MASTER

NUREG/CR-1624, Vol. 4
UCID-18674, Vol. 4

LOAD COMBINATION PROGRAM PROGRESS REPORT NO. 8

DO NOT MICROFILM
COVER

C. K. Chou, S. C. Lu, M. W. Schwartz

Prepared for
U.S. Nuclear Regulatory Commission

~~HLO~~

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

NOT MICROFILM
COVER

Available from
GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
and
National Technical Information Service
Springfield, Virginia 22161

NUREG/CR-1624, Vol. 4
UCID-18674, Vol. 4
RM

NUREG/CR--1624-Vol. 4

TI86 002760

LOAD COMBINATION PROGRAM PROGRESS REPORT NO. 8

Manuscript Completed: April 1981
Date Published:

Prepared by
C. K. Chou, S. C. Lu, M. W. Schwartz

Lawrence Livermore Laboratory
7000 East Avenue
Livermore, CA 94550

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Prepared for
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. AO133

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MGW/gsw

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

TABLE OF CONTENTS

Abstract	v
General Description.	1
Introduction	3
Objectives	4
Task Description	4
Load Combination Program	11
A. Accomplishments	11
B. Next Quarter.	12
C. Concerns	12

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ABSTRACT

This document reports progress on the Load Combination Program (LCP) in the period January 1 through March 31, 1981. The report describes the program by projects and tasks; it also gives financial summaries, technical reports generated, and meeting attendance.

GENERAL DESCRIPTION

Personnel

NRC Branch Chief: J. E. Richardson
NRC Program Manager: J. O'Brien
Contractor: Lawrence Livermore National Laboratory (LLNL)
LLNL Program Manager: C. K. Chou
LLNL Project I Leader: S. C. Lu
LLNL Project II Leader: M. W. Schwartz

Program Dates and Cost

Starting date: March 1979
Phase I completion date: September 1980
Post-Phase I starting date: October 1980
Post-Phase I completion date: September 1981
Ending date: 1985
Post-Phase I cost: Total budget for Post-Phase I is \$750,000, which is funded by the Mechanical Engineering Research Branch (MERB).

Justification

NRR User Request No. 76-5, dated June 16, 1977

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

INTRODUCTION

General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A, 10CFR50, requires that structures, systems, and components important to the safety of nuclear power plants be designed to withstand combinations of effects of natural phenomena and effects of normal and accident conditions.

Historically, the NRC has required that the structural/mechanical responses due to various accident loads and loads caused by natural phenomena be combined in the analysis of structures, systems, and components important to safety. This requirement appears in the various regulatory documents such as regulatory guides, regulation revisions, and branch technical positions, as well as in the standard review plan.

The postulated accident loads and loads caused by natural phenomena such as earthquakes are random events. Amplitude, duration, frequency content, time of occurrence, and time-phase relationship are random and stochastic. Without a systematic probability assessment, it is difficult to come up with a rationale for an appropriate combination of events. Requirements to consider dynamic events acting concurrently have, therefore, been based on judgment tending towards conservatism because no comprehensive probabilistic study and unified philosophy exists on which to base better decisions. Consequently, safety margins between various systems and from plant to plant vary widely. Trying to follow the inconsistent and fragmented load combination requirements is frustrating to the nuclear industry.

A unified approach to load combination is needed by the NRC and the nuclear industry. This approach must evolve from a rational procedure to address the following basic issues:

1. What loads need to be combined?
2. If certain loads must be combined, how can this be done?
3. What factors should be applied to load effects or responses?
4. What are appropriate service levels, load categories, and stress limits?
5. How can pipe break locations be postulated?

The Load Combination Program undertaken by the Lawrence Livermore National Laboratory (LLNL) since March 1979 represents a milestone effort funded by the NRC to resolve these difficult and important issues. Our program adopts a probabilistic approach to develop the desired reliability methodology for load combination.

The first phase effort, which started in March 1979 and was completed at the end of the summer of 1980, has accomplished two major objectives: (1) to determine the probability of a large LOCA (loss-of-coolant accident) induced by a range of earthquakes, and (2) to develop a methodology for combining generic dynamic loads for nuclear power plant design.

Because of the potential impact on licensing decisions, the NRC and the ACRS have requested formation of a National Peer Review Panel to review our results and conclusions as well as technical detail. The Review Panel comprises five experts in the areas of metallurgy and materials, risk and reliability, structural and mechanical analysis, mathematical analysis, and nuclear systems. Three review meetings have been conducted. Comments and recommendations from the Peer Review Panel have been incorporated in the development.

As instructed by the NRC, a Post-Phase-I period is designated from October 1980 to September 1981. Our task in this period is to review the technical development, check the calculations, digest the results and findings, complete reports, and continue interaction with the Peer Review Panel. It is expected that a comprehensive Phase II work plan will be developed during the Post-Phase I. We expect to start the Phase II work in October 1981.

Objectives

Overall Objectives

1. Develop a methodology to combine dynamic loads for nuclear power plants under normal plant operation, transients, accidents, and natural hazards. The methodology is to be based on the probabilistic assessment of the reliability of components, systems, and structures.
2. Establish design criteria, load factors, and component service levels for appropriate combinations of dynamic loads or responses to be used in nuclear power plant design.
3. Determine the reliability of typical piping systems, both inside and outside the containment structure, and provide the NRC with a sound technical basis for defining the criteria used in postulating pipe breaks. (We expect that NRC Regulatory Guide 1.46, Protection Against Pipe Whip Inside Containment, will be revised in accordance with the findings.)
4. Determine probabilities of a large LOCA induced directly and indirectly by a range of earthquakes.

Phase I Objectives

1. Assess the contribution to safety resulting from the requirement to combine a large LOCA and an SSE; also, assess the cost.
2. Determine the probability of a large LOCA induced either directly or indirectly by a range of earthquakes.
3. Develop a framework for the load combination methodology (LCM).
4. Develop the preliminary computational chain for combining responses.
5. Continue into Phase II the work in connection with the reliability of piping systems (see Overall Objectives item 3, above).

Post-Phase I Objectives

1. Review in detail the research work conducted by LLNL and its subcontractors in Phase I. Some confirmatory recalculation may be needed.
2. Coordinate, and incorporate the results of, program technical reviews by RES, NRR, Peer Review Panel, and ACRS.
3. Complete final reports for both Project I and Project II.
4. Develop modifications to the already existing Phase II work plan.

Task Description (Post-Phase I)

Project I: Large LOCA-Earthquake Event Combination Probability Assessment

Task 1 – Review of Phase I Work

We have computed in Phase I the probability of a large LOCA induced directly by a range of earthquakes for a selected Westinghouse four-loop PWR-1 plant, Zion Unit 1. The probability of a directly induced LOCA is related to pipe rupture of the primary loop piping caused by pipe crack growth when the pipe is subjected to the combined effects of thermal, pressure, seismic, and other cyclic loads throughout the lifetime of the plant. A large LOCA is defined as a double-ended guillotine break at the primary loop piping (hot leg, cold leg, and crossover lines). A probabilistic piping reliability model employing fracture mechanics was developed to compute the probability of pipe rupture. Because our results may have a great impact on the safety issues of nuclear power plants and because funding is limited, this task of Post-Phase I is conducted to digest and elaborate on the research already performed rather than produce new results. Essentially, Phase I work will be critically reviewed to ensure that assumptions, input data, analytical models, computational procedures, and computer codes are either justified or validated. During the review process, some confirmatory recomputation may be required. Besides LLNL's internal review, technical communica-

tion will continue between LLNL's program personnel and the Peer Review Panel members through scheduled meetings and other discussions.

Task 2 – Development of Phase I Final Report

Preparation of the final report for Project I began immediately upon conclusion of Phase I technical activities. A rough draft of the final report was completed in early November 1980. However, the final version of the report will undergo continuous revision with feedback from Task 1.

Task 3 – Development of Phase II Work Plan

The Load Combination Program is a long term, multiphase research effort. Work plans were presented to the NRC in July 1979 for Phase I and in April 1980 for Phase II. As Phase I technical activities approached completion, developments in the technical efforts and the funding situation indicated that the already existing Phase II work plan needed to be greatly modified. Development of the new Phase II work plan depends on the outcome of the December ACRS meeting, the feedback from the Peer Review Panel, LLNL program personnel's judgment, the NRC's instructions, and the funding available.

The above activities were governed by instructions from the NRC for the current available funding level. We have developed a plan to quantify the uncertainty associated with input variables so that Phase I results can be used for licensing decisions. Additional funding to support this effort is requested. When LLNL receives the funds, the detailed plan will be reviewed by NRC staff and implemented at once.

Project II: Load (Response) Combination Methodology Development

Task 1 – Phase I Final Report

The main activity of Project II will be to issue a final report on all work completed during Phase I. The draft originally submitted will need extensive revision to include responses to reviewer comments and to present the material with greater clarity.

Task 2 – Identify NRR Immediate Needs

Although the Load Combination Methodology Project is a long-term research program, some completed aspects allow us to deal with short-term licensing problems. We will cooperate with the NRR in an attempt to identify these needs and suggest solutions.

Task 3 – Phase II Work Plan

Since virtually no funds exist to develop load combination methodology during Post-Phase I, a Phase II work plan will be formulated to continue this work in FY 82. High on the list of priorities will be efforts to increase the efficiency of the codes to reduce computer costs and validate the assumptions on which the methodology is based.

Task 4 – Analysis of Extremes of Combined Load Responses

This task is intended to improve the technique for combining intermittent, time varying loads using the time-averaged mean upcrossing rate function, γ , and marginal distribution function, f , of the response time histories. Practical ways will be sought to handle nonuniformly distributed time lags between initial and initiated loads. In addition, methods will be investigated to enable the estimation of γ and f from response spectra. This task, begun during Phase I, is scheduled to run from October 1, 1980, to June 30, 1981. The M.I.T. is doing this work under the supervision of Prof. C. Allin Cornell.

Load Combination Program Post-Phase I Schedule

Task	FY81											
	O	N	D	J	F	M	A	M	J	J	A	S
Program Management	001 ▽	004 ▽	006 ▽	002 005	003	007 ▽			008 ▽	009 ▽		
Project I Large LOCA - earthquake event combination probability assessment		101 ▽	102 ▽	103 ▽		104 ▽	105 ▽	106 ▽		107 ▽	108 ▽	
Project II Load combination methodology development	201 ▽							202 ▽		203 ▽		

Load Combination Program
(Post-Phase I)
Milestones

Milestone		Target Date	Completed Date
Program Planning and Management			
001	LLNL senior consultant review meeting	10-13-80	10-13-80
002	NRC/NRR review of load combination methodology development	10-29-80	10-29-80
003	8th Light Water Reactor Research Information meeting	10-31-80	10-31-80
004	2nd Peer Review Panel meeting	11-18, 19-80	11-18, 19-80
005	3rd Peer Review Panel meeting	12-15-80	12-15-80
006	ACRS meeting	12-16, 17-80	12-16, 17-80
007	Phase II work plan development started	4-1-81	
008	4th Peer Review Panel meeting	6-30-81	
009	Phase II work plan completed	7-31-81	

Load Combination Program
(Post-Phase I)
Milestones (Continued)

Milestone		Target Date	Completed Date
Project I – LOCA-EQ Probability Assessment			
101	Rough draft of Phase I final report completed	11-5-80	11-5-80
102	Additional sensitivity study completed by subcontractor	12-5-80	12-5-80
103	Conversion of PRAISE code to LLNL system started	1-15-81	1-15-81
104	Report for Phase I piping reliability assessment completed by subcontractor	3-15-81	3-15-81
105	Benchmark calculation for validating PRAISE code started	4-1-81	
106	Phase I final report completed and issued for comment	5-15-81	
107	Review of Phase I work completed	7-1-81	
108	Phase I final report completed	8-1-81	
Project II – Load Combination Methodology Development			
201	Rough draft of Phase I final report completed	11-5-80	11-5-80
202	Final report on Phase I completed	5-8-81	
203	Final report on Analysis of Extremes of Combined Load Responses	6-30-81	

Expenditures for FY 81, Load Combination Program
(FIN A0133)

Load Combination Program
Post-Phase I Budget Summary FIN A0133

	Budgeted (\$1,000)	Expenditures (\$1,000)
Total budget for Post-Phase I	750	
Carryover funds from prior year (FY 80)	30 ^a	
Expenditures:		
Prior year (FY 80)		122 ^b
Prior year (after offset by carryover funds)		92
Current year (FY 81)		432 ^c
Total funding expenditures	750	599
Balance of funds not expended	151	

- a. Funded by the NRC in FY 80 for Peer Review Panel activities.
b. Actual invoice is about two months behind.
c. Including late invoices of FY 80 expenditures.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Load Combination Program

A. Accomplishments**1. Program Management**

Professor G. Schueller of the University of Munich, Germany, visited Lawrence Livermore National Laboratory on January 14, 1981. He indicated that a study was done in Germany to determine whether large LOCA and SSE loads need to be combined in nuclear component design for German reactors. (Currently this combination is not required in Germany.) Study results show that the probability of a large LOCA caused by fatigue crack growth induced directly by earthquakes is very small. German research results support LLNL's findings on LOCA-earthquake probability.

Professor D. Tso of McMaster University, Canada, visited the Load Combination Program at LLNL on February 6, 1981. Professor Tso is currently under a contract to the Canadian Atomic Energy Control Board (AECB) to study system qualification and testing. The purpose of his visit was to study USNRC research development on extreme load design requirements and report back to the AECB. On February 27, 1981, a cooperative team from the French nuclear industry visited the LLNL Load Combination Program. The team members were Dr. André Pellissier-Tanon and M. Bethmont of Framatome, Dr. P. Chouard of Commissariat à l'Energie Atomique (CEA) and C. Faigy of Electricity of France. The main objective of the visit was to exchange technical information on (1) reliability of a PWR reactor pressure vessel and primary piping system and (2) pipe whip and impact testing and analytical computer code development. A similar approach, with similar assumptions and a numerical solution scheme, was used by both the French researchers and the LLNL on the reliability assessments for reactor pressure vessels and primary piping systems. Pipe whip and impact testing research is in progress as a joint effort of four organizations in France. The test setup and results can be used to validate the analytical computer code now under development at the LLNL. It was agreed that a program will be negotiated to exchange French test data with LLNL computer code.

Eleven technical papers were generated by the LLNL Load Combination Program team and accepted by the Sixth International Conference on Structural Mechanics in Reactor Technology (SMiRT). The conference has invited Dr. C. K. Chou to serve as a session chairman in Division J, Loading Conditions and Structural Analysis of Reactor Containment.

2. Project I – Large LOCA-Earthquake Event Combination Probability

The PRAISE (Piping Reliability Analysis Including Seismic Events) computer code, developed by subcontractor Science Applications Inc., has been completed. Code verification has begun. Minor modification to improve the code capacity and output format is in progress. A preliminary version of the user's manual has been completed and made available to the users.

Calculations done by subcontractors are under verification at the LLNL. Some additional sensitivity test runs will be performed in a later time to confirm assumptions.

A study to compare linear-elastic-plastic, elastic-plastic, and fully plastic failure models to predict the critical criteria for the fracture of a 316 stainless steel pipe has been completed. The pipe has an inside diameter of 29 inches and thickness of 2.5 inches. A nonlinear analysis was used in the study. The results, published as UCRL-84182, will be presented to the forthcoming SMiRT conference.

The Project I, Phase I, final report is under development. It will comprise a total of 9 volumes. Volume 1 will introduce the report, summarize it, and provide linkage between the volumes. The remaining volumes will contain technical details in the various areas. Calculation verifications and code modifications will be incorporated into the final report. We expect the preliminary version to be available for comment early next quarter.

A meeting with the French visitors was informative and constructive. It was interesting to note that both the LLNL and the French researchers are using very similar assumptions on the assessment of reliability for reactor pressure vessels and primary piping systems.

3. Project II – Load Combination Methodology Development

Computer code and calculations developed by subcontractor Sargent & Lundy Engineers have been transferred to the LLNL. Verification is under way. From the preliminary review, we found that the code can be improved by LLNL computation experts in terms of increased efficiency. If the NRC wants to use the code to evaluate the reliability for the existing plant, an improvement will be worth while.

Draft copy of the Project II, Phase I final report was completed. Because of many comments and questions on the potential application of the methodology, the impact on the ASME Code, the matter of load factor versus unit factor, and so on, we decided to rearrange the report and insert additional material to clarify some of the concerns and make the report more readable to a general audience. The report is currently being edited and should be available next quarter.

The NRC has instructed us to put a lower priority on this project activity.

B. Next Quarter

Phase I final reports for both projects will be published next quarter. Modifications to the existing Phase II work plan to incorporate ACRS comments, NRR requests, and RES instructions will be under way next quarter.

C. Concerns

1. **Technical**
None.
2. **Schedule**
None.
3. **Cost**
None.

Meeting Attendance Summary

Date	Meeting	Location	LLNL Personnel Attending	Comments
1/14/81	Meeting with Prof. G. Schueller of University of Munich	LLNL	C. K. Chou	German research results support LCP Project 1 findings
2/6/81	Meeting with Prof. D. Tso of McMaster University	LLNL	C. K. Chou	Discuss LLNL's research development on extreme load design requirements
2/27/81	Meeting with French nuclear industry representatives headed by Dr. P. Chouard of Commissariat a l'Energie Atomique	LLNL	C. K. Chou, S. C. Lu, L. L. George, H. H. Woo	Both sides agreed to exchange more technical information

REPORTS GENERATED BY THE LCP

1. C. K. Chou, K. Vepa, L. George, and P. D. Smith, "Seismic Safety Margins Research Program – Project VII – Load Combination Project – Work Plan," July 10, 1979, UCID-18126.
2. C. K. Chou, R. W. Mensing, P. D. Smith, K. Vepa, J. D. Collins, C. A. Cornell, R. P. Kennedy, and M. K. Ravindra, "Seismic Safety Margins Research Program Load Combination Project – Task 3, Load Combination Methodology Development Interim Report I," January 31, 1980, UCID-18149.
3. "Reactor Coolant Loop Model, Zion Station," Sargent & Lundy Report, SL-3806, September 24, 1980.
4. C. K. Chou, S. C. Lu, and M. W. Schwartz, "Load Combination Program, Phase II Work Plan," Draft, April 15, 1980, UCID-18659.
5. "Probability of LOCAs Indirectly Induced by Earthquakes at Zion I Nuclear Power Station," prepared by Science Applications, Inc., Report SAI-003-80-13E.
6. Quarterly Progress Reports, April 15, July 15, October 15, 1979, April 15, July 15, and October 15, 1980, and January 15, 1981.
7. "Safety and Cost Assessment of the Effects of Simultaneous Occurrence of Large LOCA and SSE Loads," prepared by Dr. John Stevenson of Woodward-Clyde Consultants.
8. S. C. Lu, R. D. Streit, and C. K. Chou, "Large LOCA-Earthquake Combination Probability Assessment – Load Combination Program Project I Summary Report," NUREG/CR-1889.
9. M. W. Schwartz, M. K. Ravindra, J. D. Collins, J. Hudson, A. Cornell, C. K. Chou, "Load Combination Program Project II – Load Combination Methodology Development – Interim Report II," NUREG/CR-1782.
10. A. L. Chan, E. F. Rybicki, and D. J. Curtis, "Investigation of Non-Seismic Stresses in a Pressurized Water Reactor Primary Coolant Piping System," prepared by Science Applications, Inc.
11. D. O. Harris, E. Y. Lim, D. D. Dedhia, "Fracture Mechanics Analysis of Structural Reliability With Applications to the Influence of Seismic Events on Reactor Piping," (draft) prepared by Science Applications, Inc.
12. E. Y. Lim, "PRAISE User's Manual," (draft) prepared by Science Applications, Inc.

REPORTS TO BE GENERATED BY THE LCP POST-PHASE I

1. "Load Combination Program Project II — Load Combination Methodology Development — Phase I Final Report," Lawrence Livermore National Laboratory.
2. "Analysis of Extremes of Combined Load Response," to be prepared by M.I.T.
3. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 1: Summary," Lawrence Livermore National Laboratory.
4. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 2: Primary Coolant Loop Model," Lawrence Livermore National Laboratory.
5. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 3: Non-Seismic Stress Analysis," Lawrence Livermore National Laboratory.
6. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 4: Seismic Response Analysis," Lawrence Livermore National Laboratory.
7. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 5: Probabilistic Fracture Mechanics Analysis," Lawrence Livermore National Laboratory.
8. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 6: Failure Mode Analysis," Lawrence Livermore National Laboratory.
9. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 7: Piping System Fracture Probability Estimation," Lawrence Livermore National Laboratory.
10. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 8: Pipe Fracture Indirectly Induced by an Earthquake," Lawrence Livermore National Laboratory.
11. "Probability of a PWR Primary Coolant Loop Pipe Fracture, Vol. 9: PRAISE Computer Code User's Manual," Lawrence Livermore National Laboratory.

Technical Information Department • Lawrence Livermore Laboratory
University of California • Livermore, California 94550

DO NOT REMOVE FROM FILM
COVER

DO NOT REMOVE
COVER

NUREG/CR-1624, Vol. 4

LOAD COMBINATION PROGRAM - PROGRESS REPORT NO. 8

May 1981