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SEISMIC SAFETY MARGINS RESEARCH PROGRAM
PROJECT 1 SONGS 1 AFWS PROJECT

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ABSTRACT

The seismic qualification requirements of auxiliary feedwater systems (AFWS) of Pressurized Water Reactors (PWR) were developed over a number of years. These are formalized in the publication General Design Criteria (Appendix A to 10CFR50). The full recognition of the system as an engineered safety feature did not occur until publication of the Standard Review Plan (1975). Efforts to determine how to backfit seismic requirements to earlier plants have been undertaken primarily in the Systematic Evaluation Program (SEP) for a limited number of operating reactors.

The Three Mile Island (TMI)-2 accident further focused attention on the importance of decay heat removal systems in general and on the AFWS in particular. Nuclear Reactor Regulation (NRR) developed and implemented several short term improvements related to the AFWS, through the Bulletins and Orders Task Force, Lesson Learned Task Force and the Division of Operating Reactors. The seismic qualification of AFWS was not directly addressed by these Task Forces and thus this area remained a potential safety question for plant operation. Recently the NRC staff completed a risk study of seismically induced loss of decay heat removal for plants without a seismically qualified AFWS. Based on the results of this study, NRC has decided to permit continued operation of plants without seismically qualified AFWS. The review of this risk study was completed by Lawrence Livermore National Laboratory (LLNL). The conclusion was that a more detailed study should be conducted. Nuclear Reactor Research (RES) and NRR have requested LLNL to perform a probabilistic study on the AFWS of San Onofre Nuclear Generating Station (SONGS) Unit 1 utilizing the tools developed by the Seismic Safety Margins Research Program (SSMRP).

There are seven major tasks identified for the SONGS 1 AFWS project. The main objectives of this project are to:

- Identify the weak links of AFWS.
- Compare the failure probabilities of SONGS 1 and Zion 1 AFWS.
- Compare the seismic responses due to different input spectra and design values.

This work plan also delineates the schedule and budget for each task and their subtasks.

CONTENTS

	Page
ABSTRACT	iii
INTRODUCTION	1
ASSUMPTIONS	2
OBJECTIVES	3
WORK SCOPE	4
TASK I Model Development for Response Computation	4
TASK II Comparison of the Seismic Responses of Structures and Piping Systems of AFWS with the Design Results	5
TASK III Development of SONGS Site Specific Seismic hazard Curves Spectra, and Time Histories	6
TASK IV AFWS Fault Tree Development	7
TASK V Fragility Data Development and Fault Tree Coordination	8
TASK VI Identification of Weak Links of AFWS	9
TASK VII Compare the Probabilities of Failure of the AFWS Between SONGS 1 and Zion 1	9
SCHEDULE AND BUDGET	10
REFERENCES	18

INTRODUCTION

The seismic qualification requirements of auxiliary feedwater systems (AFWS) of Pressurized Water Reactors (PWR) were developed over a number of years. These are formalized in the publication General Design Criteria (Appendix A to 10CFR50). Guidance for the implementation of these requirements was published in 1972 as Regulatory Guide 1.26 (Quality Group Classifications and Standards for Water, Steam, and Radioactive Waste Containing Components of Nuclear Power Plants) and Regulatory Guide 1.29 (Seismic Design Classification). Although both guides identified the AFWS as important to safety and requiring protection against the seismic event, the full recognition of the system as an engineered safety feature did not occur until publication of the Standard Review Plan (1975). Efforts to determine how to backfit seismic requirements to earlier plants has been undertaken primarily in the Systematic Evaluation Program (SEP) for a limited number of operating reactors.

The Three Mile Island (TMI)-2 accident further focused attention on the importance of decay heat removal systems in general and on the AFWS in particular. Nuclear Reactor Regulation (NRR) developed and implemented several short term improvements related to the AFWS, through the Bulletins and Orders Task Force, Lesson Learned Task Force and the Division of Operating Reactors. In the course of the development of the TMI Action Plan it was concluded that these short term changes were sufficient until a comprehensive, three-year study of decay heat removal system requirements is completed (TMI-2 Action Plan Items II.E.3.1, II.E.3.2, II.E.3.3 and II.E.3.4). However, the seismic qualification of AFWS was not directly addressed by the above Task Forces and thus this area remained a potential safety question for plant operation during the period of time needed to complete the Action Plan studies and any subsequent modifications. Recently the NRC staff completed a risk study¹ of seismically induced loss of decay heat removal for plants without a seismically qualified AFWS. Based on the results of this study and until a more detailed study is available, NRC has decided to permit continued operation of plants without seismically qualified (i.e., R.G. 1.26, R.G. 1.29 and R.G. 1.60) AFWS. This decision reflects, in part, the consideration to preserve the continuity of the SEP programs and the TMI-2 action plan which may call for changes in the area of decay heat removal. It is undesirable to implement unnecessary or marginally necessary changes while these more comprehensive programs are underway. The review² of this risk study was completed by Lawrence Livermore National Laboratory (LLNL). The conclusion was that a more detailed study should be conducted.

NRR is in the process of reviewing the seismic qualification of AFWS of operating PWR's. The results of this review will be used to decide if any further action should be taken. Meanwhile, Nuclear Reactor Research (RES) and NRR have requested LLNL to perform a probabilistic study on the AFWS of San Onofre Nuclear Generating Station (SONGS) Unit 1 utilizing the tools developed by the Seismic Safety Margins Research Program (SSMRP)³. There are seven major tasks identified for the SONGS 1 AFWS project.

This work plan delineates the objective, scope, schedule and cost estimate of the seven major tasks and their individual subtasks.

ASSUMPTIONS

1. The recently designed modifications to the SONGS Unit 1 AFWS is the configuration to be analyzed.
2. Only the AFWS and the structures housing the AFWS will be included in the analysis.
3. Only the probabilities of failure due to earthquakes of the AFWS will be determined. These probabilities values will not be considered as necessarily accurate but can be used to gain insights and identify possible generic questions.
4. The principal models including the structures and the piping systems of AFWS are to be furnished by the plant owner, Southern California Edison (SCE). These models should be available by April 15, 1981.
5. Detailed information, including drawings and access to the SONGS Unit 1 will be made available by SCE. Detailed information necessary for analysis will be made available by April 15, 1981.
6. A range of earthquakes are to be studied, including the site specific spectra associated with the SSE of SONGS Unit 1.

OBJECTIVES

The proposed SONGS 1 AFWS project has the following objectives:

1. To identify the weak links of the AFWS of SONGS Unit 1.
2. To compare the probabilities of failure of the AFWS between Zion Unit 1 and SONGS Unit 1.
3. To compare the seismic responses of structures and piping systems of AFWS due to different input spectra and design values.

WORK SCOPE

Seven major tasks, designated I through VII, have been defined for the SONGS 1 AFWS Project, as outlined below.

TASK I MODEL DEVELOPMENT FOR RESPONSE COMPUTATION

Task I develops the models for soil, structures, soil-structure interaction and AFWS piping systems. Existing models furnished by SCE will be carefully studied to evaluate the efficiency of using them. If it is determined to be too inefficient to use the existing models due to, for instance, the differences in computer programs, new models will be developed. For the portion that SCE does not have existing models, new models will be developed. There are four subtasks which are described as follows:

Subtask 1.1 Develop Soil Model: Obtain and evaluate soil data for SONGS Unit 1. Equivalent linear soil properties for system analysis will be estimated.

Subtask 1.2 Develop Structural Models: Obtain, evaluate, and rerun the structure models furnished by SCE. The structure models for SMACS analysis will be prepared.

Subtask 1.3 Develop Soil-Structure Interaction (SSI) models: The impedances and scattering matrices for soil conditions in system analysis will be generated. The SSI models for SMACS analysis will be prepared.

Subtask 1.4 Develop the Models of the AFWS Piping System: Obtain the piping system models for the AFWS from SCE. Evaluate and rerun these models. Create new models if necessary, e.g., the portion of the AFWS was not recently modified. SCE may not have existing models for this portion. Identify the support points in the structures of these models.

TASK 11 COMPARISON OF THE SEISMIC RESPONSES OF STRUCTURES AND PIPING SYSTEMS OF AFWS WITH THE DESIGN RESULTS

Task 11 is to compare the seismic responses of structures and piping systems of AFWS due to different input spectra and the design results furnished by SCE. The input spectra are:

1. Original design (Housner) spectra for SONGS Unit 1 scaled up to .67 g ZPA (Zero Period Acceleration).
2. The design (Newmark and Hall) spectra for SONGS Units 2 & 3.
3. To be determined by WRC.

A set of time histories for each spectra will be generated. The soil structure interaction analysis, structure (housing AFWS) analysis, and AFWS piping analysis will be performed by SMACS. The seismic responses of structure and piping systems will be computed. These results will be compared with the design results furnished by SCE. This task has four subtasks which are described as follows:

Subtask 11.1 Develop Seismic Input Time Histories: A set of time histories will be generated for each input spectra. The response spectra of the time history will envelop their input spectra respectively. The input spectra are described above.

Subtask 11.2 Compute Seismic Responses of Structures Due to Different Input Spectra: The seismic responses of structures will be computed for each input spectra as described above. The seismic motion of the AFWS piping support points will also be computed. This seismic motion will be the input motion for the AFWS piping system.

Subtask 11.3 Compute Seismic Responses of the AFWS Piping Systems: The seismic responses of the AFWS piping systems will be computed for each input spectra.

Subtask 11.4 Comparison of the Seismic Responses of Structures and Piping Systems with the Design Results: The results computed in subtasks 11.2 and 11.3 will be compared with the design results furnished by SCE. This comparison will estimate the conservatism in the design analysis which was based on the .67 g Housner spectra.

TASK III DEVELOPMENT OF SONGS SITE SPECIFIC SEISMIC HAZARD CURVES, SPECTRA AND TIME HISTORIES

In this task, we developed the seismic input required for both the systems analysis (SEISIM) and structural analysis (SMACS). SEISIM requires, as one of its inputs, the annual exceedence probability of any level of peak ground acceleration at the SONGS site. SMACS requires as input sets of time histories which are correlated with the hazard curve used in SEISIM. To develop this required input it is necessary to first develop an Earthquake Occurrence Model which gives the locations of the earthquake relative to the SONGS site and rate of occurrence of various magnitude earthquakes. Along with the earthquake occurrence model, we also need a ground motion model which predicts the ground motion at the SONGS site from an earthquake of magnitude M located a distance R from the site. The earthquake occurrence model and ground models are input into our hazard analysis programs to generate the required input for SEISIM and SMACS. Thus three subtasks are defined and outlined below:

Subtask III.1 Develop the Earthquake Occurrence Model for the SONGS Site: A range of earthquake occurrence models will be developed using the extensive geologic and seismological investigation carried out by SCE and LLNL judgment. The SCE investigations will provide the basic zonation. Also a brief literature review will be conducted to develop a range of alternative models. Rates of occurrence will be estimated using both our data and SCE's data. Largest earthquakes will be estimated using several approaches based on fault length, strain rate, etc.

Subtask III.2 Develop the Ground Motion Model for the SONGS Site: Ground motion models must be developed to account for the saturation of the magnitude scale based on such parameters as seismic moment, stress drop, and surface wave magnitude. In addition to source modeling, statistical analysis will be performed to establish reasonable bounds for correction factors to apply to generic ground motion models to account for focusing of seismic energy from nearby earthquakes. Our models will represent an extension of a project we have with RES and analysis of near source ground motion. In addition to our model other ground motion models will be used.

Subtask III.3 Develop Hazard Curves and Time Histories for the SONGS Site: The computer programs developed in Phase I of SSMRP will be used to develop the seismic hazard and spectra at the SONGS site using the earthquake occurrence and ground motion models developed. Sensitivity studies will be carried out to determine which faults contribute most to the SEISMIC hazard. This information will be used to improve our model and reduce the uncertainty in our estimates. Time histories will be generated from the spectra developed from the improved model using SIMQ.

TASK IV AFWS FAULT TREE DEVELOPMENT

Task IV generates the fault tree for the AFWS of SONGS Unit 1. This task will also modify the AFWS fault tree of Zion Unit 1 to be comparable to SONGS Unit 1. The fault tree of the AFWS of Zion has been trimmed down considerably due to the size limitation of the SEISIM code, because there are other systems (e.g., residual heatremoval, safety injection, etc.) included in the system analysis. Since the AFWS is the only system considered in the analysis, therefore, the level of the details of fault tree could be brought up. There are two subtasks for this task:

Subtask IV.1 Develop Fault Tree of AFWS: Generate fault tree for the AFWS, including water supply, electric power buses, AFW-pump discharge to steam generators, and the steam supply to AFW-pump turbine. The fault tree will be analyzed to minimize cut sets, generate human and maintenance failure data, and generate fragility related basic event listings.

Subtask IV.2 Modify the Fault Tree of the AFWS of Zion Unit 1: Modify the AFWS fault tree for Zion Unit 1 to be comparable to SONGS Unit 1. The fault tree of steam supply to the AFW-pump turbine will be developed. The modified Fault tree will be analyzed for the input to SEISIM.

TASK V FRAGILITY DATA DEVELOPMENT AND FAULT TREE COORDINATION

Task V develops the fragility curves of the structures and the β -factors of the specific pipe sizes for SONGS Unit 1 AFWS. The fragility data for electrical and mechanical components of the Phase I of the SSMRP (which are generic in nature) will be used to the maximum extent. The fault tree will be coordinated with the responses of the electrical and mechanical components and the piping systems of AFWS. There are four subtasks. They are described as follows:

Subtask V.1 Develop the Fragility Curves for the Structures Housing the AFWS: Using loads computed in the structures as part of Subtask II.2, the load paths, critical wall shear loads and collapse mechanisms will be examined to determine the most likely modes of failure and corresponding fragility curves. These curves will include inelastic energy absorption through consideration of ductility factors. The building design specifications will also be examined for any potential local failures which might affect critical AFWS components.

Subtask V.2 Develop the β -factor for the Piping Systems of AFWS: Piping fragility is determined by scaling the computed response appropriately and then using a single master fragility curve. These scale factors (the " β " factors) must be determined for all pipe sizes. A large number have already been derived for those pipes in the Zion plant. However, some additional factors will have to be developed for pipe sizes in SONGS which were not needed in the Zion analysis.

Subtask V.3 Coordinate the Electrical and Mechanical Components of AFWS with Fault Tree and Structure Responses: The location of the components (or groups of components) for each basic event identified on the fault trees developed in Subtask IV.1 will be determined from either P & ID drawings or plant inspection, and then a table correlating all these components with their locations and fragility categories will be prepared. The minimum set of responses sufficient to provide the necessary SEISM input for all the basic events will be identified and correlated with the components on the fault trees.

Subtask V.4 Coordinate the Responses and Fault Tree of the AFWS: Coordinate the seismic responses and fault tree of the AFWS. The β -factor technique developed in the Phase I of SSMRP will be used to normalize the responses, i.e., resultant moments, of pipes. Only those valves or pipe elements identified in the fault tree of AFWS will be analyzed.

TASK VI. IDENTIFICATION OF WEAK LINKS OF AFWS

Task VI computes the probabilities of failure of the AFWS of SONGS Unit 1. The responses of structures and AFWS piping systems will be computed by the SMACS computer program. The probabilities of failure of the AFWS will be computed by the SEISIM computer program. The weak links of the AFWS will be identified. There are two subtasks. They are described as follows:

Subtask VI.1 Compute the Seismic Responses of Structures and AFWS: The responses of structures and AFWS piping systems will be computed over a range of earthquakes time histories developed in Subtask III.2. These responses will be coordinated with the basic events of the fault tree of AFWS. SMACS will be used to generate the response corresponding at its basic event as an input to SEISIM.

Subtask VI.2 Compute the Probabilities of Failure of AFWS and Identify the Weak Links: The hazard curves, responses, fragility data and fault tree will be incorporated into the SEISIM code. The probabilities of failure of the AFWS will be computed. The initial dominance ranking will be produced and additional dominance measures will be generated. The risk contributors to the failure of the AFWS will be ranked to identify the weak links of the AFWS of SONGS Unit 1.

TASK VII COMPARE THE PROBABILITIES OF FAILURE OF THE AFWS BETWEEN SONGS 1 AND ZION 1

The probabilities of failure of the AFWS of Zion Unit 1 will be computed. The initial dominance ranking will be produced and additional dominance measures will be generated. The risk contributors to the failure of the AFWS will be ranked to identify the weak links of the AFWS of Zion Unit 1. These results will be compared to the results for SONGS Unit 1.

SCHEDULE AND BUDGET

Figure 1 shows the schedule for each subtask with milestone indicated by number. The corresponding milestone dates are given in Table 1. The budget details for the project are presented in Table 2. Please note the schedule and milestone dates are based on an assumption of a free flow of information from SCE.

TASK	MONTHS AFTER NECESSARY INFORMATION RECEIVED													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Planning and Management			√	1.7										
I.1 Develop Soil Model			√	1.8										
I.2 Develop Structure Models						√	1.9							
I.3 Develop SSI Models						√	1.10							
I.4 Develop AFWS Models						√	1.12							
II.1 Develop Time Histories for Three Input Spectra			√	1.13 ⁺										
II.2 Compute Seismic Responses of Structures due to Three Input Spectra			1.14 [√]					√	1.15 ⁺					
II.3 Compute Seismic Responses of AFWS Piping Systems due to Three Input Spectra								√	1.16 ⁺					
II.4 Compare with Design Results														
III.1 Develop Earthquake Occurrence Models					√	1.18								

FIGURE 1 Schedule for SONGS 1 AFWS Project - This schedule is based on an assumption of a free flow of information from SCE.

⁺ The third input spectra for Task II should be determined by NRC prior to the end of the second month. Otherwise, these dates will be delayed accordingly.

TASK	MONTHS AFTER NECESSARY INFORMATION RECEIVED													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
III.2 Develop Ground Motion Models					7	1.19								
III.3 Develop Hazard Curves and Time Histories						7	1.20							
IV.1 Develop Fault Tree of AFWS					7	1.21								
IV.2 Modify the Fault Tree of the AFWS of Zion Unit 1		7	1.22											
V.1 Develop Fragility Curves of Structures						7	1.23							
V.2 Develop β -factor of Pipes						7	1.24							
V.3 Coordinate Electrical and Mechanical Components and Fault Trees								7	1.25					
V.4 Coordinate Responses and Fault Trees for Piping System								7	1.26					
VI.1 Compute Responses of Structures and Piping Systems						1.11	7		7	1.27				
VI.2 Compute the Prob. of Failure of AFWS and Identify Weak Links										7	1.28			

FIGURE 1 Schedule for SONGS 1 AFWS Project - This schedule is based on an assumption of a free flow of information from SCE. (continued)

TASK	MONTHS AFTER NECESSARY INFORMATION RECEIVED													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VII Compute Prob. of Failure of the AFWS of Zion Unit and Compare with SONGS Unit 1												√	1.29	
DOCUMENTATION												√	1.30*	

FIGURE 1 Schedule for SONGS 1 AFWS Project - This schedule is based on an assumption of a free flow of information from SCE. (continued)

*Two months after the design results are available or 12.5 months whichever is later.

TABLE 1 SONGS UNIT 1 AFWS PROJECT MILESTONE DATES

Milestone ^a	Target	Completed
	Date (or Months after Necessary Information Received)	Date
1.1 Kickoff meeting	11-21-80	11-21-80
1.2 SONGS Site visit	11-24-80	11-25-80
1.3 NRC-LLNL meeting	12-18-80	12-18-80
1.4 Work plan completed	1-15-81	1-22-81
1.5 Work plan revised	2-6-81	2-6-81
1.6 Work plan finalized	2-24-81	
1.7 All necessary data and models obtained	(2)	
1.8 Soil model developed	(2)	
1.9 Structures model developed	(5.5)	
1.10 SSI model developed	(5.5)	
1.11 SMACS test runs completed	(7)	
1.12 AFWS piping models developed	(5.5)	
1.13 Time histories for three input spectra developed	(2) ⁺	
1.14 First structure responses computed	(3.5) ⁺	
1.15 All structures responses computed	(8) ⁺	
1.16 AFWS piping responses computed	(8) ⁺	
1.17 Design results and SMACS results compared	**	

^a See Figure 1 - These dates are based on an assumption of free flow of information.

** One month after the design results are available or responses computed whichever is later.

⁺ The third input spectra for Task II should be determined by NRC prior to the end of the second month. Otherwise, these dates will be delayed accordingly.

TABLE 1 SONGS UNIT 1 AFWS PROJECT MILESTONE DATES (Continued)

Milestone ^a	Target Date (or Months after Necessary Information Received)	Completed Date
1.18 Earthquake Occurrence Model developed	(4.5)	
1.19 Ground motion model developed	(4,	
1.20 Hazard curves and time histories developed	(6.5)	
1.21 Fault tree of AFWS developed	(4.5)	
1.22 Fault tree of the AFWS of Zion Unit 1 modified	(1)	
1.23 Fragility curves for structures developed	(6)	
1.24 β -factor for AFWS piping system developed	(5.5)	
1.25 AFWS components, fault tree, structure coordinated	(8.5)	
1.26 Responses and fault tree of piping coordinated	(7.5)	
1.27 Seismic responses computed	(9.5)	
1.28 Probabilities of failure of AFWS computed	(10.5)	
1.29 Probabilities of failure of the AFWS of Zion computed and compared with SONGS Unit 1 result	(11.5)	
1.30 Documentation	(12.5)***	

^a See Figure 1 These dates are based on an assumption of free flow of information.

*** Two months after the design results are available or 12.5 months whichever is later.

TABLE 2 BUDGET OF SONGS UNIT 1 AFWS PROJECT

Item	Budgeted Amounts (\$1000)
Project Planning and Management	
1. Project Planning, work plan development and coordination with NRC	20
2. Interfacing with other SSMRP projects	10
3. Data and models collection	20
4. Project management and documentation	10
TOTALS	60
TASK I	
I.1 Develop Soil Model	22
I.2 Develop Structure Models	106
I.3 Develop SSI Models	73
I.4 Develop AFWS Models	76
TOTALS	277
TASK II	
II.1 Develop Time Histories	10
II.2 Compute Structure Responses	10
II.3 Compute AFWS Piping Responses	10
II.4 Compare with Design Results	5
TOTALS	35
TASK III	
III.1 Develop Earthquake Occurrence Models	33
III.2 Develop Ground Motion Models	22
III.3 Develop Hazard Curves and Time Histories	44
TOTALS	99

TABLE 2 BUDGET OF SONGS UNIT 1 AFWS PROJECT (Continued)

Item	Budgeted Amounts (\$1000)
TASK IV	
IV.1 Develop Fault Tree of AFWS	58
IV.2 Modify the Fault Tree of the AFWS of Zion Unit 1	17
TOTALS	75
TASK V	
V.1 Develop Fragility Curves of Structures	88
V.2 Develop β -Factor of Pipes	11
V.3 Coordinate Electrical and Mechanical Components and Fault Trees	33
V.4 Coordinate Responses and Fault Trees for Piping Systems	55
TOTALS	187
TASK VI	
VI.1 Compute Responses of Structures and Piping System	70
VI.2 Compute the Probabilities of Failure of AFWS and Identify Weak Links	23
TOTALS	93
TASK VII	
Compare the Probabilities of Failure Between SONGS 1 and Zion 1	44
DOCUMENTATION	30
TOTAL EFFORT	900

REFERENCES

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