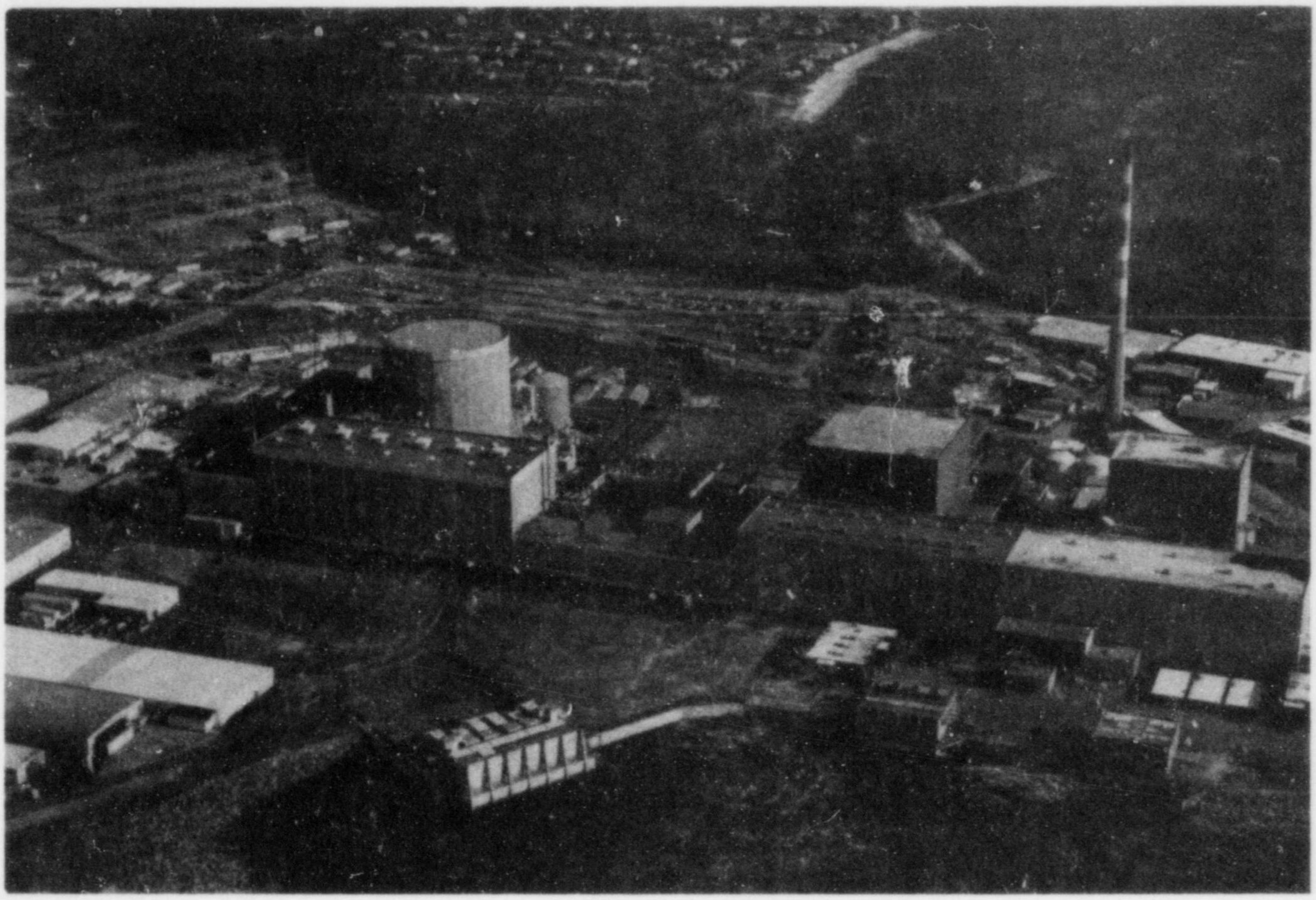
NUSCO 154

Millstone Unit 3

Evaluation of AC-Independent Containment Spray System



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Northeast Utilities Service Co.

February 1987

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ABSTRACT

On October 17, 1985 the U.S. Nuclear Regulatory Commission issued its Draft Risk Evaluation Report for Millstone Nuclear Power Station, Unit 3. A request was made of Northeast Nuclear Energy Company (NNECO) to perform a feasibility study of a manually operated, AC-independent containment spray system. Subsequently, NNECO committed to performing a feasibility study of such a system by the startup from the first refueling outage (late 1987/early 1988).

This report has been prepared by Northeast Utilities Service Company (NUSCO) Safety Analysis Branch/PRA Section on behalf of NNECO for the purpose of evaluating the feasibility and cost-benefits of conceptual designs of an AC-independent containment spray system. As a result of this evaluation it is concluded that a containment spray system independent from the existing onsite emergency AC power system could be constructed. The lowest cost proposals would be for designs that need not have to fully meet all regulatory standards. However, cost-benefit evaluations using two methods show that even these designs would not be cost-effective by substantial margins.

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1.0 INTRODUCTION AND SUMMARY

Introduction

In response to a formal request from the U.S. Nuclear Regulatory Commission (NRC), Northeast Nuclear Energy Company (NNECO) in August 1983 submitted the Millstone Unit 3 Probabilistic Safety Study (PSS). The PSS (Reference 1) evaluated the probability and consequences of severe accidents (beyond the design basis), including Station AC Blackout. In the Station AC Blackout scenario, all offsite as well as onsite sources of AC power are unavailable. The turbine-driven auxiliary feedwater pump is potentially available but the Reactor Coolant Pump (RCP) seals are assumed to degrade because of the loss of seal cooling. Without eventual recovery of either onsite or offsite power, it is not possible to provide reactor coolant system makeup to compensate for the loss of coolant through the RCP seals. This results in an eventual core melt, the potential for containment failure, and offsite consequences to the public. The Millstone Unit 3 PSS evaluated the core melt frequency of Station AC Blackout resulting from all major causes including loss of offsite power, seismic events, and fire.

Following submittal of the PSS, the NRC initiated an in-depth technical review which resulted in the issuance of the Draft Millstone Unit 3 Risk Evaluation Report (RER), NUREG-1152 (Reference 2). Two major sources of information for the RER were technical reviews provided by Lawrence Livermore National Laboratory (Reference 3) and Brookhaven National Laboratory (Reference 4).

NNECO responded to NUREG-1152 (draft) in November 1985 with a commitment to evaluate four specific recommended improvements identified by the NRC Staff (Reference 5).

In March 1986, NNECO submitted an assessment of the Station AC Blackout issue at Millstone Unit 3 (Reference 6) in light of the NUREG-1152 (draft) findings, and concluded that the Station AC Blackout risk at Millstone Unit 3 (due to internally initiated events) is significantly lower than predicted in NUREG-1152 (draft) and that no further plant specific actions are warranted pending full generic resolution of the Station AC Blackout Unresolved Safety Issue.

One of the four recommendations of NUREG-1152 was that an evaluation be made as to the feasibility of adding an AC-independent containment spray system at Millstone Unit 3. In Reference 5, NNECO committed to perform such an evaluation by the startup from the first refueling outage (estimated as late 1987/early 1988).

The feasibility and cost-benefit of adding an AC-independent containment spray system are the subject of this report.

Summary

The major findings of the report are summarized below:

- The potential accident sequences which could be mitigated by the proposed designs include all sequences where containment spray would be unavailable due to fire, seismic, or Station AC Blackout. The TE and SE plant damage states from the Probabilistic Safety Study (PSS) could be mitigated. The designs would not be effective against the interfacing systems LOCA or other sequences where the fission products are released directly to the environment, or where containment fails early on.

- The fission product source terms from the American Nuclear Society "Report of the Special Committee on Source Terms" were used in this study. Comparisons with the PSS and Sandia Siting Study are made. In general, the SST2 releases and hence consequences from the Sandia Siting Study are similar to those used in this report.

- The potential risk reduction that the AC-independent containment spray design could provide is very low (7 man-rem per year). Even using the Seismic Hazards Characterization Project (SHCP) curve, the potential risk reduction is only 60 man-rem per year.

- Based on a review of the seismic capacity of existing systems and equipment, it is concluded that the existing quench spray system is the system best suited to use with the proposed designs.

- It would be neither effective nor practical to design the AC-independent containment spray system for seismic ground acceleration beyond about 1g.

- Based on generic studies of the feasibility and cost of adding an AC-independent train of containment spray, a new train which fully meets all current regulatory requirements would cost on the order of 10 million dollars (1986 $). The design would not be cost effective by very substantial margins.

- Two plant-specific designs have been proposed in this study which provide containment spray independently from the existing onsite emergency AC power system. Both designs were pursued far enough to get a reasonable measure of their feasibility and costs. The first design (Option 1) proposed is a non-Class 1E, commercially available emergency diesel generator which would provide power to an existing quench spray pump. Only the design's interface with existing Class 1E systems would be Class 1E. The cost was calculated to be about one million dollars (1986 $). The second design (Option 2) involves the use of skid mounted diesel powered fire pumps which would pump ocean water through hoses and fittings directly into the quench spray piping. The cost of the design was calculated to be 1.15 million dollars. Both designs would be manually actuated.

- Both designs could be made feasible, although the logistics and procedures associated with Option 1 are much simpler than for Option 2. During an emergency situation, containment spray could be established much earlier with the Option 1 design (one hour or so) versus many hours for Option 2. However, there are other limitations associated with Option 1 since the design relies on the existing refueling water storage tank (RWST) for its source of water (about a 5 hour supply using continuous spraying). The seismic capacity of the design is limited by the capacity of the RWST and of the new design. To a certain extent, Option 2 provides greater potential risk reduction and flexibility but there are large uncertainties as to whether the diesel fire pumps can be transported into position following a severe seismic event. Also, up to 10,000 feet of fire hose would have to be layed and connected in order to provide sufficient flow of water from the ocean. The manpower requirements to do this would be enormous.

- o The cost-effectiveness of the two designs was determined using two different measures. The first measure is a straight calculation of the total present worth costs of the design per man-rem of averted public risk. For either option, a value of about $11,000 per man-rem averted is obtained. The second measure compares the total benefits with the total costs. The averted risks (benefits) include health effects, lost wages, relocation expenses, lost private and public property (offsite) and so on. (The proposed designs would not affect core melt frequency nor have an impact on onsite costs). Benefit-to-cost ratios of 0.01 were calculated for both options.

- o Sensitivity studies were performed which measured the effects of source term, seismic hazard curve, health effects costs, and distance from the plant over which the (averted) risk are calculated. Even using pessimistic assumptions which tend to maximize offsite risks, it is shown that the proposed designs are not cost effective.

2.0 METHODOLOGY AND ASSUMPTIONS

The methodology which is used in this study can be summarized as follows:

- Based on previous probabilistic studies for Millstone Unit 3, the potential benefits in terms of averted offsite consequences and risks resulting from an ideal AC-independent containment spray design are evaluated.

- Conceptual designs are proposed, and evaluations as to the feasibility and realistic costs of engineering and installing the designs are performed.

- The value-impact of the options are then assessed based on the expected benefits, which take into account system unavailabilities due to random failures or failure due to the initiating event (fire, seismic).

No re-analysis of the frequency of core melt accidents which might be mitigated is performed. The evaluation in this study does consider all potential accident sequences (not only Station AC Blackout from internally initiated events) where proposed designs may be of benefit. For the purpose of evaluating the consequences of core melt accidents, realistic fission product source terms are considered. The American Nuclear Society Report on Source Terms (Reference 7) is used as a basis. The offsite consequences of potential accidents are evaluated using the Sandia Siting Study (Reference 8) as a reference. Benchmarking of the source terms and consequences from the Millstone Unit 3 PSS is made with References 7 and 8 to show consistency of results. No additional calculations of fission product source terms or offsite consequences have been made in this study.

Two rather diverse options have been considered in this study. Although the designs are nowhere near complete, enough detail has been obtained to provide reasonable estimates of the material and labor required to design and install the systems.

Additional calculations which model containment thermal response to core melt accidents with and without the new designs are not performed. However, based upon insights from the PSS as well as follow-up studies regarding recovery of containment sprays, sufficient information is available to assess the effectiveness of the proposed designs.

Some of the major assumptions in the evaluation are summarized below:

- The AC-independent containment spray system would be initiated manually as a last resort, and only after core melt and reactor vessel failure are assessed to be inevitable. The system would be activated in a 4 to 6 hour time frame following accident initiation, or in a "several hours" time frame following core melt.

- The availability of the system is limited by operator action. The unavailability of equipment due to random failure (manual valves, pumps, etc.) when combined with operator error is assumed to be 0.1. Hence, an order of magnitude reduction in severe release category frequency is realized.

- The containment spray would be effective in reducing the fission product release fractions but may or may not totally prevent containment failure. The release of noble gases is delayed but not totally averted. For the purpose of cost-benefit evaluation, it is assumed that the proposed containment spray design would reduce public consequences by an order of magnitude (from what otherwise would be the case without the new design).

- "AC-independent" is taken to mean independent of the current offsite and emergency onsite AC sources. Thus, one of the options which considers the addition of a non-Class 1E electrical generator is "AC-independent".

- Since manual action within the Engineering Safety Features (ESF) building is required, the building would be accessible following core melt (i.e., radiation levels are acceptable for short-term stay in the quench spray pump room).

- No major seismic upgrades of existing piping, equipment, or structures related to containment spray are made. To do so would be impractical and prohibitively expensive.

- For the option where an existing quench spray pump is re-powered by a separate AC source, room cooling by mechanical means is not required. Natural ventilation via opening doors is assumed adequate for the duration (5 hours of continuous spraying, longer with intermittent spraying). To provide additional ventilation equipment would add substantially to the costs.

- For the option where diesel-driven fire pumps are used with fire hoses, the ultimate source of water (Long Island Sound) is accessible despite up to a 1g ground acceleration earthquake. The flat bed trailers, containing the skid-mounted pumps and other equipment remain undamaged and can be transported into position.

- Sufficient instrumentation is available following severe seismic events for the operators to diagnose the situation and take action. For the more severe ground acceleration levels where the control building is postulated to collapse, action is taken by other plant personnel to align the containment spray system in the absence of all normal indications of containment condition.

- The cost-benefit evaluation is performed assuming no other plant changes besides the upgrade of the emergency diesel generator lube oil anchor bolts. Other potential modifications under consideration which might lessen the frequency of core melt due to Station Blackout are thus not accounted for in this study. Such modifications, if implemented, would tend to lessen the potential benefits of the AC-independent containment spray system.

3.0 POTENTIAL RISK REDUCTION AND OTHER BENEFITS

3.1 Plant Damage States Affected

To determine the potential risk reduction provided by the AC-independent containment spray system, it is necessary to know the risk level with and without the proposed modification. The proposed modification would have no impact on core melt frequency; neither would the frequency nor consequences of plant damage states with containment heat removal systems available (designated C, C', and C" in the PSS) be affected (see Table 1 for definitions). The accident sequences where the new containment spray system would be of potential benefit include Station AC Blackout from internally initiated events as well as fire and seismic; accident sequences where containment heat removal (CHR) is unavailable because of support system failures (service water, DC power, etc.); and sequences where CHR fails because of containment spray pump unavailability.

Because of the early timing of core melt and possible early breach of containment from large LOCA-induced core melt without CHR (plant damage states AE and AL), the new design would probably not be of benefit for these cases. Moreover, these sequences are low in frequency and are not risk significant. Other accident sequences which are risk dominant such as the interfacing systems LOCA (or V-sequence) would be unaffected altogether by the new design.

In summary, the plant damage states that could be significantly reduced in frequency, and where significant risk reduction could be realized from the new design, include SE and TE plant damage states. Table 2 summarizes the total core melt frequency for TE and SE as determined in the PSS (Reference 1), as used in this study, and as calculated by the U.S. Nuclear Regulatory Commission (NRC) Staff using input from Lawrence Livermore National Laboratory (LLNL) and Brookhaven National Laboratory (BNL) (References 2 to 4). The values used in this study include adjustments for the most recent quantification of Station AC Blackout from internally initiated events

(Reference 6) as well as the reduction from the planned upgrade of the emergency diesel generator lube oil cooling system anchor bolts. The values calculated by the NRC staff are included for comparison and reflect a more conservative evaluation. The most significant difference is that of the frequency of TE/SE plant damage states resulting from severe seismic events. Using the Seismic Hazards Characterization Project (SHCP) curve, the NRC has calculated a frequency of TE/SE one order of magnitude higher than that calculated in the PSS and used in this study. The frequencies of TE/SE due to internally initiated events and fire as calculated by the NRC are factors of two higher.

3.2 Fission Product Release Categories

Given an accident leading to the TE/SE plant damage states, there are conditional probabilities that the accident results in particular radiological releases. Table 3 summarizes the conditional probability of releases as used in the PSS and by NRC/LLNL/BNL. Table 4 provides a qualitative description of each release category. In this study, it is assumed for simplification purposes that all TE/SE plant damage states result in a new release category with late containment failure called M7A (defined in greater detail below). This is consistent with NRC/BNL where intermediate time containment failure (M5/M6) for TE/SE is deemed unlikely. Only if containment spray were recovered and a large hydrogen burn occurred could intermediate time containment failure result (M6S), and then the release fractions are significantly reduced because of the effectiveness of scrubbing by the sprays. The offsite public consequences of M6S are less than M7, for example.

The release fractions and timing for the M7A release category are specified in Table 5. As a reference point, the release fractions for M7 from the PSS are provided (CsI model). The release fractions for M7 represent WASH-1400 methodology and do not reflect primary system retention nor particle agglomeration and settling within containment. Because of this, the method of discrete probability distributions (DPD) was used in the PSS to quantify the probability of a spectrum of reduced release fractions. Using information in the PSS, the "effective" or "weighted average" release fractions for M7 have been calculated and are depicted in Table 5. Thus, the release fractions for M7 releases in the PSS were effectively reduced by a factor of 50 (excluding noble gases) as a result of the DPD methodology. In contrast, the release fractions for M7 and M6S used by NRC/BNL reflect WASH-1400 type methodology.

In the aftermath of the 1979 TMI accident, a review of the available data from scientific investigations for light water reactors shows that the amount of radioactivity that could be released in a severe reactor accident is far less than had been estimated earlier (Reference 7). Reductions in the source term from estimates reported in the 1975 Reactor Safety Study (WASH-1400), which formed the basis for source terms in the Sandia Siting Study (Reference 8), could range from more than a factor of ten to several factors of ten for the critical fission products in most of the accident scenarios.

For the accident sequences of interest in this study (late containment failure), the results of three analyses from the ANS Source Term Report are shown in Table 5. Like Millstone Unit 3, the Surry and Zion plants are considered large dry PWR containments. Furthermore, Millstone Unit 3 and Surry both have subatmospheric containments. For the TMLB accident scenario (Station Blackout with failure of auxiliary feedwater) leading to late containment failure, the release fractions for I, Cs, and Te are seen to be one to four orders of magnitude less than for the unweighted M7 release category from the PSS. (The reductions are even greater for other plants/investigators in Reference 7 not shown here). Using an assumed release fraction of 3×10^{-3} for I and Cs in M7A is reasonable if not conservative in comparison to the three cases from Reference 7 shown here. Likewise, a release fraction of 3×10^{-3} for Te is far less than for two of the cases (but greater than for the case of basemat penetration at 12 hours). In summary, the release fractions for M7A are more in line with SST2 from the Sandia Siting Study than SST1. Since SST2 has slightly higher release fractions and much earlier release time than presumed in M7A, one should expect the offsite public consequences for SST2 at the Millstone site to be slightly higher than those for M7A.

In the BNL review of the MP-3 PSS (Reference 4), the release energy for the M7 release category was adjusted downward to 150 x 10^6 BTU/hr from 540 x 10^6 BTU/hr, even though the PSS value reflects actual calculated stored energy at the best estimate containment failure pressure. But sensitivity studies performed in the Sandia Siting Study indicate that mean early fatalities are not very sensitive to release energy in the range of interest for SST1 (see Reference 8, Table 2.7.2-1). The sensitivity would be even less for late containment failure and still less when latent effects (or man-rem) are the consequences of concern.

Therefore, the release fractions, timing, and energy represented by M7A in Table 5 are a reasonably accurate reflection of the release characteristics expected for TE/SE plant damage states. Additionally, since the release fractions and timing for SST2 from the Sandia Siting Study are more conservative than for M7A one should expect the offsite public consequences for SST2 to be greater than those for M7A for the Millstone site, all other things being equal. It is therefore reasonable to substitute the consequence calculations of SST2 for M7A whenever necessary, especially since detailed offsite financial consequences were not tabulated in the MP-3 PSS.

Table 6 summarizes the emergency response measures used in the PSS (and this study) as well as those used in the NRC/BNL review (Reference 4). Differences are observed for evacuation speed and delay time/relocation time. However, consequence calculations performed in the PSS show no variation in acute injuries for M7 for seismic and non-seismic conditions (i.e., 2 MPH, 3.38 hr. delay versus 10 MPH, 0.92 hr. delay). Latent fatal cancers and man-rem are likewise insensitive. Similarly, Table 4.2 of Reference 4 shows relatively low sensitivity of latent effects to evacuation/relocation assumptions for the intermediate/late containment failure cases (M6 and M7). Therefore, one should expect the public consequences (latent effects in particular) for SST2 to still be similar if not slightly greater than those for M7A even with the differences in evacuation modeling. Further details are provided below.

3.3 Offsite Public Consequences

The offsite public consequences from the radiological releases are calculated using the CRAC2 computer code (Reference 9). As a reference, the consequences for the M7 release category (1/100 source term except noble gases) from the PSS are provided in Table 7. The mean latent cancer fatalities (LCF) assuming 1 LCF per 10^4 man-rem are in very close agreement to those calculated in Reference 8 for SST2 for the Millstone site. The consequences for M7 as calculated by BNL using the evacuation-relocation and late-relocation models are also provided. The difference between late-relocation for severe seismic conditions ($>$ 0.5 g) and evacuation-relocation is only about 12 percent for latent effects. It is also observed from References 4 and 8 that the ratio of man-rem within 50 miles of the plant to the total man-rem within 350 miles is on the order of one-half. For cost-benefit purposes, 50 miles is used in this study (see Section 5.2 for further discussion).

In this study, all TE/SE plant damage states lead to M7A releases. In turn, the M7A release fractions are equivalent to the M7 release fraction (1/100 source term) from the PSS. For the case of severe seismic induced core melt ($>$ 0.5 g), the man-rem totals in this study have been increased by 12 percent to reflect less favorable emergency response. However, it is clear that this 12 percent difference is a second-order effect in terms of all the uncertainties and variations inherent in these studies.

3.4 Potential Risk Reduction

The potential risk reduction provided by the AC independent containment spray system is determined by factoring in the core melt frequency, conditional probability of release, and consequences of the release. Table 8 summarizes the calculation for this study using a 50 mile radius from the plant. Also shown for comparison is the derivation of the value used in the Risk Evaluation Report. This table includes the potential risk reduction for internally initiated events as well as fire and seismic. The factor of 50 difference between this study and the RER is attributable to the difference in core melt frequency (factor of 7) as well as consequences (factor of 7). Table 9 summarizes the potential risk reduction for various combinations of seismic hazard curve, source term, and distance over which the public consequences are integrated. The difference in risk between the PSS seismic hazard curve and the SHCP curve is an order of magnitude. There is also a factor of 6 or more difference attributable to source term assumption, and factors of 2 to 6 difference attributable to distance over which the public consequences are integrated.

The values in Table 9 present the potential risk reduction that an ideal, 100 percent effective, 100 percent available containment spray design would provide. In practice, the realizable risk reduction is less, as will be shown later.

3.5 Offsite Economic Risks

In addition to the potential reduction in public (health) risk, an AC independent containment spray would reduce the offsite financial consequences and risk of reactor accidents. The spray system would have no impact on core melt frequency and thus have little or no effect on onsite costs.

Reference 10 provides site-specific estimates of the financial consequences of reactor accidents. Both offsite and onsite costs are considered. Offsite costs include lost wages, relocation expense of the evacuated population, decontamination costs, lost private and public property, and interdicted land and farm crop costs. Onsite costs include plant personnel health effects, replacement power costs, cleanup costs, and capital costs. In addition, Reference 10 assigned dollar values to the various health effects for the purpose of estimating the total costs of accidents. The study treated these issues by using empirical values of society's willingness to expend resources to avert a death or injury in comparable circumstances (one million dollars per averted early fatality, one hundred thousand dollars per averted latent cancer fatality or early injury).

Therefore, the total costs represent the sum of offsite health costs, offsite property costs, and onsite costs. In Reference 10, these costs for each reactor were estimated and then discounted to 1980 dollars over the remaining life of the plant. To obtain the life cycle risk, the values from Appendix A of Reference 10 need only be multiplied by the per year frequency of each release category for the particular plant of interest. Table 10, reproduced from Reference 10, provides the plant specific values for Millstone Unit 3. It is important to note that onsite costs are invariant with the release category. This is because the onsite costs reflect mainly the costs of a core melt. Since an AC-independent containment spray system would not reduce core melt frequency, but simply reduce the magnitude of radiological releases, then the averted economic risk is obtained by subtracting the total costs of one release category from another (i.e., the containment spray design results in a change in frequency of each release category, but not of core melt). Using the NRC/BNL source terms (i.e., WASH-1400 type) as an upper bound, one might presume that the new containment spray design shifts SST1 type releases into SST2 type releases. Based on a realistic assessment of the source terms as used in this study, one might expect a shift from SST2 releases to SST3. Thus, Table 11 shows the potential economic risk reduction which could be provided by the AC-independent containment spray design. The potential savings are shown to be rather small. Even when unrealistically high fission product release fractions are combined with the severe SCHP curve the potential economic risk reduction is only six and one-half million dollars (1980) over plant life.

4.0 FEASIBILITY AND COSTS

4.1 Generic Evaluations

As part of the Industry Degraded Core Rulemaking (IDCOR) Program, feasibility and cost studies of a diesel-driven containment spray system were performed (References 11 and 12). The additional containment spray system envisioned would be manually actuated, and consist of a single diesel-driven spray train with a water source that is assumed to extend containment failure by 24 hours. A suction connection to the containment sump is not provided, and the system does not provide long-term containment heat removal. The sprays would be actuated intermittently to reduce containment pressure and would provide time for power recovery to other systems.

The conclusions from the reports are that, based on an evaluation for the Zion plants, the concept is feasible and constructable, system reliability would be high, the risk reduction would be relatively low (factor of two), and the cost of implementation would be relatively low. An estimate of 4 to 6 million dollars (1980 $) has been made. It is not clear whether the estimate is based on a design which is seismically and environmentally qualified (QA Category 1) or not.

4.2 Seismic Capacity Considerations

To the extent possible, the conceptual designs which are considered in this study utilize existing equipment. It would be impractical or prohibitively expensive to install new containment spray piping within containment or construct major buildings, for example. Likewise, a major seismic upgrade of existing piping and the Engineered Safety Features building is not practical.

In determining the seismic capacity of the AC-independent spray system that one should design for, two considerations must be addressed:

- o What is the potential benefit (i.e., risk reduction) which could be obtained as a function of g-level capacity of the design?

- o What is the seismic capacity of existing equipment and structures?

In References 2 and 4, the NRC staff and its consultants recommended that the proposed design have a seismic capacity of 1.5 to 1.6 g. However, to upgrade existing equipment and buildings to such a level would be very expensive, if not altogether infeasible, and would provide marginal benefit.

Figure 1 shows the approximate fraction of the potential benefits (i.e., relative cumulative risk contribution) versus g-level using the PSS hazard curve and the SHCP curve. References 2 and 13 were used to derive these curves. For the PSS hazard curve, seismic events of 1g peak ground acceleration or less (including the contribution from internal events and fire) contribute essentially 100 percent of the risk. Similarly, using the SHCP hazard curve it is estimated that seismic events of 1g or less contribute approximately 90 percent of the risk. The marginal benefit of designing to a higher seismic capacity is small.

Since the seismic capacity of the proposed design is limited by the "weakest link", the seismic capacity of existing equipment and structures must be taken into consideration. Table 12 provides the median g-level capacity and the g-level at which there is a 5 percent probability of failure (50 percent confidence). From this table, the following can be concluded:

- o The seismic capacity of equipment and structures related to recirculation spray (particularly the heat exchangers and service water piping) are sufficiently low that recirculation spray should not be the first choice to implement the design.

- The quench spray system provides the best option in terms of seismic capacity, and even then there is a 7 percent probability of failure (piping, pumps, header, ESF building) at the 1g level. At the 1.6g level, the failure probability is nearly 75 percent. The RWST would not be available at the higher g-levels, however.

- The control building has a low seismic capacity relative to other equipment and structures. For a 1g or greater seismic event, all control power and instrumentation would be unavailable for accident diagnosis. Also, the survivability of control room operators at these severe earthquake levels must be questioned.

Based upon the above considerations, it is concluded that the existing quench spray system is the system best suited for use. All controls for the new spray system must be independent of the control building for seismic (and fire) considerations. It is neither effective nor practical to design the AC-independent containment spray system for seismic ground acceleration beyond about 1g.

4.3 Design Considerations

A detailed engineering design is beyond the scope of this study. However, sufficient information regarding containment spray flow rate requirements is needed in order to size pumps and piping. These, in turn, affect the cost projections.

The minimum flow requirements are established by decay heat levels as well as adequate containment depressurization rates. Also, sufficient pressure drop across the spray nozzles is needed to provide proper-sized droplet production. For the accident scenarios under consideration, reactor vessel failure following core melt is estimated to occur in a four hour time frame following accident initiation at the earliest (Reference 14). This would be for a Station Blackout coincident with loss of Auxiliary Feedwater (or TMLB'). Calculations performed in Reference 15 indicate that containment spray should be established in a 2 to 5 hour time frame after vessel failure to prevent a hydrogen burn leading to containment failure. Calculations performed under IDCOR for the Zion reference plant confirm these time frames (Reference 16). Using 5 hours as a basis, decay heat rate is on the order of 10^8 BTU/hr, corresponding to a required containment spray flow rate of about 1200 GPM. To further provide adequate containment depressurization capability as well as design margin, a total flow rate on the order of 2500 GPM is necessary.

As a reference point, Table 4.1-1 from the PSS (Reference 1) provides the delivered flow rate from the existing quench spray pumps as a function of containment back pressure. At the latest time frame that containment spray should be established (6 to 9 hour time frame following accident initiation), containment pressure is estimated to be in the 55-70 psig range (References 14 and 15). Table 4.1-1 of the PSS indicates that one quench spray pump (assuming zero head from the water source) can provide 3000 GPM flow at 56.8 psig containment pressure. It is therefore concluded that the head/flow characteristics of the existing quench spray pumps are adequate. This conclusion is further supported by calculations performed in Reference 15. Further detailed calculations may show that a pump with nominal design flow rate of less than 4000 GPM is adequate. For the purpose of this evaluation, however, a pump whose capacity is comparable to that of the existing quench spray pumps (4000 GPM at 291 ft head) is assumed to be necessary.

4.4 Option 1 - Alternate Power Source

Since the flow equivalent to that from a quench spray pump is required, the first option considered is to provide an alternate power source for one quench spray pump. A non-Class 1E emergency diesel generator (DG), approximately 1000 kW in capacity, is proposed. The DG would be skid-mounted on a concrete pad and enclosed in a corrugated sheet-metal structure. A diesel fuel tank containing about 10 hours of fuel would be buried underground. A location southeast from the ESF Building has been identified. The voltage from the DG would be 4160V. A 5 kV circuit breaker would also be installed. The power cable would be run in underground conduit through existing duct banks from the DG to the ESF Building via the Fuel Building. In order to satisfy all regulatory requirements, the electrical conduit would be seismically mounted in the Fuel and ESF Buildings. Fire stops and seals would be installed at wall and floor penetrations. Also, a Class 1E manual transformer switch (4160V) would provide the interface and necessary separation between the existing Class 1E and proposed non-Class 1E power sources. The transfer switch would be environmentally qualified and seismically mounted. The DG itself is non-Class 1E to minimize costs and because its use is for beyond design basis events. However, with reasonable preventive maintenance and surveillance, the reliability of the DG and associated equipment should be acceptable. A schematic of the design is provided in Figure 2.

During a station AC blackout scenario where re-powering of a quench spray pump is required, local operation of the emergency DG, transfer switch, and circuit breaker would be necessary. Manual opening of the quench spray pump discharge motor-operated valve using the handwheel would also be required. All DG controls would be local. The entire alignment should easily be achieved in a one hour time frame.

A detailed evaluation of the costs of engineering, design, procurement of materials, and installation has been made. In 1986 dollars, the total capital cost for this option is estimated to be 1.02 million dollars. The annual cost for maintenance and surveillance is estimated to be in the 10 thousand dollar range. Total radiation exposure due to installation, maintenance and surveillance would be low. It is also concluded that the design would have no measurable adverse impact on plant safety. Procedures would be required to ensure that the power to the quench spray pump is properly aligned to the onsite emergency power source during normal plant operation.

Although the proposed DG would be "non-seismically qualified" as per regulatory guides, with relatively low effort using good engineering practice the equipment could be supported so as to have a reasonably high success probability for severe earthquakes. From Reference 13, it is shown that most of the risk from seismic events lies in the range of 0.4 to 0.8g peak ground acceleration. Without a detailed design and seismic fragility analysis, it is not possible to determine with certainty the seismic capacity of the proposed design. A median seismic capacity in the 0.4 to 0.6g range should be achievable. However, since this design relies on the RWST for its water source, the availability of the overall design would also be limited by the seismic capacity of the RWST (median capacity of 0.88g).

4.5 Option 2 - Skid Mounted Diesel Fire Pumps

The second design that is proposed involves the use of skid-mounted diesel-powered fire pumps, which provide the equivalent flow of a 4000 GPM pump at 125 psi discharge pressure. This design follows the request by Brookhaven National Laboratory (see Reference 4) that NNECO investigate the feasibility of mobile (or stationary) pumps, such as those on a fire truck, that would take suction from Long Island Sound and provide an AC-independent spray. The pump(s) would take suction from Long Island Sound, and discharge into several parallel lines of standard 5-inch fire hose. The hose would be connected to existing quench spray piping. The pumps and fire hose would be mounted on flat bed trailers and stored on site. A tanker truck would contain enough fuel for about 24 hour operation of the pumps. Proper anchoring would be required to ensure that the trailers could withstand the high g-level seismic event postulated. Three manual valves, a "tee", and associated piping would have to be installed on existing piping to provide proper isolation from the Category 1 system. Seismic analysis and supports would be required for all modifications. Fixtures would be provided to connect upto five 5-inch fire hoses to the quench spray piping via a manifold type arraingement. Figure 3 provides a simplified sketch of the proposed design.

An important consideration for this design includes the location of the source of water, the total length of fire hose and number of pumps required. The distance from the ESF Building to the ocean is 1000 to 2500 feet depending on how direct a path is taken. For the g-level seismic events postulated, it must be assumed that there is considerable obstruction. The clearest path to run the hose and the place to locate the first pump would probably be the barge slip. Another option deserving review would be to take suction from the circulating water discharge tunnel located underground only several hundred feet away from the ESF Building. However, additional piping would need to be installed in the ground to tap into the tunnel. Also, it is not clear what the seismic "capacity" of the tunnel is.

Because of net positive suction head requirements, the diesel pump would have to be hauled into position near the water source. To provide the required flow rates (3000 GPM or so) at the required pressures (in order to overcome line losses, gravitational loss, containment back pressure and pressure drop across the spray nozzles), it would be necessary to run several hoses in parallel. Large hoses of the size and quantity required are not standard nor easily handled. More standard hoses such as 5-inch result in significant pressure drops for the kinds of flow rates required.

Based on preliminary hydraulic calculations, up to three or four 5-inch hoses in parallel would be required to provide sufficient flow. This equates to as much as 10,000 ft of hose which would have to be layed and connected in the six hour time frame following a severe seismic event. Additionally, because of the large pressure drop through the fire hose, a second diesel-powered fire pump in series would be necessary to boost the pressure to the required level.

During the station blackout scenario, the fire pumps would be brought into position and the hose layed out. The hose would be mounted on reels on the trailer to expedite the process. The hose would be run through the propped-open door to the quench spray pump room and connected to the fittings. Three valves would be opened manually and two valves would be closed. Both fire pumps would then be started.

The logistics of getting the pumps and hoses into place especially following a severe earthquake is no trivial matter. Significant personnel resources would be required at a time when many other recovery actions are required following the severe seismic event. If the accident happened to occur at night or during inclement weather, additional resources would be necessary (lighting, etc.). But given sufficient resources and reasonable procedures it would be feasible to do so in the time frame available (six hours or more).

The cost of engineering, design, procurement of equipment, and installation has been estimated to be 1.15 million dollars (1986 $). An additional annual cost of 20 thousand dollars could be expected for maintenance of equipment and drill. The total radiation exposure due to installation would be reasonably low. In general, the uncertainties associated with the ultimate cost of implementing this proposed design are substantially greater than for Option 1.

5.0 COST-BENEFIT EVALUATION

5.1 Adjustments to Costs and Benefits

As stated in Section 3.4, the results shown in Tables 8 and 9 are for a 100 percent effective, 100 percent available containment spray design. In practice, these potential benefits are reduced because:

- o the AC-independent containment spray system would not prevent entirely the release of fission products to the environment
- o the system may be unavailable because of random equipment failures
- o the system may be unavailable because of seismically-induced failures.

The fraction of potential benefits obtainable is given by:

$$f = (1 - 1/CRF) \sum_{\substack{\text{all} \\ \text{g-levels} \\ i}} RRC_i \ (1 - P_{cs,i}) \qquad (1)$$

where

CRF = consequence reduction factor, assumed to be 10 as stated in Section 2.0

RRC_i = relative risk contribution from the i^{th} g-level, obtained by discretizing the curves from Figure 1

$P_{cs,i}$ = unavailability of the proposed containment spray system at the i^{th} g-level.

In turn, $P_{cs,i}$ is composed of a failure probability due to random failures as well as probability of failure due to seismically-induced events, or

$$P_{cs,i} = P_{RF} + (\text{RWST}|\text{core melt} + \text{ESFBLDG} + \text{QSPIPE} + \text{QSPUMPS} + \text{QSHEADER} + \text{ACIEQUIP})_i \quad (2)$$

where the "+" is the Boolean "OR", and

P_{RF} = system unavailability due to random failures or operator error, assumed to be 0.1 as stated in Section 2.0

RWST|core melt = failure probability of the RWST at the i^{th} g-level, given a core melt has occurred (some fraction of core melts is partly attributable to RWST failure) (Option 1 only)

ESFBLDG = failure probability of the ESF building at the i^{th} g-level

QSPIPE = failure probability of quench spray system piping at the i^{th} g-level

QSPUMPS = failure probability of quench spray pumps at the i^{th} g-level

QSHEADER = failure probability of quench spray system header at the i^{th} g-level

ACIEQUIP = failure probability of the AC-independent containment spray equipment at the i^{th} g-level.

The values for RWST|core melt, ESFBLDG, QSPIPE, QSPUMPS, and QSHEADER were obtained from the PSS. For ACIEQUIP, a seismic fragility curve with 5%, 50% and 95% failure probabilities at 0.15, 0.55, and 0.95g respectively was used for Option 1. For Option 2, no failure of the equipment due to seismic events below 1g was assumed.

The fraction of benefits to be realized is given in Table 13 for both the PSS Hazard Curve and the SHCP Curve. The smaller fractions for the SHCP Curve are a result of the greater relative contribution of large g events to overall risk for SHCP, and because of the higher likelihood of system unavailability at relatively high g-levels. The fractions for Option 2 are greater than for Option 1 because of the assumed higher g-level capacity of Option 2.

The capital costs from Sections 4.4 and 4.5 for each option reflect all direct and indirect costs for labor and materials, as well as contingencies. The cost figures do not consider the cost of money (equity and debt), taxes (state, federal, property), and insurance. An economic evaluation was performed using standard financial practices to determine the present worth of the capital expenditures. The evaluation incorporated recent changes in the federal tax code and projected economic conditions over the remaining plant life. A levelized fixed charge rate of 16.5 percent was obtained, and a present worth factor of 1.35 was calculated. That is, a $1 (1986 dollars) capital expenditure in 1989-1990 (the assumed implementation time of the proposed project) has a present worth of $1.35 (1986 dollars) when all carrying charges and taxes over the life of the plant are incorporated.

For Operation and Maintenance, it was assumed that the costs remained fixed in constant 1986 dollars over the remaining plant life.

The final adjustment that is made is to escalate the economic consequences/risks from Table 11 to reflect 1986 dollars. The Consumer Price Index was used to calculate an escalation factor of 1.42. This factor is used in the benefit-to-cost ratio.

5.2 Results

The cost-benefit evaluation for the two proposed options is presented in Table 14. The first comparison that is made is the total cost (1986 dollars) including all capital charges and O & M costs per averted man-rem of public risk. A distance of 50 miles from the plant is used in this risk evaluation, which is conservative in regard to the Commission Policy Statement on Safety Goals (51FR30028, August 21, 1986), "the population generally considered subject to significant risk as the population within 10 miles of the plant site." For Option 1, a value of $10,500 per averted man-rem to the public (from reactor accidents) is calculated. The value for Option 2 is essentially identical at $11,100 per man-rem.

The second comparison that is made is to calculate the Benefit-to-Cost ratio. The "benefits" reflect averted public risk from reactor accidents in the form of health effects, lost wages, relocation expense, lost private and public property, and so on. Reference 10 was used as the source of information. The "costs" reflect all capital and O & M costs as in the first evaluation. The result is a benefit-to-cost ratio of only 0.01 for both options, implying that costs outweigh the benefits by two orders of magnitude.

It should be noted that there is some inconsistency between the two methods. In the second method, the "benefits" were discounted as explained in Reference 10. Also, the health effects costs that were used were significantly lower than $1,000 per man-rem, and reflect the empirical values of society's willingness to avert death or injury in comparable circumstances. On the other hand, the "benefits" or averted risk in the second method reflect the impact of reactor accidents out to distances greater than 200 miles. Because detailed economic risk breakdowns by distance from the plant are not available from Reference 10, it is not possible to estimate the risk within 50 miles.

It is also interesting to note that these evaluations were based on what are, for the most part, very inexpensive designs that do not fully meet current regulatory standards (non QA Category 1, non Class 1E). Based on generic evaluations, it is estimated that a fully qualified, third AC-independent containment spray train housed in its own seismic structure would cost on the order of 10 million dollars (1986 $). There would be only a marginal increase in benefit over the proposed designs, resulting in $100,000 per man-rem and 0.001 benefit-to-cost ratio.

5.3 Sensitivity Studies

As in any study of this type, there are large uncertainties associated with the calculation of costs and benefits. The cost uncertainties mainly involve craft labor as well as engineering and design resources, since the equipment requirements are fairly well defined. Also, there is uncertainty regarding annual maintenance requirements and training. In general, the cost estimates provided are relatively certain and are possibly too high by only 20 to 30 percent or so, or too low by a factor of two.

The averted public risks or "benefits" have large uncertainties. The major uncertainties are associated with

- core melt frequency from internal events
- fission product source term
- seismic hazard curve
- seismic fragility of equipment.

To a lesser extent, there are uncertainites associated with emergency response measures, reliability of equipment, and modeling.

Several sensitivity studies were performed to provide a quantitative measure of some of these uncertainties. Since the proposed designs have been shown not to be cost effective on a best estimate basis, only assumptions which tend to maximize the averted risks (i.e., benefits) are considered here.

Table 15 shows the sensitivity of the cost-benefit evaluation to source term. Using the WASH-1400 type of source term (i.e, BNL/NRC values from Reference 4 or SST1 from Reference 8), the proposed designs are still not cost effective by a factor of two.

In Table 16, the SHCP curve is substituted for the PSS seismic hazard curve. In general, the frequency of severe earthquakes from the SHCP curve is an order of magnitude greater than the PSS hazard curve. The results indicate that again the proposed designs are not cost effective. The results from Table 16 also reflect to a certain extent the sensitivity to core melt frequency since the calculated core melt frequency is directly impacted by the hazard curve used. The differences between Option 1 and Option 2 reflect the sensitivity to seismic fragility of the proposed designs since in Option 1 a median capacity of 0.55g is assumed, and in Option 2 the design is assumed to be completely resistant to earthquakes below 1g.

Table 17 shows the sensitivity to distance from the plant over which the averted risk is calculated. Only when a distance up to 350 miles is used along with the SHCP curve is the dollars per man-rem less than 1000 (for Option 2, similarly for Option 1). When the economic consequences are calculated using the methodology of Reference 10, however, the costs are shown to outweigh the benefits by an order of magnitude or more in all cases.

Only when a distance up to 350 miles is combined with the SHCP curve and the WASH-1400 type source term might one expect a benefit-to-cost ratio of greater than one. But as noted in the BNL report (Reference 4), "...for the late containment failures considered here, the revised methodology would unambiguously predict substantially lower source terms than we have assumed in our risk estimate," and "...we are confident that the radiological releases (using WASH-1400 type methodology) have been overestimated by an order of magnitude or more." It is therefore unreasonable to use conservative assumptions across the board in the cost-benefit evaluation.

Finally, one area which may contain large uncertainty is the assignment of values for health effects. Considerable discussion is presented in Reference 10. For SST2, the portion of total offsite costs represented by health effects is about 30 percent (on average for all U.S. plant sites). A ten-fold increase in the value used for health effects would increase offsite financial cost by about a factor of four. From Table 14, column two, the benefit-to-cost ratio would still be only 0.04 even with an order of magnitude increase in health effects cost.

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16. IDCOR Technical Report 23.1Z, "Zion Nuclear Generating Station - Integrated Containment Analysis," June 1985.

TABLE 1
DEFINITION OF PLANT DAMAGE STATES

SYMBOL	DESCRIPTION
AEC	LARGE LOCA, EARLY MELT
AEC'	LARGE LOCA, EARLY MELT, FAILURE OF RECIRCULATION SPRAY
AE	LARGE LOCA, EARLY MELT, NO CONTAINMENT COOLING
ALC	LARGE LOCA, LATE MELT
ALC'	LARGE LOCA, LATE MELT, FAILURE OF RECIRCULATION SPRAY
ALC"	LARGE LOCA, LATE MELT, FAILURE OF QUENCH SPRAY
AL	LARGE LOCA, LATE MELT, NO CONTAINMENT COOLING
SEC	SMALL LOCA, EARLY MELT
SEC'	SMALL LOCA, EARLY MELT, FAILURE OF RECIRCULATION SPRAY
SE	SMALL LOCA, EARLY MELT, NO CONTAINMENT COOLING
S'E	INCORE INSTRUMENT TUBE LOCA, EARLY MELT, NO CONTAINMENT COOLING
SLC	SMALL LOCA, LATE MELT
SLC'	SMALL LOCA, LATE MELT, FAILURE OF RECIRCULATION SPRAY
SLC"	SMALL LOCA, LATE MELT, FAILURE OF QUENCH SPRAY
SL	SMALL LOCA, LATE MELT, NO CONTAINMENT COOLING
TEC	TRANSIENT, EARLY MELT
TEC'	TRANSIENT, EARLY MELT, FAILURE OF RECIRCULATION SPRAY
TE	TRANSIENT, EARLY MELT, NO CONTAINMENT COOLING
V2EC	STEAM GENERATOR TUBE RUPTURE, STEAM LEAK, EARLY MELT
V2EC'	SGTR, STEAM LEAK, EARLY MELT, FAILURE OF RECIRC SPRAY
V2E	SGTR, STEAM LEAK, EARLY MELT, NO CONTAINMENT COOLING
V2LC	SGTR, STEAM LEAK, LATE MELT
V2LC'	SGTR, STEAM LEAK, LATE MELT, FAILURE OF RECIRC SPRAY
V2LC"	SGTR, STEAM LEAK, LATE MELT, FAILURE OF QUENCH SPRAY
V2L	SGTR, STEAM LEAK, LATE MELT, NO CONTAINMENT COOLING
V	INTERFACING SYSTEMS LOCA
V3	SEISMIC-INDUCED LOCA WITH CONTAINMENT BYPASS

TABLE 1
(continued)

Key:

First letter - Describes initiating event type

- T - transient event
- S - small LOCA event (equivalent diameter 3/8 to 2 inches)
- A - large or medium LOCA event (equivalent diameter greater than 2 inches)
- S' - incore instrument tube LOCA
- V2 - steam generator tube rupture with a steam leak
- V - interfacing systems LOCA
- V3 - seismic-induced LOCA with containment bypass

Second letter - Describes core melt timing

- E - early melt (implies ECCS injection failure)
- L - late melt (implies ECCS recirculation failure)

Third letter - Describes containment sprays

- C - injection and recirculation sprays operational
- C' - injection sprays only
- C" - recirculation sprays only
- If blank, no sprays operational

TABLE 2
CORE MELT FREQUENCY (YR^{-1})

	PSS	THIS STUDY	NRC/LLNL/BNL
Station Blackout (Internal Events Only)	1.65×10^{-6} (1)	2.5×10^{-6} (2)	8.2×10^{-5} (3)
All TE/SE Plant Damage States (including Station Blackout)			
Internal Events	5.4×10^{-6} (4)	6.3×10^{-6}	1.4×10^{-5} (5)
Seismic	7.6×10^{-6} (6)	6.6×10^{-6} (7)	6×10^{-6} (8) 9×10^{-5} (9) 7×10^{-5} (10)
Fire	1.4×10^{-6} (11)	1.4×10^{-6}	3×10^{-6} (12)

NOTES:

(1) MP-3 PSS, Table V-1.

(2) MP-3 Station AC Blackout Assessment, NUSCO, p. 75 (Reference 6).

(3) NUREG-1152, Appendix B.

(4) MP-3 PSS, Figure 7.4.1-1.

(5) NUREG/CR-4143, Table 3.3 indicates $1.4 \times 10^{-5} YR^{-1}$, which includes Station Blackout contribution. Because of recovery of sprays, not all Station Blackout core melts result in SE.

(6) MP-3 PSS, Table 7.5.1-3.

(7) Includes reduction of $1 \times 10^{-6} YR^{-1}$ as per Modification 1 of NUREG-1152, Table 13, PSS Hazard Curve.

TABLE 2
CORE MELT FREQUENCY (YR^{-1})
(continued)

NOTES: - (continued)

(8) NUREG-1152, Table 2, PSS Hazard Curve.

(9) NUREG-1152, Table 2, SHCP Curve.

(10) Based on $2x10^{-5}YR^{-1}$ reduction from Modification 1 of NUREG-1152, Table 13, SHCP.

(11) MP-3 PSS, Table 2.5.2.3-1.

(12) NUREG/CR-4143, Table 3.3.

TABLE 3

CONDITIONAL PROBABILITY OF RELEASES

	RELEASE CATEGORY	PSS(1)	THIS STUDY	NRC/LLNL/BNL(2)
TE (ALL INITIATORS)	M6	---	---	---
	M7	0.9	---	0.9
	M9/M10/M11	0.1	---	0.1
	M6S	---	---	---
	M7A	---	1.0	---
SE (NON-SEISMIC)	M6	0.06	---	---
	M7	0.89	---	0.03
	M9/M10/M11	0.05	---	---
	M12	---	---	0.63
	M6S	---	---	0.34
	M7A	---	1.0	---
SE (SEISMIC)	M6	0.06	---	---
	M7	0.89	---	1.0
	M9/M10/M11	0.05	---	---
	M7A	---	1.0	---

NOTES:

(1) NUREG/CR-4143, TABLE 3.10

(2) NUREG/CR-4143, TABLE 3.11

TABLE 4
DEFINITION OF RELEASE CATEGORIES

Category	Description
M-1A	This release category is used for core melt accident sequences where a containment bypass directly to the environment exists through the RHR system and Auxiliary Building. Such a pathway can result from failure of the interfacing valves separating the high and low pressure portions of systems connected to the RCS. The V-sequence is placed in this release category.
M-1B	This release category is used for core melt accident source terms where a containment bypass directly to the environment exists through a steam generator tube rupture. The V2-sequences are placed in this release category.
M-2 M-3	These release categories are used for those accident sequences which lead to an early overpressure of the containment with no containment sprays operational. Release category M-2 accounts for early core-melt sequences with a short warning time for evacuation. Release category M-3 accounts for late core-melt sequences with a slightly longer warning time for evacuation.
M-4	This release category is used for core-melt sequences with failure of containment isolation function.
M-5 M-6	These release categories are used for those accident sequences which lead to intermediate containment failure times without containment sprays operational. Release category M-5 accounts for late melt sequences and M-6 for early melt sequences.

TABLE 4
(continued)

Category	Description
M-6S	This release category was created by BNL (Reference 4) to account for recovery of containment sprays, followed by a hydrogen burn which results in an intermediate time containment failure.
M-7	This release category is used for core-melt accident sequences which lead to late containment failure times without containment sprays operational.
M-7A	Similar to M-7 but accounts for reduced source term (used in this study only).
M-8	This release category is used for core-melt accident sequences which lead to intermediate containment failure times with functional containment sprays.
M-9	This release category is used for core-melt accident sequences which lead to late containment failure times with functional containment sprays.
M-10 M-11	These release categories are used for core-melt accident sequences which lead to basemat melt through. Release category M-10 is used for the case of containment sprays nonoperational and M-11 for operational sprays.
M-12	This release category is used for core-melt accident sequences where containment remains intact. All sequences in this release category have continuous spray operation.

TABLE 5

RELEASE CATEGORY COMPARISON

RELEASE CATEGORY	RELEASE START TIME (HRS.)	RELEASE WARNING TIME (HRS.)	RELEASE DURATION (HRS.)	RELEASE ENERGY (BTU/HR.)	RELEASE FRACTION I	Cs	Te
MP-3 PSS,M7(1)	20.1	16.0	0.5	540E6	3E-1	3E-1	3E-1
MP-3 PSS,M7,DPD weighted avg.(2)	20.1	16.0	0.5	540E6	6E-3	6E-3	6E-3
BNL/NRC,M7 (3)	20.1	16.0	0.5	150E6	1.5E-2	3E-1	3E-1
BNL/NRC,M6S(3)	11.5	5.9	0.5	70E6	7E-3	1E-3	1E-3
SURRY-TMLB-(BMI-2104,VOL V)(4)	12.0	---	---	---	2.8E-3	1.7E-4	8.1E-2
SURRY-TMLB-(STONE&WEBSTER)(4)	27	---	---	---	3.6E-5	3.5E-5	1.8E-4
ZION-TMLB-(IDCOR)(4)	32	---	---	---	2.0E-3	2.0E-3	2.0E-5
SANDIA SITING STUDY SST2(5)	3	1	2	0	3E-3	9E-3	3E-2
THIS STUDY,M7A	20.1	16.0	0.5	540E6(6)	3E-3	3E-3	3E-3

NOTES:

(1) MP-3 PSS Table 5.1-2

(2) Using Tables 5.1-2 and 5.1-5 of MP-3 PSS

(3) NUREG/CR-4143, Tables 3.15, 3.17

(4) American Nuclear Society Report of the Special Committee on Source Terms, September 1984, Tables 7.1B and 7.1C

(5) NUREG/CR-2239, November 1982, Table 2.3.1-2

(6) Table 2.7.2-1 of NUREG/CR-2239 indicates that mean latent cancer fatalities are insensitive to release energy. The value of 540E6 reflects the stored internal energy at containment failure pressure of 132 psia for MP-3.

TABLE 6. EMERGENCY RESPONSE MEASURES

	RADIUS OF EVACUATION (mi)	EVACUATION SPEED (mi/hr)	DISTANCE TRAVELLED (mi)	DELAY TIME BEFORE EVACUATION (hr)	RELOCATION TIME AFTER PLUME (hr)
MP-3 PSS (non-seismic) (1)	10	10 (2)		15	0.
MP-3 PSS (seismic)	10	2		15	
BNL/NRC EVAC-RELOC (3)					
BNL/NRC LATE-RELOC (3)	10	2		15	
THIS STUDY	N/A	N/A		N/A	N/A
M7A, severe seismic (> .5g)		see note 4			
M7A, all other initiators	10	10		15	

NOTES:

(1) MP-3 PSS, Table 6.1-4

(2) For normal weather condition.

(3) NUREG/CR-4143, Table 4.1

(4) For the M7 release category, Figure 6.1-20 of the PSS shows no sensitivity of acute injuries to seismic versus non-seismic (i.e., 2 MPH, 3.38 hr. delay versus 10 MPH, 0.92 hr. delay). Latent fatal cancers (and man-rem) are likewise insensitive. Likewise, Table 4.2 of NUREG/CR-4143 shows relatively low sensitivity of latent effects to evacuation/relocation assumptions for M6 and M7 (only 12% difference). Hence severe seismic is treated as "all other initiators" but with a consequence factor of 1.12 used in the consequence analysis. This is applicable only to late releases such as M7 (M7A).

TABLE 7
CONSEQUENCES

SOURCE TERM	MEAN EARLY FATALITIES	MEAN LATENT CANCER FATALITIES	MEAN MAN-REM WITHIN 350 MILES	MEAN MAN-REM WITHIN 50 MILES
MP-3 PSS,M7, (1) 1/100 SOURCE TERM (seismic&non-seismic)	0	1E2 (2)	1E6	5E5 (3)
BNL/NRC,M7 (4)				
EVAC-RELOC	0	1.4E3	1.8E7	3.3E6
LATE-RELOC	1.1	1.6E3	2.0E7	5.3E6 (5)
SST2 (6)	0.02	1.6E2	1.6E6 (2)	8E5 (3)
THIS STUDY,M7A (7)				
severe seismic(>.5g)	0	1.12E2	1.12E6	5.6E5
all other init.	0	1E2	1E6	5E5

NOTES:

(1) Calculated from MP-3 PSS, Figure 6.1-54, 0.01X curve.

(2) Assumes 10^4 man-rem per latent cancer fatality.

(3) Not calculated explicitly, but based on NUREG/CR-4143, Table 4.2, which for M6S [closest release fractions and timing to M7(.01X)] gives a 50 mile man-rem to 350 mile man-rem ratio of about 0.5. This is also consistent with NUREG/CR-2239, Table 2.6-6a which for SST2 gives a cumulative fraction of 0.45 at 50 miles.

(4) NUREG/CR-4143, Table 4.2.

(5) The value of 5.3E6 man-rem is not given explicitly in Table 4.2. However, the difference of 2E6 man-rem between EVAC-RELOC and LATE-RELOC for 350 miles bounds the difference for 50 miles.

(6) NUREG/CR-2239, Table C-1.

(7) The values for "all other initiators" are taken from the PSS M7, 1/100 release fraction, source term case. For severe seismic, a factor of 1.12 is used as per Table 6, note 4 of this study.

TABLE 8. POTENTIAL RISK REDUCTION OF AC INDEPENDENT CONTAINMENT SPRAY

	THIS STUDY	NRC/LLNL/BNL (SHCP)
1. CORE MELT FREQUENCY OF TE/SE PLANT DAMAGE STATES (PER YEAR)	1.4E-5 (1)	1.1E-4
2. FREQUENCY OF MAJOR MITIGABLE RELEASES (PER YEAR)	M7A= 1.4E-5	M6= 6.2E-6 (2) M7= 1.1E-4 M6S= 4.6E-6
3. CONSEQUENCES (man-rem) WITHIN 50 MILES	5E5 (3)	M6= 4.5E6 (4) M7= 3.3E6 M6S= 1.4E5
4. POTENTIAL RISK REDUCTION WITHIN 50 MILES (man-rem/yr)	7	390 (5)

NOTES:

(1) Includes DG lube oil anchorage upgrade

(2) from NUREG/CR-4143, Table 3.12; includes normal and impaired evacuation for SHCP curve, no DG lube oil anchorage upgrade

(3) normal evacuation only; severe seismic adds negligibly to risk

(4) EVAC-RELOC values only, Table 4.2, NUREG/CR-4143

(5) also obtainable from Table 7.1, NUREG/CR-4143

TABLE 9
MATRIX OF POTENTIAL RISK REDUCTION
(MAN-REM/YR)

	PSS HAZARD CURVE	SHCP
BNL/NRC (1,2) SOURCE TERM	226 [41]	2261 [390]
ANS-BASED SOURCE TERM (M7A)	14 [7]	120 [60]

NOTES:

(1) Number within brackets denotes value within 50 miles of plant. Unbracketed denotes within 350 miles.

(2) NUREG/CR-4143,Table 7.1, all but M1A, M1B, and M4 releases.

Table 10
Total Economic Costs of Reactor Accidents At Millstone Unit 3

RELEASE CATEGORY	OFFSITE HEALTH COSTS	OFFSITE PROPERTY COSTS	ONSITE COSTS	TOTAL COSTS
SST1	1.15E+10xf_1	4.80E+10xf_1	1.18E+11xf_1	1.78E+11xf_1
SST2	2.86E+08xf_2	1.13E+09xf_2	1.18E+11xf_2	1.20E+11xf_2
SST3	1.09E+06xf_3	1.89E+08xf_3	1.18E+11xf_3	1.18E+11xf_3

NOTES:

All values represent 1980 dollar-years discounted over 40 year plant life. To obtain the life cycle costs, the total costs for each release category must be multiplied by the per year frequency of each release category (f_1 , f_2 , f_3) and summed. (Reproduced from page A-76 of Reference 10).

TABLE 11

POTENTIAL ECONOMIC RISK REDUCTION

PROVIDED BY AC-INDEPENDENT

CONTAINMENT SPRAY DESIGN

	THIS STUDY	UPPER BOUND
Release Category Frequency (yr^{-1})	1.4E-5	1.1E-4
Economic Consequence Reduction (1980 $-yr)	1.2E+9 (1,2)	5.8E+10 (1,3)
Life Cycle Discounted Economic Risk Reduction (1980 $)	1.7E+4	6.4E+6

Notes:

(1) Economic consequences have been calculated out to 200 miles or more.

(2) Value represents economic consequence of SST2 minus that of SST3.

(3) Value represents economic consequence of SST1 minus that of SST2.

TABLE 12
SEISMIC CAPACITY OF CONTAINMENT SPRAY
COMPONENTS/BUILDINGS

g-level

SYSTEM/COMPONENTS	MEDIAN CAPACITY	5% FAILURE PROBABILITY (50% CONFIDENCE)	FAILURE PROBABILITY AT 1g (50% CONFIDENCE)
QUENCH SPRAY			
RWST	0.88	0.54	---
PIPING	2.17	1.10	0.03
PUMPS	2.93	2.00	NEGLIGIBLE
HEADER PIPING	3.07	1.10	0.03
RECIRCULATION SPRAY			
HEAT EXCHANGERS	0.82	0.48	---
SERVICE WATER SYSTEM			
PIPING	1.30	0.88	---
PUMPHOUSE (SLIDING)	1.30	0.88	---
SHEAR WALL FAILURE	1.60	0.93	---
PUMPS	2.40	1.44	---
RECIRCULATION PUMPS	1.71	0.93	---
RECIRCULATION PIPING	2.17	1.10	---
CONTROL BUILDING			
COLLAPSE (DIAPHRAGM)	1.00	0.67	---
FAILURE (SLIDING)	1.20	0.83	---
480V MCC	2.21	1.40	---
CABLE TRAYS	2.70	1.24	---
DWST	1.60	1.07	---
ESF BLDG.	1.70	1.15	0.01

Table 13

Fraction of Maximum Benefits That Can Be Realized

	PSS HAZARD CURVE	SHCP CURVE
Option 1	0.63	0.34
Option 2	0.80	0.78

Table 14

Cost-Benefit Results

	DOLLARS (1) PER MAN-REM	BENEFIT/COST RATIO (2)
Option 1	10,500	0.010
Option 2	11,100	0.010

Notes:

(1) Values are expressed in 1986 dollars per man-rem averted (within 50 miles) over remaining plant life.

(2) Values are obtained using total project costs in 1986 dollars, and discounted benefits as per Table 11 escalated to 1986 dollars. Note that the economic consequences were calculated out to beyond 200 miles.

Table 15

Effects of WASH-1400 Type Source Term

	DOLLARS (1) PER MAN-REM	BENEFIT/COST RATIO (2)
Option 1	1800	0.48
Option 2	1900	0.48

Notes:

(1) Values are expressed in 1986 dollars per man-rem averted (within 50 miles) over remaining plant life.

(2) Values are obtained using total project costs in 1986 dollars, and discounted benefits as per Table 11 escalated to 1986 dollars. Note that the economic consequences were calculated out to beyond 200 miles.

Table 16

Effect of SHCP Hazard Curve

	DOLLARS (1) PER MAN-REM	BENEFIT/COST RATIO (2)
Option 1	2310	0.045
Option 2	1332	0.083

Notes:

(1) Values are expressed in 1986 dollars per man-rem averted (within 50 miles) over remaining plant life.

(2) Values are obtained using total project costs in 1986 dollars, and discounted benefits as per Table 11 escalated to 1986 dollars. Note that the economic consequences were calculated out to beyond 200 miles.

Table 17

Effect of Distance from Plant Over Which Averted Risk is Calculated (Option 2)

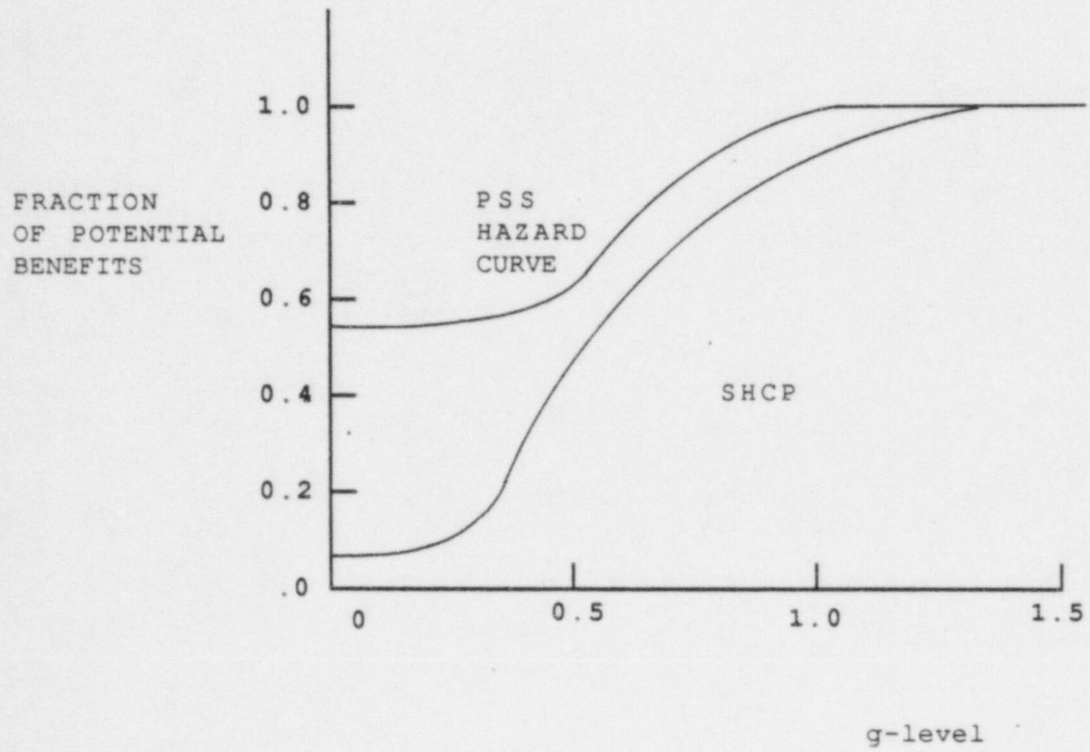
	DOLLARS (1) PER MAN-REM		BENEFIT/COST RATIO (2)	
	PSS HAZARD CURVE	SHCP	PSS HAZARD CURVE	SHCP
50 Miles	11,100	1,332	--	--
350 Miles	5,500	670	0.010	0.083

Notes:

(1) Values are expressed in 1986 dollars per man-rem averted (within 50 miles) over remaining plant life.

(2) Values are obtained using total project costs in 1986 dollars, and discounted benefits as per Table 11 escalated to 1986 dollars. Note that the economic consequences were calculated out to beyond 200 miles.

Figure 1. Approximate Fraction of Potential Benefit Obtainable From AC Independent Containment Spray System



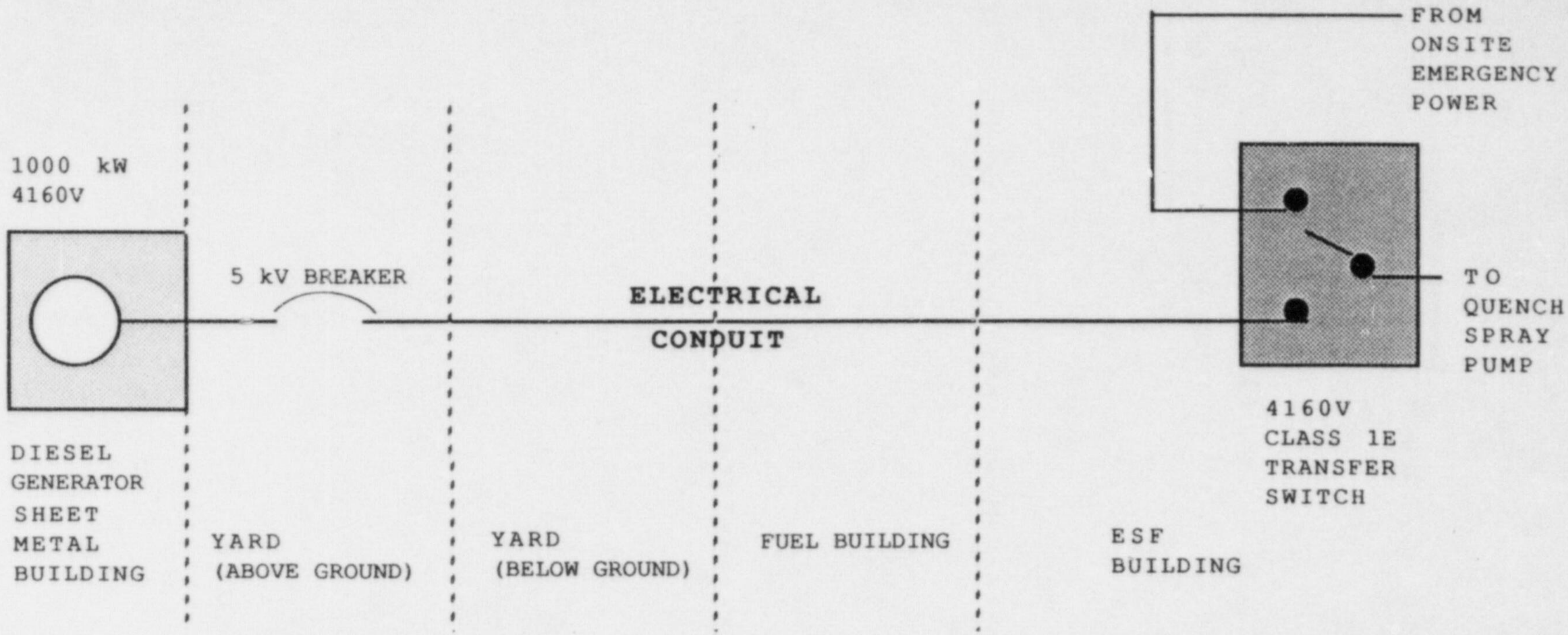


Figure 2. Conceptual Design of Option 1 Alternate Power Source

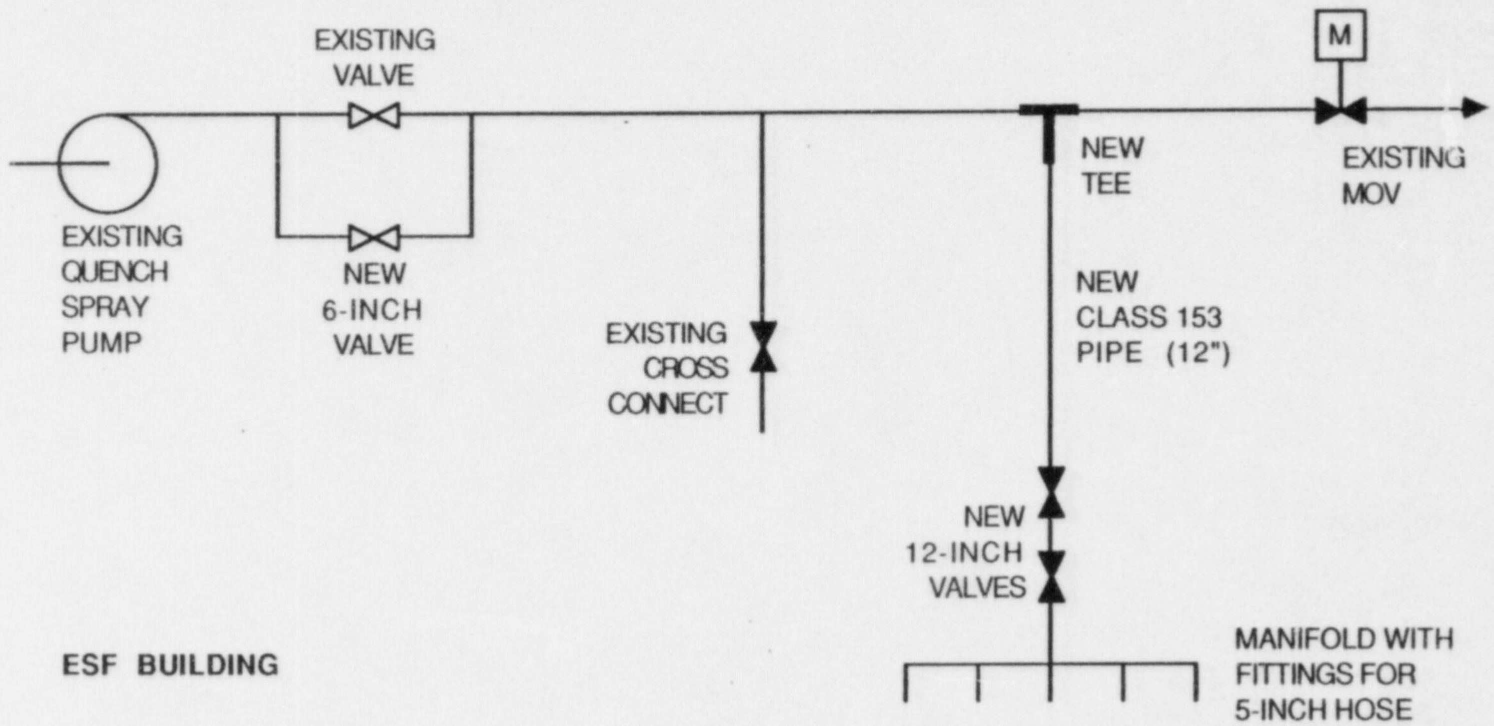


Figure 3. Conceptual Design of Option 2 Skid-Mounted Diesel Fire Pumps