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**RECOMMENDED REFORMS IN CODES AND STANDARDS,
QUALITY ASSURANCE, AND ENGINEERING PRACTICES FOR
COMPETITIVE LIQUID METAL NUCLEAR POWER PLANTS**

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1. EXECUTIVE SUMMARY

With the cancellation of the Clinch River Breeder Reactor Plant Project and the growing perception that the deployment of large-scale breeder reactor plants in the United States was no longer urgent, the Department of Energy (DOE) in 1984 reevaluated and restructured its liquid metal fast breeder reactor (LMFBR) program. It had become apparent that continued active development of the LMFBR would have to be justified on the basis of its own technical and economic merit relative to that of other power-generation concepts, both fossil and nuclear, with which it would have to compete beginning in the late 1990s. The program became known as the liquid metal reactor (LMR) program as the need for breeding was de-emphasized.

For successful market penetration, the LMR would have to be competitive in the areas of total investment cost, inherent or passive safety, and surmounting regulatory and financial impediments. Because of these requirements, there was widespread concern that misinterpretation and misapplication of codes and standards, cumbersome quality assurance (QA) practices, and ineffective engineering practices were likely to be major impediments to the marketability of the LMR. In view of this concern, the DOE Breeder Technology Projects (BTP) Office asked the staff of its Materials and Structures Technology Management Center at the Oak Ridge National Laboratory to organize and coordinate a study to identify and recommend actions for implementing more cost-effective means of achieving the legitimate goals of codes and standards, QA practices, and engineering practices in the nuclear industry, with particular reference to LMRs. The results of that study are presented in this report.

In an organizational meeting, three working committees—designated Codes and Standards, Quality Assurance Requirements and Practices, and Engineering Practices—were established, and an action plan was developed. The rosters of the working committees included representatives from five reactor manufacturers, two architect-engineers, two large private utilities, one component manufac-

turer, three consulting firms, three national laboratories, and the Electric Power Research Institute (EPRI). Representatives of DOE participated in *ex officio* capacities.

Key reference documents used by the working committees were (1) a report and subsequent case study by United Engineers and Constructors, Inc. (UE&C), on nuclear power plant cost drivers; (2) a report by the Subcommittee on Codes and Standards of the American Society of Mechanical Engineers (ASME) Advanced Reactors Committee on the evaluation of codes and standards for application to LMFBRs; (3) the results of a study coordinated by the Argonne National Laboratory on needed reforms in codes and standards identified by innovative LMR design teams and component suppliers; and (4) the reports of an EPRI study on root causes of delays in nuclear power plant construction. (Complete citations for these reports are given in the main chapters of this document.)

According to the UE&C analysis, the distribution of total investment costs for a reference 1139-MW(e) pressurized water reactor was as follows: escalation, 38%; interest, 27%; and base-construction or overnight cost, 38%. Of the base-construction costs, 58% were for site labor and engineering, 34% for equipment, and 8% for construction materials. The results of this study clearly emphasized the need for improvements in the practices that affect the time-related financial components, which total 62%, and the site labor and engineering portion of the base-construction component.

The EPRI study was based on data from 26 nuclear plants for which the average construction-related delay time was 43 months. Fifty-three percent of the delays were attributed to redesign and rework, 25% were associated with labor and materials, and 22% were classified as deliberate.

The reports of the three working committees are summarized below. Some overlap will be noted among the findings of the committees because the areas designated for study are not totally independent of each other. For example, QA practices influence the choice and management of the codes

and standards to be invoked in a given plant project, and engineering practices encompass management styles and approaches that can significantly affect QA requirements, procedures, and applications.

The document itself should be viewed as a door-opening report and not as the product of a finished work. It was not possible within the constraints of time and resources allotted for this study to comprehensively deal with the many undesirable or questionable practices developed over a generation in the nuclear power industry. Hopefully, the criticisms and recommended actions cited in the document will serve to bring improvements in the practices that were assessed and to enhance the viability of the LMR concept.

1.1 CODES AND STANDARDS

The Working Committee on Codes and Standards emphasized throughout its deliberations that standards should (1) establish and define levels of quality and reliability that suit the program and (2) insofar as reasonably possible, be based on experience and not on speculative requirements. It was also noted that costly over- or underapplication of standards can result if standards users are unaware of essential information relative to design, technology, management procedures, program costs, and schedule goals.

Overapplication occurs when requirements that are excessive are invoked or when requirements are applied prematurely. This frequently results in increased costs, cost overruns, schedule delays, or unnecessary claims against the contractor. Underapplication occurs when essential requirements are either inadvertently or deliberately omitted or relaxed with the intent of reducing costs or compressing schedules. Underapplication can result in reduced system performance, increased life-cycle cost, or early obsolescence.

The criteria for selecting items for reform were based on the information contained in the UE&C report briefly described in the introductory material above, that is, emphasizing reforms affecting site labor and engineering costs relative to those related to nuclear island equipment. The need for including cost-benefit procedures in the consensus standards process was cited, and methods for effecting needed reforms were presented. Finally, a prioritized list of 19 recommended items for reform was developed, and action statements were prepared for the following 9 highest priority items:

1. eliminate subsection NF of ASME Section III, Division 1;
2. substitute American National Standards Institute (ANSI) B31.1 and ASME Section VIII for Subsection ND of ASME Section III;
3. revise ANSI B16.1 to include tolerancing of thin-walled pipe for LMR applications;
4. request that the Nuclear Regulatory Commission (NRC) publish in-service inspection requirements for LMRs before plant design;
5. develop a document similar to 10 CFR 50, Appendix A, for LMR application that stresses performance-oriented requirements;
6. develop criteria for the design of LMRs;
7. develop criteria for reliability design;
8. develop a structural analysis standard for complete structures (e.g., buildings); and
9. develop high-temperature design criteria for concrete.

1.2 QUALITY ASSURANCE REQUIREMENTS AND PRACTICES

Based on literature reviews, discussions, and individual-member inputs, the Working Committee on QA Requirements and Practices concluded that DOE should work with the NRC and industry to reduce the cost associated with the application of QA procedures for LMR plants by

1. stressing strong management and implementing a management system that ensures adequate control over all aspects of the project;
2. motivating people and obtaining individual commitments to quality;
3. ensuring that QA program documentation is legally required and appropriate;
4. providing a framework that puts a premium on minimizing and controlling risks;
5. simulating interest in the understanding and application of Federal Aviation Administration (FAA) commercial airline experience that can be of value to the nuclear industry;
6. following the FAA practice by implementing a system whereby designated construction inspection representatives certified by the NRC witness and sign off on all key tests, inspections, and analyses as they occur and not long after the fact, as in current practice; and
7. working to provide final design earlier in the construction process, identifying and establishing acceptance criteria for the inspections, tests, and analyses that must be performed, and building all of this around value engineering.

A plant cost analysis showed that QA costs may be as high as 20% of the total plant cost. Of this 20%, 13% is related to financial costs brought about by protraction of construction time, and the remaining 7% is directly related to base-construction costs. Thus, QA reforms should emphasize shortening overall construction time. A secondary emphasis should be on the reduction of base-construction costs, such as equipment costs and site labor and engineering costs.

Savings that could reasonably be effected by QA reforms were estimated to be as high as 15% of the total plant cost. For a plant costing \$4 billion, this would correspond to \$600 million. Thus, successful pursuit and institution of QA reforms could very well result in significant reductions in the total cost of LMR plants.

The following actions regarding QA reforms were recommended:

1. QA programs that emphasize performance rather than paperwork should be implemented.
2. QA should be recognized as a necessary management tool should be recognized and emphasized during the planning phase of LMRs and carried out on a team basis during design and construction.
3. DOE should adopt ANSI/ASME NQA-1 as the base QA standard, and DOE Standard NE F2-2 should be discontinued or inactivated.
4. QA systems and procedures should be based on acceptability of the end product and not just on the acceptability of the documented system or process of getting to the end product.
5. Projects should have a single-owner QA program under which all site contractors work.
6. Management at every level should be properly educated and fully committed and should participate in the QA activities of the plant construction.
7. Bid solicitation and contract award processes should be streamlined and improved; methods for evaluating the acceptability of potential vendors should be included in this process.
8. Experienced craft and inspection personnel should participate in drafting the instructions and procedures used for fabrication and inspection of components, systems, and structures.
9. The current method of fines imposed by the NRC on utilities, vendors, and suppliers for

violations of regulatory requirements should be changed so that punitive actions are applied only in cases of gross negligence or deliberate violation or cover-up.

10. DOE should work with industry and the NRC in reducing the cost of QA by emphasizing strong management, eliminating unnecessary requirements, and educating and motivating personnel at all levels.
11. Excessive and unnecessary QA surveys of all types should be eliminated and a new system implemented whereby multifunctional audit teams that represent all concerned organizations are established and used on a planned project-wide basis; superfluous QA requirements for nonsafety systems should be eliminated.
12. The NRC should return to a centralized administration for more effective and balanced application of regulatory requirements.

1.3 ENGINEERING PRACTICES

The Working Committee on Engineering Practices defined engineering practices as anything that engineers do throughout the conception, management, design, construction, inspection, licensing, and preoperational-testing and turnover phases of a nuclear plant project. The committee then systematically delved into all phases and aspects of a nuclear plant project to identify the key cost drivers and the engineering decisions, actions, and practices that significantly affect those cost drivers. The UE&C and EPRI reports described in the introductory material of this Executive Summary were key reference documents in this study. A particularly important observation was that minimizing capital risk is probably even more important to a utility than minimizing capital cost. Clearly, if utilities are to be expected to seriously consider purchasing an LMR plant, they must be assured that it can be built within budget and on schedule.

Four major problem areas were identified:

1. **Planning and Management** This area probably has the largest potential cost impact of the four.
2. **Initial Requirements and Design** This area affects not only the base-construction cost but also the potential for subsequent costly scope changes and regulatory ratchetting.
3. **Scope Changes and Control** Unanticipated changes in design and procedures lead directly to the escalation of costs and schedules.

4. **Regulation**—Regulatory changes and ratcheting likewise promote higher costs and elongate schedules.

In each of these areas, 5 to 12 actions most critical to the realization of a cost-competitive LMR project were identified. These actions, which total 33, are presented in the report as recommended initiatives.

The **Planning and Management** recommendations point to the need for careful selection of the owner/operator, assembly of an experienced centralized team, project management continuity, integrated planning, highly visible controls and performance incentives, avoidance of adversary relations, and incorporation of domestic and foreign experience and technology developments.

The **Initial Requirements and Design** recommendations cover such diverse items as safety systems (minimize and separate them, clarify LMR safety requirements, and provide design criteria for non-safety LMR equipment); the selection and use of codes and standards (avoid overcommitment to them, particularly those not based on experience);

the use of standard designs and commercial products; specifications (use performance specifications rather than detailed requirement specifications); and realistic requirements for examination and in-service inspection and maintenance.

The **Scope Changes and Control** recommendations emphasize developing firm design specifications; establishing stable standard design data, methods, and criteria; completing design before starting construction; and developing guidelines and procedures for field routing and for repair of defect indications.

Finally, the **Regulation** recommendations focus on establishing a one-step, LMR-specific licensing process; consolidating licensing responsibility; resolving issues with regulatory bodies on an early and continuous basis; and increasing design margins to accommodate change without redesign.

Of the 33 recommended initiatives that were identified, 15 were judged to be amenable to favorable influence by DOE-sponsored activities. These initiatives were ranked according to their perceived cost-effectiveness, and an action plan was developed for each.

2. INTRODUCTION

2.1 BACKGROUND INFORMATION

Because of the congressional cancellation of the Clinch River Breeder Reactor Plant Project and the growing perception that there was no longer an urgency to deploy large-scale breeder reactor plants in the United States, the Department of Energy (DOE) in 1984 initiated a careful reevaluation and restructuring of its liquid metal fast breeder reactor (LMFBR) program. It had become apparent that if continued vigorous development and demonstration of the LMFBR concept was to be warranted, it would have to be on the basis of its own technical and economic merit compared with that of other power-generation concepts (fossil, advanced light water reactor, and high-temperature gas-cooled reactor plants) with which it would have to compete in the energy market beginning in the late 1990s. The program became known as the liquid metal reactor (LMR) program as the need for a breeding fuel cycle paled in the light of these considerations.

For successful market penetration, the LMR would have to be competitive in the categories of overnight or base-construction cost, schedule, inherent or passive safety, and surmounting regulatory and financial impediments. In this connection, considerable concern had been expressed that misinterpretation and misapplication of codes and standards, cumbersome quality assurance (QA) practices, and ineffective engineering practices constituted potential major impediments to the marketability of the LMR. In view of this concern, the DOE Breeder Technology Projects (BTP) Office under its Director, W. A. Nelson, and Deputy Director, J. L. Tew, requested that a study be undertaken to identify and recommend actions for implementing more cost-effective means of achieving the legitimate goals of codes and standards, QA practices, and engineering practices in the nuclear industry, with particular reference to LMRs.

The staff of the LMR Materials and Structures Technology Management Center (MSTMC) at the

Oak Ridge National Laboratory was asked by the DOE-BTP Office to organize and coordinate this study and to submit a report on the findings and recommendations. The present document is in response to that request.

For the purpose of organizing the effort, the MSTMC convened a meeting of representatives of industry, DOE, and national laboratories to discuss the problem and develop an action plan for carrying out the assignment. This meeting was cochaired by W. O. Harms, Director of the MSTMC, and the late C. M. Purdy of the DOE-BTP Mechanical Component Development Division.

The tone of the organizational meeting was set in introductory presentations by representatives of United Engineers and Constructors, Inc., and by W. E. Cooper, Chairman of the American Society of Mechanical Engineers (ASME) Council on Codes and Standards. There were some pertinent observations cited in these presentations and in comments by some of the other participants at the meeting:

- The misinterpretation and misapplication of codes and standards are major problems in the nuclear industry, and so are cumbersome and ineffective QA and engineering practices.
- Successful plant projects are characterized by "engineering ahead of construction."
- Manpower costs represent about 75% of the cost of a nuclear plant.
- The best cost and plant practice in the United States is about the same as the best in France.
- Persons with strong light water reactor backgrounds should be included in committees for improving or rewriting nuclear codes and standards.
- Base program participants should become more directly involved with the Nuclear Regulatory Commission (NRC) to get technical changes implemented; they should not depend upon the projects to effect this interaction, as has been the

practice in the past. (The ineffectiveness of the projects in this regard is attributed to an apparent reluctance on the part of project participants to become actively involved in such interactions with the NRC.)

Three working committees designated Codes and Standards, Quality Assurance Requirements and Practices, and Engineering Practices were established at the meeting, and an action plan covering the assignments for these committees was developed.

2.2 WORKING COMMITTEE MEMBERSHIP AND ASSIGNMENTS

A broad representation of the relevant groups and institutions involved—codes and standards bodies, utilities, reactor manufacturers, architect-engineers, and national laboratories—was emphasized in formulating the rosters of the three working committees. Representatives of DOE participated in *ex officio* capacities. A listing of the working committee members and their affiliations is presented below.

Codes and Standards

T. L. Anderson, Cochairman, Rockwell International
 W. L. Cooper, Jr., Cochairman, Oak Ridge National Laboratory
 J. R. DiStefano, Secretary, Oak Ridge National Laboratory
 V. G. Aquino, Argonne National Laboratory-West
 H. R. Brager, Hanford Engineering Development Laboratory
 E. Corrigan, Burns and Roe
 H. F. Dobel, Hartford Steam Boiler
 D. P. Edmonds,* Babcock and Wilcox
 C. S. Ehrman, Burns and Roe
 R. Kaminski, United Engineers and Constructors, Inc.
 F. N. Moschini, Westinghouse Electric Corporation
 L. Tiemann, General Electric Company-ANTO

Quality Assurance Requirements and Practices

A. W. Dalcher, Cochairman, General Electric Company-ANTO

*Formerly with the Oak Ridge National Laboratory.

W. L. Cooper, Jr., Cochairman, Oak Ridge National Laboratory
 J. A. Horak, Secretary, Oak Ridge National Laboratory
 V. G. Aquino, Argonne National Laboratory-West
 P. Bourne, Hanford Engineering Development Laboratory
 L. J. Chockie, General Electric Company-NEBO
 E. J. Corrigan, Burns and Roe
 O. Hedden, Combustion Engineering, Inc.
 E. J. Hemzy, Commonwealth Edison Company
 J. Lang, McDermott, Inc.
 J. C. Tobin, Hanford Engineering Development Laboratory
 J. E. Vessely, Florida Power and Light Company
 F. S. G. Williams, Consultant

Engineering Practices

J. M. Corum, Cochairman, Oak Ridge National Laboratory
 L. K. Severud, Cochairman, Hanford Engineering Development Laboratory
 J. J. Blass, Secretary, Oak Ridge National Laboratory
 A. G. Bernstein, United Engineers and Constructors, Inc.
 G. B. Bradshaw,** Seabrook Station
 S. W. Chapel, Electric Power Research Institute
 D. S. Griffin, Westinghouse Electric Corporation-AESD
 R. P. Karr, Argonne National Laboratory-East
 W. H. Lovelace,† Merrill Lynch Pierce Fenner & Smith
 R. J. McConneil, Argonne National Laboratory-West
 G. W. May, Bechtel Power Corporation
 R. E. Palm, Burns and Roe
 W. J. Rowan, Electric Power Research Institute-Consolidated Management Office
 R. Wray, Teledyne Engineering Services

Key items in the working committee assignments were (1) providing detailed action plans and scopes, factoring in the results of a study coordinated by the Argonne National Laboratory Special Systems and Projects Office on needed reforms in codes and standards identified by innovative LMR

**Formerly with the Florida Power and Light Company.

†Formerly with the Nuclear Regulatory Commission.

3. CODES AND STANDARDS

3.1 INTRODUCTION

The Working Committee on Codes and Standards defined standards as documents that establish engineering and technical requirements for processes, procedures, and methods that have been adopted as standard. They cover materials, items, engineering practices, processes, symbols, type designations, definitions, nomenclature, tests, and inspection, including the definition and classification of defects; they may also cover the marking of materials, items, parts, and components of equipment. Codes are the systematic collection of standards that have been made into laws.

Codes and standards have been identified as important cost producers in the construction of nuclear power plants. Many studies have found examples of unnecessary codes and standards imposing additional costs without contributing to improved system performance. However, in many instances excessive costs have resulted from the inability of, or failure by, the user to exercise appropriate flexibility in application rather than from a fundamental problem with the code or standard itself.

To identify and implement cost-effective means of achieving the legitimate goals of codes and standards, the committee first examined the purpose and applications of codes and standards and then formulated some recommended approaches to accomplishing the desired reforms.

3.1.1 Purpose of Codes and Standards

The primary purpose of a standard is to provide designers and users with recommended data and descriptions that are essential to the selection and application of items and processes in the develop-

ment and production of services and materials. Standards should establish and define levels of quality and reliability that suit the program.

3.1.2 Application of Codes and Standards

The application of standards consists of reviewing and selecting from the available body of standards those that pertain to a particular program, product, or service and contractually invoking those standards wholly, or in part, at the most advantageous point in the development, production, or construction cycle. Costly over- or under-application of standards can result if standards users are unaware of essential information relative to design, technology, management procedures, program costs, and schedule goals.

Overapplication occurs when excessive requirements are invoked or when requirements are applied prematurely. This frequently results in increased costs not really justified by the superior characteristics one would get from more demanding standards, cost overruns, schedule delays, or unnecessary claims against the contractor. Underapplication occurs when excessive requirements are either inadvertently or deliberately omitted or relaxed with the intent of reducing costs or compressing schedules. Underapplication can result in reduced system performance, increased life-cycle cost, or early obsolescence.

3.2 APPROACH

At its first meeting, the committee established an action plan for (1) preparing a list of candidate codes and standards items for reform; (2) developing recommendations, justifications, and plans for implementation; and (3) issuing a report.

To develop a list of items for reform, the committee reviewed the letter report of the Special Studies and Project Office of Argonne National Laboratory (ANL),¹ the report of the Subcommittee on Codes and Standards of the American

¹The cochairmen for the working group on codes and standards were T. L. Anderson of Rockwell International and W. L. Cooper of the Oak Ridge National Laboratory (ORNL). J. R. DiStefano of ORNL served as secretary.

Society of Mechanical Engineers (ASME) Advanced Reactors Committee,² and the report by United Engineers and Constructors (UE&C) on nuclear cost drivers.³ The responses solicited by a letter from the ANL Special Studies and Project Office were condensed and compiled into 28 groups of like comments from the several respondents (Appendix A). This compilation and 24 proposed new standards from the report of the ASME Subcommittee on Codes and Standards (Appendix B) were then distributed to the working committee members for their review and comment at a second committee meeting. Each item was reviewed to determine its potential cost impact, its justification for recommendation, and barriers to its implementation. A consensus was developed regarding the basis for recommended reforms and the priority of the items recommended.

3.3 FINDINGS

The findings of the committee can be divided into four general categories:

1. criteria for selecting items for reform,
2. the need for including cost-benefit procedures in the consensus-standards process,
3. methods for effecting needed reforms, and
4. prioritized list of recommended items for reform.

3.3.1 Criteria for Selecting Items for Reform

The committee elected to base its criteria for the selection of codes and standards for reform on the information contained in the UE&C cost-drivers report³ and the Phase V Update Report for the Department of Energy (DOE) Energy Economic Data Base Program.⁴ The results of an analysis prepared by UE&C based on these reports are presented in Table 3.1, where it is seen that 58% of the base-construction cost for the reference 1139-Mw(e) pressurized water reactor plant is associated with site labor and engineering. Accordingly, the reform of codes and standards affecting site labor and engineering costs has a relatively high probability of success and, therefore, deserves first consideration. The reform of codes and standards affecting costs of the design, manufacturing, or supply of nuclear island equipment should be considered for revision only after those issues that affect site labor and engineering costs have been addressed.

With respect to the total investment cost breakdown in Table 3.1, it is important to note that, based on the interest rate and length of construction time perceived to be reasonable at the time of this analysis, the time-related categories, namely escalation and interest, are significantly larger contributors to the total cost than are the other categories (including site labor and engineering).

3.3.2 Need for Cost-Benefit Procedures in the Consensus-Standards Process

The high cost of nuclear power plants, coupled with the possibility of consensus standards being adopted by various national regulatory bodies engaged in regulating other energy-related technologies, requires that consensus standards be cost-effective as well as technically effective. One method of improving the cost-effectiveness of standards is by tailoring them to the particular application. Tailoring is the process by which the individual requirements (as expressed in whole sections, in paragraphs, or in single sentences) of the selected standards are evaluated to determine their suitability for a given application (e.g., a specific material acquisition) and then modified to ensure that each standard reflects only the minimum needs for the application. The process of selecting and tailoring standards generally involves the input of a number of persons with specialized skills from various organizations and from various organizational levels. When standards are misapplied, users and regulators are sometimes both at fault, but for different reasons. Regulators [e.g., the Nuclear Regulatory Commission (NRC)] are motivated toward maximum application of standards to avoid the risks of failure and to fully protect the public. Users (e.g., reactor manufacturers, suppliers, architect-engineers, and utilities), on the other hand, are motivated toward full compliance to avoid nonconformance or nonresponsiveness. The tendency toward overly conservative application of standards, coupled with resistance to change, has resulted in unnecessary costs that can be avoided if the attitude toward selective application and tailoring can be improved. Project managers generally have the final responsibility. They should require justification for the inclusion of each standard document in whole or in part, as appropriate. In any case, proposed improvements in the methods of applying standards should be cost-effective.

Table 3.1. Base-construction and total investment cost distributions for an 1139-Mw(e) pressurized water reactor^a

Cost class/group	Base construction (% of cost)	Total investment (% of cost)
Material		
Structural	3.50	1.31
Electrical	0.93	0.55
Piping	0.64	0.24
Construction service	2.93	1.10
Subtotal	8.00	3.00
Equipment		
Nuclear steam supply	9.16	3.50
Turbine generator	7.20	2.75
Mechanical	5.79	2.21
Piping	4.04	1.55
Electrical/I&C	3.50	1.34
Structural	2.69	1.03
Construction service (mechanical equipment)	1.62	0.62
Subtotal	34.00	13.00
Site labor and engineering		
Structural craft	10.33	3.92
Mechanical craft	8.11	3.07
Electrical craft	5.16	1.96
Construction craft	4.09	1.55
Payroll, insurance, taxes for craft	4.83	1.83
Engineering	17.10	6.49
Field (nonmanual)	8.38	3.18
Subtotal	58.00	22.00
Escalation		35.00
Interest		27.00
Total	100.00	100.00

^aBased on data presented in Refs. 3 and 4.

Another cost-effective measure is to incorporate cost-benefit considerations into the consensus-making process. An effective cost-benefit analysis will involve an evaluation of the effect of a particular standard on a number of areas, including design, development requirements, licensing, shop practices, and field practices. The factors associ-

ated with these areas are purchasing, preparation (e.g., cleaning and painting), assembly, erection, inspection, quality assurance, startup, operation, maintenance, and decommissioning. The analysis should include (1) a comparison of the cost and the benefits of a recommended solution to those of other possible solutions within the context of both

a manufacturing and field-construction environment and (2) if possible, an assessment of the impact of a particular approach or recommendation on U.S. nuclear power goals.

Clearly, not all issues that emerge from a cost-benefit standards review will involve all of the areas and factors cited above, nor will all such issues need the same level of analysis. In any case, effective cost-benefit analyses will require the input of different disciplines and skills (both technical and economic) if the scenarios and conditions under consideration are to be properly formulated. The input of experienced cost engineers will be required.

In situations involving ASME Code committees, it is highly unlikely that the committees, their individual members, or the companies that support the members have adequate experience, scope, or resources to support effective cost-benefit analyses. It would seem to be in order, therefore, for DOE to assist in providing the means for conducting these analyses during the consensus-making process.

3.3.3 Methods for Effecting Needed Reforms

The committee identified five methods for effecting needed reforms in codes and standards for application to advanced liquid metal fast breeder reactors (LMFBRs): (1) eliminate unnecessary ones, (2) revise existing ones, (3) develop new ones, (4) resolve interfacing problems among different jurisdictional groups, and (5) improve the method of application of codes and standards (e.g., by reformatting to facilitate the selective application or tailoring of specific sections of the documents). Only methods (1), (2), and (3) were used in formatting the prioritized list of recommended reforms discussed below in Sect. 3.3.4. Method (5) is addressed in Sect. 3.4, item 10.

3.3.4 Items Recommended for Reform

The reference list of 52 consensus concerns (28 in Appendix A and 24 in Appendix B) was reduced based principally on the criteria cited in Sect. 3.3.1, to 19 for further consideration. The reduced list is shown in Table 3.2. For further prioritization, the committee members used their experience and their understanding of each issue, along with the number of responding contractors supporting a given recommendation.¹ The letter "A" was assigned to those considered to have the

greatest impact (i.e., significant effect on site labor and engineering costs), and the letter "B" was assigned to those thought to have lesser impact. It is to be understood that the listing in Table 3.2 represents the committee's "first cut." It should, nonetheless, serve as a reasonable starting point for subsequent rational reviews leading to more cost-effective designs and base-construction scenarios.

3.4 RECOMMENDED ACTIONS

Because of the limited time and resources available for this study, not all of the recommended reform items were analyzed in sufficient depth to warrant the formulation of definitive courses of action. Those for which the available information was considered to be adequate to justify action statements (see last column of Table 3.2) are listed and discussed below.

1. Eliminate Subsection NF of ASME Section III, Division 1

Problem statement. Subsection NF of ASME Section III, Division 1, contains rules for the materials, design, fabrication, examination, and preparation of reports for supports for nuclear power plant components. However, it is based on materials and design methods more appropriate to building structures than to the pressure-retaining components of the ASME Code. It also fails to recognize that supports are usually standard shelf components and that vessels are usually custom made. In addition, ambiguity in defining jurisdictional boundaries between Subsection NF and the American Institute of Steel Construction (AISC) manual has led to unnecessary delays and increased construction costs.

Recommended action. Work through the appropriate committees to eliminate Subsection NF of ASME Section III, Division 1, and use instead the AISC manual for design and construction of component supports such as pipe clamps, supports, and snubbers.

2. Substitute ANSI B31.1 and ASME Section VIII for Subsection ND of ASME Section III

Problem statement. Section III of the ASME Code embodies three quality levels: Class 1, Class 2, and Class 3. The requirements of Subsection ND (Class 3 components) have been expanded to the point that they are almost equivalent to those

Table 3.2. Recommendation for codes and standards reforms

Item	Relative cost impact ^a	Action statement prepared ^b
ASME Section III		
Eliminate subsection NF of Division 1	A	X
Substitute ANSI B31.1 and ASME Section VIII for subsection ND of ASME Section III	A	X
Revise Division 1 rules to permit enveloping of seismic system design in lieu of full analysis of each specific design	A	
Revise Division 1 to allow for cost-saving methods for examination of welds	B	
Revise Code Case N-47 to improve rules for creep-fatigue and creep-ratchetting	B	
Delete NCA-3800 relative to certification of material manufacturers	B	
ASME Section V (NDT)		
Revise to include techniques applicable to small-diameter tubing (<4 in.)	B	
ASME Section XI		
Revise Division 3 requirements relative to volumetric inspection of guard vessels; stainless steel welds; and low-temperature, dissimilar metal joints	A	
ANSI		
Revise ANSI B16.1 to include tolerancing of thin-wall pipe for LMFBR applications	A	X
NRC liaison		
Develop a document similar to 10 CFR 50, Appendix A, for LMFBR application that stresses performance-oriented requirements	B	X
Request that the NRC publish in-service inspection requirements for LMFBRs before plant design	A	X
New consensus standards recommended for development^c		
Criteria for design of LMFBRs	A	X
Criteria for reliability design	A	X
Structural analysis standards for complete structures	A	X
High-temperature design criteria for concrete	A	X
Field-installed anchors, anchor systems, and hangers for concrete and masonry	A	
Pipe clamps—functional requirements and qualification testing	B	
Snubbers—design, construction, and testing	B	
Control room design	B	

^aRecommendations thought to have a greater potential for cost savings are designated by an "A"; those with a smaller effect are designated by a "B."

^bRecommendations for which available information was adequate for justification of a plan of action (Sect. 3.4).

^cSelections are based on previous recommendations of the Subcommittee on Codes and Standards of the ASME Advanced Reactors Committee.²

required for Subsection NC (Class 2 components). The difference between standards for piping components in Subsections NC and ND is so small that Class 3 requirements would more appropriately be covered by American National Standards Institute (ANSI) B31.1. This change would provide a clearer distinction between Class 2 and Class 3 components. For the same reason, Section VIII of the ASME Boiler and Pressure Vessel (B&PV) Code would be a desirable replacement for Subsection ND.

Recommended action. Work through the appropriate committees of ASME, Section III, Division 1, to eliminate Subsection ND and use instead ANSI B31.1 for Class 3 piping and Section VIII of the B&PV Code for Class 3 vessels.

3. Revise ANSI B16.1 to Include Tolerancing of Thin-Wall Pipe for LMFBR Applications

Problem statement. Pipe tolerance standards for light water reactors (LWRs) and LMFBRs are, in principle, the same. However, LWRs primarily use thick-wall pipe because of high system pressures; LMFBRs require larger diameter, thin-wall pipe. Because of this difference, some fit-up problems have occurred when automatic welding equipment has been used in the fabrication of LMFBR piping. Therefore, tolerance standards specifically applicable to thin-wall pipe, especially specifications for roundness, are needed.

Recommended action. ANSI B16.1 should be revised to include piping tolerance specifications that are more suitable to LMFBR requirements.

4. Request that the NRC Publish In-Service Inspection Requirements for LMFBRs Before Plant Design

Problem statement. The ASME Code provides the bases for design, construction, and inspection of nuclear plants. For in-service inspections (ISIs) the NRC usually relies on the Code rules; however, the NRC requirements are not necessarily limited to those expressed by the Code. When the NRC judges the Code rules to be inadequate for the degree of control desired, it may impose supplementary requirements through such documentation as bulletins and regulatory guides. For example, because there was concern that Code requirements for ISIs of LWR pressure vessels were inadequate, additional requirements were included in Regula-

tory Guide 1.150, "Ultrasonic Testing of Reactor Vessel Welds During Preservice and In-Service Examinations," so that the NRC would have better assurance that an adequate examination is performed. Similarly, NRC Inspection and Enforcement Bulletins 82-03 and 82-02 dealing with recommended ultrasonic methods for examination of piping for intergranular stress-corrosion cracking (IGSCC) were issued because the NRC felt that the Code had not established adequate requirements. Because of these and similar examples that could be cited, it is apparent that early involvement of the NRC is desirable to ensure that adequate consideration is given to inspectability requirements during design. Accessibility for conducting ISIs is necessary to meet both Code and NRC requirements. Postdesign requirements can lead to redesign, licensing concerns, and other consequences, all of which introduce delays that result in economic penalties.

Recommended action. The NRC should (1) provide guidelines for examination and ISIs, (2) participate in conceptual and preliminary design phases to establish general design criteria, and (3) offer suggestions for implementation of acceptable ISI requirements. This course of action should lead to a firm understanding of anticipated requirements before design and construction and minimize delays in later licensing and operating activities.

5. Develop a Document Similar to 10 CFR 50, Appendix A, for LMFBR Application that Stresses Performance-Oriented Requirements

Problem statement. The NRC Code of Federal Regulations, Title 10, Pt. 50, Appendix A (10 CFR 50 A), establishes minimum requirements for meeting the principal criteria for LWR power plants. Traditionally, these criteria have been considered generally applicable to other types of nuclear power plants. This is really not the case, however, because 10 CFR 50 A was created for LWR technology and not for LMFBR technology. For example, 10 CFR 50 A does not take advantage of intrinsic LMFBR safety features.

Recommended action. The DOE should encourage and cooperate with the NRC in the preparation of a new appendix that specifically addresses the LMFBR as a unique technology. The objective would be to prepare a set of general criteria that recognizes the unique safety characteristics and problems of the LMFBR and that recognizes that

the characteristics and approaches of a commercialized LMFBR technology have not been fully formulated and demonstrated. By preparing as part of the Code of Federal Regulations generalized criteria that are performance oriented rather than prescriptive, the NRC would facilitate the development of optimal LMFBR designs that both reflect the unique characteristics of the LMFBR technology and allow for improvements in approaches to safety and technology gained from the good and bad experiences with LWR technology.

6. Develop Criteria for the Design of LMFBRs

Problem statement. No top-level document that provides overall criteria for the design of nuclear power plants exists, nor does anything exist to define the source of other criteria that might apply. An industry consensus standard embodying those regulatory requirements that are not otherwise addressed by existing or proposed industry consensus standards is required.

Recommended action. The NRC Regulatory Guides shown in Appendix C should be combined into a top-level industry consensus standard. Because of the encompassing nature of the material to be considered, implementation of this recommendation may require that technical topics be grouped into categories and that individual standards be issued for each category. If this is done, a top-level standard should exist to reference these other subtler standards.

7. Develop Criteria for Reliability Design

Problem statement. Reliability criteria are now specified uniquely for each LMFBR plant and, depending on the nature of the project, may be specified also at the shipment level. An overall reliability program standard, similar to those used in military programs, would be very beneficial.

Recommended action. A standard that is applicable to commercial LMFBRs and that would provide an economic balance between reliability designed into equipment and the life-cycle operating costs to maintain or repair the equipment, including the cost of replacement power (if appropriate), should be developed. This standard should be a programmatic document addressing the appropriate procedures for reliability analysis, methods for defining or apportioning component reliability, procurement requirements, design-methods documentation requirements, testing and

collection of data, and maintenance of records. Provisions should be included to distinguish the needs of large, single-function, passive components, such as structures, from those of multifunctional components (e.g., control rod mechanisms).

8. Develop a Structural Analysis Standard for Complete Structures

Problem statement. Current standards cover various elements of complete structures, such as piping, concrete, structural steel, etc.; none, however, is available to define how they relate to the whole structure or how they interrelate. Currently, there are several approaches to analyzing seismic effects, such as soil-structure interactions, for complete structures. This diversity makes for inefficiency (number of analyses undertaken and excessive time delays) in establishing required seismic structural margins.

Recommended action. A new standard that would define methods and approaches that are suitable for structural analysis of complete structures, such as buildings, should be developed.

9. Develop High-Temperature Design Criteria for Concrete

Problem statement. Because of the high operating temperatures of LMFBRs, it is difficult and expensive to provide insulation to maintain the temperature of concrete below 150°F. Suitable high-temperature design criteria for concrete should permit more economical designs.

Recommended action. A standard should be developed to define design criteria, degradation factors, or both, for long-term exposure of concrete to temperatures in excess of 150°F (preferably to 300°F).

10. Other Recommendations

A mechanism must be found to factor economic considerations into the consensus-standards process. The committee recommends that the industrial participants take the responsibility to evaluate the economic impact of proposed new standards and proposed changes to existing standards and disseminate the results of their findings to appropriate Code committee members. Analyses should be performed over the full range of activities relating to a nuclear plant: design and development, licensing, field installation (assembly and testing), operation and maintenance, and decommissioning.

The method of application of standards should be improved. Effective use of feedback information from both industry and DOE contractor organizations will be necessary to identify problem areas in standards and improve their cost-effectiveness. Currently, many formats present requirements in a manner that makes it difficult for selective application of individual requirements. The committee recommends that the writing and revision of standards should focus on reformatting to facilitate selective application and tailoring.

Standards are intended to establish and define levels of quality and reliability commensurate with the needs of the specific project. To avoid unproductive effort and cost, it is recommended that the purpose of each standard contain wording such as "For purposes of innovative, cost-effective design approaches, this standard should be referenced as containing guide criteria only. However, those requirements that are deemed critical for a particular design should be invoked as mandatory for the

commercial system." The DOE should work with national consensus organizations to ensure that this type of statement is included in all new and revised standards.

3.5 REFERENCES

1. M. J. Lineberry, letter to W. O. Harms, Oak Ridge Natl. Lab., Oak Ridge, Tenn., Apr. 3, 1984.
2. *An Evaluation of Codes and Standards for Application to Liquid Metal Fast Breeder Reactors*, American Society of Mechanical Engineers, Oct. 30, 1981.
3. *Nuclear Power Plant Cost Drivers*, UE&C Report 830729, prepared by United Engineers and Constructors, Inc., for the U.S. DOE, September 1983.
4. Phase V Update (1982) Report for the Energy Economic Data Base Program (EEDB-V), prepared by United Engineers and Constructors, Inc., for the U.S. DOE, July 1983.

4. QUALITY ASSURANCE REQUIREMENTS AND PRACTICES*

4.1 INTRODUCTION

The purpose of the Working Committee on Quality Assurance Requirements and Practices was to identify quality assurance (QA) reforms that could lead to reduced liquid metal fast breeder reactor (LMFBR) design and construction costs without reduction of quality. The recommended reforms that emerged from the study are focused on proposed innovative liquid metal reactor (LMR) concepts, although in some cases they are applicable to other reactor concepts as well.

Most of the current prescriptive QA concepts evolved from the statistical and/or inspection programs implemented during and shortly after World War II. Because military systems were becoming more complex and because human life was dependent on the quality of design, materials, and workmanship of the items being produced, standards such as the Executive Office of the Secretary Publications (Navy) P-1034, Mil-I-45208, Mil-Q-9858, and the National Aeronautics and Space Administration's NPC series evolved. In October 1968 the lack of definitive QA criteria for the nuclear power plants being built by various utilities caused the Atomic Safety and Licensing Board to halt public hearings on a nuclear power plant. This expedited the development of the 18 basic QA criteria in Appendix B to Title 10, Pt. 50, of the Code of Federal Regulations (10 CFR 50), which first appeared in the *Federal Register* in April 1969 and became a regulatory requirement in July 1970 for the licensing of nuclear power plants.

Nuclear power plant experience is now under evaluation to determine what has been learned over the past 10 to 15 years, including such occurrences as shutting down Three Mile Island Plant No. 2

(TMI-2) and aborting plant constructions that were from 80 to 95% complete but were plagued with problems caused by poor quality control. The latest assessment of this experience was made by the Nuclear Regulatory Commission (NRC)¹ in response to a request by Senator W. H. Ford to find out why quality problems occurred in nuclear power plants and what to do about them. These reviews showed that increased attention to QA is needed early in design, planning, and procurement. Additional identified requirements are properly qualified personnel, early training, strong owner-management involvement, and early government reviews to ensure that these actions are all being taken. Reviews will be needed before construction begins, during the early stages of completion, and at major milestones.

Definitions of quality terms used in this report have been adopted from (1) members of the QA working committee; (2) American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) Standard NQA-1, "Quality Assurance Program Requirements for Nuclear Power Plants"; (3) ASME Standard N45.2.10, "Quality Assurance Terms and Definitions"; (4) *Total Quality Control*, by A. V. Feigenbaum;² and (5) *Quality Systems in the Nuclear Industry*, by B. W. Marguglio.³

Quality Control. Those QA actions that provide a means to control and measure the characteristics of an item, process, or facility to establish requirements.

Inspection. Examination or measurement to verify conformance to specific requirements.

Reliability. Probability that an item will perform its intended function for a specified interval under stated conditions.

Quality Assurance. All those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service. This

*The cochairmen for the Working Committee on Quality Assurance Requirements and Practices were A. W. Dalcher of General Electric Company-ANTO and W. L. Cooper, Jr., of the Oak Ridge National Laboratory (ORNL). J.A. Horak of ORNL served as secretary.

definition of QA encompasses the three aforementioned quality terms.

Quality. The fitness of an item, process, or facility that will enable it to perform or satisfy its intended function.

4.2 APPROACH

The committee's basic approach to its task was to gather data, experience, and recommendations relevant to QA requirements and practices that could be reformed to reduce the costs of LMFBR plant design and construction. This information was provided by the committee members, as well as by other interested participants. From the information received, recommendations that were judged both to be most likely capable of being implemented and to be significant plant cost reducers were selected. These items were then isolated and identified as recommended actions (Sect. 4.4).

4.3 FINDINGS

4.3.1 QA Requirements

The committee identified seven programmatic QA requirements that either on the basis of their content or through their implementation contribute unnecessarily to excessive costs in the nuclear industry. It was concluded that by working with the NRC and national standards groups, DOE could help alleviate the significant impact that these requirements would have on the cost of LMFBR plants.

The seven requirements and the problems they present are described and discussed.

1. **Organizational structure.** The requirement for a proper QA organizational structure comes from 10 CFR 50, Appendix B, Criterion I, and ASME Code, Section III, Subsection NA 3700 (1974 edition) or NCA 3700 (later edition). The problem is that ASME Code survey teams sometimes invoke requirements that go beyond those set forth in these documents. In fact, the industrial participants in some cases have gone to such extremes as allowing the QA organizational structure to become an end unto itself, even to the extent that it becomes more important than the actual management of the QA program. It appeared to the committee that such organizational matters could be handled in a manner more consistent with the principles of

good management and, therefore, with more cost-effectiveness.

2. **Design control.** Misinterpretations of the requirements of the law, as implemented by standards N45.2 and NQA-1, have created excessive paperwork that is not only counterproductive but also unnecessary. That this situation exists is apparent in NRC standard review plans. It stems from inconsistencies in interpretation of the requirements by NRC initially and from overreaction (e.g., to oral or written comments) by both NRC and the implementing organization. The result is not only unwarranted excessive paperwork (e.g., design verification checklists) but also unwarranted layering of QA organization reviews. Unfortunately, these practices have led to little, if any, increase in the technical quality of the product; in most cases, they have at best only ensured that certain administrative controls have been met (e.g., that proper signatures have been entered at correct points in the process). This is also true of release controls and changes of technical drawings or documents.
3. **Instructions, procedures, and drawings.** Instructions and procedures for use by on-site craft or inspection personnel are usually written by engineering or home office QA personnel with little or no field experience. As a consequence, on-site personnel frequently cannot understand or comply with these instructions or procedures. This results in excessive delays, nonconformance reports, and rework. It is apparent that experienced craft and inspection personnel should participate in drafting the instructions and procedures to be used for fabrication and inspection of components, systems, and structures.
4. **Document control.** Many organizations overkill the requests of the Code and of standards such as NE F2-2 and N45.2 by placing the QA organization in series with the issuance of, and as a required approver of, a technical document. The committee's experience indicates that QA should provide input at the early stages of design development rather than at the final design approval stage.
5. **Control of purchased material, equipment, and services.** DOE contracts typically require unnecessary review and approval by technical and quality organizations to put contractors on bid lists. It would be better to allow bid packages to be sent to anyone who thinks he is

qualified. Outside of small and/or minority procurements required on noncritical items, contract awards should be based on either case records or Institute of Nuclear Power Organizations (INPO) performance records, or both, rather than on surveys by everyone doing business with the contractor.

6. **Imposition of fines and reporting of failures.** The 10 CFR 21 method of imposing fines and reporting failures of material and equipment furnished by vendors and suppliers⁴ should not be continued on LMFBR projects because such a practice does not accomplish the intended purpose. Vendors typically increase their prices to cover anticipated expenses, which usually do not occur. Also, failures, which are normally found by the utility and not by the vendor, are reported and transmitted through NRC bulletins.
7. **Audits.** The lack of a consistent, cost-effective policy for audits has led to the current situation in which certain vendors are audited on such a frequent basis in the same generic areas by so many independent audit teams that they have difficulty in dealing with the onslaught. At the same time, the requirements for the training and qualification of auditors have been successively ratchetted to ever-higher standards, thus forcing additional cost burdens on the nuclear vendors. The result has been an ineffective, expensive, and redundant audit program that does not meet expectations.

A remedy that could be implemented is to require mandatory use of multifunctional audit teams similar to the INPO/NRC construction appraisal teams (CATs). These teams, made up of experts in functional areas such as engineering, procurement, configuration control, and QA, would represent the interests of all project organizations. They would perform one independent audit that satisfies the needs of all the project organizations represented, thus eliminating the need for an audit by each of the organizations, as now is the case. This team would plan the audit, notify the auditee, conduct the audit, report the results to all interested organizations, and perform all necessary follow-up actions to ensure effective corrective action. It would remain in place for the duration of the project and would be responsible for all audits of a given vendor, thus eliminating the time spent in educating audit team members on the auditee's

system and past weaknesses. The team could be organized within the framework of ASME, American Society for Quality Control (ASQC), or Institute of Electrical and Electronics Engineers (IEEE) sponsorship. In this way it could achieve credibility through the standards set by professional engineers within those consensus organizations and through the ability it would have to levy meaningful penalties should audit-disclosed problems persist. The method adopted for levying penalties should differ from the present method in which fines are imposed by the NRC for violations of regulatory requirements. Rather, it should be similar to that employed by the Federal Aviation Administration (FAA), which encourages voluntary reporting of incidents for their value as "lessons learned" and for trend analysis; usually, no penalties are assessed.

4.3.2 Application of QA Procedures

A report by the Office of Technical Assessment stresses the importance of improving the quality of nuclear power plant management and discusses variations in the quality of construction and operation.⁵ The principal conclusion of a study reported by the NRC¹ is that nuclear construction projects that have significant quality-related problems in their design or construction have been characterized by the inability or failure of utility management to effectively implement a management system that ensured adequate control over all aspects of the project. This report also states that the root cause of QA program deficiencies is shortcomings in corporate and project management that manifest themselves in larger breakdowns in overall project management, including planning, scheduling, procuring, and overseeing of contractors.

A recurring theme in an international meeting on QA sponsored by the American Society of Civil Engineers was that most reactor buildings were prototypes.⁶ Many experiences with paper problems were described: for instance, (1) nuclear reactor drawings, already signed by 21 people, being changed in the field by a construction supervisor because the specified reinforcing steel would not fit and (2) inspectors from four agencies watching the same operation, each one assuming the others would make sure things were done correctly. Also at this meeting, a clear consensus emerged on the importance of several critical areas, including:

1. Human factors, including motivation, self-control, moral and ethical values, and individual commitments to quality, are dominant in QA programs and are essential for success.
2. QA program documentation should be a legal requirement for all projects, but only to the extent appropriate.
3. Economic climate has a profound effect on construction quality, with time and money pressures playing a large part.

Theodore Stern, in his remarks to an Atomic Industrial Forum meeting,⁷ said that the industry and the NRC have been wrestling, generally unsuccessfully, with an unprecedented number of construction quality issues. He believes that these problems can be attributed to one root cause: lack of discipline. He added that the industry is not sufficiently disciplined in its construction QA processes and the NRC staff is not sufficiently disciplined in its inspection and Atomic Safety and Licensing Board practices. Stern's proposed solution is to apply a team approach in which industry and the NRC would review and sign off on the actual work as it progresses instead of waiting until construction is completed. Part of his recommendation concerns the process, which should be augmented by use of designated representatives, such as that prescribed by FAA Regulations 14 CFR 183.

Stern's remarks and the interests of this committee led to a review of a study by the Electric Power Research Institute (EPRI)⁸ that systematically examines commercial air transport industry practices and procedures to identify the potential value of their experience to the nuclear power industry. Several key observations of potentially significant interest to the nuclear power industry were developed, and there appeared to be no real technical or institutional roadblocks to achieving a meaningful experience transfer. These findings are on the subjects of system and management integration; manufacturing reliability and maintainability (R&M); quantitative R&M goals, guarantees, and warranties; preventive maintenance; in-service reliability management; and information systems.

In his book *Quality Cost and Implication*, G. E. Hayes gives an excellent account of quality versus costs.⁹ He emphasizes that the design and fabrication of unnecessary quality characteristics into a product do not add value but do add cost. For example, a designer may incorporate tolerances

into a design that result in greater component accuracy than those needed to meet all performance requirements. If tolerances are too close, they not only add to fabrication costs, but they also increase inspection costs and may decrease durability and ruggedness as well. Hayes also recommends the use of value engineering for achieving cost and quality objectives. He points out that quality and cost begin with design and that the nuclear industry could do well to focus on value engineering, a time-tested concept.

Based on these literature reviews, discussions, and individual inputs, the committee concluded that DOE should work with the NRC and industry to reduce the cost associated with the imposition and application of QA procedures for LMFBR plants by

1. stressing strong management and implementing a management system that ensures adequate control over all aspects of the project;
2. motivating people and obtaining individual commitments to quality;
3. ensuring that QA program documentation is legally required and appropriate;
4. providing a framework that puts a premium on minimizing and controlling risks;
5. stimulating interest in the understanding and application of FAA-commercial airline experience that can be of value to the nuclear industry;
6. following the FAA system by implementing a system whereby designated construction inspection representatives certified by the NRC witness and sign off on all key tests, inspections, and analyses as they occur and not long after the fact, as frequently happens; and
7. working to provide final design earlier in the construction process and identifying and establishing acceptance criteria for the inspections, tests, and analyses that must be performed, and building all this around value engineering.

4.3.3 Estimates of QA Costs for Nuclear Plants

The United Engineers and Constructors (UE&C) report *Nuclear Power Plant Cost Drivers*¹⁰ was the major source of information used in this study on the role of QA in the costs of nuclear power plants. The committee attempted unsuccessfully to obtain from other sources estimates of QA-related costs for nuclear plants. Perhaps with more time and resources, additional

information, particularly that which must surely exist on the direct costs for QA staff, schedules, and resources, could be found.

Two rather striking examples of inordinately high costs of hardware for LMFBR plants caused by overly prescriptive standards were found by the committee. These examples relate to QA practice and provide meaningful insights in the search for means to lower plant costs.

In the first example, a steam generator design required Inconel cotter pins costing about \$10.00 each when stainless steel cotter pins costing \$0.20 each would have been equally satisfactory.

In the second example, some fasteners for the Fast Flux Test Facility (FFTF) fabricated to RDT standards cost over \$17,000. Identical fasteners fabricated to ASTM standards would have cost only \$740, which is less by more than a factor of 20! A breakdown of the costs of these fasteners is shown in Table 4.1.

Clearly, the addition of a value-engineering component to the design and construction process would be a positive step in correcting situations such as these.

Qualitative information from government and other publications^{1,11} indicates that the cost for QA for a nuclear power plant could range from 2 to 35% of the total plant cost. The committee agreed that DOE, working with organizations that partici-

pate in the construction of nuclear plants, could develop more quantitative data for determining the cost-to-benefit ratio for QA reforms, thus providing a more reasonable base from which to work in trying to institute such reforms. Until such a base is established, the cost-to-benefit ratio for QA reform will necessarily be imprecise.

The UE&C report actually does not contain quantitative information directly related to QA costs. However, from the data in the report, some quantitative information and some judgmental assumptions were derived. The analysis used to develop this information is presented in Appendix C, and the results are summarized below.

The analysis showed that QA costs may be as high as 20% of the total plant cost. Of this 20%, 13% is related to financial costs brought about by protraction of construction time, and the remaining 7% is directly related to base-construction costs (see Table 3.1). Thus, QA reforms should emphasize shortening overall construction time. A secondary emphasis should be on the reduction of base-construction costs, such as equipment costs and site labor and engineering costs (see Table 3.1). Estimates that are believed to be relatively conservative were made to quantify the plant savings that could reasonably be effected by QA reforms. These savings were found to be as high as 15% of the total plant cost. For a plant costing \$4 billion, this

Table 4.1. Examples of inflated FFTF fastener costs

Item	Quantity	Cost per item (\$)		Total cost (\$)	
		By RDT standards	By ASTM standards	By RDT standards	By ASTM standards
1½ × 26-in. rod (1½ in.—8 UNC × 4½ in.)	40	98.62	9.86	3,944.80	394.40
Heavy hex nut (1½ in.—8 UNC)	40	133.04	1.12	5,321.60	44.80
Drilled hex head bolt ¾ in.—10 UNC × 3½ in.)	32	96.26	4.70	3,080.32	150.40
Drilled hex head bolt (½ in.—13 UNC × 2½ in.)	18	122.80	4.00	2,228.40	72.00
Drilled hex head bolt (¾ in.—11 UNC × 3½ in.)	18	140.21	4.35	2,523.78	78.30
Total				17,098.90	739.90

would correspond to \$600 million. Thus, successful pursuit and institution of QA reforms could very well result in significant reductions in the total cost of LMR plants.

4.4 RECOMMENDED ACTIONS

Based on the findings described and discussed previously, the following actions regarding QA reforms are recommended.

1. QA programs that emphasize performance rather than paperwork should be implemented.
2. QA is a necessary management tool that should be recognized and emphasized during the planning phase of LMRs and carried out on a team basis during design and construction.
3. DOE should adopt ANSI/ASME NQA-1 as the base QA standard, and DOE Standard NE F2-2 should be discontinued or inactivated.
4. QA systems and procedures should be based on acceptability of the end product and not just on the acceptability of the documented system or process of getting to the end product.
5. Projects should have a single-owner QA program under which all site contractors work.
6. Management at every level should be properly educated and fully committed and should participate in the QA activities of the plant construction.
7. Bid solicitation and contract award processes should be streamlined and improved; methods for evaluating the acceptability of potential vendors should be included in this process.
8. Experienced craft and inspection personnel should participate in drafting the instructions and procedures used for fabrication and inspection of components, systems, and structures.
9. The current method of fines imposed by the NRC on utilities, vendors, and suppliers for violations of regulatory requirements should be changed so that punitive actions are applied only in cases of gross negligence or deliberate violation or cover-up.
10. DOE should work with industry and the NRC in reducing the cost of QA by emphasizing strong management, eliminating unnecessary requirements, and educating and motivating personnel at all levels.
11. Excessive and unnecessary QA surveys of all

types should be eliminated and a new system implemented whereby multifunctional audit teams that represent all concerned organizations are established and used on a planned project-wide basis; superfluous QA requirements for nonsafety systems should be decreased or eliminated.

12. The NRC should return to a centralized administration to ensure a more effective, balanced application of regulatory requirements.

The procedures for implementing these recommendations will vary. For all of them, the committee envisions a strong leadership role by DOE, working with other government and industry organizations as appropriate.

4.5 REFERENCES

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5. ENGINEERING PRACTICES*

5.1 INTRODUCTION AND OVERVIEW

The broad goals of the Working Committee on Engineering Practices were, first, to identify those engineering practices that, if reformed or improved, would contribute substantially to the development of a cost-competitive liquid metal fast breeder reactor (LMFBR) plant and, second, to develop recommendations for actions that could be undertaken by the Department of Energy (DOE) to bring about needed reforms in areas that it can currently influence. This chapter presents the findings and conclusions of the committee regarding engineering practice cost drivers, and it provides a concise action plan for DOE's consideration.

The committee's first task was to define engineering practices. It adopted a very broad interpretation, defining engineering practices as anything that engineers do throughout the conception, management, design, construction, inspection, licensing, and preoperational-testing and turnover phases of a nuclear plant project. With this broad definition, it was necessary for the committee to delve into all aspects of a nuclear plant project to identify the key cost drivers and the engineering decisions, actions, and practices that significantly affect those cost drivers.

Before discussing further the scope of the committee's activities, it will be worthwhile to highlight briefly some of the current problems experienced by light water reactor nuclear plant projects because these are the problems that must be avoided if a cost-effective LMFBR plant is to be realized. A recent United Engineers and Constructors (UE&C) analysis (see Sect. 3.3.1) pro-

vides the following breakdown of the cost of an 1139-MW(e) pressurized water reactor:

	Cost (%)
• Overnight base construction	
Commodities (material)	3
Equipment	13
Craft labor	12
Engineering	7
Nonmanual supervision	3
Subtotal	38
• Escalation	35
• Interest	27
Total	100

The clear message from these figures is that in addition to reducing the overnight costs lead times, which currently average 13 years (9 years for construction), must be drastically cut to reduce the costs of inflation and interest. A one-year construction delay can add hundreds of millions of dollars to the total cost of a project.

Perhaps even more important than capital cost in making an LMFBR, or any nuclear plant project, attractive to a utility is minimization of the capital risk. Utilities must be assured that a plant can be built within budget and on schedule. Recent plant experiences have generally provided anything but that assurance. Because of schedule extensions, commodity requirement increases, and craft labor productivity decreases, the average cost of a nuclear plant has increased 20% per year in the last few years. From 1974 to 1981, lead times increased 70% according to UE&C.¹ Nuclear Regulatory Commission (NRC) reviews increased threefold over the same period. The experience of the Tennessee Valley Authority (TVA), whose Browns Ferry Nuclear Plant was one of the early

*The cochairmen for the working group on engineering practices were J. M. Corum of the Oak Ridge National Laboratory (ORNL) and L. K. Severud of the Hanford Engineering Development Laboratory. J. J. Blass of ORNL served as secretary.

nuclear plant projects, is fairly typical of the industry in general. Browns Ferry required 36.1 million construction work-hours to complete in the 1970s; it is estimated now, however, that TVA's Bellefonte Nuclear Plant, currently under construction, will require some 93 million work-hours. Design time has similarly increased from 3.6 million to 12 million work-hours.²

Unfortunately, it has not been possible in the past to forecast very accurately these slipping schedules and spiraling costs, and they vary significantly from plant to plant. For example, a recent article in *The Energy Daily*³ reported that in terms of estimated total cost per kilowatt, Long Island Lighting Company's Shoreham plant will be the most expensive of the 41 plants currently under construction, costing an estimated \$5,122 per kilowatt. By contrast, Texas Utilities Generating Company's Comanche Peak plant is expected to

come in at just \$1,353 per kilowatt. And, though the industry's average construction time is 9 years, Florida Power and Light Company's St. Lucie Unit 2 was completed in June 1983, exactly 6 years after its construction permit was issued. Its cost was \$1,750 per kilowatt.⁴

The reasons for the increasing lead times and costs and for their wide variations from plant to plant are complex. However, a recent study^{5,6} sponsored by the Electric Power Research Institute (EPRI) sheds significant light on the subject. The study, which was based on data for 26 nuclear units that experienced an average of 43 months of construction-related delay, identified the root causes of critical-path construction delays (Fig. 5.1). The dominant cause of all delays was redesign and rework problems, which amounted to 53% of the delay.

Fig. 5.1. Hierarchical classification of causes of construction delays in nuclear power plants. The average months of delay per unit and the percentage of total delay caused by each root cause are shown. *Source: An Analysis of Power Plant Construction Lead Times, Vol. 1: Analysis and Results.* EPRI Report EA 2880, prepared by Applied Decision Analysis, Inc., February 1983.

Lead-time variations from plant to plant, the study concluded, can be attributed to six fundamental factors:

1. deliberate delays,
2. the regulatory era (i.e., construction permit before or after 1972),
3. physical plant characteristics (e.g., capacity, region, and configuration),
4. industry-wide changes (primarily new and retroactive regulations),
5. uncontrollable events (e.g., bad weather and national labor strikes), and
6. utility project management practices.

It is significant that the first four items above accounted for roughly two-thirds of the observed lead-time variations. While the management role is difficult to quantify, its major significance is readily apparent.

What role does engineering practice play in all of this? The committee concluded that it plays a very large one. Obviously, design and construction engineers and engineers as managers affect many of the root causes of lead-time delays, as well as the variations from plant to plant (the risk factor). Engineering also has a dramatic effect on overnight capital costs, as shown Table 5.1.

Table 5.1. Dramatic effect of early engineering decisions on overnight capital costs

Engineering phase	Degree of completion (%)	Portion of capital cost effectively fixed (%)
Concept selection	0-1	40-60
Concept development	1-3	60-80
Preliminary design	3-10	80-90

Source: Presentation by G. W. May of Bechtel to the Working Committee on Engineering Practices, contained in the microfiche insert to Appendix E.

With the above information as background, the Working Committee on Engineering Practices set about identifying the various engineering practices that are potential impediments to a cost-effective nuclear plant, particularly an LMFBR plant. As an aid to doing this, the following 16 areas in which engineering practices are significant were identified:

1. definition and documentation of project and system design requirements;

2. development of operating and safety performance specifications and system design descriptions;
3. choice of applicable codes, standards, and regulatory guides;
4. development of project organization, plans, and schedules;
5. design, analysis, and testing;
6. development of procurement specifications;
7. shop fabrication;
8. field construction and installation;
9. examination;
10. licensing;
11. system testing, turnover, preoperational testing, and documentation;
12. operation;
13. surveillance and in-service inspection;
14. maintenance;
15. repair; and
16. general/miscellaneous.

Within each of these 16 areas, the committee compiled a list of potential engineering practice impediments to a cost-effective plant. By a voting process, these impediments, which numbered over 100, were rated by cost impact; then comments and suggested remedial actions were obtained from each committee member. The committee used the resulting compilation of information as a basis for developing more precise statements of problem areas and final recommendations.

Keeping in mind that lower capital costs and, more importantly, reduced financial risk should be the objectives, the committee determined that the potential engineering practice impediments could be grouped into four major problem areas:

1. *Planning and Management*—Although not very amenable to immediate DOE influence, this area probably has the largest potential cost impact of the four.
2. *Initial Requirements and Design*—As discussed in the previous paragraphs, early engineering decisions have a tremendous impact on overnight cost. They also directly affect the potential for subsequent scope changes and regulatory ratcheting.
3. *Scope Changes and Control*—Unanticipated changes in project design and procedures lead directly to escalating costs and schedules that can easily become uncontrolled.

4. **Regulation**—Regulatory changes and ratcheting likewise lead to escalating costs and schedules.

The Engineering Practices Working Committee established ad hoc working groups to address each of these four areas. Those groups identified, based on the previously compiled comments and suggested actions, five or ten of the factors most critical to development of a cost-competitive LMFBR project. In total, 33 of these critical factors were identified. They are presented as recommended initiatives.

Finally, the overall committee determined that 15 of these factors or initiatives, mostly from the categories of Initial Requirements and Design, Scope Changes and Control, and Regulation, could be favorably influenced by DOE-sponsored activities. For each of these 15 factors, short statements of the problem and of recommended corrective actions were developed. Six of the 15 were assigned highest priority based on cost-to-benefit considerations. These six highest priority recommendations are

1. incorporate domestic and foreign plant experience and technology developments;
2. clarify LMFBR safety requirements;
3. provide guidelines for avoiding overcommitment to codes, standards, and regulatory guides;
4. establish stable and standard design data, methods, and criteria;
5. develop guidelines and procedures for field routing; and
6. establish an LMFBR-specific regulatory approach.

The results of these exercises make up the committee's findings and recommendations, which are described in more detail in Sect. 5.2. Section 5.3 focuses specifically on an action plan for the 15 areas recommended for DOE near-term attention.

5.2 APPROACH AND FINDINGS

The Working Committee on Engineering Practices held two meetings of 2 days each. The remainder of the committee's activities were handled by correspondence.

At the first meeting, presentations were made by each member on light water reactor plant experience, unique LMFBR cost drivers and causes, and perceived problems with engineering practices.

These presentations formed an overview of the problems and focused the committee's subsequent discussions. The view graphs and handouts associated with these presentations served, together with a number of references,¹⁻⁹ as the resource material for the committee. Because of the pertinent information contained in the view graphs and handouts, they are included in microfiche form in Appendix E. A brief summary of each presentation is also given.

Also at the first meeting, the committee compiled a list of over 100 potential impediments to a cost-effective LMFBR plant. Subsequent to the meeting, each committee member chose from the list of over 100 the 20 items felt to have the highest potential cost impact; the results of these choices were used to prioritize the items. Each member also commented on, and suggested corrective actions for, the various items.

The results of that exercise are included in this report as Appendix F. This prioritized listing of nuclear plant engineering practice cost drivers, together with comments and suggestions, is a key part of the findings of the Working Committee on Engineering Practices, and it should be reviewed by the interested reader.

The second meeting of the committee focused on (1) reorganizing and combining the cost drivers in a more concise and logical way and (2) formulating recommended actions for eliminating those critical-few cost drivers that can be influenced by near-term DOE-sponsored activities. The results of the first part of this effort are tabulated below as 33 key initiatives that, if successfully undertaken, will contribute significantly to an LMFBR plant having low overnight capital cost and minimum financial risk. The initiatives are divided into solutions to four broad potential problem areas. The asterisks designate the 15 initiatives the committee considered amenable to DOE action.

Planning and Management

- Carefully select owner/operator:
- Assemble experienced team
- Use integrated planning
- *Incorporate domestic and foreign experience and technology developments
- Centralize team
- Provide project management continuity
- Establish highly visible controls
- Avoid adversary relations with regulators and contractors

Provide performance incentives
Adopt Business Roundtable recommendations⁸

Initial Requirements and Design

- *Minimize and separate safety systems
- *Clarify LMFBR safety requirements
- *Establish design criteria for nonsafety equipment
- *Provide more realistic definition of low-probability events
- *Avoid overcommitment to codes, standards, and regulatory guides
- Resist breeder standards not based on experience
- *Use standard component designs
- *Avoid impractically close tolerances
- Emphasize cost-to-benefit considerations
- Use equipment performance specifications rather than detailed requirement specifications
- Maximize use of commercial products
- *Establish realistic requirements for examination, in-service inspection, and maintenance

Scope Changes and Control

- Complete design before starting construction
- *Develop firm design specifications
- *Establish stable standard design data, methods, and criteria
- *Develop guidelines and procedures for field routing
- *Develop guidelines for repair of defect indications

Regulation

- *Establish an LMFBR-specific regulatory approach
- Resolve issues with regulatory bodies on early and continuous basis
- Establish standard plant designs
- *Include design margins to accommodate change without redesign
- Establish one-step licensing process
- Consolidate licensing responsibility

The final activity of the committee was to develop a brief action plan for addressing the 15 areas identified as amenable to DOE action. That action plan is presented in Sect. 5.3 as recommendations to DOE.

Although judged not to be amenable to, or not to require, specific DOE action at present, the remaining initiatives are equally important to a successful LMFBR plant. They should be viewed as critical recommendations to those involved in the development, design, and construction of a cost-effective LMFBR plant.

5.3 RECOMMENDED ACTIONS INVOLVING DOE

Each of the 15 initiatives that was judged to be amenable to near-term influence by DOE activities is, in terms of its scope and potential impact, multifaceted and interrelated with the other initiatives. The problems and suggested actions are addressed repeatedly in Appendixes E and F. The reader should review those appendixes for more detail than is provided here. The purpose of this section is to present, for each of the 15 initiatives, a concise statement of the problem and of the recommended action. It will provide a quick overview and a ready reminder of the kind and scope of action that is needed.

After developing problem and action statements for each of the 15 initiatives, the Working Committee on Engineering Practices performed a cost-to-benefit assessment of the 15 areas for input to DOE. The perceived cost of implementing each action and the expected plant cost-reduction payback were each assigned a rating: L (low), M (medium), H (high), or VH (very high). Six areas had L/H or M/VH cost-to-benefit ratios. They are listed first in the action plan and are the highest priority recommendations. The other areas are then listed in the same order as given in Sect. 5.2.

1. *Problem:* Applicable U.S. and foreign experience is not adequately factored into LMFBR development activities in this country. Foreign light water reactor plants, as well as some plants in this country, have been built relatively cheaply and quickly. Planning and management information from these successful projects is available to U.S. LMFBR program participants only on a piecemeal basis; making detailed information generally available would substantially benefit development of a cost-effective LMFBR. Likewise, foreign LMFBR plant experience and technology developments should be factored into current U.S. efforts. This information does not generally reach working-level engineers responsible for LMFBR development.

Action (by DOE): Concerted efforts should be made to obtain pertinent foreign experience and technology and to get them to usable working levels. Working level contacts with foreign projects and technology programs

should be facilitated. A project management and engineering practices data base should be created and made available to all concerned.

Cost/Benefit: L/H

2. *Problem:* Safety goals for LMFBRs are ill-defined, which opens the way for regulatory uncertainty and ratchetting. Key areas of uncertainty include source terms, system and event categorization, and classification [e.g., safety categories inconsistent with American Society of Mechanical Engineers (ASME) Code classifications].

Action (by DOE, EPRI, and NRC jointly): Establish appropriate safety goals.

Cost/Benefit: L/H

3. *Problem:* Overcommitment to inapplicable or unnecessary codes, standards, and regulatory guides has a significant subsequent cost and schedule impact. Guidelines are needed for initially establishing requirements.

Action (by DOE through advanced concepts and requirements-development efforts): Develop guidelines on establishing the minimum number (or portions) of required codes, standards, and regulatory guides, as well as guidelines for avoiding inappropriate applications. Identify areas where additional standards, etc., are needed.

Cost/Benefit: L/H

4. *Problem:* Unstable, unverified design methodology leads to scope changes, regulatory delays, and backfitting, with a resulting increase in lead time and cost. The Clinch River Breeder Reactor Plant Project licensing experience demonstrated the need for stable, standardized, and defensible design data, methods, criteria, and margin definitions.

Action (by DOE contractors/national consensus-standards groups): Complete needed research and development to (1) stabilize and standardize methods and criteria (including less conservative, more generally applicable simplified methods) for seismic and high-temperature structural design, (2) accurately establish design margins, and (3) establish guidelines and cost-effective construction

tolerances (see item 11). Transfer information to consensus-standards bodies and foster inclusion in codes and standards.

Cost/Benefit: M/VH

5. *Problem:* Uncontrolled, unguided field routing of pipe and cable and installation of large numbers of supports and hangers lead to interferences, disqualify previous construction, and ultimately extend construction lead times.

Action (by DOE contractors and national consensus-standards groups): Develop good-practice guidelines, standard support designs, and installation procedures for field routing. Provide information to consensus-standards bodies for inclusion in national consensus standards.

Cost/Benefit: L/H

6. *Problem:* Lack of an LMFBR-specific regulatory approach results in over-specification, regulatory ratchetting, scope changes, etc.

Action (by DOE, EPRI, and NRC jointly): Work together to develop a specific approach to LMFBR safety and licensing that is consistent with LMFBR characteristics.

Cost/Benefit: M/VH

7. *Problem:* Proximity of safety- and nonsafety-related equipment greatly increases plant costs because of the need to ensure that failure of the nonsafety equipment will not affect the safety systems and because of conflicting work and quality requirements (nuclear vs non-nuclear).

Action (by DOE through advanced concepts and requirements-development efforts): Develop strategies (e.g., physical separation and separate work forces) for minimizing safety portions of an LMFBR and separating them from nonsafety portions. Obtain NRC understanding and agreement.

Cost/Benefit: M/H

8. *Problem:* The latest LMFBR designs limit safety functions to the primary system plus a few specific safety systems. The intermediate loop and the balance of plant are not safety

related and can, therefore, it is hoped, be built to industrial standards such as ASME Code Sects. VIII (Pressure Vessels) and B31.1 (Pressure Piping). These codes do not, however, adequately address the cyclic thermal transient loadings and associated creep damage accumulation that can lead to structural cracking and failure in LMFBRs.

Action (by DOE contractors and ASME Code groups): To provide the necessary life assurance consistent with the classification, develop either supplemental requirements as a DOE NE standard augmenting ASME Code Sects. VIII and B31.1 or improve Code Case N-253 (Construction of Class 2 and Class 3 Components for Elevated Temperature Service), which is currently too restrictive.

Cost/Benefit: M/M

9. *Problem:* Excessive attention to low-probability events, such as seismic loadings, sodium fires, etc., often leads to a reduction in overall plant integrity and a substantial increase in cost. The classic example of this is the use of large numbers of snubbers to render pipelines rigid for resisting earthquakes. Snubber malfunctions can result in a line that is restrained against thermal expansion and, thus, unreliable.

Action (by DOE contractors and consensus-standards groups): Initiate an active effort to assess overdesign margins for extreme events, such as earthquakes and tornadoes, with the goal of establishing requirements on a more probable risk or hazards basis. Events (number, frequency, and magnitude) that must be considered should be consistent with safety goals. Guidelines, perhaps leading to national consensus standards, should be developed.

Cost/Benefit: M/H

10. *Problem:* One-of-a-kind design, fabrication, and construction are costly and lead to rework and ratchetting. Standard component designs would significantly simplify preparation of specifications, design, analysis, procurement, construction, and licensing.

Action (by DOE contractors and plant designers): Develop standard designs for repli-

cated features such as nozzles, pipe hangers and clamps, thermal shields, and valves.

Cost/Benefit: H/H

11. *Problem:* Specification (or implication by default) of impractically close tolerances for piping and supports, rebar location, welds, etc., leads to construction confusion, rework, and schedule slippage.

Action (by DOE contractors, subcontractors, and consensus-standards organizations): Develop, with the participation of construction people and design analysts, guidelines for tolerances required in specific situations. Where appropriate, the guidelines should be offered for adoption by consensus-standards groups.

Cost/Benefit: M/H

12. *Problem:* Overly restrictive and questionable requirements for examination (ASME Code Case N-49), testing (ASME Code Case N-50), in-service inspection (ASME Code Sect. XI), and maintainability lead to excessive accessibility requirements, costly equipment, construction complications, and frequent unnecessary rework (e.g., of welds that carry little load). Specific examples are (1) overly prescriptive in-service inspection requirements on LMFBR core support structures and reactor vessels that do not account for redundancy, load distribution, low stress levels, consequence of failure, etc.; (2) pressure test requirements for low-pressure LMFBR components; and (3) the requirement for double volumetric inspection of weld metal and adjacent base metal for high temperature as opposed to the single volumetric examination required for lower temperatures.

Action (by DOE and DOE contractors): Work with NRC and the ASME Code groups (Sect. XI and the Sect. III Subgroup on Elevated Temperature Construction) to develop more realistically based and practical criteria.

Cost/Benefit: L/M

13. *Problem:* Ambiguous, changing design specifications for systems and components lead to scope changes and regulatory uncertainties.

Items—such as basic system functional parameters, safety and seismic categories, ASME classifications, interface requirements, thermal and mechanical loadings, seismic loads, soil-structure interactions, and sodium-water reactions—need to be established and agreed to as early as possible, certainly before starting a project.

Action (by DOE contractors): Although portions of the design specifications are plant specific, much can be done now to support the development of firm specifications. Early agreement should be obtained with NRC on guidelines for classification of events, loads, and systems; a unified standard on system design description requirements should be prepared. Stable and defensible methods for predicting loads imposed on systems and components should be developed.

Cost/Benefit: M/H

14. *Problem:* Unnecessary repair of defect indications leads to time delays, increased costs, and perhaps decreased integrity in some cases.

Action (by DOE contractor): Develop the methodology and guidelines for carrying out high-temperature flaw assessment procedures. Develop repair criteria and obtain industry consensus acceptance.

Cost/Benefit: M/M

15. *Problem:* Many regulatory changes could be absorbed without redesign if sufficient margins relative to design limits had been included in the original design; frequently, the margins are insufficient for this.

Action (by experienced DOE-contractor and consensus-standards bodies): Identify regulatory requirements most subject to change and develop, based on feasibility and cost/benefit studies, industry consensus guidelines for

incorporating contingency margins that are not excessively conservative.

Cost/Benefit: M/M

5.4 REFERENCES

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APPENDIX A

CODES AND STANDARDS REFORMS RECOMMENDED BY DOE CONTRACTOR ORGANIZATIONS IN THE STUDY COORDINATED BY THE SPECIAL STUDIES AND PROJECT OFFICE OF THE ARGONNE NATIONAL LABORATORY*

Problem identification	Suggested change
1. Section XI, Division 3 (American Society of Mechanical Engineers [ASME])	
A. Section XI, Division 3 rules were oriented toward a Clinch River Breeder Reactor type plant and require extensive evaluation of overly restrictive requirements.	A. Considering the unique features of liquid metal fast breeder reactors (LMFBRs), perform a general review of in-service inspection requirements and revise requirements to permit more flexibility.
B. Because of misinterpretation and/or lack of Nuclear Regulatory Commission (NRC) guidelines during design stages, plants are often constructed such that in-service inspection (ISI) is difficult or impossible. This can require costly redesign and rework or can significantly increase the time required for, and costs of, each ISI.	B. The NRC should be encouraged to formulate and publish their ISI requirements for LMFBRs before design of the next plant begins.
C. Section XI, Division 3 requirements for volumetric inspection of carbon steel welds, potential volumetric inspection of stainless steel welds and deck structure carbon steel welds, and inspection of dissimilar vessel support welds have direct negative impact on costs.	C. Revise Section XI, Division 3 to (1) permit construction of guard vessels from carbon steel without volumetric inspection, (2) provide analytical alternatives to unconstrained application of volumetric inspection of stainless steel welds, (3) eliminate requirements to volumetrically inspect dissimilar metal welds for joints exposed to relatively low temperature, low stress conditions, and low fluence/flux environments.
D. During Clinch River Breeder Reactor Plant (CRBRP) licensing activities, the NRC expressed a desire to implement Section XI, Division 1 requirements for volumetric inspection.	D. Same as B.
E. Equipment and procedure developments are needed for high-temperature ultrasonic inspection of piping and for remote viewing of reactor vessel weldments.	*From M. J. Lineberry, letter to W. O. Harms, Oak Ridge Natl. Lab., Oak Ridge, Tenn., Apr. 3, 1984.
(ESG, W-HEDL, ORNL, W-APSD, ASME C/S Report)	
2. Code Case N-47 (ASME)	
A. ASME Code Case N-47 is too complex and costly and has technological uncertainties, exemplified by the recent CRBR licensing activities.	A. The NRC should be requested to publish its official position for elevated-temperature design in a regulatory guide and bring its Standard Review Plan up-to-date before design of the next plant begins.

(continued)

Problem identification	Suggested change
<p>B. N-47 creep-fatigue rules for low-cost materials are not clearly defined.</p> <p>C. The rules of N-47 are overly prescriptive for (1) elastic creep-fatigue, (2) strain limits, (3) procedures for weldments and transition joints, (4) notch-like discontinuities, (5) buckling, and (6) limited construction materials allowed.</p>	<p>B. Clarify creep-fatigue rules and rewrite Appendix T.</p> <p>C. Change Code Case N-47 to</p> <ol style="list-style-type: none"> 1) Provide relevant examples of the use of inelastic creep-fatigue rules 2) Revise the creep-fatigue rule for 304 and 316 stainless steel 3) Extend creep-fatigue to cover modified 9 Cr - 1 Mo 4) Provide specific screening of simplified methods for creep-fatigue evaluation of nozzles. <p>Develop design rules based on the elastic method of analysis founded on a combined analytical and test program.</p> <p>D. Add a notation in N-47 to the effect that the data do not reflect the effects of postweld heat treatment.</p>
<p>(ESG, ETEC, W-APSD, ORNL, W-HEDL, ASME C/S Report)</p>	
<p>3. Code Case N-48 (ASME)</p> <p>Overly prescriptive on allowable time-temperature conditions allowed for cold-worked components. (W-HEDL)</p>	
<p>4. Code Case N-49 (ASME)</p> <p>Overly prescriptive on methods for volumetric examination of all weld metal and adjacent base metal, such as requiring both X-ray and ultrasound. (W-HEDL)</p>	
<p>5. Code Case N-253 (ASME)</p> <p>Overly prescriptive rules for creep effects and cyclic operation. (W-HEDL)</p>	
<p>6. Draft Standard DS75.09 (Instrument Society of America)</p> <p>Control valve stability has been a recurring problem, particularly for application involving valves with critical dynamic response requirements. Valve manufacturers are not familiar with stability test criteria terminology, test methods, or interpretation of test results. This has resulted in unnecessarily high procurement costs and high testing costs. (Energy Technology Engineering Center [ETEC])</p>	<p>Test demonstration of valve system stability is necessary to ensure reliability and to reduce costs.</p>

(continued)

Problem identification	Suggested change
7. Section III, Division 1 (ASME)	
A. The current requirements of Section III, Division 1 are not specifically appropriate for, and do not take advantage of, the unique characteristics of the LMFBRs.	A. Establish a separate division of Section III of the ASME Boiler and Pressure Vessel (B&PV) Code for LMFBRs. Provisions that might properly be included in such a separate section are (1) elimination of pressure test for certain categories of equipment (e.g., reactor vessel), (2) reassessed elevated temperature volumetric examination requirements, (3) simplified requirements for stress relief of stainless steel, and (4) simplified elevated temperature design criteria.
B. The lack of ASME Code approval for modified 9 Cr - 1 Mo for appropriate product forms discourages its implementation in plant design.	B. Continue current programs to gain necessary ASME Code coverage.
C. Stellite valve seats and backseats are seal-welded to the pressure-retaining valve body and bonnets. Because stellite is not listed in Appendix I of Section III, Division 1 Appendices, seal welding is currently not permitted and must be requested via a Code Case.	
D. Substantial stress analysis and a stress analysis report are required for Class 1 components. Also, the higher classification requires more analysis and more stringent certifications, inspection, and testing, but the reliability of performance will not necessarily be better than would result from a lower classification.	D. In many cases, use of Section VIII or lower classification will result in acceptable reliability at less cost.
E. The requirements of Subsection ND (Class 3 components) have been expanded to the point that components designed to Subsection ND are almost the equivalent of Class 2. This makes Subsection ND redundant.	E. Subsection ND should be deleted.
F. Procurement of materials for nuclear power plant application has become complex and difficult to implement. The requirements of NCA-3800 are particularly detailed and restrictive.	F. Material manufacturers should not be required to be certified by ASME. Testing required by NX-2200 and NX-2300 and the examinations and repair requirements of NX-2500 should be the only activities required to be verified under a quality assurance program. Establish a more cost-effective way to ensure that materials have the desired chemical and mechanical attributes than those now embodied in Section III, Division 1.
G. Appendix N is overly prescriptive in seismic Operating Basis Earthquake (OBE) and piping damping criteria.	

(continued)

Problem identification	Suggested change
<p>H. Appendix F is overly prescriptive in elastic analysis limits for evaluation of service loadings with Level D service limits.</p> <p>I. Subsection NF is too costly and overly prescriptive on design, documentation, and use of code materials for pipe clamps, supports, snubbers, etc. Ambiguity in Subsection NF definition of jurisdictional boundaries between NF and American Institute of Steel Construction has led to increased cost.</p> <p>J. Section III, Division 1 emphasizes film radiography for examination of welds.</p> <p>K. Tolerances on rolled and welded pipe of diameters larger than 18 in. can create during installation a mismatch that requires costly weld buildup and/or bore tapering.</p>	<p>I. Subsection NF should not be a part of Section III, Division 1.</p> <p>J. Modify Section III, Division 1, to allow use of cost-saving methods such as direct-viewing radiography and ultrasonic.</p>
(ESG, GE, W-HEDL, ORNL, W-APSD, ETEC)	
8. Section V (ASME)	
<p>A. The film density variability (contrast between light and dark areas) requirements in Section V are too restrictive for small-diameter (≤ 4 in.) components. Wrapping the film around a small component and using a Code-required source strength result in greater density variations than currently permitted at the edge of the film. This can result in substantial costs because of repeated radiography of some parts. (ESG)</p> <p>B. Section V, Article 8, Appendix I—Eddy-current examination method for installed nonferromagnetic steam generator heat exchanger tubing is very specific about equipment details and procedures to match commercial practice. Commercial procedures often fail to detect or interpret defects while advanced procedures improve inspection capability. (ORNL)</p>	<p>B. Modify Code to allow use of advanced technology where warranted. (ORNL)</p>
9. Section IX (ASME)	
<p>A. Extensive and costly duplication of effort has been the result of Section IX requirement that each fabricator must qualify his own welding procedure specifications, welders, and welding operators. (ETEC)</p> <p>B. Section IX welding operator performance qualification has only one requirement, qualification in the welding process. The existing requirements do not ensure that</p>	<p>A. Support American Welding Society and ASME Section IX Subcommittee joint action to draft a common standard for procedure and performance qualification that would be acceptable to both. (ETEC)</p> <p>B. Section IX Subcommittee has a task group to reevaluate requirements for performance qualification of operators. Welding operator performance qualification requirements should</p>

(continued)

Problem identification	Suggested change
the welding operator is properly trained on each machine, thus resulting in significant shop and field rework costs. (ETEC)	consider change in welding equipment with respect to manufacturer or mode. (ETEC)
10. NE Standards [formerly Reactor Development and Technology (RDT) Standards] (DOE-NE)	
A. Many of the schedule and cost problems encountered with the use of NE standards (formerly RDT standards) may be too prescriptive	A. Continue retirement or conversion to national consensus standards. The recent retirement of many of the material standards has furnished considerable relief.
B. The mandated use of RDT F2-2 has meant that contractors and their suppliers had to undergo an educational process with new requirements stemming from new interpretation of requirements by people who were imposing RDT F2-2.	B. Use NQA-1 rather than RDT F2-2.
C. RDT F8-6T requirements have caused many additional costs and schedule impacts. Significant items from a cost and schedule impact are (1) too prescriptive material requirements, (2) too restrictive design requirements, (3) formal lifting procedure for all critical lifts, and (4) too frequent testing and inspection.	C. Equipment that meets Occupational Safety and Health Administration requirements should not be upgraded. Periodic testing and inspection, rather than maintaining equipment histories, should suffice. Proof testing of slings at 150% of rated capacity should be changed to 125%.
D. NE Standard M 13-1T, Reactor Grade Sodium, is unnecessarily restrictive, causing procurement cost to be much higher than necessary.	D. The low-calcium requirement should be relaxed. Impurities could be removed by operation of facility purification systems. This change should be reflected in the standard being prepared by American Society for Testing and Materials Committee C26.02.
E. NE Standards F9-4T and F9-5T—NRC had concern about some of the methodologies used in these standards. The majority of vendors are not familiar with F9-4T and F9-5T and are not willing to modify their standard operating practices. (ETEC, GE, ORNL, W-HEDL)	E. NE Standards F9-4T and F9-5T should not be invoked. If supplemental rules to Code Cases N-47 and N-253 are required, F9-4T and F9-5T should be used as the basis for requesting Code Case development.
11. ANS-54.1/ANSI N214 (ANS); 10 CFR 50 Appendix A	
A. ANS-54.1 and 10 CFR 50, Appendix A, contain requirements for two control systems of different design principles. This requirement translates to two independent, diverse, and redundant reactivity control systems, each having independent sensing and shut-down capability. Each secondary control rod subsystem adds approximately \$750,000 to the cost. (W-APSD)	A. Change codes and standards using these bases: (1) the compilation of data contained in numerous Fast Flux Test Facility and CRBRP test reports, which provide relevant reliability and performance data, into an engineering design basis document and (2) completion of the Primary Control Rod System seismic test program that was disrupted by the CRBRP termination. (W-APSD) ANS-54.1 is recommended for further review and assessment. (GE)

(continued)

Problem identification	Suggested change
<p>B. Cost increases have resulted from the establishment of requirements that are associated with the redundancy, interconnections, leak detection, and isolation capabilities for residual heat removal. (W-APSD, ESG)</p>	<p>B. Establish and document regulatory and industry standards for acceptable risk and reliability requirements.</p>
<p>12. Hypothetical Core Disruptive Accidents (HCDAs)</p>	
<p>Features to mitigate the consequence of HCDAs result in significant cost increases. Standards, such as American National Standards Institute (ANSI) N214, place unwarranted emphasis on retention of coolant boundary integrity beyond the reactor vessel. (W-APSD, ESG)</p>	<p>Use inherent safety features to reduce the probability of HCDA or to mitigate the consequences. Reform standards, such as ANS 54.10, 54.11, and 54.12, to allow Probabilistic Risk Assessment techniques for HCDA. HCDA should be excluded from the design base for the plant. (W-APSD, ESG)</p>
<p>13. Site Suitability Source Terms (SSSTs)</p>	
<p>Significant costs are associated with the design and construction of containment systems to meet the nonmechanistic SSSTs. Radioactivity containment/confinement criteria include site boundary dose limits and assumed releases of noble gases, halogens, solid fission products, and Pu inventory (refer to NUREG-0786 and 10 CFR 100.11). (W-APSD, ESG)</p>	<p>Develop data to support a mechanistic (SSST) and address fission products from fuel, fission product interaction with sodium, and fission product/aerosol migration. Investigate and use French and Japanese rationale and data for their SSSTs. Alternative industry standards should be established based on ANS-54.7, IDCOR (EPRI), and ANL/LANL work. (W-APSD, ESG)</p>
<p>14. 10 CFR (NRC)</p>	
<p>A. The NRC uses primarily a "prescriptive design requirements" approach to licensing. This is in contrast to other countries (e.g., Canada) that place much more reliance on performance-based criteria.</p>	<p>A. NRC should be approached with the recommendation that prescriptive requirements be replaced with performance-based requirements.</p>
<p>B. 10 CFR 50, Appendix A, is overly prescriptive on (1) residual heat removal regarding required redundancy, independence, and diversity in systems, components, and features; (2) containment design basis; and (3) fracture prevention of containment pressure boundary by expanding from "ferritic" to "metallic."</p>	<p>B. NRC should adopt a low-risk policy similar to DOE in DOE Order 5480.1A.</p>
<p>C. The interval specified in 10 CFR 50, Appendix J, for conduct of the containment Integrated Leak Rate Test (ILRT) has presented difficulty and considerable impact on plant operation.</p>	<p>C. The interval for conducting the ILRT should be extended from approximately 3 to 5 years; also, should consider whether ILRTs are ever needed on plants that have containment margin systems that can safely vent the containment building without significant pressure buildup.</p>
<p>D. 10 CFR 100, Appendix A, is overly prescriptive in requiring OBE to be equal in magnitude to 1/2 Safe Shutdown Earthquake. Seismic design standards are overdone.</p>	<p>D. Uniform Building Code with proper attention to dynamic amplification and design detail should be sufficient.</p>

(continued)

Problem identification	Suggested change
<p>E. Current NRC regulations are based on a 10^{-4} recurrence frequency for design basis tornadoes.</p> <p>(ESG, W-HEDL, GE, W-APSD)</p>	<p>E. A more appropriate recurrence frequency would be 10^{-5} or higher for consistency with overall safety goals.</p>
<p>15. Regulatory Guides (NRC)</p> <p>A. The intent of many NRC Regulatory Guides as applied to LMFBRs is overly conservative. Some specific problems are</p> <ol style="list-style-type: none"> 1) Reg. Guide 1.26—Requires more items to be safety class and requires higher ASME Code classification than is technically appropriate. 2) Reg. Guide 1.29—Requires too many items to be classified as Seismic Category I. 3) Reg. Guide 1.31—Overly restrictive requirements that result in high testing and administrative costs and virtually eliminate the use of some weld processes and material combinations. 4) Reg. Guide 1.61—Overly prescriptive in the seismic design damping value criteria, especially for heavily insulated piping typical of LMFBR. The unrealistically low damping values result in cost increases and excessively massive structures. 5) Reg. Guide 1.75—Establishes minimum cable and cable tray spatial separation distances that can be decreased with representative testing. However, NRC is reluctant to sanction design-specific testing as acceptable. <p>B. A number of Reg. Guides define NRC positions that supplement the requirements in existing industry consensus standards.</p> <p>(W-HEDL, ESG, GE W-APSD, ASME C/S Report)</p>	<p>A. Work with NRC to agree on the criteria and ground rules for assigning classification to LMFBR systems. Terms such as "important to safety," "safety-related," and "test is performed under suitable environmental conditions" should be properly defined and documented. Revise damping values from the unrealistic and overly conservative Reg. Guide values to appropriately conservative values.</p> <p>B. Standards that are endorsed by Reg. Guides should be reviewed and appropriate changes made to accommodate the regulatory requirements, some of which may need amendment to include the special features of LMFBRs.</p>
<p>16. Standard Review Plan (NRC)</p> <p>The Standard Review Plan (NUREG-0800) is overly restrictive in (1) requiring design to be based on five OBEs in plant life (3.7.3), (2) criteria for dynamic decoupling in seismic analysis (3.7.2), and (3) criteria for LMFBR application in determination of rupture locations and dynamic effects associated with the postulated rupture of piping (3.6.2). (W-HEDL)</p>	

(continued)

Problem identification	Suggested change
<p>17. ANSI N45.2.2 (ASME)</p> <p>ANSI N45.2.2 does not address methods of handling sodium, nor methods for handling items containing, or contaminated with, sodium. (ASME C/S Report)</p>	<p>Appropriate requirements should be added to the standard to cover handling of sodium and handling of items containing, or contaminated with, sodium.</p>
<p>18. ANSI N45.2.1 (ASME)</p> <p>The water flushing procedures described in ANSI N45.2.1 are not appropriate for sodium systems. (ASME C/S Report)</p>	<p>Add to ANSI N45.2.1 a section that describes suitable methods and criteria for sodium systems.</p>
<p>19. ANSI B16.1 (ASME)</p> <p>Tolerancing of thin-wall pipe used in LMFBRs must be different from the tolerancing of thick-wall pipe to permit use of automatic welding equipment. Of particular concern is out-of-roundness conditions. (ASME C/S Report)</p>	<p>ANSI B16.1 should be revised to reflect the LMFBR needs.</p>
<p>20. ISA-RP7.1 (ISA)</p> <p>Minor leakage from pneumatic control circuits may be untenable in an LMFBR plant because of potential overloading of the nitrogen atmosphere purification systems. Use of halogens for pressure testing in LMFBR plant is not considered acceptable in certain areas of the plant. (ASME C/S Report)</p>	
<p>21. ANSI N45.2.4 (ASME)</p> <p>ANSI N45.2.4 does not cover inspection of instrument leads attached to pressure boundary by welding. (ASME C/S Report)</p>	<p>ANSI N45.2.4 should be reviewed and modified as applicable to ensure that features of LMFBR plants are included.</p>
<p>22. ANSI N45.2.8 (ASME)</p> <p>ANSI N45.2.8 is not entirely compatible for construction testing of systems filled with sodium. (ASME C/S Report)</p>	<p>ANSI N45.2.8 should be reviewed and modified to include the special requirements of an LMFBR.</p>
<p>23. Power Test Code (PTC) 8.2 (ASME)</p> <p>PTC 8.2 covers acceptance testing of pumps and with some specific changes should provide a suitable basis for testing of sodium pumps used in LMFBRs. (ASME C/S Report)</p>	<p>Revise PTC 8.2 to (1) permit use of NaK-filled transmitters, (2) add an acceptable table of thermodynamic properties of sodium, (3) delete measurement of the velocity profiles in the case of sodium pumps, and (4) permit use of E/M flowmeters for liquid metal pumps.</p>
<p>24. PTC 12.2 (ASME)</p> <p>PTC 12.2 covers acceptance testing of steam condensing apparatus and is generally suitable for LMFBR applications with the exception of the allowable leak rate, which is too high. (ASME C/S Report)</p>	

design teams and component suppliers (Appendix A) and the proposal of the Subcommittee on Codes and Standards of the ASME Advanced Reactors Committee (Appendix B), and (2) issuing interim and final reports.

2.3 ORGANIZATION OF THE REPORT

The main portion of this document consists of three chapters, each representing the report of one of the working committees—Chapter 3 on Codes and Standards, Chapter 4 on Quality Assurance Requirements and Practices, and Chapter 5 on Engineering Practices. Each chapter is set in the format of an independent report covering the approach used, the findings, and the recommended actions; each chapter has its own set of references and full-wording of acronyms. Some overlaps inevitably exist among these chapters because the three areas designated for study by the committees are not independent of each other. For example, QA practices influence the choice and management of

the codes and standards to be invoked in a given plant project, and engineering practices encompass management styles and approaches that can significantly affect QA requirements, procedures, and applications.

The terms LMFBR and LMR are used interchangeably: for the issues under consideration in this study, whatever applies to one applies to the other as well. Detailed information applicable to the main chapters is provided in six appendices.

Finally, this document should not be viewed as an end unto itself, but more as a door-opening report; it was not possible in such a short time and with the limited resources available to comprehensively deal with the many undesirable or questionable practices developed over a generation in the nuclear power community. Hopefully, the criticisms and recommended actions cited will serve to bring about improvements in the practices that were assessed and to enhance the viability of the LMR concept.

(continued)

Problem identification	Suggested change
<p>25. PTC 32.1 (ASME)</p> <p>PTC 32.1 covers determination of the efficiency and output of steam supply systems and with some specific changes should provide a suitable basis for application to LMFBR steam supply systems. (ASME C/S Report)</p>	<p>Revise PTC 32.1 to (1) provide a schematic for an LMFBR steam producing island, (2) provide calculational methods for insulation losses, (3) provide means for calibrating E/M flowmeters, and (4) provide standardized means for measuring normal heat losses.</p>
<p>26. NQA-1 (ASME)</p> <p>None, although amplification is recommended. (ASME C/S Report)</p>	<p>Supplement NQA-1 with a matrix covering LMFBR systems and components and applicable quality assurance program requirements consistent with the importance of the item or service. The matrix in International Atomic Energy Agency SG-QA-1 could be used as a basis for this recommendation.</p>
<p>27. Safety Classification</p> <p>Many of the balance-of-plant systems, sub-systems, and components are inappropriately classified as safety grade, which results in unnecessary and excessive costs. Costs are driven up by the required analyses and tests for safety-related equipment. Examples of electrical system code requirements include Institute of Electrical and Electronics Engineers 279, 308, 317, 334, 336, 344, 379, 387, 450, and the National Electrical Code. (W-APSD)</p>	<p>Carefully evaluate each balance-of-plant system and establish the safety classification or safety grade based on a direct or secondary relationship to safety considerations. Use available component reliability and operational data to support the selection of industrial-grade classifications. Immediately address components that have not yet been addressed by NRC Reg. Guides.</p>
<p>28. Low-Cost Materials</p> <p>Wide operating temperature ranges, excessive fission gas release criteria, lack of confirmatory materials data, excessive margins, and failure criteria result in the use of materials that are less cost-effective than desirable. (W-APSD)</p>	<p>Develop new industry consensus specifications for more cost-effective core materials. The process should include the establishment of (1) realistic design and failure criteria, (2) realistic reliability criteria, and (3) realistic fission gas release criteria.</p>

APPENDIX B
NEW STANDARDS PROPOSED FOR LMFBRs BY THE SUBCOMMITTEE
ON CODES AND STANDARDS OF THE ASME ADVANCED
REACTORS COMMITTEE (OCTOBER, 1981)*

Design Basis—Criteria and Analytical Methods

1. Criteria for Design
2. Establishment of Maintenance Programs
3. Standard Transportation Conditions
4. Criteria for Reliability Design
5. Set Point Calculation Methods for Radiation Monitoring Equipment
6. Wind Forces on Structures
7. Structural Analysis Standards
8. High-Temperature Concrete Design Criteria
9. Pipe Clamps, Functional Requirements, and Qualification Testing
10. Snubbers, Design, Construction, and Testing
11. Inflatable Elastometric Seals
12. Control Room Design

Shop Construction/Fabrication—Procedures and Testing

13. Cleanness and Control of Instrumentation and Control Items
14. Cleaning of Components
15. Preloading of Threaded Fasteners for Pressure Boundary Components
16. Shop Handling of Nuclear Components

Field Installation/Assembly and Testing

17. Hoisting and Rigging of Components
18. Field-Installed Anchors, Anchor Systems, and Hangers for Concrete and Masonry
19. General Construction Test Code
20. Construction Testing and Inspection of Insulation and Preheat Systems
21. Core Acceptance Testing Alignment, Plant Dimensional Tolerances, and Equipment Alignment
22. Cleanness and Cleanness Control

*Reprinted from *An Evaluation of Codes and Standards for Application to Liquid Metal Fast Breeder Reactors*, American Society of Mechanical Engineers, Oct. 30, 1981.

Decommissioning

23. Decontamination and Decommissioning of Contaminated Facilities

Nomenclature

24. Nomenclature for LMFBR Applications

APPENDIX C

REGULATORY REQUIREMENTS RECOMMENDED FOR COMBINING INTO A TOP-LEVEL INDUSTRY CONSENSUS STANDARD, INCLUDING MODIFICATIONS FOR APPLICATION LMFBRs*

Regulatory requirement	Source	Recommended modifications for application to LMFBRs
Seismic requirements	Reactor Development and Technology Std. F9-2T & Nuclear Regulatory Commission Std. Review Plan--Chaps. 2 & 3	
Seismic design response spectra	Reg. Guide 1.60	
Development of floor response spectra for design of floor-mounted equipment	Reg. Guide 1.122	
Combining model responses & spatial components in seismic response analysis	Reg. Guide 1.92	
Damping values for seismic design	Reg. Guide 1.61	
Seismic design classification	Reg. Guide 1.29	Identify unique LMFBR systems and components that should be classified seismic Category I.
Design limits & loading combinations for metal containment systems	Reg. Guide 1.57	
Design basis tornado	Reg. Guide 1.76	Identify specific LMFBR structures and components. Characterize tornado-generated missiles. Expand scope of coverage to include areas outside of continental United States. Provide methods for estimation of tornado characteristics.
Tornado design classification	Reg. Guide 1.117	Include unique LMFBR requirements in appendix.
Environmental constraint criteria	Not identified	Include sodium and Dowtherm spillage, site suitability source term, design basis accidents, and internal LMFBR environments for Class 1E equipment.
Flood protection	Reg. Guide 1.102	
Estimating aquatic dispersion of effluents	Reg. Guide 1.113	
Ultimate heat sink	Reg. Guide 1.27	Include heat rejection by means other than water.
Normal water level & discharge	Reg. Guide 1.135	
Measuring evaluation & reporting radioactivity in solid wastes & releases of radioactive materials in liquid & gaseous effluents	Reg. Guide 1.21	

*Reprinted from *An Evaluation of Codes and Standards for Application to Liquid Metal Fast Breeder Reactors*, American Society of Mechanical Engineers, Oct. 30, 1981.

(continued)

Regulatory requirement	Source	Recommended modifications for application to LMFBRs
On-site meteorological program	Reg. Guide 1.23	
Shared emergency & shutdown electrical systems	Reg. Guide 1.81	
Independence between redundant standby power systems & distribution systems	Reg. Guide 1.6	
Availability of electric power sources	Reg. Guide 1.93	
Instrumentation to assess plant conditions during & following an accident	Reg. Guide 1.97	Revise to include unique LMFBR requirements such as leak detection by presence of sodium aerosols.
Fire protection guidelines	Reg. Guide 1.120	Supplement with criteria for sodium fire protection systems (Ref. National Fire Protection Association No. 802).
Control room habitability assumptions following a hazardous chemical release	Reg. Guide 1.78	
Instrument lines penetrating primary containment	Reg. Guide 1.11	
Design guidance for residual heat removal	Reg. Guide 1.139	Include coverage of direct heat removal systems.
Protection against low-trajectory turbine missiles	Reg. Guide 1.115	
Cost-benefit analysis for radwaste systems	Reg. Guide 1.110	
Spent fuel storage facility design basis	Reg. Guide 1.13	Revise to include LMFBR concerns such as sodium spills, sodium fires, and residual heat removal.
Control of stainless steel weld cladding of low-alloy steel components	Reg. Guide 1.43	
Initial test programs	Reg. Guide 1.68	Revise Appendices A and B to address unique LMFBR requirements such as heating and filling of sodium systems.
Structural acceptance test of concrete reactor containment	Reg. Guide 1.18	
In-service inspection of concrete containment structures	Reg. Guide 1.35	
Periodic testing of on-site diesel generating units	Reg. Guide 1.108	
Preoperational testing of instrument air systems	Reg. Guide 1.80	
Design basis floods	Reg. Guide 1.59	<ul style="list-style-type: none"> • Consider potential effects on sodium coolant. • Address tsunami flooding. • Provide methods for estimating surges in Great Lakes and along Pacific Coast.

APPENDIX D

ANALYSIS OF QA COSTS

D.1 EQUIPMENT COSTS

From Table 3-1 of the United Engineers and Constructors (UE&C) Report,¹ the average cost multipliers for nuclear safety class equipment above commercial equipment were determined. With these multipliers, commercial power plant costs were derived from the breakdown of equipment costs for an 1139-MW(e) pressurized water reactor (PWR) given in Table 3-2 of the UE&C Report.² The results are shown in this report in Table D.1.

The cost difference for equipment from Table D.1 is $\$182 \times 10^6$. One-half of this difference ($\$91 \times 10^6$) is assumed to be due to added quality assurance (QA) related activities and requirements. QA for nonnuclear plants has been estimated at one-sixth that of nuclear plants. Therefore, the QA cost for nonnuclear plant equipment is

$$(463 - 281) \times \frac{1}{5} \times \frac{1}{2} = \$18 \times 10^6 .$$

And, therefore, the relative QA costs for plant equipment are

$$\begin{aligned} \text{Nuclear plant} &= 91 + 18 = \$109 \times 10^6 \\ \text{Nonnuclear plant} &= \$18 \times 10^6 . \end{aligned}$$

Preconstruction time for a nuclear plant averages 5 years. If it is assumed that the QA portion extends construction time in proportion to its cost, the preconstruction time associated with QA is

$$5 \text{ years} \times \frac{109}{463} = 1.2 \text{ years} .$$

**Table D.1. Comparison of equipment costs for 1139-MW(e)
nuclear and nonnuclear plants**

Equipment item	Nuclear plant cost ($\$ \times 10^6$)	Nuclear class cost multiplier	Nonnuclear plant cost ($\$ \times 10^6$)
Steam supply system	136	1.6	85
Turbine generator	107	1.2	89
Mechanical	86	3.3	26
Valves/supports/specialists	26	9.5	3
Electrical/instrumentation and control	49	1.2	41
Structural	35	1.6	22
Construction equipment	24	1.6	15
Total equipment	463	1.6	281

D.2 MATERIAL

The QA content for material is conservatively assumed to be nil for this analysis.

D.3 LABOR

Table 5-3 of the UE&C Report presents a breakdown of labor time lost on nuclear plants.¹ Including the inspection activity as a QA function and assuming that five-sixths of this is related to nuclear (vs nonnuclear) requirements and assuming that one-half of the nuclear plant rework is due to overly scrupulous (unnecessary) QA, the percent of labor time lost because of QA activities is

$$\begin{aligned}\text{Rework} &= 5.7 \text{ h} \times \frac{1}{2} = 2.8 \text{ h} \\ \text{Inspections} &= 3.4 \text{ h} \times \frac{5}{6} = 2.8 \text{ h} \\ \text{Total hours lost} &= 5.6 \text{ h} \\ \text{Percent of time lost} &= 100 \times \frac{5.6}{40} = 14\%.\end{aligned}$$

This percentage is assumed to be all that is attributable to nuclear QA. The corollary to this assumption is that there is no increase in basic labor costs (either for qualification or effort on the job) because of nuclear QA requirements. For the purpose of this analysis, this is judged to be conservative.

The percentage of QA-related activities associated with other labor activities has been determined as follows. "Construction services" are assumed to be 33% QA related. Engineering time spent on QA is estimated to be 15%, based on the statement in the UE&C Report that a *significant* portion of engineering and management time was spent on QA.¹ Field nonmanual labor was assumed to be 33% QA. The total labor costs, then, related to QA on a nuclear plant are

$$\begin{aligned}\text{Craft labor} &= 384 \times 14\% = \$ 54 \times 10^6 \\ \text{Construction services} &= 67 \times 33\% = 22 \\ \text{Engineering} &= 278 \times 15\% = 42 \\ \text{Field nonmanual} &= 136 \times 33\% = 45 \\ \text{Total QA-related labor} &= \$163 \times 10^6.\end{aligned}$$

The amount of construction time attributable to QA is assumed to be equal to the percentage of time lost because of QA as derived above (14%). Based on a 7-year average construction time, QA is responsible for $7 \times 14\% = 1$ year of that time.

D.4 COST MODEL

The UE&C cost model is not stated, but it is reasonable to assume it is exponential (compound interest). Therefore,

$$\begin{aligned}\text{Escalation cost} &= \$1367 \times 10^6 = \text{BCC} (F_e - 1), \text{ and} \\ \text{Interest cost} &= \$1065 \times 10^6 = \text{BCC} (F_i - 1),\end{aligned}$$

where

$$\begin{aligned}F_e &= (1 + i_e)^{n_e} = \text{escalation factor,} \\ F_i &= (1 + i_i)^{n_i} = \text{interest factor,} \\ n_e &= \text{number of years for cost escalation (12 years for base case),} \\ n_i &= \text{number of years for interest payment (7 years for base case),}\end{aligned}$$

BCC = base construction cost = $\$1482 \times 10^6$,
 i_e = effective escalation rate,
 i_i = effective interest rate.

The factors and rates can be determined from the data.

$$\begin{aligned} F_e &= \frac{1367}{1482} + 1 = 1.92, \\ F_i &= \frac{1065}{1482} + 1 = 1.72, \\ i_e &= (1.92)^{1/12} - 1 = 5.6\%, \\ i_i &= (1.72)^{1/7} - 1 = 8.1\%. \end{aligned}$$

These values and this cost model will be used subsequently to determine total QA costs and potential cost savings.

D.5 OVERALL COST SUMMARY

As derived previously, the QA costs are as follows:

Equipment costs	=	$\$109 \times 10^6$
Material	=	0
Labor	=	163
Total BCC	=	$\$272 \times 10^6$.

Preconstruction time attributable to QA was determined to be 1.2 years. QA-related construction time was determined to be 1 year. Using these estimates and the derived cost model, the QA-related escalation and interest costs are determined:

$$\begin{aligned} n_{e_0} &= 12 - 1.2 - 1 = 9.8, \\ F_{e_0} &= (1.056)^{9.8} = 1.71, \\ (1.71 - 1)BCC &= \$1046 \times 10^6, \end{aligned}$$

which represents the escalation cost without QA. Therefore, the QA contribution to the escalation costs is

$$\$1367 \times 10^6 - \$1046 \times 10^6 = \$321 \times 10^6.$$

Similarly,

$$\begin{aligned} n_{i_0} &= 7 - 1 = 6, \\ F_{i_0} &= (1.081)^6 = 1.60, \\ (1.60 - 1)BCC &= \$883 \times 10^6, \end{aligned}$$

which represents the interest cost without QA. Therefore, the QA contribution to the interest cost is

$$\$1065 \times 10^6 - \$883 \times 10^6 = \$182 \times 10^6.$$

The calculated total QA-related costs of an 1139-MW(e) PWR plant using the UE&C model are then

Base construction cost	= $\$272 \times 10^6$
Escalation	= 321
Interest	= 182
Total QA costs	= $\$775 \times 10^6$

This total cost represents 20% of the total plant cost. This value is considered to be an upper bound.

D.6 POTENTIAL COST SAVINGS

It is assumed that the necessary QA on a nuclear plant is greater than that for a nonnuclear plant, but reforms could provide a factor of 3 reduction in time and costs related to equipment. Also, it is assumed that 75% of the lost labor time could be recovered by reformed QA requirements, practices, and management. With these assumptions and the previously derived data, cost savings that could potentially be brought about by extensive reform of QA requirements and practices were calculated. The results are shown in Table D.2. The potential savings is $\$575 \times 10^6$, or approximately 15% of the total plant cost.

Table D.2. Breakdown of potential cost savings with extensive QA reform for an 1139-MW(e) nuclear plant

Item	Total QA cost with reforms (\$ $\times 10^6$)	QA savings (\$ $\times 10^6$)	Total plant cost with QA savings (\$ $\times 10^6$)
Equipment	36	73	390
Material	0	0	154
Labor	41	122	743
Escalation	91	230	1137
Interest	32	150	915
Total	200	575	3339

D.7 REFERENCES

1. *Nuclear Power Plant Cost Drivers*, UE&C Report 830729, prepared by United Engineers and Constructors, Inc., September 1983.

APPENDIX E

PRESENTATIONS TO WORKING COMMITTEE ON ENGINEERING PRACTICES

The initial presentations made by each member of the Working Committee on Engineering Practices defined the scope of the problems and properly focused the committee's subsequent deliberations. Because of their pertinence, the view graphs and source materials for these presentations are included in this appendix in microfiche form. The contents are summarized below.

Contents

1. Background and Department of Energy (DOE) Perspective J. M. Corum, Oak Ridge National Laboratory (ORNL)

This presentation gave, as background, the DOE perspective on codes, standards, quality assurance, and engineering practices as nuclear plant cost drivers.

2. Introductory Remarks L. K. Severud, HEDL

The objectives and scope of the Working Committee on Engineering Practices were discussed.

3. Power Plant Construction Lead Times S. Chapel, Electric Power Research Institute (EPRI)

This presentation reviewed the findings of an EPRI-sponsored study, carried out by Applied Decision Analysis (ADA), Inc., of nuclear power plant lead times. Lead time is defined as the period between the issuance of a construction permit and the start of fuel loading and is considered to be the key to controlling capital costs and risk. The ADA study included case studies of a number of plants. It was found that two-thirds of construction lead time variations was explained by four factors: deliberate delays, regulatory era, plant characteristics (such as size), and technological change. The remaining variation was attributed to uncontrollable events (such as bad weather) and project management characteristics. Although difficult to quantify, the keys to good project management are experience, control, adaptability, initiative, commitment, communication, and coordination.

4. Large-Scale Prototype Breeder Cost Drivers (LSPB) W. J. Rowan, EPRI-Consolidated Management Office

This presentation discussed the principal factors affecting the economic competitiveness of a liquid metal fast breeder reactor (LMFBR) plant. Reductions can be made in first-of-a-kind engineering costs, capital costs, cost of funds, and operating and maintenance costs. Efforts to reduce capital costs for LSPB were covered, including use of a rectangular reactor containment building, American Society of Mechanical Engineers (ASME) Code Section VIII

steam generators, favorable seismic site characteristics, syphon breaks to eliminate the need for guard vessels, and nonsafety-grade hardware.

5. Ingredients of a Successful Nuclear Power Plant Construction Project G. B. Bradshaw, Florida Power and Light

This talk was based on the St. Lucie 2 project, which took 71 months from start of construction to fuel loading. This record was achieved through management commitment, financial resources, realistic and firm schedule, clear decision-making authority, flexible project control tools, teamwork and individual commitment, engineering ahead of construction, early involvement in plant startup, organizational flexibility, ongoing critique of the project, establishment of a project office in Bethesda to handle issues with the Nuclear Regulatory Commission, and the owner taking the lead role in project decisions.

6. Nuclear Plant Design and Construction Problems and Possible Solutions J. M. Corum, ORNL

This presentation was based largely on previous discussions held with the Tennessee Valley Authority's Office of Engineering Design and Construction. It reflects the views of a fairly typical utility in terms of nuclear plant project experiences and lessons learned. In terms of solutions, the focus was on a strong early project planning and engineering phase, design before construction, improved productivity, standardization, conservative design features and margins for absorbing later regulatory changes, careful choice of applicable codes, regulatory reform, scope control, and improved treatment of seismic events.

7. The Architect-Engineer's Perspective G. May, Bechtel

An architect-engineer's perspective on the reduction of nuclear power plant costs was presented. The importance of preliminary engineering, design simplification, separation of safety- and nonsafety-grade construction, control of commodities, completion of 60 to 80% of engineering before start of construction, and standardization was stressed.

8. Cost Contributing Factors from the Clinch River Breeder Reactor Plant (CRBRP) Design Experience R. E. Palm, Burns and Roe

This presentation reviewed the evolution of the CRBRP design, pointed out unique design features or requirements of LMFBRs, reviewed the practices implemented on CRBRP, and discussed the applicability of the CRBRP experience to future LMFBRs.

9. Engineering Practices That Lead to Increased Costs D. S. Griffin, Westinghouse Electric Corporation-AESD

Examples of engineering practices that lead to time delays and increased costs were presented. Specifications, design, analysis, fabrication, inspection, construction, licensing, operation, maintenance, and repair were covered.

10. Argonne National Laboratory (ANL) Pump, Steam Generator, and Components Development Activities R. P. Karr, ANL-East

Information on sodium pump, steam generator, and component development activities was provided. It was emphasized that system requirements can lead to more costly design approaches.

11. Engineering Practices and Plant Costs L. K. Severud, HEDL

This presentation reviewed the results of the United Engineers and Constructors cost study

(continued)

Regulatory requirement	Source	Recommended modifications for application to LMFBRs
		<ul style="list-style-type: none"> • Review and standardize erosion computation methods and outflow hydrographic estimating methods for partially failed dams (Ref. American National Standards Institute Std. N170-1976). • Identify LMFBR structures, systems, and components to be protected against flooding.
Vibration assessment of reactor internals during preoperational & initial startup testing	Reg. Guide 1.20	
Quality assurance (QA) requirements for packaging, shipping, receiving, storage, & handling	Reg. Guide 1.38	
Housekeeping requirements	Reg. Guide 1.39	
Welder qualification for areas of limited accessibility	Reg. Guide 1.71	
Glass-reinforced plastic piping for spray ponds	Reg. Guide 1.72	
QA requirements for installation, inspection, and testing of mechanical equipment & systems	Reg. Guide 1.116	
Service limits and loading combinations for Class 1 linear type component supports	Reg. Guide 1.124	
Reactor coolant pressure boundary leakage detection system	Reg. Guide 1.45	Consider sodium and blanket gas leak detection into air or inert environment.
Calculation of potential radioactive materials releases in gaseous and liquid effluents	Reg. Guide 1.112	Provide an appendix for radioactive source term calculations for LMFBRs.
Control of combustible gases	Reg. Guide 1.7	Provide criteria for hydrogen release from sodium reactions with concrete and water.
Standard format and content for safety analysis reports	Reg. Guide 1.70	

and the Florida Power and Light construction project guidance and presented numerous examples of, and reasons for, the cost increases in light water reactor (LWR) plants and in the Fast Flux Test Facility.

12. Engineering Practices R. J. McConnell, ANL-West

This presentation stressed the need to engineer out problems, rather than designing to mitigate them, and to avoid overly specific codes and standards. The carryover of LWR design approaches to LMFBRs was pointed out, and the need to establish an LMFBR program focus was stressed. Seismic design and ANS-54 were emphasized in particular as high-priority areas of needed reform.

APPENDIX F

ENGINEERING PRACTICE IMPEDIMENTS TO COST-EFFECTIVE NUCLEAR PLANTS

This appendix contains the results of efforts by the Working Committee on Engineering Practices to compile a listing, together with comments and individually suggested corrective actions, of nuclear plant cost drivers related to engineering practices. More than 100 such potential cost drivers, with comments, are listed. They are grouped under the following 16 categories of activities associated with a nuclear plant project.

1. Definition and Documentation of Project and System Design Requirements
2. Development of Operating and Safety Performance Specifications and System Design Descriptions
3. Choice of Applicable Codes, Standards, and Regulatory Guides
4. Development of Project Organization, Plans, and Schedules
5. Design, Analysis, and Testing
6. Development of Procurement Specifications
7. Shop Fabrication
8. Field Construction and Installation
9. Examination
10. Licensing
11. System Testing, Turnover, Preoperational Testing, and Documentation
12. Operation
13. Surveillance and In-Service Inspection
14. Maintenance
15. Repair
16. General/Miscellaneous

After these potential cost drivers were identified, each committee member was asked to individually identify, from the more than 100 items listed, the 20 items that were thought, if corrected, to have the greatest impact on achieving an economical plant. The results of that "vote" are shown in the left-hand margin of the listing. Twelve responses were received, and the number of votes for any individual item ranged from 0 to 9. Within each of the 16 major categories, the order of the items reflects the priority established by the vote.

Also shown to the left of each individual cost driver is a designation of high (H), medium (M), or low (L) priority. Twenty-six items received four or more votes; they are designated as high priority and could be considered as the critical-few most important items for improvement. Nineteen items received three votes; these are labeled as medium priority. All the rest are labeled low priority.

1. DEFINITION AND DOCUMENTATION OF PROJECT AND SYSTEM DESIGN REQUIREMENTS

M(3) 1.a. Excessive Conservatism

- Need better definition within codes and standards of to what, when, and where they are applicable, and assurance by management that they will not be misused in interests of being "unquestionably" correct.
- Need clearly defined design rules and requirements. Owner should specify system design requirements. Need experienced owner.
- This item usually stems from poorly defined/understood design requirements.
- Specify Seismic Category I and American Society of Mechanical Engineers (ASME) Code only where absolutely required. Use commercial practice wherever possible. Separate noncritical from critical components.
- Evaluate potential conservatisms and determine which conservatisms would be cost-effective to reduce.
- Perform studies, publish guidelines, modify codes/standards, etc., to provide more consistent and minimal conservatism.
- Compare requirements to actual operating plants and reduce observed conservatisms.
- Need more involvement of technical disciplines in preparing project and system requirements.
- Provide guidelines with specific examples to demonstrate application of methods. Much work has already been done along these lines. Results need to be brought through to the average user.
- The Electric Power Research Institute (EPRI) and the Nuclear Regulatory Commission (NRC) should write a standard for acceptable and appropriate margins.
- Each design group adds its own margins. Nuclear plant designs evoke excessive conservatisms. Contingency needs to be addressed overall. Specialization promotes poor communications. More value engineering and a quality circle approach are needed.

M(3) 1.b. Overspecification of Safety and Seismic Classifications

- Early interaction with NRC is needed to resolve classification issues.
- This item also usually arises from poorly defined or understood design requirements.
- Obtain early agreement with NRC on classification of events and systems. Separate nuclear steam supply system (NSSS) from balance of plant (BOP). Strive for plant layout such that sodium-water reactions (SWR) and sodium fires can be treated as faulted events or less. Get early involvement of technical people.
- In the design, separate areas of plants affecting public safety from those whose loss would involve only economic concerns.
- Evaluate current practice and attempt to reduce the amount of hardware requiring extensive safety and seismic requirements.
- Attempt to reduce the number of requirements imposed.
- Unify and delineate standards on classifications. Provide justification for specifying classification and submit for peer group review.
- Provide specific design criteria rules and methods for classification of events based on failure criteria and probabilistic considerations. Provide guidelines with specific examples to demonstrate application of methods. Much work has already been done along these lines. Results need to be

brought through to the average user. Provide regional seismic zone maps based on computer-based national seismic data base with interactive graphical query system to aid in presite selection. If a plant is placed in a less restricted zone at the start, a less costly plant design will be required.

- Write a consensus standard applicable to each seismic region of the United States.
- Designers must be willing to use plant-specific data rather than design envelopes.

M(3) 1.c. Lack of Hard General Design Criteria (e.g., Classification of Events)

- Develop plant-specific design criteria where general criteria are lacking.
- Obtain early agreement with NRC on classification of events and systems. Separate NSSS from BOP. Strive for plant layout such that SWR and sodium fires can be treated as faulted events or less. Get early involvement of technical people.
- Use probabilistic risk assessment to define design criteria such as event classification.
- Prepare guidelines and rationale document; use historical data base information.
- Provide specific design criteria rules and methods for classification of events based on failure criteria and probabilistic considerations.
- Provide guidelines with specific examples to demonstrate application of methods. Much work has already been done along these lines. Results need to be brought through to the average user.
- Write a consensus standard.
- ANS-54 should work on this. The General Design Criteria (GDC) should be written on a completely independent basis. What we now have is a set of light water reactor (LWR) GDCs that has been modified.

M(3) 1.d. Lack of Owner Involvement

- Owner should be project manager and should write system design requirements, or it should be done under his close direction.
- Owner involvement can be a plus or minus according to owner personnel; train people for job.
- Goals and objectives of owner and contractors/vendors are different. Corrective action not clear; must educate owners to alternatives and their impact.

L(2) 1.e. Ambiguous System Design Requirements

- Define and document project and system design criteria (and operating and safety performance specifications) based on early coordination with NRC, the Environmental Protection Agency (EPA), and other state and federal regulatory agencies.
- Complete system design requirements in advance of design. Get early interaction with NRC and owner.
- Need up-front definition of design requirements and coordination with interfacing systems.
- Need unified standard on system design description (SDD) requirements and format.
- Develop simple, standardized requirements for each system.
- Need early involvement of technical staff.
- EPRI should write a standard for system requirements, as the Maritime Administration did for the Maritime Industry.
- Not a significant problem unless owner gives mixed messages.

- Develop SDD Sects. 1 and 2 before start of system design; establish all design interfaces, both input and output; require review and approval by all parties before start of design. Confirm applicable codes and standards.

L(2) 1.f. Lack of Firm Requirements (e.g., Seismic, Source Terms, Geology)

- Resolve before initiation of design effort.
- Need preapproved construction sites with defined seismicity.
- Involve NRC in planning stage.
- Need unified standards and elimination of prescriptive rules.
- Use data base information in preparation of requirements.
- Provide regional seismic zone maps based on computer-based national seismic data base with interactive graphical query system to aid in presite selection. If a plant is placed in a less restricted zone at the start, a less costly plant design will be required.
- EPRI and NRC should write a standard.
- Requirements are usually known sufficiently. (It is recognized that there are problem plants, but these are exceptions.)

L(2) 1.g. Premature Selection Without Cost/Benefit Considerations

- Cost/benefit incentive hasn't been a strong influence in the past, especially for one-of-a-kind liquid metal fast breeder reactor (LMFBR) design. Incentives should provide for developing cost-saving designs. Screen hardware for potential cost-saving benefits.
- Perform conceptual studies to identify cost drivers. Evaluate alternatives.
- EPRI and the Department of Energy (DOE) should do a cost/schedule analysis of commercial plant designs and set up cost/benefit analysis standards, plus literature search.
- Need more cost/benefit considerations.
- Provide sufficient lead time in schedule for performing cost/benefit evaluations. Owner/operator involvement is important.

2. DEVELOPMENT OF OPERATING AND SAFETY PERFORMANCE SPECIFICATIONS AND SYSTEM DESIGN DESCRIPTIONS

M(3) 2.a. Lack of Clear Constructibility, Maintainability, and Inspection Requirements

- Define and document (along with project and system design requirements) based on early coordination with NRC, EPA, and other state and federal regulatory agencies.
- Develop generic requirements for LMFBR plants.
- Need early agreement on Surveillance and In-Service Inspection (SISI) and maintenance requirements with NRC. Then build in access where readily needed, that is, snubber and weld SISI.
- This problem symptomatic of a young industry; attempts should be made to develop sound requirements based on industry experience to date.
- Develop and unify LMFBR requirements. Submit to peer group reviews.
- Use of standard design would help to provide more clear and consistent requirements for constructibility, maintainability, and inspection.
- Write a consensus standard.

- Need more organizational integration and better understanding of user needs.
- Constructibility, maintainability, and inspection requirement considerations should be integral to the design process at the start of the project and addressed in a formal manner through the SDD, equipment installation and removal studies, use of a scale model for reviews in these areas along with check lists, and delineation of requirements on construction drawings and/or specifications.
- Constructibility is currently ignored. Recognition of what is feasible during construction is critical. Design criteria must be constrained by constructibility.

L(2) 2.b. Ambiguous, Rigid Interface Requirements

- Equipment is typically warranted for a fixed distribution of nozzle loads. Should specify ranges to allow flexibility in pipe design. Standardized nozzle design would be a good idea.
- Simplify interface requirements and provide tolerance bands where possible.
- Involve technical disciplines early in the development of interface requirements. Use formal review process.
- Need more standardization.
- More design reviews. *Not always bad.* May be necessary evil in nuclear field.
- Develop a comprehensive listing of all interfacing requirements early in the design process, provide a clear and comprehensive description of each interface requirement to ensure clear understanding by interfacing parties, and obtain agreement from "requester" and "supplier." Phase the interfaces to provide the supplier with reasonable time to develop the information.

L(1) 2.c. Use of LWR Requirements and Designs Not Applicable to LMFBRs

- Develop LMFBR-specific requirements.
- Use LMFBR-specific damping values for piping. LMFBRs are more heavily insulated than LWRs.
- Not necessarily bad. Standardized requirements make for stronger, more informed industry base. Should only impose specialized LMFBR requirements where really needed.
- Investigate those areas that are unique to LMFBRs, for example, higher pipe damping values.
- Develop and unify LMFBR requirements. Submit to peer group reviews.
- Provide requirements based on specific reactor type, addressing unique features and concerns as appropriate. Safety analyses work on the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor Plant (CRBRP) should be summarized to provide appropriate requirements for LMFBRs.
- EPRI/NRC should revise and build on CRBRP Project Applicability Document.
- Engineers probably know what is important.
- The planned DOE/NRC interaction program should alleviate this cost driver to a large extent. Corrective action is to ensure the interaction takes place.
- This is a basic gut issue. We must stop using LWR subsystem and system designs for LMFBRs. As an example, CRBRP was a LWR filled with sodium. A new cost-effective design is needed.

L(1) 2.d. Too Much Detail in System Design Descriptions

- Disagree; pertinent detail is often missing.
- Write zero-base SDDs; that is, start from scratch.
- Change format. Provide summary information with justifications and discussions in appendices.

- The use of standard designs would provide standard SDDs.
- SDDs should be sufficiently detailed. It is better to have too much detail than to be insufficient.
- EPRI and reactor manufacturers (RMs) should prepare a standard SDD for guidance.

L(1) 2.e. Excessive Manpower Spent on SDD Sections 3-6 Too Early

- Use of an SDD format selected for different purposes than today's needs is an example of poor resource use that increases cost. Consideration of a revised SDD formation is recommended.
- Disagree.
- Use "to be determined" (TBD) to eliminate number of rewrites/revisions.
- The use of standard designs would reduce manpower effort because SDD would be standard except for some local requirements.
- EPRI/RMs should prepare a standard SDD for guidance.

3. CHOICE OF APPLICABLE CODES, STANDARDS, AND REGULATORY GUIDES

M(3) 3.a. Premature Commitment to Unnecessary Requirements

- Carefully review (early in project planning and engineering phase) codes, standards, and regulatory guides to be followed (based on total applicability, ability to follow, etc.). Specify only those portions definitely needed.
- Obtain an early resolution of what the requirements are. Get early interaction with NRC.
- This item could be avoided by conducting *realistic* design reviews, where requirements and their interpretations are questioned.
- Unnecessary requirements, premature or not, are cost drivers.
- Reform/unify codes, standards, and guides to provide simpler, clearer, and more easily applied rules.
- EPRI/RMs/architect engineers (AEs) should generate a standardized, optimized applicability document.
- Tied to conservatism issue. Designers should defend their requirements one by one.
- Owner/engineers should agree at early stage on codes, etc., that clearly are applicable to the project design. All requirements should be confirmed at completion of preliminary design and before submittal of the preliminary safety analysis report. Provide technical justification at that time if codes or standards or other requirements that were not initially agreed upon are to be applied to the design.

M(3) 3.b. Lack of Criteria and Guidance for Choice

- Prepare guidance on codes and standards (or appropriate portions) that should definitely be used for next LMFBR.
- This item could be avoided by conducting *realistic* design reviews, where requirements and their interpretations are questioned.
- Requirements for lifting, handling, and maintenance equipment need to be better defined. Blind application of factors of safety of five on ultimate or three on yield may lead to overly conservative designs.
- Need less conservative elastic or simplified inelastic analysis methods (especially for components just above the creep threshold).

- Need to reform/unify codes, standards, and guides to provide simpler, clearer, and more easily applied rules.
- Criteria documents should provide examples and guidance in areas of uncertainty. There should be an ongoing effort to update areas of uncertainty as new information becomes available. Thus, manufacturers must share information for mutual benefit.
- Write users documents.
- Criteria and guidance are needed and may help costs. More emphasis on standardization is needed. Must encourage creative thinking in design.
- If a consistent and well-understood set of GDC is not in hand, then there is no possibility of producing a consistent and rational set of codes and standards.

**L(2) 3.c. Adoption of Code Requirements Beyond Either Original Intent or System Needs
(e.g., Small Valves, Scratch Removal, Weld Repair)**

- Amen. The codes as they exist can lead to this type of overly conservative interpretation. Rhetorically, where do these requirements cease?
- Total ASME Code should be reassessed, considering its total effect.
- Resolve with NRC.
- This item could be avoided by conducting *realistic* design reviews, where requirements and their interpretations are questioned.
- May be necessary for reliability in high-temperature designs. Need guidance so applications are uniform (like F 9-2T and F 9-5T).
- Reform/unify codes, standards, and guides to provide simpler, clearer, and more easily applied rules.
- A clear definition of intent and examples where criteria are appropriate or not appropriate would help to reduce needless requirements.
- General Electric (GE) wrote some field engineering guides. Do literature search on what's available.
- Weld repair problem is an example. Need checks and balances. There is overconservatism on the part of the technical people--no balance of inspector's view.

L(1) 3.d. Lack of Relevant Codes (e.g., Section XI)

- Too many codes exist for a technology that is under development. How can a code (which should be based on experience) be written without any in-depth experience upon which to write it?
- Code Case N-47 lacks relevant or reasonably economical simplified methods; these should be developed. Rules and guidelines should be developed to the point of being more consistently interpreted. New design rules are needed for nonsafety piping for LMFBRs.
- Develop relevant codes (e.g., Section XI).
- This item could be avoided by conducting *realistic* design reviews, where requirements and their interpretations were questioned.
- Reform/unify codes, standards, and guides to provide simpler, clearer, and more easily applied rules.
- EPRI should take lead in developing relevant codes.
- In LWRs, code usage is widely known and accepted. May not be relevant to LMFBR.

L(0) 3.e. Lack of Clear Definition of Scoping Boundaries for Code Applicability (e.g., Supports)

- Resolve with NRC.
- True. Why use ASME Code for nonpressure boundary supports? American National Standards Institute and American Institute of Steel Construction should be adequate for these parts.
- Clarify existing ASME Code.
- Needs clarification relative to system boundaries and code overlap.
- Latest issue of ASME Section III, Subsection NF, clarifies support question.

4. DEVELOPMENT OF PROJECT ORGANIZATION, PLANS, AND SCHEDULES

H(9) 4.a. Lack of Strong, Early Project Manager and Management Team

- Assign project manager and develop strong project management organization early in project planning and engineering phase (before initiating detailed design). Scope of formal procedures to be followed should be minimized and streamlined but established early in project.
- This problem is present in the early concept studies where too many decisions that drive costs for the life of the project are made. It often becomes impossible to change these issues, which were sometimes picked without understanding their impact.
- Owner should be project manager. He should get someone who is experienced in nuclear construction.
- True. Need dedicated organization to control, resolve problems, and keep the job moving along right track.
- Develop early in project design strong, knowledgeable project coordinators.
- Require fixed-cost contracts and provide management incentives for meeting costs and schedules.
- Develop team with prior large-project experience.
- Provide incentive (bonus) program for management.
- Develop early a strong project manager with capability for close integration of all aspects of the project; provide timely engineering decisions and ability to freeze design evolution at appropriate times.
- A strong, experienced management team is one of the successful factors in building a nuclear plant. Don't repeat past mistakes made by WPPSS.
- Management team should be trained. Argonne National Laboratory (ANL) has a course in this area.
- Need top management commitment with higher pay and career path incentives.

H(6) 4.b. Lack of Top Management Support and Commitment

- This thread applies throughout the problems with all nuclear facilities that have experienced, or are now experiencing, problems. Not only does a lack of support often exist, but also a lack of sophistication to handle such problems.
- There seems to be no cure for this. If you don't have it, it is not likely you will get it. The solution is not to build.
- This problem is present in the early concept studies where too many decisions that drive costs for the life of the project are made. It often becomes impossible to change these issues, which were sometimes picked without understanding of their impact.

- Need an incentive plan.
- Require on-site management team, including all vendors. Require fixed-cost contracts and provide management incentives for meeting costs and schedules.
- Top management should also be a part of the team.
- Finding people with commitment is difficult. Possibly do a psychological profile of appropriate successful managers.

H(4) 4.c. Insufficient Integration/Coordination

- Establish strong procurement expediting effort to support design and construction.
- Provide strong management team. Do early planning. Keep design ahead of construction.
- Need strong central design management organization to resolve conflicts between disciplines, control configuration, interface with NRC, etc.
- Develop early in project design strong, knowledgeable project coordinators.
- Require on-site management team, including all vendors.
- Hold monthly project status meetings, such as FFTF "Show-and-Tell."
- Centralize project disciplines under project management.
- Use of standard designs would help because experience would be gained in providing optimum schedules based on experience in constructing similar plants.
- Divide the responsibilities among different organizations.
- Centralize the coordination and determination of all phases of operation with the support and consensus of all participant organizations.
- EPRI/RM/AEs should develop a standardized schedule guide.

H(4) 4.d. Too Many Vendors Involved in Single Design

- This problem is present in the early concept studies where too many decisions that drive costs for the life of the project are made. It often becomes impossible to change these issues, which were sometimes picked without understanding of their impact.
- Hard to achieve consistent quality, too easy to pass the buck when many vendors involved. Should be one chief, lots of Indians.
- Minimize number of vendors to allow extended relationship to be developed.
- Allow more sole-source contracts; remove government regulations.
- A major portion (greater than 75%) of a design should be awarded to a single vendor, and he should be designated as the *leader*.
- Can't do much with need for competitive bidding.
- Procurement/contract document should be clear on performance standards, boundaries, etc.
- This is a management problem that, if controllable at all, must be controlled by the owner.
- Assign responsibility to a single organization with expertise to integrate and manage the end product.
- All recent U.S. LMFBR designs have been by committee; thus, the basic designs have remained essentially unchanged. Recent innovative designs by Westinghouse, Atomics International, GE, and ANL demonstrate the need to discontinue the design-by-committee approach.

M(3) 4.e. Insufficient Time For, and Attention to, Developing Plans and Schedules

- Develop project plan, including design and construction schedules and cost estimates, in project planning and engineering phase.
- Start early. Stay ahead of construction.
- Again, this problem is present in the early concept studies where too many decisions that drive costs for the life of the project are made. It often becomes impossible to change these issues, which were sometimes picked without understanding their impact.
- Set up formal organization for planning and scheduling. Provide centralized office space to enhance coordination and resolve conflicts; dedicate time only to that activity of planning/scheduling.
- Use of standard designs would help because experience would be gained in providing optimum schedules based on experience in constructing similar plants.
- Fundamental to controlling cost. Must have input from all participants. Must be realistic and then followed religiously. Use of workarounds (engineer likes the least).

**M(3) 4.f. Lack of Integrated Schedule with Understanding and Agreement (U & A)
by All Appropriate Participants**

- Need strong, early project manager and management team.
- True. Needs close coordination.
- Establish formal organization for planning and scheduling. Provide centralized office space to enhance coordination and resolve conflicts; dedicate time only to that activity of planning/scheduling.
- Must be understood by all. Difficult to get engineering support of schedule.
- As noted under other items, schedules including lead times, prerequisites, and interfaces must be coordinated and reviewed by all involved participants, including the owner and constructor.

L(2) 4.g. Premature Commitment to Construction Schedule

- Do planning and get understanding and agreement first.
- True. Look at Japanese approach. Needs support of NRC to allow requirements to be frozen at some stage so design requirements can be fixed. With requirements fixed, design should proceed to 80 to 90% point before construction starts. Should be no NRC shifts after construction starts.
- Guarantee funding appropriations will exist, thus eliminating quick start to secure funding.
- Establish an optimum standardized schedule or computer model with key events.
- Engineering documents may not be sufficiently complete. This can lead to change. Must have high engineering completion before starting construction.
- Commit to a construction schedule that ensures an advanced state of completion of engineering (including detailed construction drawings) before start of construction. Include all necessary design prerequisites, such as testing, design reviews, and long-lead procurement items.

L(1) 4.h. Lack of Resource Loaded Scheduling

- For every activity, indicate amount of manpower and work schedule. Only through this can you do planning. This is resource-loaded scheduling.
- Get resource-loaded schedule.

- Can be a big problem. Many people don't understand resource loading. Threatens managers.
- Manloading should always be considered in proper scheduling whether design or construction. Involvement of experienced personnel in schedule development and review is a must.
- Establish an optimum standardized schedule or computer model with key events.

L(0) 4.i. Adoption of Demand Schedules That are Unreasonable

- Don't demand unrealistic times for doing something, particularly where the critical path is affected.
- Develop a schedule that is realistic and follow it no matter what.
- Avoid schedules that don't allow the analysis to keep up with construction.
- Impose penalties for poor performance against schedules, as well as awards for good performance.
- Demand schedules may be good sometimes.
- Establish an optimum standardized schedule or computer model with key events.

5. DESIGN, ANALYSIS, AND TESTING

H(6) 5.a. Continual Redesign

- Symptomatic of changing, vague, expanding regulatory guidelines plus, in some cases, lack of coordination. Stable, settled regulations plus good management are the solutions.
- Avoid changes in operating requirements and specifications. Design initially with margin so that design requirements can change modestly without necessitating redesign.
- Involvement of stress/thermal analysis in conceptual design stages would lead to a better initial design.
- Need early agreement with NKC on design requirements to avoid redesigns. Need good communication and flexibility among participants. Need management commitment to resolve interface problems without redesign insofar as possible.
- Develop more standard designs to avoid having design iterations or untried design concepts.
- Use automated design procedures and/or scoping studies to study design iterations.
- Standardization of design would seem to be cost-effective. Use proven designs. Too much emphasis is placed on state-of-the-art improvements without cost/benefit studies.
- The use of standard designs should greatly reduce the need for redesign once designs have been established.
- This may be caused by lack of experience or knowledge of regulatory actions. A good design should be obtained in the beginning -- do it right the first time.
- Need better-trained design managers.
- Establish configuration control board early in project. Justify all design changes from cost/benefit standpoint.
- Establish a senior technical review committee that would evaluate proposed design changes to determine if the changes are absolutely necessary. If not, change is not to be implemented. Committee should be represented by owner, engineer, and constructor.

H(5) 5.b. Failure to Separate Safety and Nonsafety Portions of Plant

- This leads to use of ASME Section III NF standards in areas that are not applicable. NF standards are *not* cost-effective.

- Even in safety area, use zonal separation techniques for piping systems, etc.
- Get early resolution with NRC.
- Would allow nonsafety-related portions of plant to be designed to fossil fuel standards. Need to separate loops to avoid sodium fires and SWR concerns that developed on CRBRP. Need to avoid Category 3 in same general area as Category 1 equipment.
- Consider items such as Seismic "3 over 1" (3/1) problems early in the design.
- This is already being done but would probably pay dividends if worked a little harder. Perhaps alternative designs that would reduce the number of safety components could be pursued.
- Develop and unify safety standards and simplify such that they are more easily interpreted.
- Safety functions and systems must be clearly identified; however, 3/1 concerns must also be addressed and minimized to reduce cost. The use of modular standard designs would provide an incentive to optimize the design with respect to cost and safety.
- Do better standard designs.
- This is being done on LWR systems--downgrading of systems. May be a problem on LMFBRs.
- Separation by either space or suitable barriers should be considered in conceptual design phase. For LMFBRs, sodium systems should be segregated from water systems in a similar manner. Design should concentrate on shrinking the safety boundary to minimize excessive costs associated with separation, redundancy, diversity, etc.

H(5) 5.c. Lack of Margins to Allow for Construction Tolerances, Future Changes in Loads, Etc.

- Identify, based on early agreement with NRC, etc., specific areas of regulatory uncertainty as bases for establishing necessary design conservatism. Piping supports, for example, should have some significant, but not excessive, load margins.
- Initially provide margins in the design.
- How much is enough?
- Anticipate and cover in design specification and design analyses.
- Need probabilistic design approach to address variances in loads, material response behavior, and construction tolerances. However, this is inherent in existing code requirements. Future changes in loads are often difficult to anticipate, and significant changes resulting from failures of supporting structures are not considered at the design stage but must be analyzed as unique in-service events.
- A good design should include sufficient but not overly conservative margins.
- Educate engineers or prepare a standard.
- Very significant. Engineering must be forced to stay within criteria documents. Must have minimal standards for design.
- Define a practical range of loads or dimensions in the criteria that can be applied to the design calculations or analytical models. These limits should be included on drawing details or specifications. The great majority of loadings and tolerances are nominal, and broadened limits can be allowed without added costs.

H(5) 5.d. Preoccupation with Low-Probability Events

- Develop realistic design requirements. Get agreement with NRC. Look at total design reliability rather than specific events.

- Even in AE containment design, a large amount of time is spent here, to the detriment of a more-comprehensive design effort.
- Development of criteria that allow probabilistic arguments to be used.
- Must address as a design requirement.
- Allow protection for low-probability events to be provided by higher levels of defense inherent in the structural systems.
- I have often felt the "tail was wagging the dog." Action? Not sure, but efforts should be made to reduce the impact these low-probability events have on cost and design.
- Develop simple, inherently safe design to satisfy low-probability concerns.
- Use data base information on earthquakes, thermal transients, pressure pulses, etc., to identify most-susceptible equipment. Focus design analysis/testing on this equipment; use statistical data base to qualify other equipment for low-probability events.
- The use of standard designs would help to spread the cost of treating low-probability events.
- Educate engineers or prepare a standard.
- This is a regulatory/public concern. Better defend need for technology and high cost of over-design for safety.
- Establish designs of systems and components for normal plant operation that also have inherent features that can cope with low-probability events, for example, use of natural circulation to remove decay heat in the event of total loss of power. Focus design on credible events (high probability) and evaluate for low-probability events.
- Beyond-design-basis-accidents should be a nonissue in regards to the plant design. Action should be to eliminate beyond-design-basis accidents; either the design should accommodate an event or the event should be a nonissue.

H(5) 5.e. Lack of Standard Designs

- Must be based on standard rules and procedures. Units must be "slide along" as opposed to "opposite hand." Plants must use identical equipment, even in BOP.
- Develop standard design concepts through modularization, seismic isolation, data base computer-aided engineering (CAE) systems, etc.
- Use of standard designs wherever possible would reduce analysis, construction, and procurement costs.
- Use standard designs within a plant, for example, three identical piping loops.
- More off-the-shelf components should be developed if the industry is to be competitive. Perhaps vendors could be given more guidance from government and utilities (e.g., EPRI) about which standard designs are feasible.
- Unfortunately, each plant is unique.
- Provide a set of generic designs to address various levels of environmental concerns, thus providing economical alternatives, depending on local requirements, and protection against common mode failures. Designs should be modular in concept and stored on CAD system for ease of modification, integration to site-specific requirements, and increased shop fabrication.
- EPRI/DOE should address this.
- Needed for overall plant, not just components. Difficult to attain based on free-market environment.

- Under current conditions, even if designs were standard, there are inexperienced utilities and constructors trying to build plants: Something must be done to keep inexperienced organizations out of projects.

H(5) 5.f. Poorly Defined and Overly Restrictive Seismic Acceptance Criteria

- Seismic requirements must be stabilized, analytical methods standardized, and conservatism minimized.
- Develop more realistic design criteria, reduce conservatism (e.g., damping values), and get concurrence with NRC in advance.
- Need to obtain realistic Operating Basis Earthquake level so Safe Shutdown Earthquake controls. Need realistic damping. Current response spectra analysis technique is adequate with above changes. High cost is caused by changing earthquake level after design is complete. Plastic design limits could result in added savings.
- Get early agreement on seismic criteria by all organizations that will be approving final analyses and design.
- EPRI should fund development programs to reduce seismic requirements.
- Develop and unify realistic criteria by using available data bases. Involve technical user community to ensure criteria are workable and technically adequate.
- Each plant should not be considered unique but should fall within a group on environmental concerns that would establish the choice of a standard design from a set of standard designs.
- Prepare a consensus standard.
- Licensing issue on frequency of occurrence.
- Specifications should include optional acceptance criteria based on the following acceptable methods: static analysis, dynamic analysis, or qualification tests.

H(5) 5.g. Unrealistic Details and Tolerances

- This is often the result of overly conservative interpretation of design criteria.
- Include key construction personnel in design efforts (to ensure familiarization and constructibility).
- Ensure early interaction between design and manufacturing (or field erection). Provide assessment methods that allow determination of effects of tolerances.
- Was not a big problem in FFTF.
- Document rationale for tolerances on the blueprints.
- Improve design review process. Hold early design reviews. Involve appropriate technical disciplines in review process.
- Details and tolerances should be based on realistic concerns.
- Educate engineers or prepare a standard.
- Very significant. Engineering must be forced to stay within criteria documents. Must have minimal standards for design.
- Design tolerances do not recognize what is feasible in field construction—must integrate design and construction feasibility.

L(2) 5.h. Lack of Cost-Effective Methods

- Develop cost-effective analysis methods and criteria based, where possible, on elastic analysis. Develop design practice manual.

- Develop more cost-effective methods. But this is probably not a significant problem relative to overall cost; it is more important to quality.
- Develop an equipment qualification program based on available seismic experience data base.
- Need standard designs for nozzles and simplified methods for small pipe. Need economical clamp design for small high temperature pipe.
- Use CAD methods; define larger tolerances to allow use of simpler, cheaper methods.
- Reform codes, develop simplified methods, and develop and use standardized, validated designs.
- Application of certain design analysis methods can be quite costly, particularly when nonlinear effects are to be modeled. The development of more efficient and cost-effective methods should be encouraged. This requires a closer marriage of hardware and software and a greater understanding of material behavior under complex loading and environmental conditions.
- This may be caused by lack of experience or knowledge or regulatory actions. A good design should be obtained in the beginning; do it right the first time.
- Clarify, that is, do a literature search for, good methods. EPRI/RMs might do a standard design.
- Use models, simulators, etc.

L(2) 5.i. Dictated Designs (i.e., Where Certain Designs or Components Are Prespecified for Use)

- Little improvement will be made as long as the LMFBR designs are forced to use base program component designs. Do not constrain plant design with component development program hardware.
- Dictated designs may be acceptable if standardized and mutually agreed to with both owner and NRC. It's changes that hurt most.
- If a dictated design is a standard, proven design, then it is cost-effective.
- Standardization of design would seem to be cost-effective. Use proven designs. Too much emphasis on state-of-the-art improvements without cost/benefit studies.
- No basis. The procurement specification dictates design.
- Design/develop alternative components.

L(2) 5.j. Overly Restrictive Interpretation of Criteria

- Get early resolution with NRC.
- Criteria should be better defined. In particular, criteria for lifting, handling, and maintenance equipment could use improvement.
- Need more guidelines on how to document.
- Make criteria clear enough to avoid misinterpretation.
- Designers should rewrite criteria to minimize and simplify them.
- Better guidelines are needed on application of criteria.
- Provide code intent and background with specific examples as part of code documentation to establish a common understanding of bases, intent, and degree of implicit conservatism. This is particularly important in high-temperature and fluence applications. NE Standards F 9-5, -7, -8, and -9 are attempts in this direction, but more needs to be done. It is important that test results be incorporated with specific examples where appropriate so that intent of code can be clearly demonstrated.
- Educate engineers or prepare a standard.

L(1) 5.k. Insufficient Design Methodology Base

- Design methodology base should be developed to the point of being sound, settled, well-founded, experimentally supported, and defensible before start of next plant. Outstanding unresolved

licensing issues lead to costly, snowballing delays. Examples of shortcomings are lack of design and assessment procedures for weldments at high temperatures and lack of validation of applicability of design methodology to notch-like discontinuities.

- Continue development of design methodology and hard data base.
- Generally good methodology base. Needs improvement in limited areas, such as welds, new material creep-fatigue data, and simplified methods for elevated-temperature designs.
- For LMFBRs, would probably occur naturally with more experience in industry. Existing methodology could be reviewed and best selected for guidance.
- Require design methodology handbooks as part of vendor contracts.
- Review design methodologies in other industries and use as applicable and/or appropriate.
- Provide code intent and background with specific examples as part of code documentation to establish a common understanding of bases, intent, and degree of implicit conservatism. This is particularly important in high temperature and fluence applications. NE Standards F 9-5, -7, -8, and -9 are attempts in this direction, but more needs to be done.
- Continuing and reinforcing base technology and applied technology development.
- Educate engineers or prepare a standard.

L(1) 5.1. Lack of Well-Developed Design by Test Methodology

- By testing, rather than analysis, it should be possible to prove adequacy of design both more economically and efficiently.
- More testing in lieu of rigorous analysis would seem to be warranted.
- Borrow from aerospace technology.
- Use *standard*, well-tested components.
- Review test methods of mature industries and identify areas where design-by-test is cost effective. Perform trade studies on cost/benefits between test and analysis.
- Start early on defining a comprehensive component test program and integrate with project schedule.
- Educate engineers or prepare a standard.
- This has not been a big concern in LWRs.
- Need for testing must be identified early, as part of either design process or licensing requirement. Avoid need for test programs if at all possible. Cost/benefit should be considered.

L(1) 5.m. Inexperienced and Inadequately Trained Engineers

- Pay the price for first-class talent.
- Create incentives to keep engineers on specific projects for longer lengths of time. Experience at FFTF has been that cognizant engineers move around frequently because of reorganization, etc. One cog starts a job; another finishes it.
- Good management can compensate.
- Work closer with universities in developing young engineers.
- Provide in-house and continuing education seminars and special classes to keep engineers current with technology. Such activity should be actively pursued and encouraged at all levels.
- Nobody is experienced at the beginning. Continuous on-the-job training and dedicated engineers are required.
- Educate them or provide guides.

- Motherhood—always a problem. Engineers need more freedom to learn and do more design functions. Engineers need field experience first.

L(0) 5.a. Insufficient Lead Times

- Complete 100% of design drawings required for early scheduled construction (85% of total design effort) in preconstruction design baseline phase. Issue remaining drawings with adequate lead time for construction planning before construction effort.
- Lay out a realistic schedule for design, analysis, and testing and stick to it.
- Complete the design before start of fabrication and construction.
- Prepare generic schedule and/or do computer modeling.
- Tied to schedule needs. Does happen because of poor scheduling.
- Better management is needed.
- Commit to a construction schedule that ensures an advanced state of completion of engineering (including detailed construction drawings) before start of construction. Include all necessary design prerequisites, such as testing, design reviews, and long-lead procurement items.

L(0) 5.o. Lack of Standard Methods

- Methods should be standardized in design guide and must be developed to the point of being sound, efficient, and experimentally verified before the initiation of the next LMFBR project.
- Develop standard methods and designs. Avoid use of unique design features.
- Methods are pretty well standard.
- Establish standard computer codes to be used throughout the life of the project.
- For LMFBRs, would probably occur naturally with more experience in industry. Existing methodology could be reviewed and best selected for guidance.
- Require standard design methodology documents for all vendors.
- Develop and/or use existing methods manuals from more-mature industries such as aircraft.
- Lack of simplified standard methods. The development of simplified standard methods should be encouraged, but it is important that results of applying simplified methods be compared to more-detailed methods and actual tests to establish a measure of the inherent conservatism or lack thereof.
- Adequate but simplified standard methods should be developed.
- Consistent with the overall theme of minimizing design changes and, thus, construction costs, standard methods and approaches, including project procedures, specifications, and drawings, should be used.

L(0) 5.p. Lack of Computer-Aided Engineering Models to Handle Interface Requirements, Etc.

- Base final design on a scale design model (to reduce interference, minimize congestion, improve system interfacing, and minimize costly paper design).
- Use CAE. Great potential for savings here in the layout and construction stage. However, St. Lucie 2 held schedule without CAE.
- No. Computer is just another tool.
- Use CAE so that technicians can perform routine modeling.
- Stimulate development of CAE methods and particularly development of next-generation computer technology, which is needed to effectively apply CAE methods. Hardware and software

- development must go hand-in-hand in making the power of CAE technology more accessible at all levels of the design stage.
- CAE is the trend of future plant design. Tremendous savings in paperwork can be achieved by adopting CAE design concept. This would minimize interface errors, speed access to the correct information, and provide many benefits.
 - Should be developed.
 - Will be a big time saver. Will allow more optimal design.

6. DEVELOPMENT OF PROCUREMENT SPECIFICATIONS

H(4) 6.a. Failure to Use "Run-of-the Mill" Materials, Etc.

- This is the result of overconservatism in interpretation of codes and standards and lack of realization of cost impact. Result of lack of proper management oversight.
- Greater use must be made of commercial-quality components and materials. Consideration should be given to source screen of commercial products as opposed to special production runs.
- Develop list of standard materials for specific applications.
- Expand list of acceptable high-temperature materials. N-47 currently only recognizes 304, 316, Inconel 800, and 2½ Cr-1 Mo.
- Make BOP nonnuclear.
- Industry available shapes, sizes, and materials should be used even in one-of-a-kind designs.
- Educate engineers on broad plant requirements.
- Provide strong technical leadership and supervision to guide designers toward using standard available materials and "off-the-shelf" equipment.

M(3) 6.b. Lack of Attention to Cost/Benefit Considerations

- This is the result of overconservatism in interpretation of codes and standards and lack of realization of cost impact. Result of lack of proper management oversight.
- More incentive needs to be given to *all* involved to produce more cost-effective designs.
- Do a generic cost/benefit guide. The U.S. Maritime Commission has done work in this area.
- Need more attention on amount of information given to vendor. Avoid overspecification by engineers. More interaction.

M(3) 6.c. Imposition of Unnecessary Codes and Standards Requirements

- Yes. This is the result of overconservatism in interpretation of codes and standards and lack of realization of cost impact. Result of lack of proper management oversight.
- Resolve with NRC in advance what is necessary and what is not.
- Need hard look early in program, with discussions with technical and safety people.
- Choose right people to develop specifications.
- Focus should be on satisfying code intent.
- Educate engineers.
- Applicable codes and standards should be addressed in SDD development phase. Additions to the specifications should be screened through vendors before bid stage.

L(2) 6.d. Requirements for Vendor to Develop Special Procedures

- Use standard designs and fabrication procedures.
- Use standard plant designs.
- Educate engineers.
- Use conformance specifications and tailor detailed specifications to vendor.

L(1) 6.e. Lack of Knowledge of Broad Plant Requirements

- Need early planning. Harden plant requirements by completing system design requirements in advance and getting early interaction with NRC and owner.
- Perhaps we need to develop more engineers with a broader perspective. We tend to be pigeon-holed and unaware of the potential impact (on cost) of our individual decisions.
- Choose right people to develop specifications.
- Persons involved in planning, design, procurement, etc., should have full knowledge of the entire plant requirements.
- Educate engineers with broad plant requirements and/or write a text.

L(1) 6.f. Lack of Interaction with Vendors Beforehand

- Bring vendors on board in early stages of design.
- Educate engineers.
- This interaction should be guarded to avoid tailored specifications that may prove unwieldy and costly. At least two vendors should be consulted and positive input provided from *both*.

L(1) 6.g. Inflexible Requirements Prohibiting Innovative Engineering

- Early resolution with NRC on innovative concepts. Innovative concepts must be tempered by use of methods that are familiar to vendors. There is a tradeoff here between innovation and the need for standardization.
- Although specific requirements are necessary to provide some focus, their intent should be clearly documented so that alternate and innovative cost-effective methods may be applied to meet intent of requirements.
- Educate engineers on how to be innovative.
- High impact to vendor.

L(0) 6.h. Incomplete Information Provided

- Need early planning. Provide complete information.
- Need technical people involved early.
- Make sure vendors understand all analysis requirements; for example, what seismic analyses are required?
- Prepare a generic guide.

7. SHOP FABRICATION**M(3) 7.a. Excessive Requirements for Inspection, Surface Finish, Repair, Tolerances, Fit-Up, Etc.**

- Integrate design and manufacturing.
- Prepare a generic guide. GE Field Engineering did one.
- Same as excessive engineering requirements. Need cost/benefit analysis.

L(1) 7.b. Insufficient Amount of Shop Fabrication

- Design for modular construction. Use standard designs.
- Standardized designs would allow use of shop-built modules. Shop generally offers better control in fabrication. Usually higher quality at lower cost. Should maximize.
- Provide a set of generic designs to address various levels of environmental concerns, thus providing economical alternatives depending on local requirements and protection against common mode failures. Designs should be modular in concept and stored on CAD system for ease of modification, integration to site-specific requirements, and increased shop fabrication. The use of standard modular design would encourage increased shop fabrication, thus providing high-quality, cost-effective plants.
- This must be addressed in conceptual design.
- In general, the more the better. Lower cost, better control of quality, etc., will result.
- New designs should maximize system and subsystem modules that can be shop fabricated. Studies should be conducted to determine the best plant size for module design.

L(1) 7.c. Poor Records (e.g., Weld Repairs)

- Provide strong quality assurance (QA) and project management.
- Strong management and controls will eliminate this isolated problem.
- Automate QA procedures.
- Records should be incorporated into computer-based data base for ease of retrieval and manipulation of data for alternate forms of graphical and/or tabular display.
- Provide better QA.
- Establish initially with the vendor the need for record traceability and a procedure to ensure this requirement is fulfilled to minimize the potential of discovering flaws after the fact, a situation that usually results in higher costs and significant schedule delays.

L(1) 7.d. Lack of Continuing Interfacing to Control Configuration (With Engineering)

- Integrate design and manufacturing.
- Need specialist sign-off on changes and strong management to insist on configuration control.
- Provide strong representation at design reviews from Project Office that can provide timely decisions when necessary. Allow for broad representation.
- Better QA and design engineering management.
- Establish more checks and balances with shop.

L(1) 7.e. Lack of Prior Validation of Scaling Capabilities for Components

- Develop acceptance criteria for testing.
- Better engineering management would eliminate this.

L(1) 7.f. Cost and Schedule Performance of Vendors

- Establish better contracts.

L(0) 7.g. Poor Practices for Heat Treatment, Etc. (Lack of Process Control)

- Need clear specifications and strong QA.
- Need more shop fabrication to control.
- Automate.
- American Society for Testing and Materials addresses these. Prepare a practices guide.

L(0) 7.h. Use of Precision Beyond Need

- Document rationale for precision on blueprints and procurement documents.
- Educate engineers.

L(0) 7.i. Lack of Shop Qualification by Owner Engineers

- Use team approach. Place owner engineers in vendor's shop.
- Provide better engineering management.

L(0) 7.j. Lack of Engineering Involvement in Final Inspection and Testing Before Shipping

- Use team approach. Place owner engineers in vendor's shop.

8. FIELD CONSTRUCTION AND INSTALLATION**H(7) 8.a. Construction Started Too Early, (Relative to Planning and Issuance of Drawings)**

- This results in inefficient use of craft labor and an unacceptable (costly) amount of rework because of later design changes.
- Keep design ahead of construction. Avoid redesign. Avoid changes.
- Try to minimize as-built changes.
- Seems closely related to poor planning and management attention and involvement.
- Provide a set of generic designs to address various levels of environmental concerns, thus providing economical alternatives depending on local requirements and protection against common mode failures. Designs should be modular in concept and stored on CAD system for ease of modification, integration to site-specific requirements, and increased shop fabrication. Use of standard designs should virtually eliminate this concern.
- Good planning should cover this deficiency.
- Prepare a generic schedule with plus and minus impacts.
- Require better integration of engineering/procurement/construction schedule.
- Because construction costs (including the associated cost of money) have been historically a major cost driver of nuclear plants, it is clear that an essential requirement will be to control these costs very tightly. Among other actions that are needed to do so, the engineering and design should be well advanced (70 to 80%) before construction. This will reduce the likelihood of field changes resulting from design changes, thus reducing construction costs.

H(5) 8.b. Excessive Congestion Affecting Productivity

- Smaller work forces work more efficiently. Indications are that approximately 1800 is the maximum force that can be controlled to produce efficiently.

- Use construction models to facilitate construction, construction planning, and drawing discrepancies. Design should provide adequate space allocations within containment and buildings; minimizing volume is often not cost-effective beyond a point.
- Limit workers on-site.
- Reflects a design problem.
- Separating NSSS from BOP could help.
- Should be covered by design and scheduling.
- Provide better management. Educate them.
- Part of resource loading (scheduling manpower).
- In development of conceptual plant arrangements, include space allocations for key system routings, envelopes for construction access and maintenance, and component supports. More emphasis should be placed on modularization and shop prefabrication.

H(5) 8.c. Lack of Use of Modular Construction and Standard Designs

- Develop standard designs and design concepts for modular construction.
- Good planning consisting of broad plant requirements should be established.
- Standard designs save analysis time and allow for more efficient construction.
- Need to reduce one-of-a-kind designs.
- Use standardized design.
- Provide data base information from which modular construction and standard designs can be selected.
- Provide a set of generic designs to address various levels of environmental concerns, thus providing economical alternatives depending on local requirements and protection against common mode failures. Designs should be modular in concept and stored on CAD system for ease of modification, integration to site-specific requirements, and increased shop fabrication. A modular standard design concept is essential to the future of nuclear industry.
- Good thinking, but get NRC involved first.
- Do it; EPRI/DOE should prepare a standard design guide.
- Maximize. Reduces field productivity problems.
- Consistent with other items under this Sect. 8, the use of standard designs and modular construction will enhance productivity and reduce costs. A sensitivity to *not* "reinventing the wheel" is paramount to establishing and adhering to standard designs.

H(4) 8.d. Low Work Force Productivity

- Improved planning making use of work studies (work sampling to identify proportions of time spent in various nonproductive activities). Design changes must be minimized, tracked, controlled, and responded to rapidly to minimize snowballing.
- Need advanced planning and scheduling. Limit number of people on-site at any time in construction. Do design before construction. Get quick resolution of problems in the field. Authority to make decisions should be in the field.
- Appears that there is too much paperwork, QA, etc., in getting simple tasks accomplished in the field. Paperwork for certain simple tasks should be greatly limited.
- Need to examine reasons and correct. Included are poor management, poor scheduling, rework, etc. Union jurisdictional disputes often cause. Need commitment from labor leaders to avoid. Perhaps need test to identify drug users.

- Avoid excessive changes to provide positive work force morale.
- Keep projects small; provide incentive schemes.
- Provide closer and adequate supervision.
- Use nonunion crafts.
- Do more piecework.
- Provide and encourage a more cooperative work incentive between management and work groups. Provide for better scheduling of resources and construction, which would be a natural fallout of a modular standard design.
- Everyone—management, engineers, field supervisors, and labor—should strive for increased productivity.
- Use more shop fabrication.
- See studies from University of Texas. Many articles, etc., on subject. Don't reinvent the wheel!
- The labor force should be thoroughly trained by using detailed construction drawings before actual plant construction, similar to the auto industry where every individual has been trained and becomes expert at his task. Although this will require a great deal of preplanning and training, it will ultimately result in higher productivity.

M(3) 8.e. Uncontrolled Field Routing with Subsequent Impacts/Inability to Field Route

- Use CAE for layouts. Plan in advance. Minimize field routing.
- Field routing is necessary to achieve good productivity in electrical and noncritical or small pipe. Needs control to avoid interference with critical engineered components. Separating safety and noncritical equipment and phased scheduling could help.
- Schedule field routing after critical systems such as piping have been installed.
- CAE involvement should minimize this problem a great deal.
- Provide better engineering management. Provide better training.
- More emphasis on control drawings on small bore piping, cable tray, etc. Duke probably does better with their own construction force—more pride.
- Establish system-routings priorities and paths or envelopes for low-priority systems on a cell-by-cell or area-by-area basis. Use of a scale model in design and construction phases avoids this significant cost driver.

L(2) 8.f. Lack of Resource Scheduling

- Schedule resources so that there is an even flow over the total project. This is largely a planning and management problem.
- Field management should anticipate the problem before it arises and take actions to resolve it.
- Do generic schedule with plus and minus impacts.
- Develop estimate before finalizing schedule. Base milestones on resource-loaded schedule.
- Engineering and construction schedules must include manpower loadings from both practical and cost- and management-control standpoints. Manloading should always be considered in proper scheduling whether design or construction. Involvement of experienced personnel in schedule development and review is a must.

L(2) 8.g. Lack of Effectual Use of Design Engineering On-Site

- This is a given requirement, especially for a first-of-a-kind plant. Large on-site engineering group is a necessity.

- Transfer key designers to field engineering; establish small design office at site.
- Establish team approach. Integrate design and construction.
- Need sufficient data and means to resolve problems at site quickly.
- Reduce restriction and paperwork requirements to allow more time in field and more flexibility in using crafts.
- With CAE involvement this problem would be minimized.
- Educate managers.
- They should be near the site but would be lost at the site—too many distractions. Site needs some construction engineers.
- Key engineering personnel experienced on the project should be assigned to the site before construction start to assist in preplanning and clarification of design requirements. These personnel can render decisions during construction on field changes and design modifications to minimize any potential delays in construction.

L(2) 8.h. Over- and Under-Utilization of QA; Poor QA Planning

- This ties into overly conservative interpretation and use of codes and standards, which, in turn, requires more quality assurance and quality control than might really be necessary.
- Implement a strong but reasonable QA program that emphasizes quality rather than paperwork.
- Recognize that QA is necessary. Bring QA into planning phase. Establish QA as a team activity.
- Need closer cooperation between QA and Engineering so QA knows engineering concerns.
- Educate managers.
- See Zimmer, Marble Hill, South Texas, Diablo Canyon, and Midland. Can overuse QA, for example, Seabrook. Need a single-owner QA program that all site contractors work under.
- Refocus QA on the acceptability of the end product and not the acceptability of the process to get there.

L(1) 8.i. Poor Scheduling

- Start early. Complete planning and scheduling before construction.
- Use automated scheduling schemes such as PERT.
- Field management should anticipate the problem before it arises and take actions to resolve it.
- Educate planners. Develop a generic schedule with plus and minus impacts.
- Involve construction supervision in development of schedule.

L(1) 8.j. Poor Procurement Scheduling/Material Control

- A basic problem in logistics that can be corrected by good planning, scheduling, and management control.
- Educate planners.
- Always a concern—make maximum use of material control systems (computerized).

9. EXAMINATION

M(3) 9.a. Lack of Proper Engineering Disposition of Indications; Lack of Guidelines for Disposition

- Develop high-temperature flaw assessment procedures.
- Develop specific guidelines for size and shape of indications that must be repaired, as in FFTF piping.
- Educate engineers or provide standards.
- High potential for schedule impact and cost overruns. Use generic guidelines for similar problems. Identify major and minor changes.

M(3) 9.b. Lack of Trained, Knowledgeable Inspectors (Understanding of Intent, Implications, Etc.)

- Incompetents should be retrained or taken off the job.
- Provide training on design and inspection requirements.
- Train inspectors to know why they are looking for various items and what the consequences of poor inspection are.
- Educate engineers or provide standards.
- More formal training, plus interactions with the engineers, is needed. Quality control (QC) should be removed from construction organization.

L(1) 9.c. Inconsistent, Excessively Tight Requirements Relative to Design Needs (e.g., Duplicate Requirements, Weld Bead Size, Etc.)

- Need clear definition of inspection requirements. Inspection requirements should be based on design needs.
- Educate engineers or provide standards.
- Engineers need to have QC-inspector mentality and be willing to compromise margins. Use Control Board to monitor trends and take corrective action.

L(0) 9.d. Attention to Trivia

- Train inspectors to know what is important and what is trivial, for example, how deep a pipe surface blemish is important.
- Educate engineers or provide standards.

L(0) 9.e. Lack of Continuity Between Field and In-Service Procedures

- Develop realistic in-service inspection (ISI) requirements, consistent with needs and capabilities.
- Good planning consisting of broad plant requirements should be established.
- Educate engineers or provide standards.

10. LICENSING

H(7) 10.a. Vague, Changing, and Ratchetting Regulatory Guidelines

- Depoliticize the NRC or replace with a less adjudicatory body.
- Attempt to get early agreement and stabilization from NRC. Reg guide evolution could be

slowed for LMFBRs through joint NRC-DOE cooperative effort to resolve issues before committing to a plant. The hundreds of Reg guides must be made more explicit so they aren't so ambiguous.

- Work with NRC to clarify guidelines and to develop responses to new guidelines that require a minimum of change.
- Corrective action will require changes in NRC's way of doing business.
- Regulatory guidelines need to be firmed up and held constant for a given plant.
- Freeze requirements for project much as is done in ASME Code applications of revisions/editions.
- Should at least look to what other countries do on the changing regulatory guidelines. Some countries do not allow guidelines changed after the plant design has been approved. Changing guidelines should consider the cost effect.
- Educate management; provide selection guide; put better people on both sides of the table.
- Often overstated. Need to communicate design to NRC.

H(6) 10.b. Lack of Early Involvement and Commitment (U & A) of NRC and Other Regulatory Bodies

- Engineering data base should be reviewed with NRC, etc., during "project planning and engineering phase" to establish common interpretation of requirements to be folded into the design. Work to obtain earliest possible commitment of approval of design baseline by NRC.
- Obtain early and continuous involvement of NRC and other regulatory bodies. Keep them informed and involved.
- Corrective action will require changes in the NRC's way of doing business.
- Have on-site offices for NRC and regulatory bodies to enhance involvement and turnaround when issues arise.
- The use of standard designs would greatly reduce involvement of NRC in licensing phase of particular plants. Their efforts could be focused on day-to-day operation requirements, maintenance and repair, and review of candidate standard designs.
- Educate management. Provide selection guide.
- Need better owner scheduling.
- The applicant must first have a comprehensive design and safety approach defined with a plan directed to a "one-step" licensing approach. Both the applicant and the NRC should commit to this plan at the earliest possible stage of project development.

H(4) 10.c. Lack of LMFBR-Specific Licensing Approach

- NRC must be motivated to develop position *before* next LMFBR project initiation.
- Develop LMFBR-specific licensing approach in close coordination with NRC.
- Not so bad. CRBRP did get approval for construction.
- We need a trial balloon (e.g., CRBRP). Experience is lacking.
- Need to develop LMFBR-specific licensing approach based on FFTF and CRBRP experience. Provide requirements based on specific reactor type, addressing unique features and concerns as appropriate. Safety analysis work on FFTF and CRBRP should be summarized to provide appropriate requirements for LMFBRs.

- It is believed that an effective LMFBR-specific licensing approach has not been established at this date. NRC should start working on this. In turn, items 10.a, 10.f, 10.i, 10.k, and 10.l should be completed (or nearly completed) preceding this item.
- NRC will react to problems. Set up a new approach? Doubtful.
- Need to establish dialogue with NRC.
- DOE's planning includes an ambitious LMFBR/NRC interaction program leading to Topical Reports, Reg Guides, SRPs, and plant-specific interaction.

H(4) 10.d. Excessive Financial Risk Associated with Process

- Develop an LMFBR-specific licensing approach and work continuously with NRC to resolve issues. Some change is inevitable and should be built into planning. Need a successful demonstration.
- Needs Congressional pressure.
- Financial risk will prohibit anyone except government from building first-of-a-kind plant. The need to license such plants must be eliminated.
- This is a result, not a cost driver. It is caused by uncertainty of costs and revenues from project.

M(3) 10.3e. Adversary Relations

- Maintain close coordination with NRC, etc., to ensure all criteria are satisfied.
- Make NRC aware of problems or deficiencies as soon as they arise. Get their involvement in resolution.
- Corrective action will require changes in NRC's way of doing business.
- Excessive, prolonged harassment strategies on the part of certain special interest groups should be minimized.
- Be willing to reach a compromise. Work on clear communications. Identify common objectives.

L(2) 10.f. Lack of Early NRC Commitment to Technology Research and Development (R & D) Needs (Focused on Specifics)

- NRC must be motivated to address LMFBR prior to initiation of next plant project.
- Obtain early resolution with NRC.
- NRC judges. RMs, AEs, and other owners' agents are to provide supportive data.
- An integrated R&D program approach with joint involvement and support by DOE, NRC, and industry will eliminate later questions and issues on adequacy and applicability of tests and evaluations.

L(1) 10.g. Inability of Government to Build Unlicensed Demo Power Plant (1974 Energy Reorganization Act)

- Change the law. Use FFTF to resolve the issues.
- Doubt this can be turned around without quantum positive jump in public perception of nuclear power.
- Law must be changed. It is no longer realistic to be able to license a new first-of-a-kind plant within a reasonable cost and schedule.

L(1) 10.h. Multistep Licensing Approach

- Start early on each step.
- True. Financial risk is too high.
- Probably needed for a prototype.
- The current "stop and go" licensing process can be improved by a one-step approach that will clearly remove design uncertainties and low overall productivity. Standard plant designs that have been prereviewed/approved by NRC would make such a process practical. DOE-proposed legislation would appear to achieve that objective.

L(1) 10.i. Lack of Focus on Safety vs Reliability

- Develop an LMFBR-specific licensing approach that adequately accounts for the difference between LWRs and LMFBRs.
- Develop quantitative relationships between safety and reliability.
- EPRI/DOE could bring this into focus.
- Requires a commitment by NRC to define measurable safety goals and abandon nonmechanistic and arbitrary assumptions/rules dictated in safety evaluations.

L(1) 10.j. Lack of Clear Boundaries Between NRC and State Authority

- Clarify. Priority of Federal regulations has been upheld in court.
- Need general licensing. Looks like reform of total NRC process is in order. How effective has it been in the past? Eliminate areas of little or no payback. Focus on areas that have proven effective. Reduce overall cumbersome nature of the process. Establish licensing authorities on site.
- Doubt this is a problem. The insurance underwriters are of more concern than state authorities are—or should be.
- Not usually a problem. But is always a concern. It has a major schedule impact.
- The entire regulatory structure in its current form needs reform along the lines of the proposed DOE legislation now before the Congress.

L(0) 10.k. Lack of NRC Funding and Motivation to Address LMFBR Issues in a Timely Fashion

- Nothing can be done without a national commitment to LMFBR.
- Obviously needed.
- To improve decision-making process, a major restructuring of the NRC is needed, consolidating various overlapping functions and appointing highly qualified technical and management personnel to reduce the reliance on outside consultants, thus improving the timeliness of addressing critical issues.

L(0) 10.l. Lack of Understanding and Agreement by NRC of Safety Classifications

- Important to motivate NRC to address this as soon as possible.
- Resolve with NRC.
- Pressure needs to be brought to bear on NRC.

11. SYSTEM TESTING, TURNOVER, PREOPERATIONAL TESTING, AND DOCUMENTATION

H(5) 11.a. Lack of Early Organization and Management Attention

- Need better management involvement and more knowledgeable managers.
- Planning and scheduling should be completed in the early stages. Schedule should be maintained. Management problem.
- Should get experienced management team in first.
- Educate engineering and construction management.
- All tied together. Must have a schedule and program (staff and systems) to ensure early test and turnover to identify problems.

H(5) 11.b. Lack of Component and System Tests at Earliest Point (Under Hot Functional Conditions)

- Carry out hot functional testing on schedule. Firm management control (called teamwork) to turn over system for testing. This is critical point in schedule.
- Educate engineering and construction management.
- All tied together. Must have a schedule and program (staff and systems) to ensure early test and turnover to identify problems.

M(3) 11.c. Lack of Early Development of Preoperational Test Procedures

- Better management involvement by more knowledgeable managers.
- Early development and planning.
- Educate engineering and construction management. Also, generate a generic schedule.

12. OPERATION

L(2) 12.a. Overly Restrictive Technical Specifications Limits

- Integrate operational requirements with the early phases of design.
- Involve technical specification writers with analysts on a continuing basis. As analyses are changed and updated, technical specifications should be changed.
- Perform frequent technical-specification upgrades by using operation experience and other plant experiences.
- Educate engineering management about cost effects.
- This is a nuisance item that has operation and maintenance impact.

L(1) 12.b. Lack of Early Attention to Operating Experience

- Monitor operational experience and feed results back to planning.
- Educate engineering and construction management.
- Depends on meaning. Need operating experience to critique design and aid turnover and rise to power testing.
- Probably does not affect \$/KW(e) capital cost but can have a dramatic impact on \$/KW(e) generated. The answer is to have input from experienced operating plant personnel at all stages of design.

L(0) 12.c. Lack of Properly Trained and Experienced Operators and Safety Personnel

- Start training early. Need management commitment to provide funds.
- Base salaries on experience and safety records. Make salaries competitive with others operating expensive equipment that has dire public safety consequences if abused or improperly operated.
- Educate and train them. Rickover did it. EPRI and utilities can do likewise.
- Big at Three Mile Island. Not usually considered a cost driver, however.

13. SURVEILLANCE AND IN-SERVICE INSPECTION**M(3) 13.a. Overly Restrictive, Uncertain ISI Requirements (e.g., Section XI, Division 3)**

- Develop ISI requirements based on design conservatism, design life, realistic inspection limitations, and consequences of failure.
- Review historical problems and payoffs of ISI. Reformulate ISI requirements with emphasis on utility and success in verifying life or safety assurance.
- Put good money and people to work on it.
- Black art. Should have less ambiguous tests. Has big schedule impact. Tests don't correlate. Repair (Section III) and inspection (Section XI) should be to same code. This is a code committee action.

L(1) 13.b. Lack of Philosophy Related Back to Design and Life Assurance

- Must develop experimentally supported, high-temperature flaw assessment procedures.
- Take account of the fact that the consequences of failure are different for LMFBRs and LWRs.
- Review historical problems and payoffs of ISI. Reformulate ISI requirements with emphasis on utility and success in verifying life or safety assurance.
- Put good money and people to work on it.
- Need to establish relationships between.

L(0) 13.c. Overly Restrictive Integrated Leak Rate Test Requirements for LMFBR

- Develop realistic leak rate test requirements based on test data.
- Review historical problems and payoffs of ISI. Reformulate ISI requirements with emphasis on utility and success in verifying life or safety assurance.
- Put good money and people to work on it.
- Problem with some LWRs. *Loosen up on criteria.*
- Stringent leak rate requirements should be limited only to containment boundary and not individual cells or other plant areas.

14. MAINTENANCE**L(1) 14.a. Not Built Into Design**

- Specify maintenance requirements in design specifications. Integrate maintenance requirements with design. Participation of owner/operator in design phase.
- Specify requirements in design spec. Base requirements on cost/benefit considerations as well as safety.

- Provide standard modular design that incorporates maintenance and repair eventualities such as tube failures in steam generators.
- Provide standard instrumentation for early detection diagnostics and trend determination.
- Do a study of cost impacts of maintenance and ways to better the design to reduce costs. A course could be provided for design engineers.
- Better design review from maintenance point of view.
- Constructibility, maintainability, and inspection requirement considerations should be integral to the design process at the start of the project and addressed in a formal manner through the SDD, equipment installation and removal studies, and the use of a scale model for reviews in these areas, along with check lists and delineation of requirements on construction drawings and/or specs. In development of conceptual plant arrangements, include space allocations for key systems routings, envelopes for construction access, and maintenance and component supports. Place more emphasis on modularization and shop prefabrication.

15. REPAIR

L(1) 15.a. Lack of Criteria for Determining Need for Repair

- Must develop high-temperature flaw assessment procedures.
- Develop flaw and crack acceptance criteria. Develop procedures for measuring "damage."
- Develop guidelines for repair, such as was done at FFTF.
- Write a generic guide; GE boiling water reactor Field Engineering did.

L(0) 15.b. Inadequate Procedures Such as for Weld Repair

- Develop repair procedures, particularly for welds, and the criteria to determine when repair is needed.
- There are plenty of procedures available.
- Procedures must exist at site.

L(0) 15.c. Inability to Use Original Code

- This is a fact of life. Must have a procedure for assessing effects of code modifications on design. Must have margin in the design so that code changes do not require a design modification.
- Freeze requirements.
- Doubt this is feasible. You would be arguing against progress.
- (Don't know if this is true.) Section XI, Article IWA 7000, Paragraphs 7110 and 7210—these paragraphs state that repair and replacement of components can be made to the original version of the code used.

16. GENERAL/MISCELLANEOUS

H(4) 16.a. Lack of Early Owner/Operator Involvement

- Get early owner/operator involvement. Owner must be committed to spend money—lots of it.
- Educate owner management.

- The owner/operator, as well as the constructor, should be involved in plant design development from the onset. This includes criteria and SDD development and review of conceptual plant arrangement drawings, followed by reviews of final construction drawings and specs.

H(4) 16.b. Poor Management

- This is the thread throughout. It affects all detailed decision-making.
- Good management, obviously, is needed. Owner should be project manager. Project organization rather than matrix or functional organization should be used.
- Utilities should hire "operating companies" to operate groups of reactors.
- Better use of available experienced people within the LMFBR community. Each project seems to start from scratch, not benefitting from lessons learned by others.
- Educate managers.
- More attention should be given to high-quality management team.

H(4) 16.c. Regulatory Uncertainty

- I have checked this again because it will probably be the single main reason that a utility will not commit to a new nuclear plant.
- Bring pressure to bear on NRC to straighten up their act.
- Utility must take control. Communications with NRC are a must. Mu. also have good project engineer. Direct utility involvement with NRC. Establish utility office in Bethesda.

H(4) 16.d. Lack of Early Concentration of Engineering and Planning

- This is critical. Needs management commitment and experience to initiate early and complete planning.
- Educate managers and develop a generic guide.

M(3) 16.e. Changing Design Criteria

- High-temperature structural design criteria must be finalized and experimentally confirmed before initiation of next LMFBR plant project to eliminate outstanding issues and changing requirements.
- The corrective action is to design to accommodate changing design criteria (e.g., leave margin in the design) so that redesign can be avoided. Need stable design data.
- Need to settle NRC down. Isolate operability from safety concerns.
- For LMFBRs the criteria have been on somewhat of a bootstrap basis. We need to firm up the state-of-the-art and build a commercial plant (experience/maturity lacking).
- Educate managers and develop a generic guide.
- This is closely associated with Sect. 10, Licensing, particularly items 10.c, 10.k, and 10.i.

L(2) 16.f. Lack of Innovative Cost-effective Design

- Need active project to develop a cost-effective, inherently safe design and involvement of NRC to resolve the safety and licensing issues in the design stage.
- Incentives need to be initiated for producing cost-effective designs.

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- Provide tangible incentives for developing cost-effective designs.
- Use task force approach to design, as is often done in resolving problems or ill-conceived designs.
- The use of standard designs could stifle the development of innovative cost-effective designs once a set of standard designs has been accepted. Designers/manufacturers must be provided with incentives to continue to develop more cost-effective standard designs. Pressures of competing with alternate energy sources should provide this incentive.
- Research and develop new ideas.
- Continuing current on-going base technology and applied technology development.
- New design should include a study of cost-effectiveness and be documented.
- Brainstorming is needed. Review teams outside industry should be established. Engineering guidelines should be developed to force consideration of cost. Force alternatives and documentation of which ones were considered.
- Traditional defense-in-depth philosophy of design needs to recognize that simplicity and passivity may be a better approach than redundancy and diversity. Requires an early commitment to initiate design by using a simple approach.
- We have been designing uncompetitive plants. The reason is that we have followed what, until recently, seemed to be a successful approach, that is, LWRs. What we must now do is reverse what has been done in the past, thus avoiding at all cost what has been done in the LWR area.

L(1) 16.g. Lack of Attention to Plant Availability in Design (Cost/Benefit Considerations, Etc.)

- This is not a cost driver relative to original cost, which is the problem with LMFBRs. However, need to integrate design, manufacture, ISI, service, and maintenance in the design phase. Early involvement by all concerned is needed.
- Keep plant size smaller than 1000 MW(t).
- Has a lot of attention. Need better management.

**L(0) 16.h. Plant Dominated by Nuclear Steam Supply (NSS) Consideration
(NSSS Small Part of Overall Cost)**

- This does not seem to be a problem. Deliver the NSSS on schedule.
- Educate managers. Write generic cost/schedule guide.

16.i. Remote Site Locations

- Replicate of a typical plant design or a "standard" design in "Nuclear Parks," considering four, five, and six units rather than single or twin units at a common remote site. Use of a prequalified site, common facilities, and replicate units has significant potential cost advantages.

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