Task B-6

Loads, Load Combinations and Stress Limits

Lead NRR Organization: Division of Systems Safety (DSS)

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Applicability: Light Water Reactors

Projected Completion Date: September, 1981

1. DESCRIPTION OF PROBLEM

In the analysis of structures, systems, and components important to safety, the NRC has required the combination of structural/mechanical responses due to various accident loads and loads caused by natural phenomena, particularly earthquakes. This requirement flows from 10 CFR Part 50, Appendix A, General Design Criterion 2 which was issued in 1971 and calls for an appropriate combination of the above loads to be reflected in the design bases of safety equipment. The requirement has been implemented in various ways both within the NRC and the nuclear industry.

The loads due to postulated accidents and natural seismic phenomena often yield dynamic responses of short duration and rapidly varying amplitude in the structures and components exposed to the loads. These loads usually have no physical time phased relationship in the accident analysis either because the loads are random in nature or because the loads have simply been postulated to occur together (e.g., LOCA and SSE) without a known or defined coupling. Lacking a

physical basis for relating some of the loads in question, they have been required to be combined for design purposes in the licensing process according to the absolute or linear sum methodology, i.e., summation of peak structural responses due to each of the individual loads. This approach may lead to overly conservative design requirements for certain plant systems and may result in more rigid systems which is not beneficial when designing for thermal stresses which are present in normal day to day operation.

The requirement in GDC-2, to a large degree, was intended to provide a measure of margin in the dynamic strength of equipment important to safety. These margins are nonuniform since the portion of equipment strength available to accomodate seismic or accident loadings varies widely for equipment within a plant and from plant to plant.

The load combination requirement in GDC-2 was also intended to provided defense in depth, i.e., to protect against the very low probability event of a severe accident (e.g., LOCA) being caused by a severe

natural phenomenon (e.g., SSE), even though the plant is required to be designed to prevent a LOCA being caused by an SSE and the combined event is not defined in GDC-2 as a design basis accident. The consideration and selection of dynamic events like SSE and large LOCA occurring simultaneously/concurrently was originally largely a matter of regulatory philosophy for containment design. Requirements to consider other dynamic events acting concurrently has been based on judgement which tends towards conservatism due to an absence of data on which to base better founded decisions. Present technology probably affords better means for specifying and measuring margin in the dynamic strength of safety equipment.

2. PLAN FOR PROBLEM RESOLUTION

A. Present Activities

The staff has already modified certain of its design requirements for combining loads and is concentrating on the easier question of how to combine loads, not to the more difficult and long term questions of

'whether' to combine them. The technical work to develop an adequate design bases on whether to combine dynamic loads will require considerable developmental effort since little experimental evidence is now available for analysis verification.

The methods to be used in the combination of loads is being addressed in a number of current staff technical activities. These activities include consideration of the combination of various accident loads (e.g., LOCA discharge loads plus suppression pool dynamic loads), combination of accident loads and earthquake loads (SSE), and combination of operational loads (e.g., SRV discharge) with anticipated earthquake loads (OBE). A DSS/DOR working group issued a report NUREG-0484, "Methodology for Combining Dynamic Responses." In the report the working group recommended the use of Square Root of the Sum of the

Squares (SRSS) method of combining short duration rapidly varying dynamic responses to SSE and LOCA loads for piping systems, components and supports within the Reactor Coolant Pressure Boundary (RCPB). During the course of a recent review of an application for an Operating License, the staff concluded that SRSS method is appropriate for combination of LOCA and SSE responses for all ASME Class 1, 2, and 3 systems. Work is also underway to extend the SRSS methodology to other systems, components and structures, and to other dynamic load combinations (e.g., OBE and SRV).

Westinghouse has filed two topical reports on this general subject area. WCAP 9283 entitled, "Integrity of the Primary Systems of W Nuclear Plants During Postulated Seismic Events" deals with the question of whether to combine LOCA and SSE loads; WCAP 9279 entitled "Combination of SSE and LOCA Responses from Faulted Condition Evaluation of Nuclear Power Plants" treats load combination methodology.

The DSS technical assistance contract at Brookhaven National Laboratory has produced a draft review of the Westinghouse submittal WCAP 9283. The staff believes that both the Westinghouse report and the BNL review significantly advance current understanding of decoupling LOCA and SSE loads.

General Electric Company has filed topical report NEDE 24010-P entitled, "Technical Bases for the Use of the SRSS Method for Combining Dynamic Loads for Mark II Plants." Similar work has also been submitted by Nuclear Services Corporation, and Engineering Decision Analysis Corporation for the Mark II Owner's Group. Dr. R. Kennedy and Dr. Nathan Newmark have worked with the Mark II Owner's Group to develop criteria for combination of responses using SRSS.

Brookhaven National Laboratory under technical assistance contract from DSS is performing sensitivity studies for investigating methodologies of combining dynamic responses and is evaluating the acceptability of the Kennedy Newmark Criteria for application to the Mark II dynamic response combinations.

B. Plan for Future Activities

(1) Evaluation will be performed of existing NRC requirements including all current regulation, regulatory guides, branch technical positions, etc. for treating loads and their structural responses in combination.

(2) Identify the intent of how each item covered in (1) was meant to be used; (e.g., interpretation of GDC-2) cover scope in terms of design for system consequences of event combinations as well as structural design.

(3) Identify current treatment of environmental and postulated event scenarios and loads in combination for various systems, fuel, and structures.

(4) Develop rationale for decoupling effects of specific loads now treated in combination for elimination of overly conservative requirements and the provisions for the need for a more detailed guidance under certain loading circumstances.

(5) Development of loads, load combinations, and any systems criteria such as redundancy or single active failure, for which specific systems, fuel supports, structures have to be designed.

(6) Load Combination Methodology

(a) Various methods and limits

(b) Response Combination and Load Combination

(c) Extend NUREG 0484

(7) Stress Limits

(a) Relate concept of probability of occurence to stress limit.

(b) Develop proper choice of service limit (stress/strain) for each load or load/response combination.

(c) Consideration of operability and functional capability

(8) Revise Standard Review Plan, develop Regulatory Guide and make Regulation Changes

The results of the study (items (1) thru (7)) will result in a more rational basis for the establishment of regulatory requirements and it may also lead to some relaxation of the current requirements.

such relaxation would be based on improved knowledge of loads, load combinations and stress limits, it is expected that these relaxations will improve the safety standards.

3. BASIS FOR CONTINUED OPERATION AND LICENSING PENDING COMPLETION OF TASK

Criterion 2 of GDC requires that the design bases for structures, systems, and components shall reflect "appropriate combinations of the effects of the normal and accident conditions with the effects of natural phenomena." In view of this statement, the question arises as to why operating reactors (which have been designed before GDC-2 was instituted and to load combiantions that may not have considered normal and accident conditions together with the effects of natural phenomena) are safe or why their continued operation is acceptable.

There are several conservatisms utilized in the design of operating plants which may provide sufficient safety margin against low probability events such as the combined effect of SSE and LOCA. Some of these conservatisms are:

(a) Elastic analysis is used in the design for condition involving SSE and/or LOCA. An appreciable margin would exist if inelastic system and component analysis were utilized.

(b) The ASME Code service limits are equivalent static limits. Since SSE and LOCA loads/responses are dynamic in nature, the available margin for dynamic loads may be considerably higher (for ductile materials) than the margin available when the loads are static or quasi-static.

(c) The probability of SSE or LOCA occuring alone is very low. The probability of their simultaneous occurance with peaks combining is extremely low.

Some of the recent plants that have been licensed have used absolute summation of loads, i.e., using unlikely peak combinations of various dynamic loads/responses and therby making systems more rigid. Stresses in these more rigid systems are higher for normal operation than would be the case for less rigid system, although still within code allowable limits. This seemingly extremely conservative philosophy does not

enhance the reliability for normal operation especially when thermal stresses are present and flexibility is desirable.

The purpose of this task is to develop improved and more uniform requirements for dynamic loads, their responses and combination of responses and to assess the effect of these requirements on plant operation under various conditions. While this task is being completed, the existing criteria, which has been in use, are adequate to assure that continued operation of licensed plants and continued licensing of plants now under review impose no undue hazard to public health and safety.

4. NRR TECHNICAL ORGANIZATIONS INVOLVED:

A. Mechanical Engineering Branch, Division of Systems Safety (MEB/DSS). MEB/DSS is responsible for overall program management and the following specific tasks for piping systems, equipment and supports:

(i) Evaluation of current NRC regulation requirements and licensee procedures.

(ii) Develop load/response combiantion methodology for piping systems,

equipment and supports.

(iii) Develop a rationale for decoupling of specific loads/responses now treated in combination and develop listing of loads and load combinations including all system transients required for the design of each system.

(iv) Determine proper service limits for each load/response or for each load/response combination.

(v) Extend NUREG 0484.

(vi) Prepare a final report describing findings of studies and conclusions.

(vii) Coordinate with Mechanical Engineering Research Branch (MERB/RSR) the findings of their studies on 'Nuclear Power Plant Design Load Combination Research' and 'Seismic Safety Margin Research Program.'

(viii) Develop Standard Review Plan, Regulatory Guide and proposed Regulation changes.

Manpower Estimates: 10.0 man months in 1979, 11 man months in 1980, 9 man months in 1981.

B. Structural Engineering Branch, Division of Systems Safety (SEB/DSS)

SEB/DSS is responsible for the following specific tasks for PWR and BWR containment and structures:

(i) Evaluation of current NRC regulaiton requirements and licensing procedures.

(ii) Develop load/response combination methodology.

(iii) Develop a rational for decoupling specific loads/responses which are currently treated in combination. Develop a listing of loads and load combinations required for design of structures.

(iv) Determine proper load factors and service limits for each load or load/response combination.

(v) Coordinate with MEB/DSS in writing NUREG 0484 Revision.

(vi) Prepare a final report describing findings of studies initiated by SEB and the conclusions.

(vii) Coordinate with MEB/DSS in revising Standard Review Plan (SRP),

develop Regulatory Guide (R.G) and make regulation changes.

Manpower Estimates: 8 man months in 1979, 9 man months in 1980, and 7 man months in 1981.

C. Materials Engineering Branch, Division of Systems Safety (MTEB/DSS).

MTEB/DSS is responsible for the following specific tasks:

(i) To determine what size of an undetected flaw in the reactor coolant system under SSE excitation could lead to a large LOCA. Extend the task to include other high energy lines (e.g., main steam line, feedwater line).

(ii) Develop a rationale for decoupling SSE and LOCA load/response combination.

(iii) Coordinate with MEB/DSS to define piping stresses for determining critical flaw sizes under the operational and SSE loads.

(iv) Coordinate with Metallurgy and Materials Research Branch (MMRB/RES) the findings of their studies on 'Mechanism and Probability of Pipe Failure' and 'Large LOCA Induced by Seismic Crack Growth' and 'J-R Curve Testing of Reactor Pressure Vessel and Primary Piping Steels.'

(v) Coordinate with MEB/DSS to revise SRP, develop R.G., and make regulation changes.

Manpower Estimates: 3 man months in 1979, 2 man months in 1980, and 2 man months in 1981.

D. Core Performance Branch, Division of Systems Safety (CPB/DSS)

CPB/DSS is responsible for the following tasks:

(i) Develop fuel damage criteria for an SSE.

(ii) Develop fuel damage criteria for LOCA.

(iii) Develop fuel damage criteria for combination of seismic and LOCA loads/responses.

(iv) Modify S.R.P., Section 4.2.

Manpower Estimates: 3 man months in 1979, and 1 man month in 1981.

E. Reactor Systems Branch, Division of Systems Safety (RSB/DSS)

(i) RSB/DSS is responsible for evaluating system consequences for decoupling the dynamic loads effects of SSE and LOCA.

(ii) For the design load combinations identified in A(iii), develop

a listing of these systems which are required to operate and the systems criteria (e.g., redundancy, single active failure) which are applicable for such systems.

Manpower Estimates: 1 man month in 1979, 1 man month in 1980. and 1 man month in 1981.

F. Auxiliary Systems Branch (ASB/DSS). For the design load combinations identified in A(iii), ASB/DSS will coordinate with RSB/DSS the task of developing a list of those systems which are required to operate and the systems criteria (e.g., redundancy, single active failure) which are applicable for such systems.

Manpower Estimates: 1 man month in 19p79, 1 man month in 1980, and 1 man month in 1981

G. Systematic Evaluation Program Branch, Division of Operating Reactors (SEPB/DOR) SEPB/DOR will evaluate the effects of decoupling Seismic and LOCA load/ responses on reactor coolant system and safe shutdown system of nuclear power plants involved in SEP program.

Manpower Estimates: 1 man month in 1979 and 1 man month in 1980.

5. TECHNICAL ASSISTANCE

Contractor	Amount		Program Objectives
	FY 79	FY 80	
A. Brookhaven National Lab. (Managed by MEB/DSS)	$90K	$50K	To study methodology of combining dynamic responses

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Contractor	Amount FY 79	Amount FY 80	Program Objectives
B. Brookhaven National Lab (Managed by MEB/DSS	$55K		Evaluation of Mark II SRSS Load Combination Criteria and to investigate the acceptability of Kennedy/Newmark Criteria
C. Teledyne Engrg. Services (Managed by MEB/DSS)	$35K		Effect of faulted condition load combinations on normal operations.
D. Naval Research Lab. (Managed by MTEB/DSS)	$43K	$40K	Assess available experimental data and systematically evaluate to determine stable flaw size in piping.
E. To be selected (Managed by MTEB/DSS)	$35K	$40K	Perform tearing stability analyses for LWR piping to determine under what load and material conditions stable crack extension will be assured.
F. To be selected (Managed by SEB/DSS)	$150K	$150K	Perform reliability estimates for different seismic Category I structures subjected to various safety significant events.

Contractor	Amount FY 79	Amount FY 80	Program Objectives
G. To be selected (Managed by SEB/DSS)	$50K	$50K	Develop methods for load combinations for structures and determine the significance of each load in the load combinations through probabilistic approach.
H. To be selected (Managed by SEB/DSS)		$75K	Determine load factors for each load in factored load combinations by probabilistic methods.

6. ASSISTANCE REQUIREMENT FROM OTHER NRC OFFICES

A. Office of Standards Development, Division of Engineering Standards, Structures and Components Standards Branch (SCSB/SD). SCSB/SD will specify the original item of treating loads/responses in combination for each of the current regulations, regulatory guides, and branch positions on the subject.

SCSB/SD will coordinate with MEB the task of developing an appropriate Regulatory Guide and changes in the Regulations that might be needed to complete this task action plan.

B. Office of Nuclear Regulatory Research, Division of Reactor Safety Research, Mechanical Engineering Research Branch, (MERB/RES). MERB/RES is funding a major program on evaluating and developing load combination criteria for the design of commercial nuclear power plants. The project contains three major tasks, viz (1) Assess the contribution to safety resulting from the requirement to design for simultaneous large LOCA and SSE and the cost incurred due to this requirement, (2) Assess the probability of a LOCA induced directly or indirectly by a range of earthquakes; and (3) Evaluate and recommend generic techniques and standards for combining dynamic loads. The Metallurgy and Materials Research Branch (MMRB/RES) is assisting MERB/RES in completing this program and is funding the development of fracture mechanics methodology for evaluating piping integrity. MEB/DSS will coordinate with MERB/RES to provide input to the NRR task action plan (B-6). MTEB/DSS wil coordinate with MMRB/RES to provide input to task action plan B-6.

C. ACRS

The ACRS Subcommittee on Load Combination has been established and this task will be coordinated with the committee as the task progresses.

7. INTERACTION WITH OUTSIDE ORGANIZATIONS

A. Mark II Owner's Group

This is an "ad hoc" organization of utilities constructing Mark II BWR facilities. They have engaged G.E., Engineering Design Analysis Corporation, Nuclear Services Corporation, Dr. Robert Kennedy and Dr. Nathan Newmark for resolution of generic dynamic load/response combination methodology and to work with NRC in establishing an acceptance criteria (Ref: NEDE 24010, Supplement 1 and 2).

B. General Electric Company

G.E. has filed topical report NEDE-24010-P entitled "Technical Bases for the Use of the SRSS Method for Combining Dynamic Loads for Mark II Plants." The topical is being reviewed by NRC staff.

C. Westinghouse Electric Corporation

Westinghouse has filed two topical repo-cs, (1) WCAP 9779 entitled, "Combination of SSE and LOCA Responses for Faulted Condition Evaluation of Nuclear Power Plants" which treats load combination methodology and (2) WCAP 9283 entitled, "Integrity of the Primary Piping Systems of W Nuclear Plants During Postulated Seismic Events" which deals with whether to combine LOCA and SSE loads. The staff is reviewing these reports with the help of BNL.

D. Atomic Industrial Forum Inc. (AIF)

The AIF Committee on Reactor Licensing and Safety has formed an "Ad Hoc" committee on Load Combinations. The committee will be looking at generic, long-range load/response combinations related issues. They may develop a technical standard dealing with the general load combination/stress limit issue and the necessary value impact for the Standard. If developed, the Standard may be endorsed in the Regulatory Guide Series.

E. American Society of Mechanical Engineers (ASME)

Interaction is required with the Task Force on Dynamic Loads of Section III of the ASME Boiler and Pressure Vessel Committee to ensure consistency of staff requirements with the ASME Code requirements when they are developed.