	---	9.726-2
	2GA	8.510-2	8.389-2	8.721-2	8.810-2	---	9.382-2
2H	2H1	8.169-2	8.175-2	8.481-2	8.632-2	---	9.282-2
	2H2	9.162-2	8.744-2	9.138-2	9.072-2	---	9.478-2
	2H3	1.005-1	9.688-2	9.863-2	9.857-2	---	1.005-1
	2H4	1.112-1	1.077-1	1.087-1	1.085-1	---	1.094-1
	2H5	5.269-1	5.433-1	5.214-1	5.207-1	---	4.937-1
	2H6	8.251-2	8.221-2	8.537-2	8.670-2	---	9.300-2
	2H7	9.244-2	8.827-2	9.205-2	9.144-2	---	9.532-2
	2H8	1.016-1	1.794-2	9.964-2	9.956-2	---	1.014-1
	2H9	1.903-1	1.908-1	1.851-1	1.846-1	---	1.777-1
	2HA	8.334-2	8.272-2	8.595-2	8.712-2	---	9.322-2
	2HB	9.329-2	8.913-2	9.275-2	9.219-2	---	9.591-2
	2HC	1.115-1	1.080-1	1.090-1	1.088-1	---	1.098-1
	2HD	8.417-2	8.325-2	8.654-2	8.756-2	---	9.347-2
	2HE	9.502-2	9.085-2	9.428-2	9.375-2	---	9.726-2
	2HG	8.510-2	8.389-2	8.721-2	8.810-2	---	9.382-2

Table 2.4
Nonseismic and Seismic Conditional Split Fractions
Scheduled Maintenance on Diesel 13*

Top Event	Split Fraction	Renamed Split Fraction	Nonseismic		Renamed Split Fraction	Seismic	
			PG&E	BNL		PG&E	BNL
GF	GF1	GFF	1.0	1.0	GFF	1.0	1.0
GG	GG1						
	GG2	GG4	4.344-2	4.393-2	GG5	8.114-2	8.218-2
	GG3						
GH	GH1						
	GH2	GH7	4.324-2	4.377-2	GHA	8.064-2	8.181-2
	GH3	GH8	4.784-2	4.751-2	GHB	8.685-2	8.629-2
	GH4						
	GH5	GH9	4.344-2	4.393-2			
	GH6						
2G	2G1						
	2G2						
	2G3	2GC	4.631-2	4.599-2	2GI	8.531-2	8.471-2
	2G4						
	2G5						
	2G6	2GE	4.324-2	4.377-2			
	2G7						
	2G8						
	2G9						
	2GA						
2H	2H1						
	2H2						
	2H3	2HI	4.585-2	4.552-2			
	2H4	2HJ	5.573-2	5.560-2			
	2H5						
	2H6						
	2H7						
	2H8						
	2H9						
	2HA						
	2HB						
	2HC						
	2HD						
	2HE						
	2HG						

*Renamed split fractions were used to evaluate conditional core damage sequences that involved maintenance of the swing DG. The DG split fractions not listed for this case were not needed to quantify these sequences.

3. CORE DAMAGE FREQUENCY AND RISK RATIO CALCULATIONS

3.1 General

Fifty initiating event categories, including six seismic levels are quantified in the DCPRA. For the AOT study, however, only the leading sequences (contributing approximately 82% of the total core damage frequency) were selected to be potential subjects of modification due to changes in the diesel-related top event split fractions. This subset of sequences is called the "Dominant Sequence PRA Model" in the AOT study. The omitted sequences are taken into account by appropriate correction factors. The model consists of two parts: 1) non-seismic sequences and 2) seismic sequences. 420 leading non-seismic sequences constitute "the non-seismic part" and 791 leading seismic sequences constitute "the seismic part." The non-seismic and seismic contributions to the total core damage frequency are 83.2% and 16.8%, respectively. The 420 non-seismic and the top 200 seismic sequences are listed in the AOT study. Each leading sequence is represented as the algebraic product of the frequency of a single initiating event and the unavailabilities of the plant safety systems under specific boundary conditions, or "top event split fractions." Where appropriate, sequence-specific recovery actions are also included in the sequence. Normally, the system success probabilities (availabilities) are very close to unity and therefore can be conservatively omitted. For sequences in which this is not the case, the system success probabilities were included to avoid over-conservatism. The DG success probabilities are included in the non-seismic part. In the seismic part, all the success probabilities are considered.

3.2 Core Damage Frequencies Without Contribution Due to Swing Diesel Overhaul

For core damage frequency calculations in which there is no scheduled maintenance performed on the swing DG while a unit is at power, both non-seismic and seismic sequences (420 and 791 sequences, respectively) were used. The BNL audit focussed on the non-seismic sequences because for the seismic failures the DCPRA treated the DGs as completely correlated and because the seismic sequences show a practically negligible (order of $\sim 10^{-7}$) dependency on the change of the total maintenance unavailability of the diesels, i.e., AOT.

The core damage frequency (according to the terminology of the AOT study, the absolute risk) was evaluated by propagating the top event split fractions determined with various mean diesel maintenance times through the dominant sequence PRA model. This was done for both diesel configurations; for 5DG and 6DG systems. To represent the 6DG configuration, the swing diesel was modelled as always being aligned to Unit 1. This was accomplished by setting the swing diesel alignment top event split fraction SW always to 0. This is an acceptable modelling approach.

In order for BNL to check the internal consistency of the calculations and to express the core damage frequency as a function of the total diesel maintenance unavailability (i.e., AOT), sensitivity and consistency runs were done, in addition to the audit computations.

The results obtained are shown in Table 3.1 along with those obtained by PG&E. The logically connected calculations are grouped together for the 5DG and 6DG configurations. (These are: 5DGs-Calculations No.5, 1A, 1B, and 1C, and 6DGs-Calculations No.4A, 4B, 4, and 4C).

Figure 3.1 shows the core damage frequency as a function of the total maintenance unavailability, F_T for the 5DG and 6DG configurations. One can observe that the functional correlation between the CDF and the total maintenance unavailability can be fairly approximated by straight lines. The lines for 5DG and 6DG configurations run (almost) parallel, showing that under any reasonable AOT condition the 6DG configuration always provides smaller risk than the 5DG configuration.

3.3 Core Damage Frequencies With Contribution Due to Swing Diesel Overhaul

For the calculations where maintenance of the swing diesel is considered (Calculations 2, 3, and 3A) the quantification process is different. The calculations are based on the conditional core damage frequency calculations when the swing diesel is considered to be down for one year; i.e., when top event GF is set to 1.0 (GFF), and the modified and renamed top events of Table 2.4 are used. (The ID numbers of these calculations are: 6A, 6, and 6B.) These latter calculations are rather intricate and complex, especially the seismic parts. Some numerical values and interpretation of the variables were not provided in the AOT study; BNL received them more recently as supplemental information.[4]

Calculations 2, 3, and 3A essentially contain the sum of two terms; the first one is the CDF without scheduled maintenance and the second is the conditional CDF multiplied by the fraction of time the swing diesel is in scheduled maintenance.

The results obtained from the above calculations are also listed in Table 3.1 along with the original PG&E data. The conditional core damage frequency if the swing diesel is down for a year (5DG configuration) is also plotted as a function of the total maintenance unavailability, P_T, at the bottom part of Figure 3.1. The curve reflects a strong linear dependency.

Comparing the results obtained by PG&E and BNL associated with the swing diesel overhaul (Calculations 2, 3, and 3A) one observes that:

a. By changing the AOT from three to seven days (from Calculations 2 and 3) PG&E calculated a risk increase of about 1.3%, while BNL obtained a risk increase of 1.4%. These correspond to a mean diesel maintenance frequency of 7.74-4 hr^{-1}.

b. If one takes for the diesel maintenance frequency the value used for the reliability calculation, i.e., 1.06-3 hr^{-1}, and considers the results of BNL's Calculations 3 and 3A which characterize the AOT change, the risk increase would be less than 2.8%.

3.4 Risk Ratio Calculations

This section compares the results of the risk ratios obtained by BNL with those calculated by PG&E. Since the risk ratios are defined differently for unscheduled and scheduled maintenances, they are discussed in the following two subsections.

3.4.1 Risk Ratios for Unscheduled Maintenance

The risk ratio for unscheduled maintenances is defined by the formula:

$$RR_{u.m.} = \frac{MMD}{BP} * \frac{CCDF_{13}}{CDFOM} ,$$

where, MMD is the mean maintenance duration of a DG,

BP is the base period with no DG maintenance (i.e., average interval between DG outages,

$CCDF_{13}$ is the conditional core damage frequency when the swing diesel is assumed to be down for a year (in Table 3.1, Calculations 6A, 6, and 6B), and

CDFOM is the core damage frequency when there is no maintenance of any of the DGs (in Table 3.1, Calculation 5).

The RR values obtained by PG&E for the 5DG and 6DG configurations are listed in the column PG&E of Table 3.2.A. These values were obtained by using the same base period for both the 5DG and the 6DG configurations. The base period was determined by the DG maintenance frequency, 7.74-4 hr^{-1}. Per unit basis, it was assumed that the frequency of one of three DGs being out for maintenance is three times the individual DG maintenance frequency. The interval between DG maintenance outages is then the inverse of this value. The ratio $CCDF_{13}$/CDFOM was also treated to be the same for 5DG and 6DG configurations.

By comparing the PG&E RR values with each other, one notices that while there is an increase in the relative risk when the AOT changes from three days to seven days for the 5DG configuration; the relative risk does not decrease if one keeps the AOT the same but increases the system redundancy from 5DGs to 6DGs. In other words, the PG&E calculation does not indicate any advantage of installing the 6th DG.

According to BNL, the cause of this discrepancy is that PG&E used an incorrect base period for the 5DG configuration. BNL presumed that whenever a dedicated diesel is put into unscheduled maintenance at Unit 2, the swing diesel will be assigned to that unit, thus from the point of view of Unit 1 the swing diesel has an outage. (Both units are assumed to be operating.) Thus, on a per unit basis, the frequency of one of three DGs being out for maintenance is five times the individual DG maintenance frequency (the swing diesel counts three). Of course, in the case of 6DGs (three dedicated DGs per unit) the PG&E reasoning is correct.

BNL performed two relative risk calculations. In the first one, the DG maintenance frequency was assumed to be 7.74-4 hr^{-1} corrected by the maintenance frequencies of the LCVs. In the second one, the DG maintenance frequency was calculated by using the Diablo Canyon outage data (Table 5-7 of the AOT study[1]). This roughly corresponds to a DG maintenance frequency of 1.06-3 hr^{-1}.

The length of base periods used and the obtained RR results are listed in the columns "BNL" of Table 3.2.A. The results show a risk ratio increase of about a factor of two higher than the increase obtained by PG&E when the AOT changes from three days to seven days. For the same time periods, the BNL results correctly reflect the expected decrease of the risk ratio when the redundancy of the system increases (5DGs to 6).

In other words, the BNL calculations definitely indicate the advantage of the installation of the 6th DG.

3.4.2 Risk Ratios for Scheduled Maintenances

The risk ratio for scheduled maintenance is defined by the formula:

$$RR_{s.m.} = \frac{SCHD}{RP} \times \frac{CCDF_{13}}{CDF} ,$$

where, SCHD is the scheduled outage duration (10 days for 3-day AOT and 7 days for 7-day AOT),

RP is the period between scheduled maintenances of the swing diesel (i.e., the refueling period, 1.5 years),

$CCDF_{13}$ is the conditional core damage frequency when the swing diesel is assumed to be down for a year (in Table 3.1, Calculations 6A, 6, and 6B), and

CDF is the core damage frequency calculated with various mean maintenance durations (in Table 3.1, Calculations 1A, 1B, and 1C).

The results of the BNL calculations are shown in Table 3.2.B along with those of PG&E. There is an overall agreement between the two sets of data. Notice that the risk ratio for the 6DG configuration is zero. There is no scheduled maintenance during operation, hence, by definition $RR_{s.m.} = 0$.

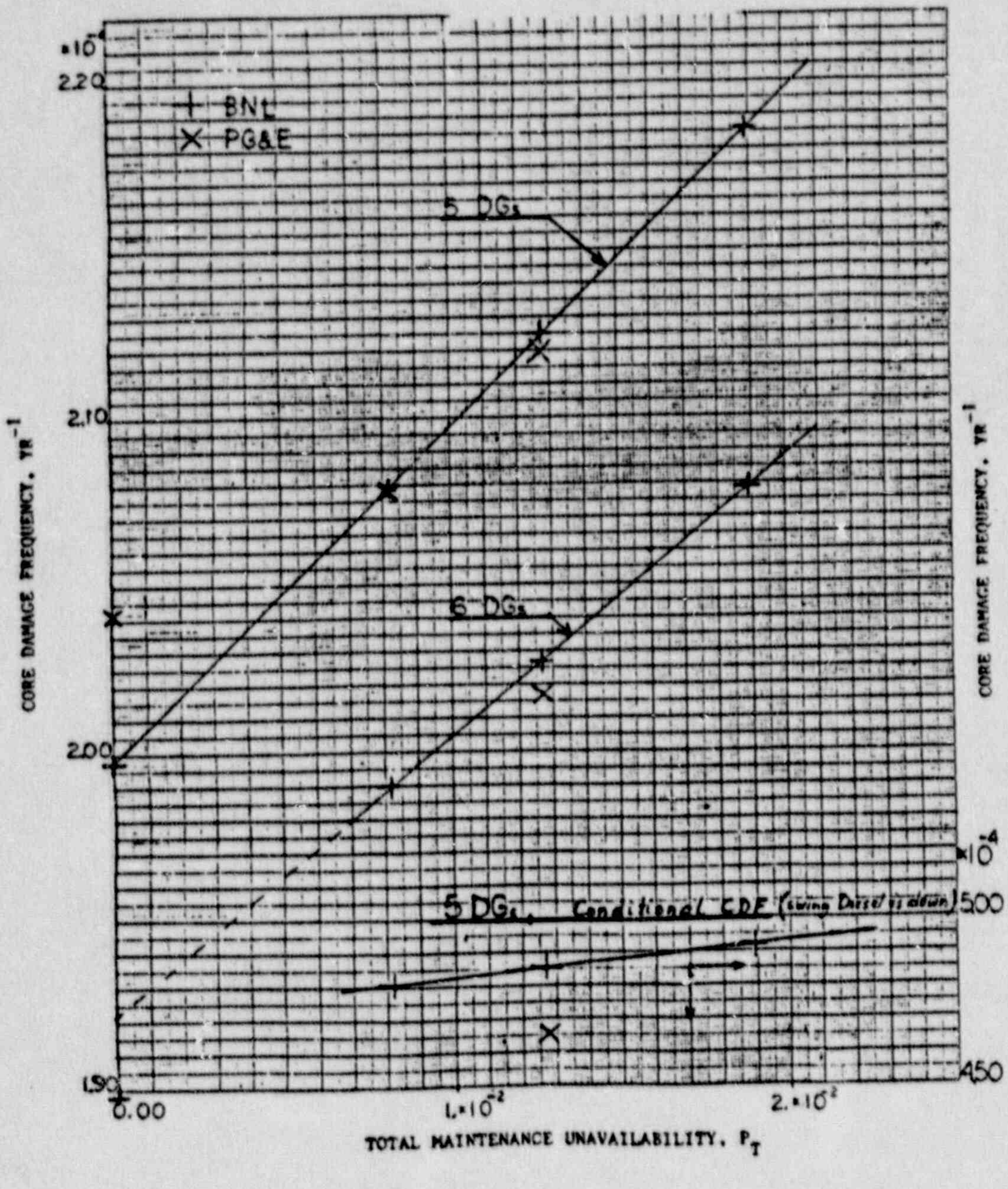


Figure 3.1 Core damage frequency as a function of total maintenance (diesel plus level control valve) unavailability for the present (5 DGs) and the planned (6 DGs) diesel configurations. Bottom curve: conditional core damage frequency for the present configuration, if the swing diesel is down for a year.

Table 3.1
Core Damage Frequencies
(Based on the Risk Analysis Approach)

				With One Unit at Power			
Number of Calculation	Number of DGs	Allowed Outage Time, AOT (Days)	Mean DG Maintenance Duration, MMD (Hrs)	Overhaul Period of Swing Diesel (Days)	Overhaul Period of DGs of the Other Unit (Days)	CDF (Yr^{-1}) PG&E	 BNL
5	5	*	0	0	0	2.042-4	1.971-4
1A	5	3	10.1	0	0	2.078-4	2.080-4
1B	5	7	16	0	0	2.120-4	2.125-4
1C	5	7	24	0	0	---	2.186-4
2	5	3	10.1	10	0	2.124-4	2.130-4
3	5	7	16	7	0	2.152-4	2.160-4
3A	5	7	24	7	0	---	2.221-4
4A	6	*	0	0	0	---	1.898-4
4B	6	3	10.1	0	0	---	1.990-4
4	6	7	16	0	0	2.017-4	2.027-4
4C	6	7	24	0	0	---	2.078-4
6A	5	3	10.1	1 year	0	---	4.812-4
6	5	7	16	1 year	0	4.650-4	4.857-4
6B	5	7	24	1 year	0	---	4.919-4

o DG maintenance.

Table 3.2.A
Risk Ratio Results
Unscheduled DG Maintenance

Definition: RR - Risk of Core Damage During Mean Maintenance Duration/Risk of Core Damage During Base Period With No Maintenance

			PG&E		BNL			
DG Configuration	AOT, Days	Mean Maintenance Duration, Hrs	Length of Base Period, Hrs	$RR_{s.m.}$	Length of Base Period*, Hrs	$RR_{s.m.}$	Length of Base Period, Hrs	$RR_{s.m.}$
5 DGs	3	10.1	448.0	.05	245.5	.10	---	---
		11.9	---	---	---	---	188	.15
	7	16.0	448.0	.08	245.5	.16	---	---
		17.5	---	---	---	---	184.9	.24
	7	24.0	---	---	245.5	.25	---	---
6 DGs	3	10.1	---	---	409.2	.06	---	---
		11.9	---	---	---	---	312	.09
	7	16.0	448.0	.08	409.2	.09	---	---
		17.5	---	---	---	---	369.9	.12
	7	24.0	---	---	409.2	.15	---	---

*Maintenance frequencies of LCVs are included.

Table 3.2.B
Risk Ratio Results
Scheduled DG Maintenance

Definition: RR = Risk of Core Damage During Scheduled Outages/Risk of Core Damage Between Refuelings (1.5 Years)

DG Configuration	DG Maintenance Policy Between Refuelings		Scheduled Outage Duration, Days	PG&E $RR_{s.m.}$	BNL $RR_{s.m.}$	Remarks
	AOT, Days	Mean Maintenance Duration, Hrs				
5 DGs	3	10.1	10	.041	.042	
	7	16.0	7	.028	.029	
	7	24.0	7	--	.029	
6 DGs	7	16.0	--	0.0	0.0	No scheduled DG outage is planned during unit operation.

4. CONCLUSIONS

BNL performed a thorough review of the PG&E AOT study. The review focused on the risk analysis approach.

The review identified some problematic spots in the analysis:

- The diesel top event split fractions 2G and 2H do not include the unavailability contribution of the overhauls of Unit 2 diesels performed with Unit 1 at power. PG&E performed conditional core damage calculations when the swing diesel is considered to be down and also (as sensitivity calculations) when the dedicated Unit 1 diesels are down. There are no calculations as to what is the conditional core damage frequency if Unit 2 diesels are down (i.e., when top events 2G or 2H are set to 1).
- The AOT analysis as well as the DCPRA are tacit about the coupling of the swing diesel when a dedicated diesel undergoes unscheduled maintenance with both units at power. For Unit 1, the swing diesel is unavailable if it is coupled to Unit 2 while a dedicated Unit 2 diesel is in maintenance.
- The risk analysis uses a low value for the maintenance frequency of the diesels. This means that the absolute risks are underestimated at a given AOT. With more realistic maintenance frequencies, the correct risk values for the present and suggested AOTs lie around the risk values obtained with the low maintenance frequency and mean maintenance times of 16 hours and 24 hours, respectively.

The BNL review found an overall agreement between the top event split fraction values obtained by BNL and PG&E. The small inconsistencies appearing sporadically are presumably due to the fact that BNL used point estimates, while PG&E used a Monte Carlo approach in the split fraction quantification. There is also an overall agreement between the BNL and PG&E core damage frequency values (disregarding the "no maintenance" base). There is a slight tendency that the BNL CDF values lie somewhat higher than those of PG&E.

BNL concurs with PG&E's findings that:

- The risk reduction effect of a adding the sixth DC is greater than the effect of changing to a seven day AOT. This is demonstrated by Figure 3.1, which shows that the CDF curve for the 6DG configuration always runs below and almost parallel with the CDF curve for 5 DG configuration.
- The effect on risk of changing from a three day to a seven day AOT is insignificant, on the order of 2 to 3%. (The curves in Figure 3.1 provide practical tools to evaluate risk changes for any combinations of diesel maintenance duration and frequency values.)
- The increase of the risk associated with a seven day AOT over a three day AOT performing scheduled maintenance on the swing diesel is also insignificant; less than 2.8%. The risk ratios determined by PG&E for this case are in agreement with those obtained by BNL for both 5DG and 6DG configurations.

BNL found that the risk ratios associated with unscheduled diesel maintenance are higher by a factor of 2 or 3 in absolute value than the values determined by PG&E for the 5DG configuration for any AOTs. The risk ratio increase associated with changing the AOT from three days to seven days was also found to be a factor of two higher than that of PG&E.

In contrast with the finding of the AOT study,[1] BNL's risk ratio calculations definitely indicate the advantage of the installation of the sixth DG.

REFERENCES

1. Diesel Generator Allowed Outage Time Study, Pacific Gas & Electric Company, May 1989.
2. Final report on the Diablo Canyon Long-Term Seismic Program, Pacific Gas and Electric Co., Diablo Canyon Power Plant, Docket Nos. 50-275 and 50-323, July 1988.
3. Diesel Generator Allowed Outage Time Study, Supplemental Information on DG Maintenance Duration, PG&E Letter to NRC, July 18, 1989.
4. Diesel Generator Allowed Outage Time Study, Supplemental Information Regarding the Equations Presented in Appendix B, p.B-15, September 5, 1989.
5. Lofgren, E.F. and F. Varcolik, "Probabilistic Approaches to LCO's and Surveillance Requirements for Standby Safety Systems," NUREG/CR-3082, November 1983.
6. Cho, N.Z., et al., "Analysis of Allowed Outage Times at the Byron Generating Station," NUREG/CR-4404, June 1986.
7. Driscoll, G.D., et al., "Surveillance Monitoring and Diagnostic Techniques to Improve Diesel Generator Reliability," EPRI NP-5924, July 1988.
8. Worrel, R.B. and D.W. Stack, "A SETS User's Manual for the Fault Tree Analyst," Sandia National Laboratories, NUREG/CR-0475, November 1978.

APPENDIX I

DATA ON MAINTENANCE DURATION OF DGs AND DG SUBSYSTEMS

Table I.1
Discretized Prior For Generic Maintenance Duration Distribution of DGs Having 72 Hour AOT*

Maintenance Duration (Hours)	Probability	Cumulative Probability
2.15+0	2.12-1	2.12-1
4.24+0	2.20-1	4.31-1
6.48+0	5.63-2	4.88-1
7.25+0	2.54-2	5.13-1
7.75+0	2.37-2	5.37-1
8.25+0	2.22-2	5.59-1
8.75+0	2.07-2	5.30-1
9.15+0	1.18-2	5.92-1
9.45+0	1.13-2	6.03-1
9.80+0	1.44-2	6.17-1
1.01+1	1.04-2	6.27-1
1.04+1	9.97-3	6.38-1
1.08+1	1.27-2	6.50-1
1.12+1	1.50-2	6.65-1
1.17+1	1.41-2	6.80-1
1.22+1	1.33-2	6.93-1
1.27+1	1.25-2	7.05-1
1.40+1	4.34-2	7.49-1
1.64+1	4.97-2	7.98-1
2.61+1	2.02-1	1.00+0

	Percentiles		
Mean	5th	50th	95th
10.5 hours	.507	6.85	23.7

*From "Supplemental Information to Diesel Generator AOT Study," PG&E Letter.[3] Data provided to PG&E by PL&G. Mosleh, A., et al., "A Data Base for Probabilistic Risk Assessment of LWRs," Pickard, Lowe and Garrick, Inc. PLG-0500, 1987.

Table I.2
Diesel Subsystem Downtimes Ranked in Decreasing Order and Subsystem Failure Rates*

Rank, i	Major Sub-system Failure	Mean Failure Rate x 10^{-3} F_i(Failures/ Diesel-Mth)	Mean Downtime Per Failure D_i(Hours)	Expected Downtime $F_i \times D_i \times 10^{-3}$ Hrs/Diesel-Mth
1	Engine, Mechanical	1.7	308	530
2	Turbocharger	2.3	82.6	190
3	Coolant Pumps, Motors & Associated Electrical	1.3	58.4	75.9
4	Lubricating Oil Contamination, Clogged Filters	1.0	50.3	50.3
5	Generator, Mechanical & Electrical	3.3	43.5	142
6	Air Motor Mechanical	1.4	26.9	37.7
7	Coolant Leakage	3.1	26.8	83.0
8	Exhaust System	1.1	22.0	24.2
9	Oil Leakage	1.9	20.0	38.0
10	Start Air Leakage	1.6	18.6	29.8
11	Electric Start	.54	17.8	9.6
12	Control & Instrumentation-Switches, Relays and Wiring	3.2	15.1	48.3
13	Start Air Signal	1.9	13.5	25.7
14	Governor Setpoint & Synchronizing Errors	1.9	12.4	23.6
15	Fuel Leakage	1.8	12.0	21.6
16	Voltage Regulator	3.0	10.8	32.4
17	Lubricating Oil Miscellaneous	1.4	10.8	15.1
18	Protective Trips	2.4	9.5	22.8
19	Start Air - Moisture, Rust & Contamination	2.1	9.4	19.7
20	Governor Oil	1.8	9.3	16.7
21	Injectors, Engine Fuel	1.4	9.3	13.0
22	Governor Sensing & Control	3.7	9.2	34.0
23	Oil Pumps, Prelube & Associated Electrical	.63	9.0	5.7
24	Fuel-Water, Air & Contamination	1.9	8.5	16.2
25	Tachometer	1.5	8.4	12.6
26	Governor-Hydraulic/Air Booster, Servomechanism & Linkage	2.5	7.5	18.8
27	Coolant-Heat Exchanger, Radiator	1.0	7.4	7.4
28	Load Sequencing Timers	3.8	6.5	23.4

Table I.2 (Continued)

Rank, i	Major Subsystem Failure	Mean Failure Rate x 10^{-3} F_i(Failures/ Diesel-Mth)	Mean Downtime Per Failure D_i(Hours)	Expected Downtime F_i x D_i x 10^{-3} Hrs/Diesel-Mth
29	Start-Air Valve Electrical & Mechanical	2.2	6.5	13.7
30	Start-Air Compressor & Miscellaneous	.63	6.0	3.8
31	Fuel Transfer Pumps & Associated Instrumentation & Electrical	1.3	5.1	6.6
32	Control Electric Power	1.1	4.8	5.3
33	Cooling-Miscellaneous	1.1	4.3	4.7
34	Output Breaker-Associated Circuitry & Control	1.9	3.1	5.9
Sums		$\sum_i F_i = 63.4$		$\sum_i F_i D_i = 1607.5$

Overall Mean Downtime, Per Failure $\bar{D} = \sum_i F_i D_i / \sum_i F_i = 25.35$

<u>Assuming Lognormal Downtime Distribution</u>

Maximum Likelihood $\mu = 2.6203$	
Maximum Likelihood $\sigma^2 = .8137$	
Overall Median Downtime Per Failure	13.74
Overall Mean Downtime Per Failure	20.64
5th Percentile	3.[illegible]
95th Percentile	60.59

*From Driscoll, G.D., et al., "Surveillance, Monitoring, and Diagnostic Techniques to Improve Diesel Generator Reliability," EPRI-NP-5924, July 1988.

PART 2

REVIEW RESULTS OF THE SYSTEM ANALYSIS IN THE DCPRA: DIESEL GENERATOR AND DIESEL FUEL TRANSFER SYSTEMS

1. INTRODUCTION

1.1 Objectives

The main objective of this letter report is to summarize the results, to date, of reviewing the unavailability analysis of the Diesel Generator and Diesel Fuel Transfer Systems described in the DCPRA.[1] The review was carried out with special attention to the details of the unavailability modelling of the maintenance activities on the DGs. (This particular emphasis was prompted by a request of the Pacific Gas and Electric Co to change the Allowed Outage Time (AOT) of the DGs from the present outage of three days to seven days, and the fact that the study[2] supporting this request derived data on expected core damage frequency changes based mainly on the DCPRA.) This report reflects BNL's current understanding of the subject systems and as such must be considered interim results. Final results will be provided in the NUREG/CR to be issued at the end of the project. That will reflect, at that time, any additional supporting input submitted by PG&E as well as any direct feedback on these preliminary findings.

1.2 Organization of the Report

Section 2 provides condensed descriptions about the configurations and functions of the Diesel Generator and the Diesel Fuel Oil Transfer Systems. It also describes the dependency of these systems on support equipment, the surveillance and maintenance conditions, the unavailability modelling in the DCPRA, and the original PRA results. The purpose of this approach is to present the reader stand alone documentation to which the review's findings can be directly compared. Section 3 contains the results of the BNL review and presents the current preliminary findings.

For completeness, the ranked cut sets of hardware unavailabilities (both independent and total) obtained by BNL for various diesel configurations are given in Appendix A.

2. UNAVAILABILITY MODELLING OF THE DIESEL GENERATOR AND DIESEL FUEL OIL TRANSFER SYSTEMS

2.1 Diesel Generator System Description, Configurations and Functions

The Diesel Generator System at the Diablo Canyon plant consists of five diesel generators: two dedicated to Unit 1, two dedicated to Unit 2, and one (a "swing diesel") shared between the two units. According to the DCFSAR,[3] the individual diesel generator units are isolated from each other and from other equipment. The swing diesel is physically located in Unit 1. Each diesel generator supplies power to its associated 4.16kV vital bus (H, G, and F - Units 1 and 2). In the event of a loss of electrical power from the main generator (due to a unit trip, a safeguard signal or a loss of voltage on a vital bus) the vital 4.16kV buses are automatically disconnected from the main generator and transferred to the offsite standby source. (The Unit 1 main generator provides power through auxiliary transformer 12. The standby power is provided through startup transformers 11 and 12.) If this transfer is unsuccessful or the standby power is unavailable, the diesel generators must start and provide power to the affected buses. The diesel generators start on undervoltage signals from their respective buses, load onto those buses (the output breakers are normally open), initiate reloading of the vital loads and continue delivering power at normal frequency to the buses. A safety injection actuation signal (SIS) from either Train A or B of the SSP System will also start the diesels (Train A will start 11 and 13, Train B will start 11 and 12).

The swing diesel (13) may supply power to either Unit 1 or Unit 2 vital Bus F. It will start with an undervoltage or an SI signal from either unit (SSPS Train A). Because the output is not shared simultaneously by the units, only one of its two circuit breakers is closed at a time. The breakers have individual sets of control and protection circuits. If one of the units receives an SI signal (earlier than the other), it is given priority of using the swing diesel.

The DGs are 2750 kW, 18 cylinder, vee configuration, ALCO made units. Each unit consists of a self-contained diesel engine directly connected to an alternating current generator. Each diesel has dual train electrical starting circuits and air system with turbocharger, ventilation, fuel oil system, self-contained radiator cooled jacket cooling water system, lube oil system, and speed control governor system.

- Each independent starting circuit has its own dc power source (DG11; dc panels 13, 12. DG12; dc panels 12, 11. DG13; dc panels 11, 13. DG21; dc panels 22, 21. DG22; dc panels 23, 22). The operating control circuit is common. Without control power a unit keeps running. A mechanical trip handle, located in the diesel compartment serves to shut the unit down.

- The air start system consists of two trains. Each train includes a compressor, a dryer, an air receiver and two air-driven motors. Air from receivers is fed through regulator valves and up to the starting air system solenoid valves. Only one motor is needed to start a diesel. Power supply to the compressor trains are provided by 480V ac buses: [DG11; Trains A and B; 1H, 1G. DG12; Trains A and B; 1G, 1F. DG13; Trains A and B; 1F (backup 2F), 1H (backup 2F). DG21; Trains A and B; 2G, 2F. DG22; Trains A and B; 2H, 2G.] One solenoid control valve of an air driven motor in each compressor train gets its "open" signal from the normal control, the other solenoid valve receives signal from the backup control. Upon initiation of a start, the solenoid valves open supplying air to the motors. After initiation, pressure switches located on the discharge of the jacket water pump shuts off the air supply. The air start system supplies air to the Level Control Valves (LCVs) of the diesel fuel oil day tanks. There is one air supply line per LCV.

- The air start system also includes an air operated turbocharger for quick starting and load pickup. The associated air subsystem consists of one turbo air compressor, one starting air receiver tank, and an air dryer. Two solenoid operated shut-off valves, one on each of the two supply lines, control the air supply to the turbocharger. A solid state speed-loss sensor controls the turbo-assist air supply to prevent a critical loss of speed when a sudden large load increase occurs.

- Each diesel has also another air system: the combustion air and exhaust system (ventilation), containing the intake and exhaust silencers and the two motor-driven crankcase exhauster fans.

- The engine fuel oil system involves the fuel oil day tank. Fuel oil is supplied by the Diesel Fuel Oil Transfer System (see its description in Section 2.2). The fuel oil level in the day tank is controlled by two redundant level control valves (LCVs). Each LCV has two 480V ac control power sources; a normal supply and a backup supply. The power sources for LCVs associated with the primary fuel oil transfer pump (Train 02) are: 480V ac buses 1G and 2G. Power sources for LCVs associated with the secondary fuel oil transfer pumps (Train 01) are: 480V ac buses, 2H and 1H. The valves may be actuated also manually.

- The cooling of a diesel unit is provided by a closed loop jacket cooling water system. The jacket water pump takes water from the lube oil cooler and the turbocharger aftercooler. There is a 50-gallon expansion tank connected to the suction side of the pump. The pump discharges water through the engine block and turbocharger to a common return line. Engine water temperature is maintained at 170°F by a thermostatically controlled three-way valve set. Overheated water is sent to a water radiator, where it is cooled by forced air (engine driven fan) taken from outside the building.

- The lubricating oil system consists of an oil reservoir, an engine driven pump and a heat exchanger. The heat exchanger is cooled by the engine jacket cooling water system. Lubricating oil temperature is thermostatically controlled. The oil is kept in the range of 90°-110°F circulated by a small pre-circulation pump even if the generator is idle, to reduce wear during the engine start period. The diesel automatically stops if the oil pressure drops below 40 psig.

- To control the fuel delivery and therefore the engine's speed and generator output frequency to a predetermined value, an engine governor speed control unit is used. The governor has electrical and mechanical controls; both of which act through a hydraulic actuator to control the fuel supply.

The diesels cannot respond to a start signal under the following conditions:

1. Shutdown relay tripped.
2. Manual test condition.
3. Low fuel level in the day tank.
4. Low pressure in both starting air receivers.
5. Loss of dc control power.
6. Voltage regulator on manual.

The eventual problems of the diesels are annunciated by various alarms (14 groups of signals) in the control room.

The loads of the diesels are listed in Table 2.1. Each diesel has enough capacity to handle some extra startup load. The loading of the diesels during the recirculation phase of a LOCA is under the control of the operator.

Each generator compartment is provided with an automatic flooding CO_2 gas system for fire protection.

2.2 <u>Diesel Fuel Oil Transfer System, Configuration and Function</u>

The diesel fuel oil transfer system maintains a supply of fuel oil to each DG day tank from two large underground storage tanks (capacity: 40,000 gallons per tank). It contains two trains (01 and 02), each having a rotary screw type positive displacement pump. These pumps are self priming. A single pump has enough capacity [illegible] gpm at 50 psig) to supply all the five diesels. (The fuel consumption rate is about 3.2 gpm per DG). Each pump train has a fuel oil distribution header supplying all five of the DGs.

Manual crosstie valving between headers allow either transfer pump to deliver to either header. Also, it is possible to pump from either of the storage tanks.

Local controls for the system are located at each DG. There are two sets of controls; one for pump train 01 and another for pump train 02. These are the LCV switches: a total of 10 (5x2). Each switch starts the transfer pumps and opens the LCV of its respective train. The pump start levels are different: 252 gallons for train 01 and 271 gallons for train 02. Once a pump is started it will remain running until shut down by the operator. If all the LCVs are closed (the day tanks are full) the fuel oil will recirculate back to the main storage tank.

The motors that drive the pumps are powered by 480V vital ac buses (pump train 01 by either bus 1H or 2H, from Units 1 and 2 respectively, and pump train 02 by either bus 1G or 2G). A manual transfer switch determines the alignment, the only criterion for alignment is that the pumps should be powered by different units.

The operation of the oil fuel transfer system is made on a demand basis: when one of the day tanks reaches a low level set point, the fuel transfer pumps start and remain running until all diesels have been shut down. For the six hour mission time (24 hours for seismic events) of the diesels, the fuel transfer system must remain functioning to replenish the fuel supply to each running diesel. The minimum total storage in the storage tanks is sufficient for seven days of power generation.

The importance of the operability of the fuel oil transfer system for the plant safety is obvious: if the fuel transfer system is unavailable, it results in failure of all the DGs of both units, Unit 1 and Unit 2. For events when both ac powered fuel transfer pumps might become unavailable, a dedicated portable fuel oil driven pump is kept at hand. This pump takes suction directly from the main storage tank and connects to one of the fuel delivery headers. Flexible hoses are used to make the appropriate connections.

2.3 Top Event Definitions, Success Criteria

Associated with the unavailability of the diesel generators, the DCPRA defines six top events in the electric part of the support system event tree. The designators of these top events and their relationships with the diesels are:

- Top Event GF - Diesel Generator 13 ("swing diesel")
- Top Event GG - Diesel Generator 12
- Top Event GH - Diesel Generator 11
- Top Event 2G - Diesel Generator 21
- Top Event 2H - Diesel Generator 22
- Top Event SW - Units alignment of the swing diesel, 13

If the offsite grid is available (top event OG in the support system event tree is successful) only the "G" events (GF, GG, GH) are questioned in the support systems event tree. If the offsite grid fails, all the five top events are questioned. The boundary conditions of these top events depend on the status of the preceding diesel generators in the event tree. Thus, top event GF has only one boundary condition (GF1) corresponding to the case when all support is available. GG has three boundary conditions (GG1, when GF succeeded; GG2, when GF failed; and GG3, when GF was bypassed, i.e., not demanded). Similarly GH has 6, 2G has 10, and 2H has 15 boundary conditions. Top event SW has four boundary conditions: one for LOCAs; one for LOOPs, when an equal number of diesels are operating at Unit 1 and Unit 2; and two for LOOPs, when an unequal number of diesels are operating at the two units.

Only one top event is defined in the DCPRA for the support system event tree associated with the diesel fuel oil transfer system . The designator of this top event is: LO. It is evaluated for six boundary conditions, depending on the availability of 480V ac buses at both of the units (i.e., 1G, 2H, 2G, and 1H).

The success criteria of the above top events are described in Table 2.1. The Technical Specification requirements with respect to the operability of the associated systems are also indicated.

2.4 Logic Model of the Diesels and Diesel Fuel Oil Transfer System Dependency on Other Support Systems

The generic reliability block diagram for the diesel generators is shown in Figure 2.1. The diagram is constructed from blocks (supercomponents) of the DG system. The boundaries of the supercomponents (for instance: GH-1, GH-2A, GH-2B) are indicated in Figures 2.2 through 2.9. Notice, that the equipment boundaries for each of the diesels start with the diesel generator and include the output breaker, the fuel oil day tank, the day tank level control valves, and the undervoltage and transfer control relays. The diesel starting air system was not modelled separately because it was included as part of the diesel start failure data.

The reliability block diagram shows the dependencies on the supercomponents of the plant (ac and dc) electrical systems.

The reliability block diagram for the diesel fuel oil transfer system (Top Event, FO) is presented in Figure 2.10. The boundaries of the pump train blocks are indicated in Figure 2.11. The reliability block diagram shows also the system dependencies on other supercomponents of the plant (ac and dc) electrical systems.

2.5 Quantification of Top Event Split Fractions

The definitions of the boundary conditions and the associated split fractions for top events associated with the DG system are listed in Table

2.3. Table 2.4 presents a similar list for the diesel fuel oil transfer system (Top Event, LO).

Table 2.5 presents the values of diesel generator related top event split fraction values quantified by PG&E. Notice, that to provide better train-wise dependency tracking in the event tree model, the split fractions are expressed in terms of unavailabilities of various diesel state combinations (conditional split fractions, CSF). The arithmetic is explained in the DCPRA, Chapter D.2.1.5. The table presencs also the total unavailability value (TTL) used in the calculation of each CSF, along with the main contributors to the total unavailabilities, such as hardware (HW), maintenance (MN), test (TS), and human error (HE). At a given boundary condition the hardware contribution relates to the normal alignment, when no test or maintenance activities are being performed. To provide complete information, the table also indicates the two constituent parts of the hardware contribution to the unavailability: the independent (HWI) and the dependent (HWD) (i.e., common cause) failures of the supercomponents of the diesels.

The maintenance contribution is a significant contributor to the total unavailability. The DCPRA assumes that, due to Technical Specification limitations, only one diesel or level control valve may be in maintenance at a time. The following relevant quantities are used in the maintenance unavailability quantification:

Diesel maintenance frequency, ZMDGSF: 7.74-4/hr (Mean Value). Variance = 2.33-8, 5th Percentile = 5.25-4, Median = 7.52-4, 95th Percentile = 9.66-4.

Diesel maintenance duration, ZMGSD: 1.01+1 hr (Mean Value). Variance = 3.99, 5th Percentile = 6.65, Median = 9.74, 95th Percentile = 13.3.

Level control valve maintenance frequency, ZMGNDF: 2.03-5/hr (Mean Value). Variance = 3.52-11, 5th Percentile = 1.14-5, Median = 1.91-5, 95th Percentile = 2.97-5.

Level control valve maintenance duration, ZMCN3D: 1.89+1 hr (Mean Value). Variance - 597.0, 5th Percentile - 1.54, Median - 10.1, 95th Percentile - 51.3.

Notice that the total maintenance unavailability of a diesel unit is determined by the diesel (as defined in DCPRA) maintenance unavailability plus the LCV maintenance unavailability. When a diesel is unavailable (not for reason of preventive maintenance) the other diesels must be surveillance tested once within 24 hours to verify operability. The DCPRA includes the unavailability contribution due to this type of test in the maintenance unavailability (MN).

The test contribution to the total unavailability is modelled in the DCPRA as to be due to the scheduled monthly surveillance tests, which include the manual test of the fuel transfer system to the diesels and the quarterly stroke test of the LCVs.

There is no explicit human error contribution to the total unavailability, because human errors occurring after maintenances and tests due to leaving diesel components in misalignment are included in the maintenance and test contributions.

Table 2.6 lists the split fraction values for the various boundary conditions of the FO top event. The table, as the previous one, details the hardware (independent and dependent components), maintenance test and human error contributions to the total unavailability values. Notice there are no explicit test or human error contributions. All the tests on fuel oil transfer system can be performed without making the system inoperable, human errors occurring leaving a fuel oil transfer train in misalignment after maintenance are included in unavailability values due to maintenance.

2.6 Quantification of Seismic Split Fractions for DG Top Events

The basis for detailing the seismic split fraction quantification for the DG top events is to provide insight into how the maintenance unavailability (and through it, the AOT) affects the seismic top events and consequently the seismic contribution to the core damage frequency. (This particular investigation was done as part of the parallel BNL DG AOT review as discussed in Section 1.)

All diesel generator components susceptible to failures by seismic events contribute to the diesel unavailability. The components considered to be the most vulnerable to seismic effects are the following:

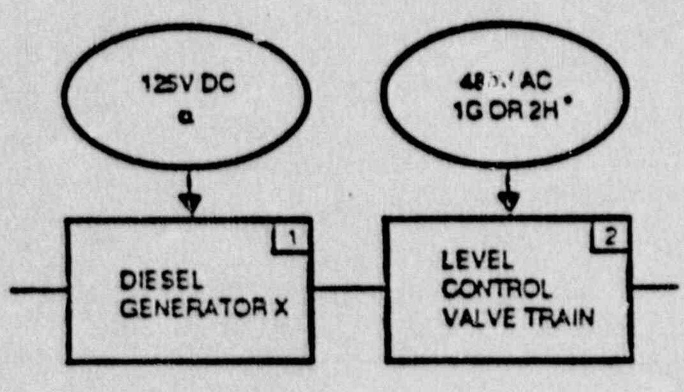
Component	Fragility Designator
DG Control Panel	ZDGCPN
DG Excitation Panel	ZDGEXC
DG Radiator/Water Pump	ZDGRWP
Diesel Generator Itself	ZDGSLGN

By using the conditional seismic failure probabilities ("fragilities"), the DCPRA combines them into a "seismic term" denoted by SEIST. SEIST has seven values corresponding to the seven seismic levels (i.e., spectral acceleration ranges) defined in the DCPRA. The seven SEIST values were determined by the mean fragilities of the diesel components listed in Table 6-44 on p.6-175 of Reference 1.

In order to calculate seismic split fractions, the DCPRA combines the SEIST values with the total unavailability values (TTL) coming from the conventional hardware, maintenance, test and human failures. In the case of seismic events, however, the DCPRA (correctly and innovatively) treats many human failures as seismic level-dependent; that is, the human factor probabilities are also dependent upon the seismic level.

To be more *specific*, the human failure which affects the TTL unavailabilities is the "failure to reestablish fuel oil transfer to day tanks by aligning a portable fuel oil transfer pump (see also Figure 2.10) and by controlling the day tank LCVs manually;" its designator is ZHEF06. For numerical values as a function of seismic level, see Appendix G of the DCPRA Table G.1-2, transmitted recently to BNL by PG&E.[4]

By using the resultant unavailabilities (SEIST + seismic level dependent TTL) the conditional seismic split fractions were determined for each diesel top events according to the rules of the sequential diesel failure model. These split fractions are listed as a function of the seismic level in Table 2.7. Each value of the table has a slight AOT dependence through the maintenance contribution to the TTL component of the unavailability.



X	α
13	11
12	12
11	13
21	22
22	23

DIESEL GENERATOR
CONTROL POWER

* THESE ARE THE NORMAL POWER SUPPLIES FOR THE TWO LCV TRAINS. THE BACKUPS ARE 2G AND 1H RESPECTIVELY

Figure 2.1. Reliability block diagram for the diesel generators.

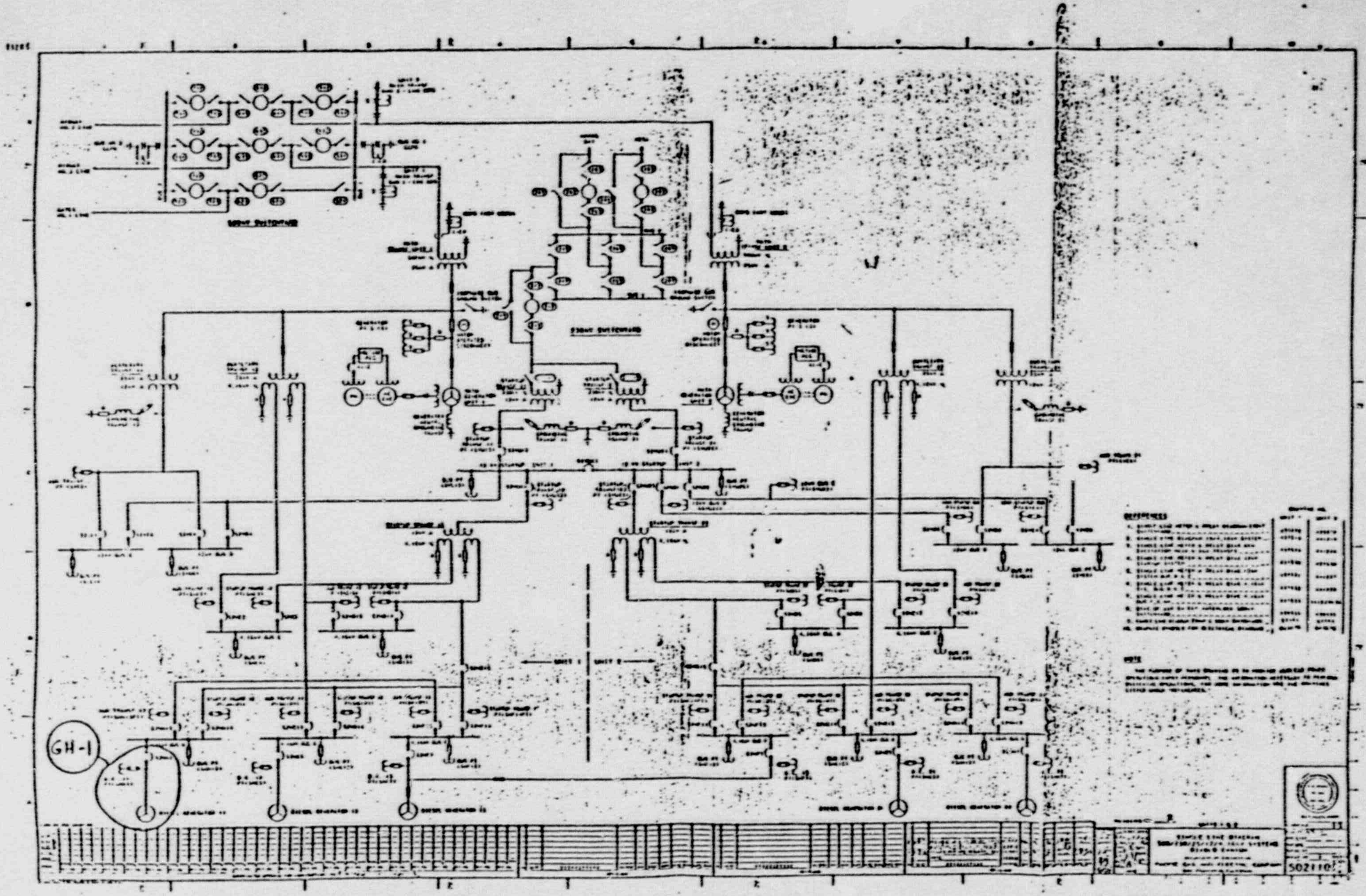


DIAGRAM D.2.1.S-1

Figure 2.2. Diesel Generators; Supercomponents.

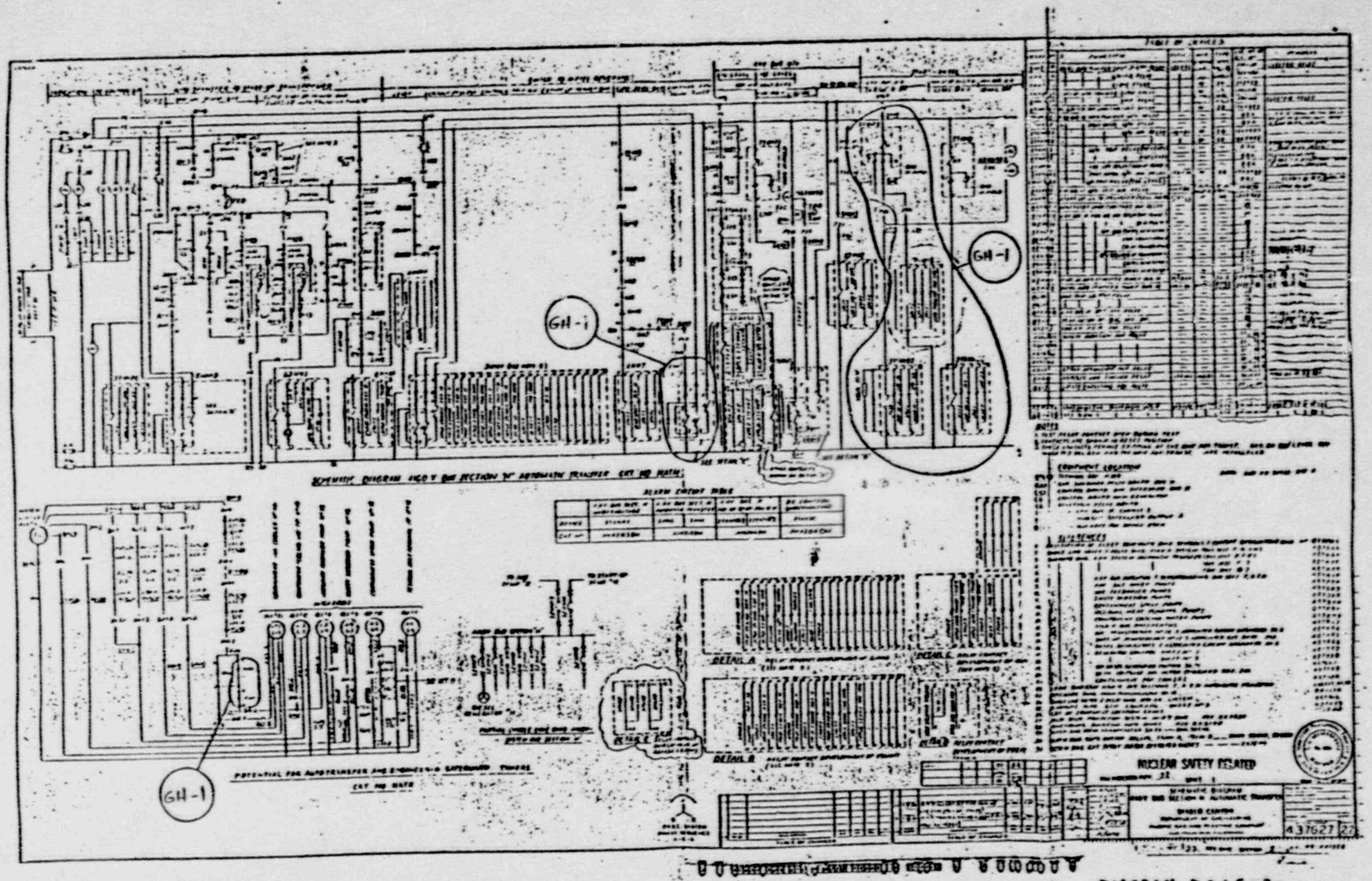


DIAGRAM D.2.1.5-2

Figure 2.3. Diesel Generators; Supercomponents.

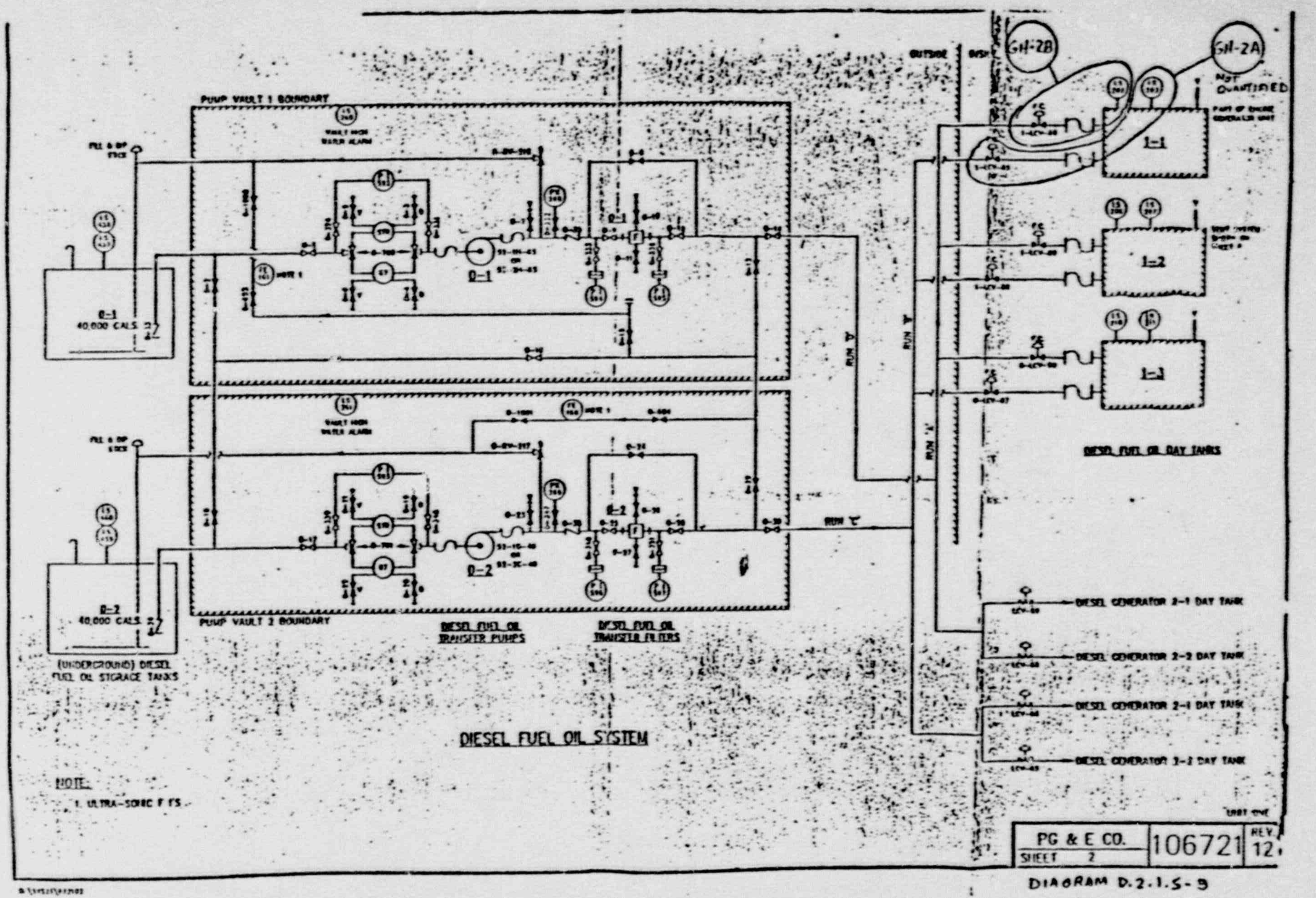


Figure 2.4. Diesel Generators; Supercomponents.

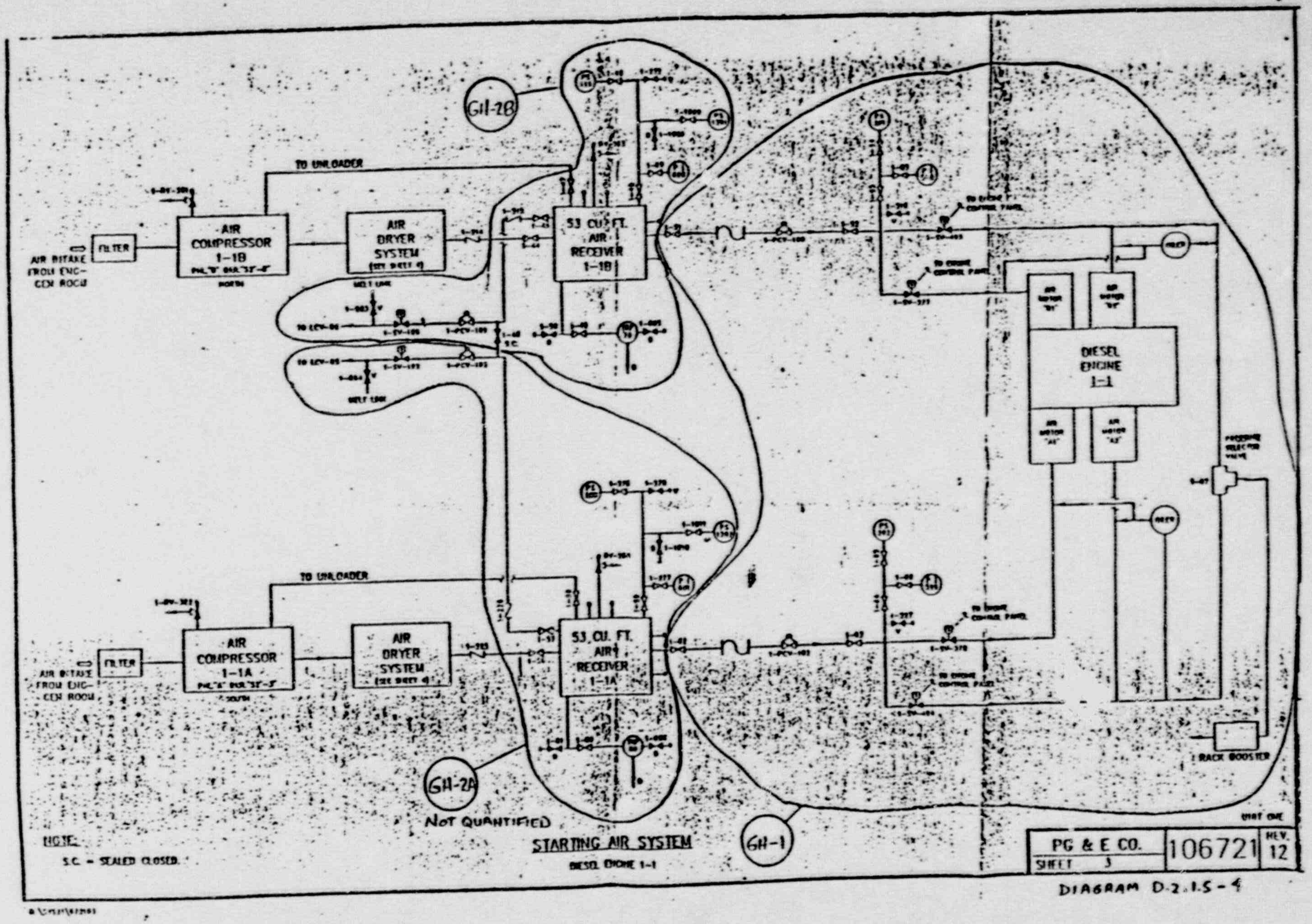


Figure 2.5. Diesel Generators; Supercomponents.

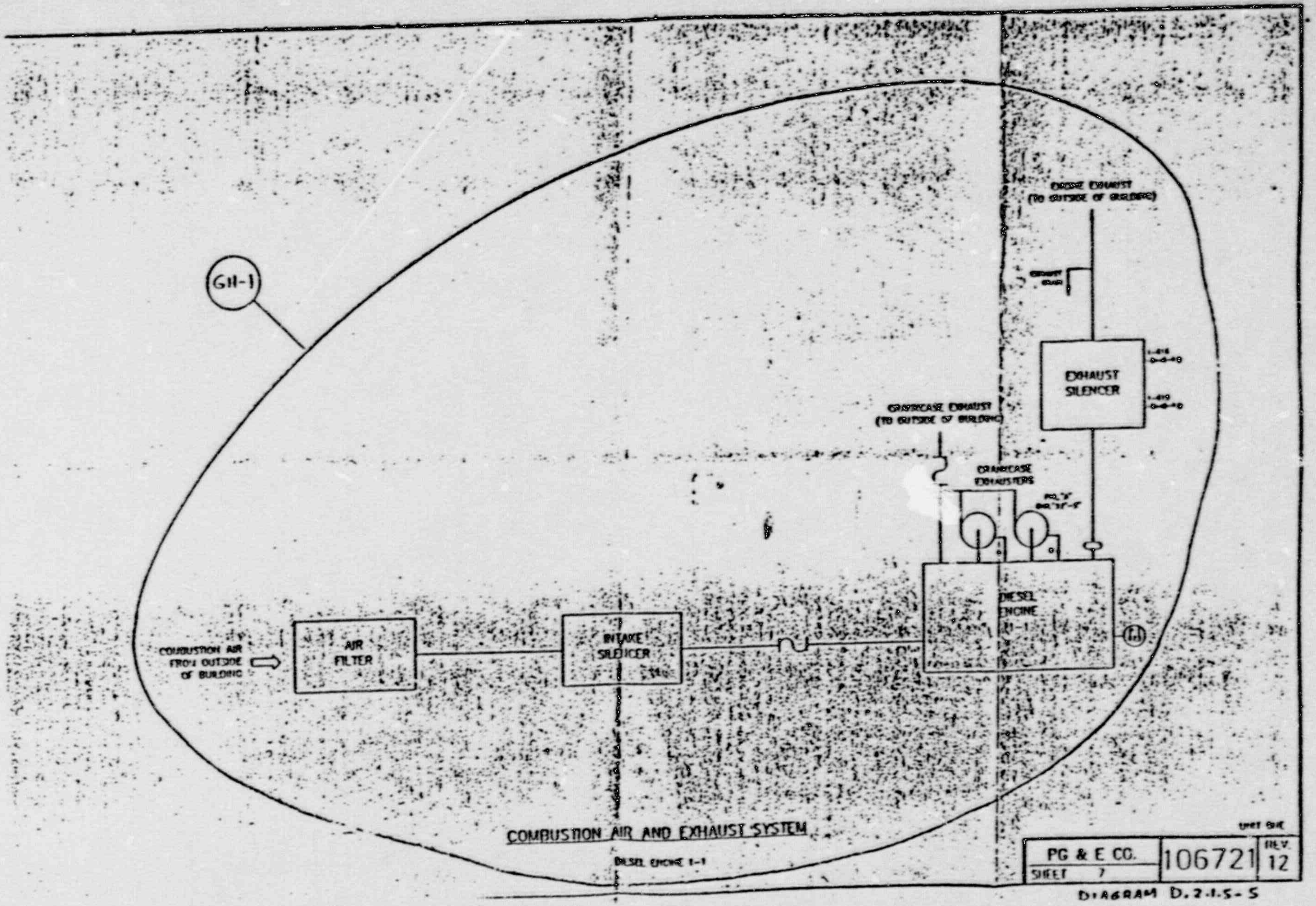
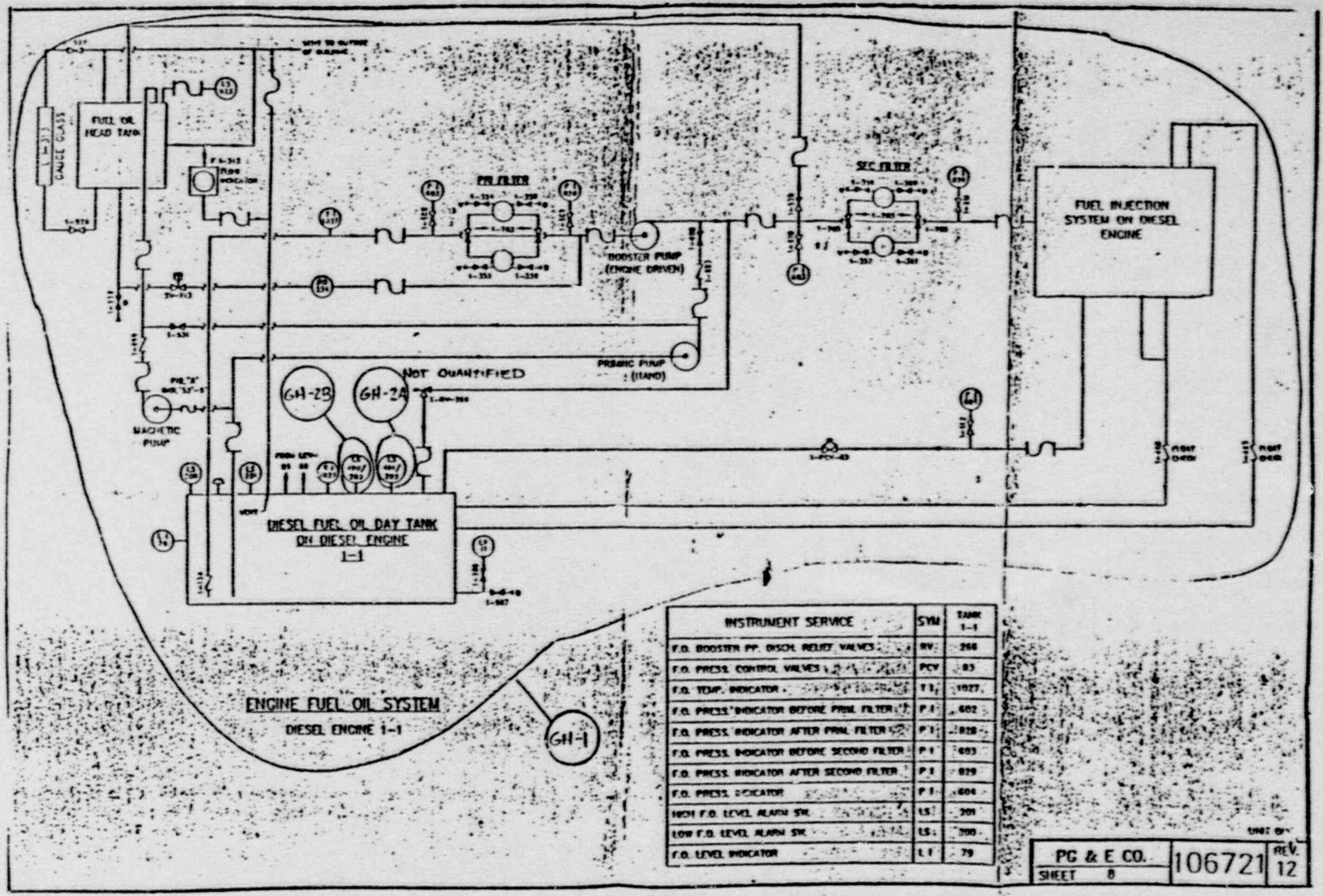


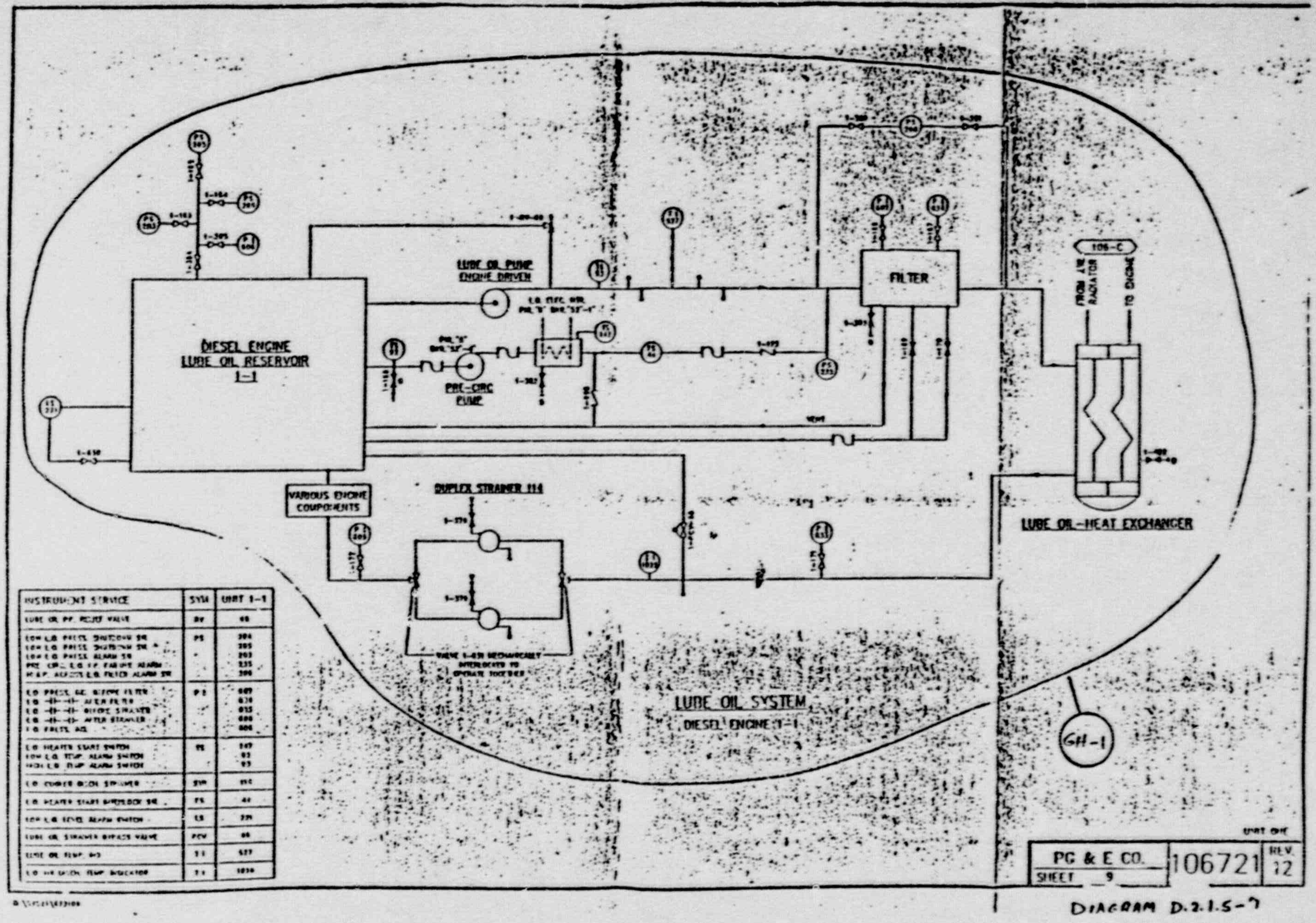
Figure 2.6. Diesel Generators; Supercomponents.



INSTRUMENT SERVICE	SYM	TANK 1-1
F.O. BOOSTER PP. DISCH. RELIEF VALVES	RV	266
F.O. PRESS. CONTROL VALVES	PCV	83
F.O. TEMP. INDICATOR	T I	1027
F.O. PRESS. INDICATOR BEFORE PRIM. FILTER	P I	602
F.O. PRESS. INDICATOR AFTER PRIM. FILTER	P I	828
F.O. PRESS. INDICATOR BEFORE SECOND FILTER	P I	693
F.O. PRESS. INDICATOR AFTER SECOND FILTER	P I	829
F.O. PRESS. INDICATOR	P I	604
HIGH F.O. LEVEL ALARM SW.	LS	201
LOW F.O. LEVEL ALARM SW.	LS	200
F.O. LEVEL INDICATOR	L I	79

DIAGRAM D.2.1.5-6

Figure 2.7. Diesel Generators; Supercomponents.



INSTRUMENT SERVICE	SYM	UNIT 1-1
LUBE OIL PP. RELIEF VALVE	RV	48
LOW L.O. PRESS. SHUTDOWN SW	PS	204
LOW L.O. PRESS. SHUTDOWN SW *		205
LOW L.O. PRESS. ALARM SW	"	203
PRE-CIRC. L.O. P.P. FAILURE ALARM		235
H.D.P. ACROSS L.O. FILTER ALARM SW		390
L.O. PRESS. IND. BEFORE FILTER	PI	607
L.O. —II— —II— AFTER FILTER		631
L.O. —II— —II— BEFORE STRAINER		605
L.O. —II— —II— AFTER STRAINER		633
L.O. PRESS. IND.		604
L.O. HEATER START SWITCH	TS	107
LOW L.O. TEMP. ALARM SWITCH		92
HIGH L.O. TEMP ALARM SWITCH		93
L.O. COOLER BLOCK STRAINER	STR	114
L.O. HEATER START INTERLOCK SW	FS	41
LOW L.O. LEVEL ALARM SWITCH	LS	221
LUBE OIL STRAINER BYPASS VALVE	PCV	46
LUBE OIL TEMP. IND	TI	527
L.O. HX OUTLET TEMP INDICATOR	TI	1029

DIAGRAM D.2.1.5-7

Figure 2.8. Diesel Generators; Supercomponents.

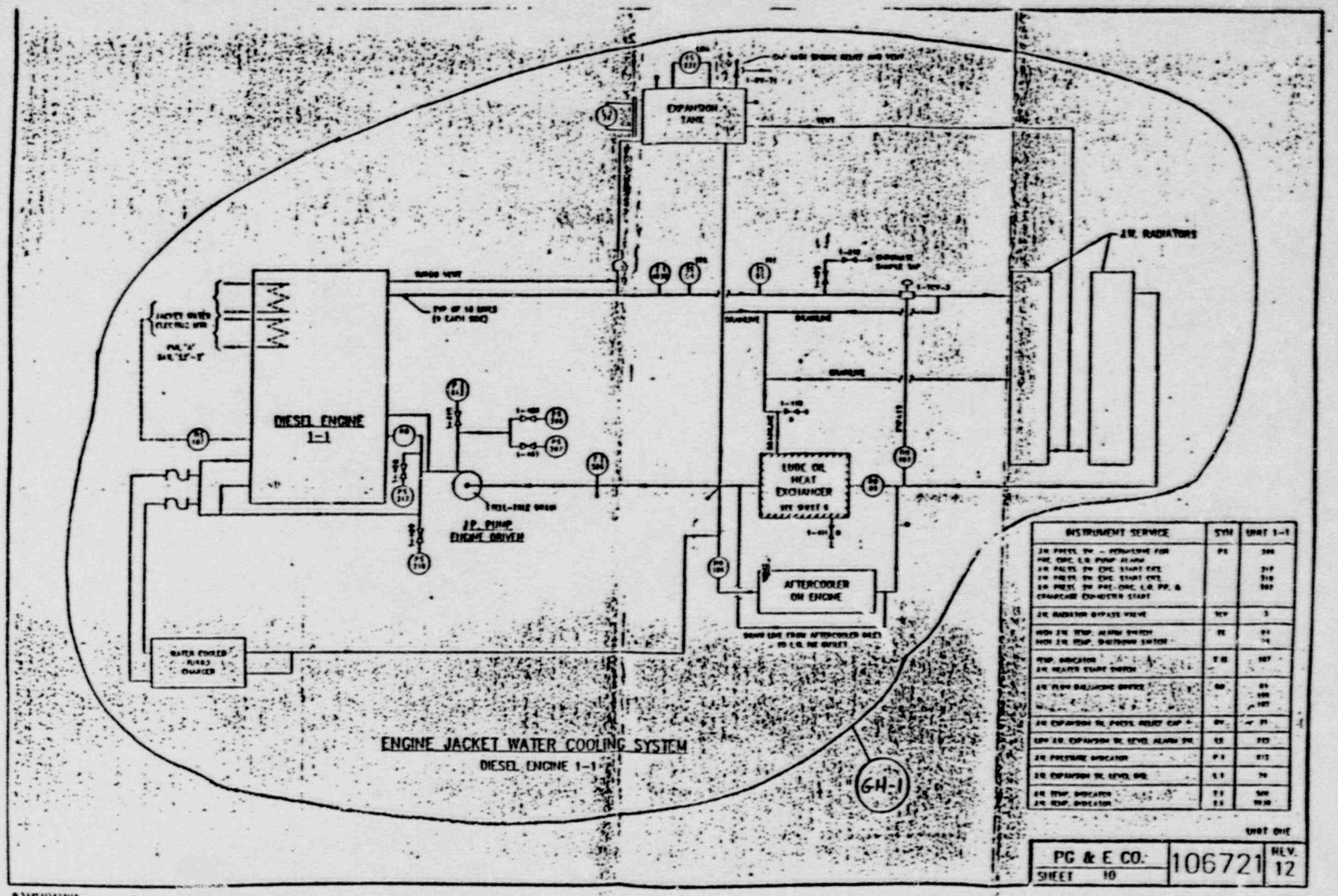
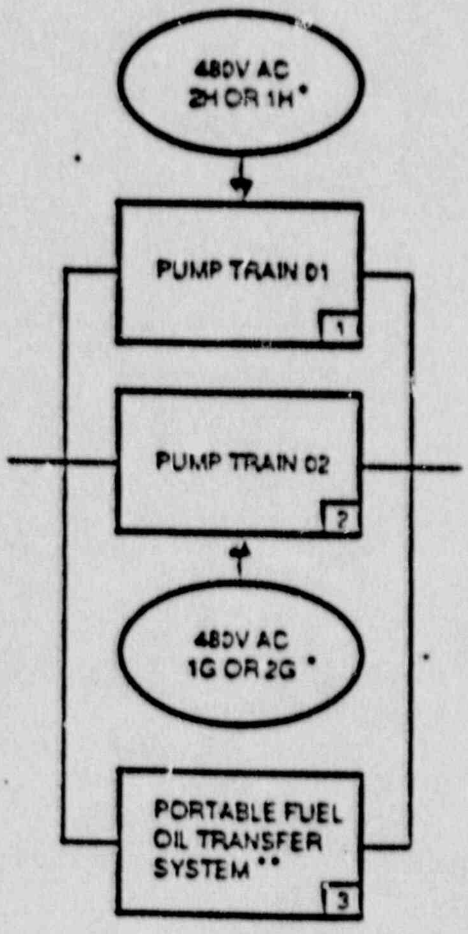


DIAGRAM D.2.1.5-8

Figure 2.9. Diesel Generators; Supercomponents.



* BACKUP POWER SOURCE

** THE PORTABLE FUEL OIL TRANSFER SYSTEM IS EVALUATED IN THE ELECTRIC POWER RECOVERY MODEL

Figure 2.10. Reliability block diagram for the diesel fuel oil transfer system (Top Event, FO).

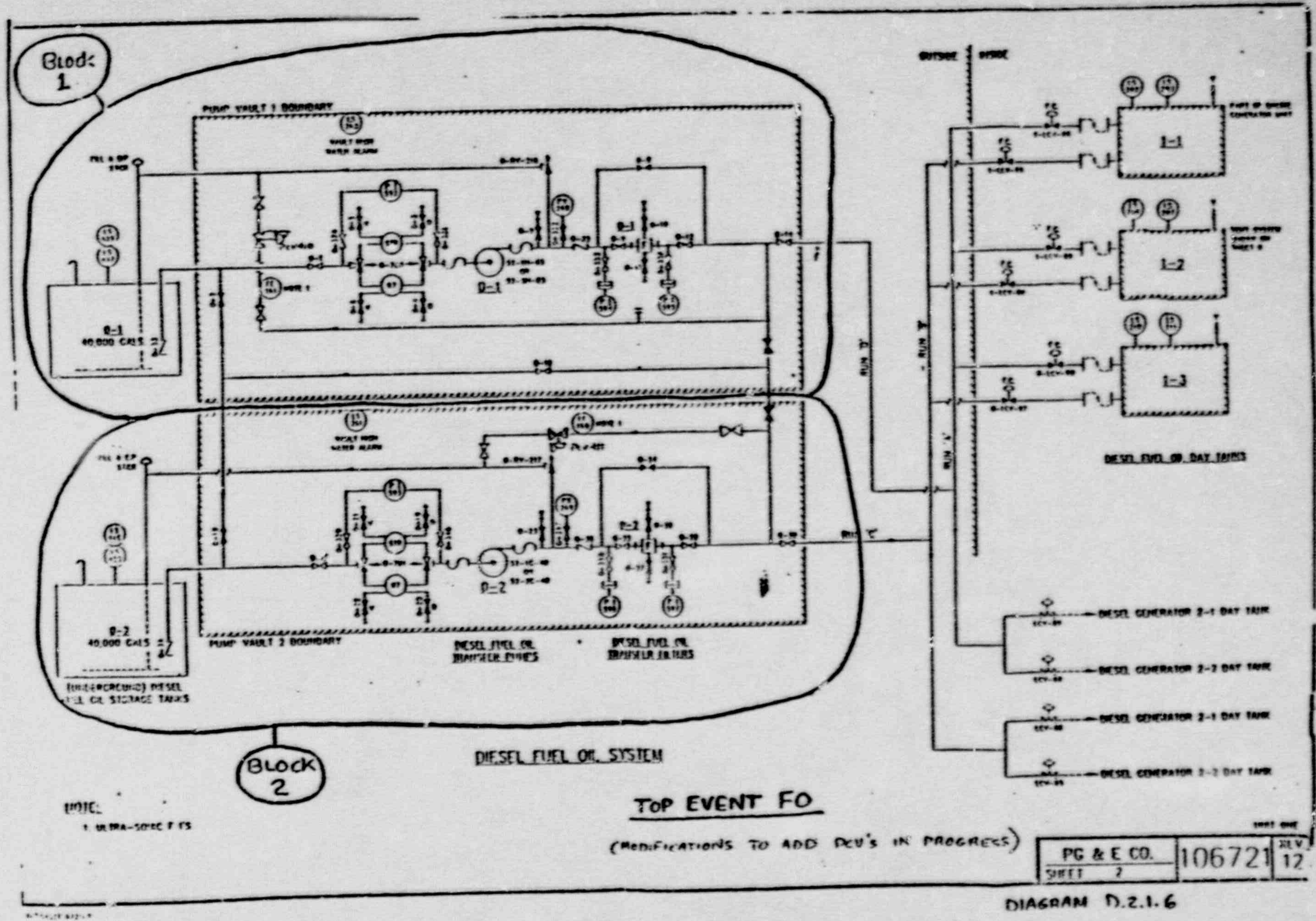


Figure 2.11. Top Event, FO - Supercomponents. Diesel fuel oil transfer system.

Table 2.1

Bus	DG	Vital Safety-Related Loads
F	1-3 (Swing)	Centrifugal Charging Pump No.1
		Safety Injection Pump No.1
		Containment Fan Cooler Unit No.2
		Containment Fan Cooler Unit No.1
		Component Cooling Water Pump No.1
		Auxiliary Saltwater Pump No.1
		Auxiliary Feedwater Pump No.3
G	1-2 (2-1)	Centrifugal Charging Pump No.2
		Residual Heat Removal Pump No.1
		Containment Fan Cooler Unit No.3
		Containment Fan Cooler Unit No.5
		Component Cooling Water Pump No.2
		Auxiliary Saltwater Pump No.2
		Containment Spray Pump No.1
H	1-1 (2-2)	Safety Injection Pump No.2
		Residual Heat Removal Pump No.2
		Containment Fan Cooler Unit No.4
		Component Cooling Water Pump No.3
		Auxiliary Feedwater Pump No.2
		Containment Spray Pump No.2

Table 2.2
Top Event Definition and Success Criteria
Diesel Generator and Diesel Fuel Transfer Systems

Top Event Designator	Top Event Definition			Top Event Success Criteria
GF	DG13	provides power for	$F_{1,2}$	Each top event is successful if the corresponding DG starts on undervoltage signal from its bus, takes bus loads and continues powering loads for the appropriate mission times (6 hours or 24 hours).
GG	DG12	6 hours (24 hours	G_1	
GH	DG11	for seismic events)	H_1	
2G	DG21	to 4.16kV ac buses	G_2	
2H	DG22		H_2	
	(Bus index numbers indicate plant Unit No.)			
SW	Swing diesel alignment. DG13 is normally aligned to Unit 1.			The value of SW determines whether DG13 goes to Unit 2. A value of 0 indicates it does not, a value between 0 and 1 represents the probability that it does.
FO	Diesel fuel oil transfer system provides fuel oil for each of the DGs for six hours (24 hours for seismic events).			One of two pumps starts on low day tank level and refills each day tank for the period that each diesel operates.

FSAR Success Criteria:

Any two of three DGs and their associated buses are adequate to serve the vital loads necessary for safe shutdown of a single unit (although one DG may supply power to two vital buses at the same time, no credit is currently given this mode of operation).

The diesel fuel oil transfer system must remain operable and deliver fuel to each of the DGs for the time the DGs are required to operate. There must be enough fuel in storage tanks for seven days of power generation.

Technical Specifications:

With a single DG inoperable, demonstrate the operability of the remaining ac sources within 24 hours. Restore the diesel within 72 hours.

With two DGs inoperable, demonstrate the operability of the two offsite ac circuits (one 230kV and one 500kV line) within one hour and at least once every eight hours. Restore at least two of the inoperable diesels within two hours.

Table 2.3
Boundary Condition and Split Fraction Identifications for Top Events GF, GG, GH, 2G, 2H, and SW

Top Event	Case	Diesel Conditions 13	12	11	21	22	Comments
GF - Unavailability of DG13 under the following conditions:							
	GF1						All support available.
GG - Unavailability of DG12 under the following conditions:							
	GG1	0					Offsite grid succeeded, GF succeeded.
	GG2	1					Offsite grid succeeded, GF failed.
	GG3	-					Offsite grid succeeded, GF bypassed (not demanded)
GH - Unavailability of DG11 under the following conditions:							
	GH1	0	0				Offsite grid succeeded, both GF, GG succeeded.
	GH2	0	1				Offsite grid succeeded, GF-S/F, GG-F/S (two possible combinations).
	GH3	1	1				Offsite grid succeeded, both GF, GG failed.
	GH4	0	-				Offsite grid succeeded, GF-S/B, GG-B/S (two possible combinations).
	GH5	1	-				Offsite grid succeeded, GF-F/B, GG-B/F (two possible combinations).
	GH6	-	-				Offsite grid succeeded, both GF, GG bypassed.
2G - Unavailability of DG21 under the following conditions:							
	2G1	0	0	0			Offsite grid failed, all GF, GG, and GH succeeded.
	2G2	0	0	1			Offsite grid failed, two of GF, GG, and GH succeeded, the third failed (three possible combinations).
	2G3	0	1	1			Offsite grid failed, two of GF, GG, GH failed, the third succeeded (three possible combinations).
	2G4	1	1	1			Offsite grid failed, all GF, GG, GH failed.
	2G5	0	0	-			Offsite grid failed, two of GF, GG, GH succeeded, the third bypassed (three possible combinations).

Table 2.3 (Continued)

Top Event	Case	Diesel Conditions 13	12	11	21	22	Comments
	2G6	0	1	-			Offsite grid failed, one of GF, GG, GH succeeded, one failed, the third bypassed (six possible combinations).
	2G7	1	1	-			Offsite grid failed, two of GF, GG, GH failed, the third bypassed (three possible combinations).
	2G8	0	-	-			Offsite grid failed, one of GF, GG, GH succeeded, the other two bypassed (three possible combinations).
	2G9	1	-	-			Offsite grid failed, one of GF, GG, GH failed, the other two bypassed (three possible combinations).2GA---Offsite grid failed, all of GF, GG, GH bypassed.
2H - Unavailability of DG22 under the following conditions:							
	2H1	0	0	0	0		Offsite grid failed, all of GF, GG, GH, 2G succeeded.
	2H2	1	0	0	0		Offsite grid failed, one of GF, GG, GH, 2G failed, the other three succeeded (four possible combinations).
	2H3	1	1	0	0		Offsite grid failed, two of GF, GG, GH, 2G failed, the other two succeeded (six possible combinations).
	2H4	1	1	1	0		Offsite grid failed, three of GF, GG, GH, 2G failed, the fourth succeeded (four possible combinations).
	2H5	1	1	1	1		Offsite grid failed, all of GF, GG, GH, 2G failed.
	2H6	0	0	0	-		Offsite grid failed, three of GF, GG, GH, 2G succeeded, the fourth bypassed (four possible combinations).
	2H7	0	0	1	-		Offsite grid failed, two of GF, GG, GH, 2G succeeded, one failed, the fourth bypassed (12 possible combinations).
	2H8	0	1	1	-		Offsite grid failed, two of GF, GG, GH, 2G failed, one succeeded, the

Table 2.3 (Continued)

Top Event	Case	Diesel Conditions 13	12	11	21	22	Comments
							fourth bypassed (12 possible combinations).
	2H9	1	1	1	-		Offsite grid failed, three of GF, GG, GH, 2G failed, the fourth bypassed (four possible combinations).
	2HA	0	0	-	-		Offsite grid failed, two of GF, GG, GH, 2G succeeded, the other two bypassed (six possible combinations).
	2HB	-	-	1	0		Offsite grid failed, two of GF, GG, GH, 2G bypassed, one failed, the fourth succeeded (12 possible combinations).
	2HC	-	-	1	1		Offsite grid failed, two of GF, GG, GH, 2G bypassed, the other two failed (six possible combinations).
	2HD	-	-	-	0		Offsite grid failed, three of GF, GG, GH, 2G bypassed, the fourth succeeded (four possible combinations).
	2HE	-	-	-	1		Offsite grid failed, three of GF, GG, GH, 2G bypassed, the fourth failed (four possible combinations).
	2HG	-	-	-	-		Offsite grid failed, all of GF, GG, GH, 2G bypassed.
SW	SW0						LOCA, the swing diesel locked to the Unit 1.
	SW1						LOSP, with equal chance for swing diesel to operate on each unit.
	SW2						LOSP, with more DGs aligned to Unit 2 than Unit 1.
	SW3						LOSP, with more DGs aligned to Unit 1 than Unit 2.

Notes: 0 = Succeeded
1 = Failed
- = Bypassed

Table 2.4
Diesel Fuel Oil Transfer System Boundary Conditions for Top Event, LO

Split Fraction ID	
FO1	All support available.
FO2	Support available to one train only.
FO3	1/2 normal support available; recover support to the other train by realignment to backup support.
FO4	2/2 normal support unavailable; recover supports by realignment to backups.
FO5	2/2 normal supports unavailable; recover only 1/2 backup support by realignment.
FO6	All support unavailable (guaranteed failure).

Table 2.5
Unavailability Values (Conditional Split Fractions) for the
Diesel Generator System

Top Event	Case	Calc.	CSF	TTL	HW	HWI	HWD	TS	MN	HE	Comment #
GF	GF1	PG&E	4.523-2	4.554-2	3.703-2	3.689-2	1.393-4	2.950-4	8.217-3	--	
		BNL	4.571-2	4.603-2	3.754-2	3.695-2	5.860-4	2.934-4	8.198-3		
GG	GG1	PG&E	4.477-2	4.554-2	) as GF1						
		BNL	4.527-2	4.603-2							
	GG2	PG&E	5.561-2	2.702-3	1.749-3	1.536-3	2.129-4	4.989-5	9.025-4	--	
		BNL	5.474-2	2.540-3	1.581-3	1.366-3	2.149-4	4.980-5	9.089-4	--	
	GG3	PG&E	4.523-2	4.554-2	) as GF1						
		BNL	4.571-2	4.603-2							
GH	GH1	PG&E	4.436-2	4.554-2	) as GF1						
		BNL	4.490-2	4.603-2							
	GH2	PG&E	5.408-2	2.702-3	) as GG2						
		BNL	5.322-2	2.540-3							
	GH3	PG&E	8.265-2	2.339-4	1.264-4	7.438-5	5.204-5	3.173-5	7.566-5	--	
		BNL	8.097-2	2.066-4	1.034-4	5.057-5	5.284-5	3.128-5	7.194-5	--	
	GH4	PG&E	4.477-2	4.554-2	) as GF1						
		BNL	4.527-2	4.603-2							
	GH5	PG&E	5.561-2	2.702-3	) as GG2						
		BNL	5.474-2	2.540-3							
	GH6	PG&E	4.523-2	4.554-2	) as GF1						
		BNL	4.571-2	4.603-2							
2G	2G1	PG&E	4.396-2	4.554-2	) as GF1						
		BNL	4.453-2	4.603-2							
	2G2	PG&E	5.364-2	2.702-3	) as GG2						
		BNL	5.271-2	2.540-3							
	2G3	PG&E	6.250-2	2.339-4	) as GH3						
		BNL	6.246-2	2.066-4							
	2G4	PG&E	2.898-1	6.369-5	2.597-5	4.314-6	2.166-5	3.049-5	7.221-6	--	
		BNL	2.910-1	5.995-5	2.363-5	1.874-6	2.176-5	3.017-5	6.176-6	--	

Table 2.5 (Continued)

Top Event	Case	Calc.	CSF	TTL	HW	HVI	HWD	TS	MN	HE	Comment #
	2G5	PG&E	4.436-2	4.554-2	) as GF1						
		BNL	4.490-2	4.603-2							
	2G6	PG&E	5.408-2	2.702-3	) as GG2						
		BNL	5.322-2	2.540-3							
	2G7	PG&E	8.265-2	2.339-4	) as GH3						
		BNL	8.097-2	2.066-4							
	2G8	PG&E	4.477-2	4.554-2	) as GF1						
		BNL	4.527-2	4.603-2							
	2G9	PG&E	5.561-2	2.702-3	) as GG2						
		BNL	5.474-2	2.540-3							
	2GA	PG&E	4.523-2	4.554-2	) as GF1						
		BNL	4.571-2	4.603-2							
	2H1	PG&E	4.356-2	4.554-2	) as GF1						
		BNL	4.417-2	4.603-2							
	2H2	PG&E	5.320-2	2.702-3	) as GG2						
		BNL	5.219-2	2.540-3							
	2H3	PG&E	6.206-2	2.339-4	) as GH3						
		BNL	6.196-2	2.066-4							
	2H4	PG&E	6.922-2	6.369-5	) as 2G4						
		BNL	7.003-2	5.995-5							
	2H5	PG&E	7.729-1	5.034-5	1.851-5	3.020-7	1.820-5	3.039-5	1.436-6		
		BNL	8.294-1	4.975-5	1.842-5	6.950-8	1.836-5	3.006-5	1.272-6		
	2H6	PG&E	4.396-2	4.554-2	) as GF1						
		BNL	4.453-2	4.603-2							
	2H7	PG&E	5.364-2	2.702-3	) as GG2						
		BNL	5.271-2	2.540-3							
	2H8	PG&E	6.250-2	2.339-4	) as GH3						
		BNL	6.246-2	2.066-4							
	2H9	PG&E	2.898-1	6.369-5	) as 2G4						
		BNL	2.910-1	5.995-5							

Table 2.5 (Continued)

Top Event	Case	Calc.	CSF	TTL	HW	HWI	HWD	TS	MN	HE	Comment #
	2HA	PG&E	4.436-2	4.554-2	as GF1						
		BNL	4.490-2	4.603-2							
	2HB	PG&E	5.408-2	2.702-3	as GG2						
		BNL	5.322-2	2.540-3							
	2HC	PG&E	8.265-2	2.339-4	as GH3						
		BNL	8.098-2	2.066-4							
	2HD	PG&E	4.477-2	4.554-2	as GF1						
		BNL	4.527-2	4.603-2							
	2HE	PG&E	5.561-2	2.702-3	as GG2						
		BNL	5.474-2	2.540-3							
	2HG	PG&E	4.523-2	4.554-2	as GF1						
		BNL	4.571-2	4.603-2							
	SW0	PG&E		0.000							
		BNL		0.000							
	SW1	PG&E		5.000-1							
		BNL		5.000-1							
	SW2	PG&E		1.767-3							
		BNL		1.770-3							
	SW3	PG&E		9.981-1							
		BNL		9.982-1							

Table 2.6
Unavailability Values (Split Fractions) for the Diesel Fuel Transfer System

Top Event	Case	Calc.	TTL	HW	HWI	HWD	TS	MN	HE
FO	FO1	PG&E	2.164-4	1.919-4	1.176-5	1.802-4	0.0	2.445-5	0.0
		BNL	2.092-4	1.848-4	8.533-6	1.763-4	0.0	2.447-5	0.0
	FO2	PG&E	7.040-3	3.113-3	2.933-3	1.802-4	0.0	3.930-3	0.0
		BNL	7.048-3	3.097-3	2.921-3	1.763-4	0.0	3.951-3	0.0
	FO3	PG&E	3.509-4	1.919-4	1.176-5	1.802-4	0.0	2.445-5	0.0
		BNL	3.460-4	1.848-4	8.533-6	1.763-4	0.0	2.447-5	0.0
	FO4	PG&E	2.263-2	1.919-4	1.176-5	1.802-4	0.0	2.445-5	0.0224
		BNL	2.250-2	1.848-4	8.533-6	1.763-4	0.0	2.447-5	0.0223
	FO5	PG&E	5.079-2	3.113-3	2.933-3	1.802-4	0.0	3.930-3	0.0224
		BNL	2.292-2	3.097-3	2.921-3	1.763-4	0.0	3.951-3	0.0223
	FOF	PG&E	1.0						
		BNL	1.0						

Table 2.7a
Conditional Split Fractions for DG Top Events as a Function of Seismic Level

Split Fraction ID	Seismic Level (spectral acceleration, g)						
	0.0-0.2	0.2-1.25	1.25-1.75	1.75-2.0	2.0-2.5	2.5-3.0	3.0-4.0
[illegible]	8.5100E-02	8.5100E-02	8.5660E-02	9.3020E-02	1.0550E-01	1.7000E-01	2.8270E-01
GG1	8.4170E-02	8.4170E-02	8.4170E-02	8.7670E-02	8.7670E-02	1.0560E-01	1.0560E-01
GG2	9.5020E-02	9.5020E-02	1.0150E-01	1.4510E-01	2.5700E-01	4.8460E-01	7.3210E-01
GG3	8.5100E-02	8.5100E-02	8.5660E-02	9.3020E-02	1.0550E-01	1.7000E-01	2.8270E-01
GB1	8.3340E-02	8.3340E-02	8.3340E-02	8.6700E-[illegible]	8.6700E-02	1.0430E-01	1.0430E-01
GB2	9.3290E-02	9.3290E-02	9.3290E-02	9.7810E-02	9.7810E-02	1.1630E-01	1.1630E-01
GB3	1.1150E-01	1.1150E-01	1.7450E-01	4.2380E-01	7.1[illegible]20E-01	8.7630E-01	9.5750E-01
GB4	8.4170E-02	8.4170E-02	8.4170E-02	8.7670E-02	8.7670E-02	1.0560E-01	1.0560E-01
GB5	9.5020E-02	9.5020E-02	1.0150E-01	1.4510E-01	2.5700E-01	4.8460E-01	7.3210E-01
GB6	8.5100E-02	8.5100E-02	8.5660E-02	9.3020E-02	1.0550E-01	1.7000E-01	2.8270E-01
[illegible]G1	8.2510E-02	8.2510E-02	8.2510E-02	8.5740E-02	8.5740E-02	1.0310E-01	1.0310E-01
[illegible]G2	9.2440E-02	9.2440E-02	9.2440E-02	9.6770E-02	9.6770E-02	1.1490E-01	1.1490E-01
[illegible]G3	1.0160E-01	1.0160E-01	1.0160E-01	1.0740E-01	1.0740E-01	1.2650E-01	1.2650E-01
[illegible]G4	1.9030E-01	1.9030E-01	5.1950E-01	8.5400E-01	9.5770E-01	9.8210E-01	9.9440E-01
[illegible]G5	8.3340E-02	8.3340E-02	8.3340E-02	8.6700E-02	8.6700E-02	1.0430E-01	1.0430E-01
[illegible]G6	9.3290E-02	9.3290E-02	9.3290E-02	9.7810E-02	9.7810E-02	1.1630E-01	1.1630E-01
[illegible]G7	1.1150E-01	1.1150E-01	1.7450E-01	4.2380E-01	7.1720E-01	8.7630E-01	9.5750E-01
[illegible]G8	8.4170E-02	8.4170E-02	8.4170E-02	8.7670E-02	8.7670E-02	1.0560E-01	1.0560E-01
[illegible]G9	9.5020E-02	9.5020E-02	1.0150E-01	1.4510E-01	2.5700E-01	4.8460E-01	7.3210E-01
[illegible]	8.5100E-02	8.5100E-02	8.5660E-02	9.3020E-02	1.0550E-01	1.7000E-01	2.8270E-01
[illegible]B1	8.1690E 02	8.1690E-02	8.1690E-02	8.4800E-02	8.4800E-02	1.0190E-01	1.0190E-01
[illegible]B2	9.1620E-02	9.1620E-02	9.1620E-02	9.5780E-02	9.5780E-02	1.1360E-01	1.1360E-01
[illegible]B3	1.0030E-01	1.0030E-01	1.0030E-01	1.0600E-01	1.0600E-01	1.2470E-01	1.2470E-01
[illegible]B4	1.1120E-01	1.1120E-01	1.1120E-01	1.1890E-01	1.1890E-01	1.3930E-01	1.3930E-01
[illegible]B5	5.2690E-01	5.2690E-01	8.9720E-01	9.7970E-01	9.9470E-01	9.9750E-01	9.9920E-01
[illegible]B6	8.2510E-02	8.2510E-02	8.2510E-02	8.5740E-02	8.5740E-02	1.0310E-01	1.0310E-01
[illegible]B7	9.2440E-02	9.2440E-02	9.2440E-02	9.6770E-02	9.6770E-02	1.1490E-01	1.1490E-01
[illegible]B8	1.0160E-01	1.0160E-01	1.0160E-01	1.0740E-01	1.0740E-01	1.2650E-01	1.2650E-01
[illegible]B9	1.9030E-01	1.9030E-01	5.1950E-01	8.5400E-01	9.5770E-01	9.8210E-01	9.9440E-01
[illegible]BA	8.3340E-02	8.3340E-02	8.3340E-02	8.6700E-02	8.6700E-02	1.0430E-01	1.0430E-01
[illegible]BB	9.3290E-02	9.3290E-02	9.3290E-02	9.7810E-02	9.7810E-02	1.1630E-01	1.1630E-01
[illegible]BC	1.1150E-01	1.1150E-01	1.7450E-01	4.2380E-01	7.1720E-01	8.7630E-01	9.5750E-01
[illegible]	8.4170E-02	8.4170E-02	8.4170E-02	8.7670E-02	8.7670E-02	1.0560E-01	1.0560E-01
[illegible]BE	9.5020E-02	9.5020E-02	1.0150E-01	1.4510E-01	2.5700E-01	4.8460E-01	7.3210E-01
[illegible]BG	8.5100E-02	8.5100E-02	8.5660E-02	9.3020E-02	1.0550E-01	1.7000E-01	2.8270E-01
SW0	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01
SW1	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01	5.0000E-01
SW2	1.7500E-03	1.7500E-03	1.7500E-03	1.0000E-02	1.0000E-02	5.0000E-02	5.0000E-02
SW3	9.9820E-01	9.9820E-01	9.9320E-01	9.9000E-01	9.9000E-01	9.5000E-01	9.5000E-01

Table 2.7b
Conditional Split Fractions for DC Top Events as a Function Seismic Level

BNL

Split Fraction ID	Seismic Level (spectral acceleration, g) 0.0-0.2	0.2-1.25	1.25-1.75	1.75-2.0	2.0-2.5	2.5-3.0	3.0-4.0
DF1*	8.339E-02	8.339E-02	8.445E-02	9.193E-02	1.044E-01	1.694E-01	2.815E-01
DB1*	8.325E-02	8.325E-02	8.325E-02	8.687E-02	8.687E-02	1.054E-01	1.054E-01
DB2*	9.085E-02	9.087E-02	9.748E-02	1.419E-01	2.551E-01	4.831E-01	7.309E-01
DB3*	8.389E-02	8.389E-02	8.445E-02	9.193E-02	1.044E-01	1.694E-01	2.815E-01
DH1*	8.272E-02	8.272E-02	8.272E-02	8.618E-02	8.618E-02	1.044E-01	1.044E-01
DH2*	8.913E-02	8.913E-02	8.913E-02	9.417E-02	9.417E-02	1.145E-01	1.145E-01
DH3*	1.000E-01	1.082E-01	1.747E-01	4.306E-01	7.250E-01	8.774E-01	9.570E-01
DH4*	8.325E-02	8.325E-02	8.325E-02	8.687E-02	8.687E-02	1.054E-01	1.054E-01
DH5*	9.085E-02	9.087E-02	9.748E-02	1.419E-01	2.551E-01	4.831E-01	7.309E-01
DH6*	8.389E-02	8.389E-02	8.445E-02	9.193E-02	1.044E-01	1.694E-01	2.815E-01
[illegible]	8.221E-02	8.221E-02	8.221E-02	8.553E-02	8.553E-02	1.034E-01	1.034E-01
[illegible]	8.827E-02	8.827E-02	8.827E-02	9.306E-02	9.306E-02	1.130E-01	1.130E-01
[illegible]	9.794E-02	9.794E-02	9.794E-02	1.048E-01	1.048E-01	1.264E-01	1.264E-01
[illegible]	1.908E-01	1.929E-01	5.374E-01	8.614E-01	9.603E-01	9.823E-01	9.944E-01
[illegible]	8.272E-02	8.272E-02	8.272E-02	8.618E-02	8.618E-02	1.044E-01	1.044E-01
[illegible]	8.913E-02	8.913E-02	8.913E-02	9.417E-02	9.417E-02	1.145E-01	1.145E-01
[illegible]	1.000E-01	1.082E-01	1.747E-01	4.306E-01	7.250E-01	8.774E-01	9.578E-01
[illegible]	8.325E-02	8.325E-02	8.325E-02	8.687E-02	8.687E-02	1.054E-01	1.054E-01
[illegible]	9.085E-02	9.087E-02	9.748E-02	1.419E-01	2.551E-01	4.831E-01	7.309E-01
[illegible]	8.389E-02	8.389E-02	8.445E-02	9.193E-02	1.044E-01	1.694E-01	2.815E-01
[illegible]	8.175E-02	8.175E-02	8.175E-02	8.492E-02	8.492E-02	1.024E-01	1.024E-01
[illegible]	8.744E-02	8.744E-02	8.744E-02	9.200E-02	9.200E-02	1.115E-01	1.115E-01
[illegible]	9.688E-02	9.688E-02	9.688E-02	1.034E-01	1.034E-01	1.246E-01	1.246E-01
[illegible]	1.077E-01	1.077E-01	1.077E-01	1.166E-01	1.166E-01	1.382E-01	1.382E-01
[illegible]	5.433E-01	5.495E-01	9.073E-01	9.812E-01	9.952E-01	9.975E-01	9.992E-01
[illegible]	8.221E-02	8.221E-02	8.221E-02	8.553E-02	8.553E-02	1.034E-01	1.034E-01
[illegible]	8.827E-02	8.827E-02	8.827E-02	9.306E-02	9.306E-02	1.130E-01	1.130E-01
[illegible]	9.794E-02	9.794E-02	9.794E-02	1.048E-01	1.048E-01	1.264E-01	1.264E-01
[illegible]	1.908E-01	1.929E-01	5.374E-01	8.614E-01	9.603E-01	9.823E-01	9.944E-01
[illegible]	8.272E-02	8.272E-02	8.272E-02	8.618E-02	8.618E-02	1.044E-01	1.044E-01
[illegible]	8.913E-02	8.913E-02	8.913E-02	9.417E-02	9.417E-02	1.145E-01	1.145E-01
DHC*	1.000E-01	1.082E-01	1.747E-01	4.306E-01	7.250E-01	8.774E-01	9.578E-01
[illegible]	8.325E-02	8.325E-02	8.325E-02	8.687E-02	8.687E-02	1.054E-01	1.054E-01
DHE*	9.085E-02	9.087E-02	9.748E-02	1.419E-01	2.551E-01	4.831E-01	7.309E-01
[illegible]	8.389E-02	8.389E-02	8.445E-02	9.193E-02	1.044E-01	1.694E-01	2.815E-01
[illegible]	0.000E-01	0.000E-01	0.000E-01	0.000E-01	0.000E-01	0.000E-01	0.000E-01
SW1*	5.000E-01	5.000E-01	5.000E-01	5.000E-01	5.000E-01	0.000E-01	0.000E-01
SW2*	1.770E-03	1.770E-03	1.770E-03	1.000E-02	1.000E-02	5.000E-02	5.000E-02
SW3*	9.982E-01	9.982E-01	9.982E-01	9.900E-01	9.900E-01	9.500E-01	9.500E-01

3. RESULTS OF THE BNL REVIEW

3.1 General

The unavailability modelling of the Diesel Generators and the Diesel Fuel Transfer System in the DCPRA were reviewed by BNL with special emphasis because of the following:

a. The DGs are the most important support systems; impacting the safety of the majority of plant operations, including cold shutdown.

b. As discussed in Section 1, a request for changing the Allowed Outage Time (AOT) of the Diesel Generators was submitted to the NRC by PG&E and the study[2] supporting the request is based mainly on the DCPRA. BNL is reviewing this study in a parallel effort to this review.

Therefore, to check the adequacy of the DCPRA modelling for "system-specific" effects which may also influence granting permission for AOT changes, BNL used the following approach: BNL compared the vendor-specific (ALCO) diesel failure events with those obtained from generic diesel data. This was done to see how well the DCPRA model reflects the vendor-specific "experience" and to estimate the expected downtime distribution of the diesels. The evaluation was carried out by reviewing the failure modes and maintenance unavailabilities involved in the diesel model. In order to check for calculational inconsistencies, all of the split fractions were recalculated (seismic inclusive).

3.2 Comparison of ALCO Type DG Failures With All Types of DG Failures

In order to see whether the ALCO-type DGs used at the Diablo Canyon power plant have some subsystem- or component-specific failure modes (and thus, some subsystem or component specific expected downtimes) BNL compared the leading failure contributions of subsystems and components of ALCO diesels with those of all other types of DGs. The data were taken from a recent study performed at Battelle on aging of diesel components.[5] Table 3.1 presents the results.

One can see that the Instruments and Control System's (and within it the governor's) failures are the main contributors to the generic failures of ALCO diesels. Also with ALCO diesels, the Cooling System and to a lesser extent the Lubrication System seem to be more prone to failures than in the total generic DG population. A positive feature of the ALCO diesels is that the starting system appears to be less vulnerable to failure than the generic DG population. Finally, the ALCO fuel system does not seem to be any more prone to failures than the generic one.

3.3 Remarks on the Unavailability Modelling of the Diesels and Fuel Oil Transfer System in the DCPRA

a. The system modelling of the DGs in the DCPRA represents an elaborate sequential unavailability analysis of a "five train" system, where one train (the swing diesel) is playing a special role. There is no question that the approach used is mathematically appealing because it uses the symmetry aspects of the diesel configuration and renders the results of the analysis very suitable for integration into the DCPRA. The complexity of the calculation, however, for casual readers is difficult and for eventual uses (e.g., change of AOT) is rather cumbersome.

b. In contrast with the systems modelling, the unavailability modelling of the individual diesels (the fault tree modelling) was kept simplistic by using the standard "diesel fails to start and run" failure modes. The diesel starting air system (i.e., air compressors, receivers, etc.) were not modelled separately because they were considered to be included as part of the diesel start failure data. An attempt was made to display some components of the diesel subsystems in the model. This effort, however, tended to be inconsistent in that only some support failures were modelled and inconsequential in that the modelled failures were of such low probability. For example, each supercomponent "2A" and "2B" contains the failure rates: "DG Air Receiver - Rupture During Operation: ZTTK1B = 2.66-8/hr," "Air Check Valve - Transfer Closed During Operation: ZTVCOP = 1.04-

8/hr," etc. The failure contribution of the turbocharger, however, with an estimated[2] failure probability of 2.73-4/d was neglected.

Another example: while the diesel supercomponent boundaries indicate several subsystems as part of the supercomponents (see Figures 2.6, 2.8, and 2.9), one cannot find any representative component failure rate contributing to the combined unavailability of those supercomponents. Such subsystems are: the cooling, the lubrication and the combustion air systems. Table 3.1 shows that the cooling system is the second largest contributor to the failure of the ALCO type diesels.

c. The following remark also has relevance in connection with the AOT study[2] and concerns the expected downtime distribution of the diesel systems. The DCPRA models the maintenance frequency and duration of the LCVs as separate quantities from those of the diesels. If the day tank and other fuel system components are included in the maintenance data of the diesel, it is not clear why the LCV is treated separately. Given that it is treated separately, the mean and 95th percentile of the "effective" downtime distribution of the diesel system would be determined by the combination of the diesel and the LCV maintenance duration distributions (the 95th percentile value of the LCV maintenance durations is 51.3 hours).

d. The DCPRA considers only unscheduled maintenances performed on Unit 2 diesels as contributing to the unavailabilities of the associated top events, "2C" and "2H." Unavailabilities due to large overhauls lasting over a protracted period of time performed when Unit 1 is operating and Unit 2 is in refueling (or cold shutdown) (say two times 10 to 16 days each) were not included in the model.

e. In Table 2.6 the PG&E total split fraction value, FO5 seems to be in variance with that obtained by BNL. The probable cause of the discrepancy is that the human error contribution was double counted in the DCPRA. The PG&E value is seemingly also in contradiction with the PG&E seismic values given at the lowest three seismic levels in Table 6-46 (p.6-182) of Reference 1.

f. The detailed analysis of the Fuel Oil Transfer System (see Figure D.2.1-3 Sheet 3 of 4) contains the following item (Item No.12): "In an emergency where it is necessary to get into the fuel oil pump vault to manipulate valves, it may take several hours to get security to open the vault." This item renders questionable the estimates of the human factors (among others the value of ZHEF06 used in the diesel analysis) considered for recovery of the Fuel Oil Transfer System and through it, the recovery of electrical power.

g. Among the DG failure related LERs filed by the Diablo Canyon power plant,[6] there was one failure in the Fuel Oil Transfer System which would affect all the DGs. This common cause failure involved the degradation of the diesel oil in the underground reserve tanks caused by fungi. According to PG&E, the problem does not exist any more. However because of its peculiarity and importance it is quoted here:

> LER 88-14. This report is being voluntarily submitted for information purposes only as described in Item 19 of Supplement No.1 to NUREG-1022. On May 4, 1988, during performance of surveillance test procedure (SRP) M-96, "diesel generator 24 hour load test," the diesel generator (DG) 1-1 load decreased below the value specified in the SRP acceptance criteria. An investigation showed that a high differential pressure existed across the primary fuel oil filter. After switching to the standby primary fuel oil filter, the load returned to the required value. An investigation determined that the DG day tank contained a fungus and that the first primary filter was clogged by fungus. The other DG day tanks also contained a fungus and fungus spores were found in the main storage tanks. The fuel oil in the day tanks was diocided and filtered until the fuel oil met the criteria of STP M-108, "diesel fuel oil analysis," for particulate contamination, flash point, API gravity and viscosity. The day tanks were drained, inspected and cleaned. The bottom of main storage tanks 0-1 and 0-2 were suctioned out and a biocide was added. A biocide program will be developed and implemented to inhibit the growth of fungus in the DG fuel oil storage system. Also, a sampling and inspection program for the DG day tanks will be developed. Both will be incorporated into plant procedures.

h. It is not clear how the fire suppression (CO_2) system in the DG rooms responds to various levels of seismic event. The safety concern is that if an earthquake fails the diesel units without causing fire, one or more DG rooms might be flooded with CO_2, and therefore rescue personnel may not be able to recover the DGs within proper time intervals.

3.4 Audit Calculations

In order to scrutinize the quantified split fractions themselves, BNL performed audit calculations for each of the split fractions associated with each of the boundary conditions. The calculations were extended for both non-seismic (mission time: 6 hours) and seismic (mission time: 24 hours) cases. Seismic calculations were not performed for the Fuel Oil Transfer System. In these audit calculations the same assumptions, input data, maintenance and test frequency and duration, as well as mean fragility and human factor values were used as in the DCPRA. The SETS code[7] and locally generated PC software were used for the computations. The use of the SETS code allowed the identification of the most important cut sets contributing to the hardware unavailabilities. These cut sets are not readily accessible for direct review in the DCPRA. Appendix A lists the ranked cut sets for single, double, triple, quadruple and quintuple diesel failures. The definition of the basic events appearing in the cut sets are identical to those given in Chapter D.2.1.5 of the DCPRA.

The results obtained by the audit calculations are presented in Tables 2.6 and 2.7.b for the DGs and for the Fuel Oil Transfer System, respectively. They are denoted by "BNL" to be compared with the values given in the DCPRA (denoted by "PG&E"). It has to be emphasized, that if the review of the fragilities would identify incorrect values characterizing diesel components or the use of incorrect human failure rates would be detected during the review of the human factors, complete requantification of the Table 2.7.b split fractions would be necessary.

By comparing the PG&E and BNL results one can see that there is an overall agreement between the data. The agreement is even better, if one takes into account that BNL used point estimates, while PG&E mainly used a Monte-Carlo approach in the split fraction quantification.

3.5 Conclusions

The BNL review identified several inconsistencies and neglection of failures of diesel subsystems in the unavailability modelling of diesel generators in the DCPRA and the omission of the unavailability contribution from Unit 2 (and swing) diesels overhauls. The combined effect of these neglections may result in underestimation of the associated top event split fractions and through them the expected core damage frequency value of Unit 1.

The above remarks made in connection with the DCPRA simultaneously represent preliminary results concerning the verification of the Diesel Generator AOT study. In fact, the results of the audit calculations can also be considered as verification of the "base case" (i.e., present AOT conditions) in the PG&E diesel AOT study.[2]

Table 3.1
Systems and Components Contributing Most to Failures at All Types of DGs and at ALCO Type DGs

Systems and Components	Percent of All Failures		Percent of Failures at ALCO DGs	
Instrument and Controls System	25		26	
Governor		10		15
Sensors		3		3
Relays		2		1
Startup Components		2		1
Fuel System	11		10	
Piping on Engine		3		1
Injector Pumps		2		1
Fuel Oil Pumps				5
Starting System	10		6	
Controls		3		3
Starting Air Valve		2		
Starting Motors		2		2
Air Compressor		1		1
Switchgear System	10		10	
Breakers		3		4
Relays		5		4
Instrument and Controls		1		1
Cooling System	9		14	
Pumps		2		1
Heat Exchangers		2		1
Piping		2		6
Lubrication System	7		8	
Heat Exchangers		2		3
Pumps		2		3
Lube Oil		1		
Other Systems	28		26	

Date Base: 1984 failure event recorded between 1974 and 1984 in Reference 5.
Nuclear plants where ALCO Diesel Generators have been used in 198 :
Indian Point 1 and 2, Power Authority of the State of NY
Salem 1 and 2, Public Service Electric and Gas Company
Palisades, Consumers' Power Company
Pilgrim 1, Boston Edison
Ginna, Rochester Gas and Electric

REFERENCES

1. Final report on the Diablo Canyon Long-Term Seismic Program, Pacific Gas and Electric Co., Diablo Canyon Power Plant, Docket Nos. 50-275 and 50-323, July 1988.

2. Diesel Generator Allowed Outage Time Study, Pacific Gas & Electric Company, May 1989.

3. Units 1 and 2 Diablo Canyon Power Plant, "Final Safety Analysis Report Update," Pacific Gas and Electric Co., December 1988.

4. PG&E letters to NRC signed by J.D. Shiffer, No. DCL-88-238, October 10, 1988, No. DCL-88-260, October 28, 1988, No. DCL-88-285, November 29, 1988, No. DCL-88-297, December 9, 1988, No. DCL-89-010, January 16, 1989, and No. DCL-89-152, June 2, 1989.

5. Hoopingarner, K.R., Vause, J.W., Dingee, D.A., Nesbitt, J.F., "Aging of Nuclear Station Diesel Generators: Evaluation of Operating and Expert Experience," NUREG/CR-4590, August 1987.

6. DOE/RECON, Nuclear Safety Information Center (NSIC), 1963 to present.

7. Worrel, R.B. and Stack, D.W., "A SETS User's Manual for the Fault Tree Analyst," Sandia National Laboratories, NUREG/CR-0475, SAND77-2051, November 1978.

APPENDIX A

HARDWARE UNAVAILABILITY CUT SETS FOR THE DIESEL GENERATORS

Hardware Unavailability Cutsets in Case of One DG

Total Hardware, HW =

```
 1   3.6736E-02   FIDIF *
 2   2.1339E-04   HEV * FIVIF *
 3   1.1077E-04   DDC *
 4   1.1077E-04   DDA *
 5   1.1077E-04   DDD *
 6   1.1077E-04   DDB *
 7   1.7707E-05   GDG *
 8   1.6417E-05   TDA *
 9   1.6417E-05   TDC *
10   1.6417E-05   TDE *
11   1.6417E-05   TDB *
12   1.6417E-05   TDF *
13   1.6417E-05   TDD *
14   5.9176E-06   HEV * DVC *
15   5.9176E-06   HEV * DVA *
16   5.9176E-06   HEV * DVD *
17   5.9176E-06   HEV * DVB *
18   4.1269E-07   HEV * TVA *
19   4.1269E-07   HEV * TVC *
20   4.1269E-07   HEV * TVE *
```

Independent Hardware, HWI =

```
 1   3.6736E-02   FIDIF *
 2   2.1339E-04   HEV * FIVIF
```

July 25, 1989

Hardware Unavailability Cutsets in Case of Two DGs

Total Hardware, HW =

```
 1   1.3495E-03   FID1F * FID1G *
 2   1.1273E-04   DDA *
 3   1.7703E-05   DDG *
 4   1.6417E-05   TDB *
 5   1.6417E-05   TDA *
 6   1.6417E-05   TDC *
 7   7.8392E-06   FID1F * HEV * FIV1G *
 8   7.8392E-06   HEV * FIV1F * FID1G *
 9   5.9176E-06   HEV * DVA *
10   4.0678E-06   FID1F * DDF *
11   4.0678E-06   FID1G * DDC *
12   4.0678E-06   FID1F * DDG *
13   4.0678E-06   FID1F * DDE *
14   4.0678E-06   FID1G * DDD *
15   4.0678E-06   FID1G * DDB *
16   1.1384E-06   HEV * FIV1F * FIV1G *
17   6.3309E-07   FID1F * TDI *
```

Independent Hardware, HWI =

```
 1   1.3495E-03   FID1F * FID1G *
 2   7.8392E-06   FID1F * HEV * FIV1G *
 3   7.8392E-06   HEV * FIV1F * FID1G *
     1.1384E-06   HEV * FIV1F * FIV1G
```

July 25, 1989

Hardware Unavailability Cutsets in Case of Three DGs

Total Hardware, HW =

```
 1  4.9776E-05   FID1F * FID1G * FID1H *
 2  1.7703E-05   DDG *
 3  1.6417E-05   TDA *
 4  4.0678E-06   FID1H * DDA *
 5  4.0678E-06   FID1F * DDB *
 6  4.0678E-06   FID1G * DDC *
 7  6.0209E-07   FID1H * TDC *
 8  6.0209E-07   FID1F * TDH *
 9  6.0209E-07   FID1F * TDG *
10  6.0209E-07   FID1G * TDD *
11  6.0209E-07   FID1H * TDE *
12  6.0209E-07   FID1G * TDE *
13  4.1265E-07   HEV * TVA *
14  3.1996E-07   HEV * GFD *
15  2.8798E-07   HEV * FIV1F * FID1G * FID1H *
16  2.8798E-07   FID1F * HEV * FIV1G * FID1H *
17  2.8798E-07   FID1F * HEV * FID1G * FIV1H *
18  2.1372E-07   HEV * FID1H * DVA *
```

Independent Hardware, HWI =

```
1  4.9774E-05   FID1F * FID1G * FID1H *
2  2.8798E-07   FID1F * HEV * FIV1G * FID1H *
3  2.8798E-07   HEV * FIV1F * FID1G * FID1H *
4  2.8798E-07   FID1F * HEV * FID1G * FIV1H *
5  4.1821E-09   FID1F * HEV * FIV1G * FIV1H *
6  4.1821E-09   HEV * FIV1F * FIV1G * FID1H *
7  4.1821E-09   HEV * FIV1F * FID1G * FIV1H *
8  6.0735E-09   HEV * FIV1F * FIV1G * FIV1H
```

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Hardware Unavailability Cutsets in Case of Four DGs

Total Hardware, HW -

```
 1   1.7703E-05   GDG *
 2   1.9212E-06   FID1F * FID1G * FID1H * FID2G
 3   6.0309E-07   FID2G * TDA *
 4   6.0309E-07   FID1H * TDB *
 5   6.0309E-07   FID1G * TDC *
 6   6.0309E-07   FID1F * TDD *
 7   3.1996E-07   HEV * GFD *
 8   1.4943E-07   FID1H * FID2G * DDA *
 9   1.4943E-07   FID1F * FID2G * DDE *
10   1.4943E-07   FID1G * FID2G * DDB *
11   1.4943E-07   FID1G * FID1H * DDD *
12   1.4943E-07   FID1F * FID1G * DDH *
13   1.4943E-07   FID1F * FID1H * DDF *
14   2.2155E-08   FID1F * FID2G * TDH *
15   2.2155E-08   FID1G * FID2G * TDE *
16   2.2155E-08   FID1G * FID1H * TDF *
17   2.2155E-08   FID1H * FID2G * TDG *
     2.2155E-08   FID1F * FID1G * TDJ *
     2.2155E-08   FID1F * FID1H * TDI *
20   1.5160E-08   HEV * FID1G * TVD *
```

Independent Hardware, HWI -

```
 1   1.9212E-06   FID1F * FID1G * FID1H * FID2G *
 2   1.0579E-08   FID1F * HEV * FIV1G * FID1H * FID2G *
 3   1.0579E-08   HEV * FIV1F * FID1G * FID1H * FID2G *
 4   1.0579E-08   FID1F * HEV * FID1G * FID1H * FIV2G *
 5   1.0579E-08   FID1F * HEV * FID1G * FIV1H * FID2G *
 6   1.5363E-09   FID1F * HEV * FIV1G * FID1H * FIV2G *
 7   1.5363E-09   FID1F * HEV * FIV1G * FIV1H * FID2G *
 8   1.5363E-09   HEV * FIV1F * FID1G * FID1H * FIV2G *
 9   1.5363E-09   HEV * FIV1F * FID1G * FIV1H * FID2G *
10   1.5363E-09   HEV * FIV1F * FIV1G * FID1H * FID2G *
11   1.5363E-09   FID1F * HEV * FID1G * FIV1H * FIV2G *
12   2.2311E-10   HEV * FIV1F * FIV1G * FIV1H * FID2G *
13   2.2311E-10   FID1F * HEV * FIV1G * FIV1H * FIV2G *
14   2.2311E-10   HEV * FIV1F * FID1G * FIV1H * FIV2G *
15   2.2311E-10   HEV * FIV1F * FIV1G * FID1H * FIV2G *
16   3.2400E-11   HEV * FIV1F * FIV1G * FIV1H * FIV2G
```

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Hardware Unavailability Cutsets in Case of Five DGs

Total Haroware, HW =

```
 1   1.7707E-05    DDG •
 2   3.1994E-07    HEV • GFD •
 3   6.6905E-08    FID1F • FID1G • FID1H • FID2G • FID2H •
 4   2.2155E-08    FID1F • FID2G • TDH •
 5   2.2155E-08    FID1G • FID2G • TDE •
 6   2.2155E-08    FID1G • FID2H • TDD •
 7   2.2155E-08    FID2G • FID2H • TDA •
 8   2.2155E-08    FID1H • FID2H • TDB •
 9   2.2155E-08    FID1F • FID2H • TDG •
10   2.2155E-08    FID1H • FID2G • TDC •
11   2.2155E-08    FID1G • FID1H • TDF •
12   2.2155E-08    FID1F • FID1H • TDI •
13   2.2155E-08    FID1F • FID1G • TDJ •
14   5.4896E-09    FID1G • FID2G • FID2H • DDB •
15   5.4896E-09    FID1G • FID1H • FID2H • DDC •
```

Independent Hardware, HWI =

```
1   6.6905E-08    FID1F • FID1G • FID1H • FID2G • FID2H •
2   3.8864E-10    FID1F • HEV • FIV1G • FID1H • FID2G • FID2H •
3   3.8864E-10    HEV • FIV1F • FID1G • FID1H • FID2G • FID2H •
4   3.8864E-10    FID1F • HEV • FID1G • FID1H • FID2G • FIV2H •
5   3.8864E-10    FID1F • HEV • FID1G • FID1H • FIV2G • FID2H •
6   3.8864E-10    FID1F • HEV • FID1G • FIV1H • FID2G • FID2H •
7   5.6430E-11    FID1F • HEV • FIV1G • FID1H • FID2G • FIV2H •
8   5.6430E-11    FID1F • HEV • FIV1G • FID1H • FIV2G • FID2H •
```

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