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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Critical Materials and Fabrication Issues *for*

pressure vessels, piping, pumps, and valves

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Critical Materials and Fabrication Issues

for pressure vessels, piping, pumps, and valves

Preview of AN ASME SYMPOSIUM
Co-Sponsored by the National Bureau of Standards
and to be held at the St. Francis Hotel,
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August 14-15, 1980

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PREFACE

In April 1978, the Steering Group of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping (PVP) Division, initiated the planning of a trend-setting symposium entitled "Critical Issues." Under the then chairmanship of Prof. Richard Roberts of Lehigh University, the Steering Group invited the Symposium Organizing Committee to identify technical issues most likely to be critical in the 1980's, to foster orderly debates on different approaches to resolving these issues, and to challenge the technical community and the public to address these issues until they become fully resolved.

Since then, a total of twelve issues on technical problems in the materials and fabrication aspects of the pressure vessels and piping industry have been identified. As the planning effort progressed, technical issues were first proposed at various subcommittee meetings held in the United States during 1979. The issues were then discussed, debated, and sharpened with inputs from committee members and invited reviewers during the latter part of 1979 and the early months of 1980. In March 1980, all twelve issues were presented in draft form to members of the ASME-PVP Materials and Fabrication Committee for comments and approval. The presentation took place on March 13-14 at a meeting held at the National Bureau of Standards in Gaithersburg, Maryland.

This report contains extended abstracts of the twelve issue papers as prepared by their authors known as "issue champions." At the end of each extended abstract, a summary of the reviewers' comments which the champion(s) chose not to incorporate is included under the authorship of one of the co-editors. This style of editing insures that the reader is provided with not only the views of the issue champion(s) on each critical issue but also the arguments of those who disagree. As a pre-symposium document, this preview is intended to stimulate comments and debate on the merits of twelve technical questions with the expectation that by the end of the August 1980 symposium a consensus may emerge to help ASME embark upon its second century of service.

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Washington, DC, June 10, 1980

ACKNOWLEDGEMENT

The technical content of this publication is made possible by the authors and, also, the unheralded efforts of the reviewers. This body of technical experts, whose dedication, sacrifice of time and effort and collective wisdom went into reviewing the papers, must be acknowledged. On behalf of the Symposium organizers, we acknowledge with appreciation their contribution.

The Symposium Editorial Committee is grateful to Mary L. Hope, Linda A. Johnson, Nancy E. Mollory, and Barbara A. Uglik, all of the National Bureau of Standards, for their timely assistance in the typing of the final manuscript. To Bette Johnson, our Managing Editor of this preview, the Organizing Committee is particularly grateful for her efficient and gentle control of the flow of information from more than one hundred contributors over an 18-month period for the completion of the review process.

Finally, it gives us great pleasure to acknowledge the generous support of the National Bureau of Standards through its

- Office of the Director, National Measurement Laboratory,
- Office of Nondestructive Evaluation, National Measurement Laboratory,
- Center for Materials Science, National Measurement Laboratory, and
- Center for Applied Mathematics, National Engineering Laboratory,

without which this preview would probably be merely another good idea lying somewhere in the minutes of the symposium committee.

SYMPOSIUM ORGANIZING COMMITTEE

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ABSTRACT

As part of its centennial observances in August 1980, the American Society of Mechanical Engineers (ASME) will co-sponsor with the National Bureau of Standards and others a unique symposium entitled "Critical Issues." Through an intensive two-year series of debates, meetings, presentations, and reviews, a total of twelve issues on the materials and fabrication aspects of technical problems in the pressure vessels and piping industry were identified for discussion at the August 1980 meeting. The twelve issues are: (1) The role of engineering judgment and the computer in the management of material property data; (2) Curve-fitting vs. modeling for formulating design rules; (3) New material property data: Terminal vs. incremental tests; (4) Variability of data: Standards for applications; (5) On-line monitoring of critical components to improve reliability; (6) Upgrading welders' skill and educational level: How and why; (7) Reliability of nondestructive evaluation (8) Characterization of the subjective component of inservice data; (9) Should there be a methodology for failure analysis? (10) Accelerated development of a more rational basis for nonlinear fracture mechanics; (11) Safety factors in Fatigue Design: Arbitrary or Rational? (12) The ASME Code and product liability: Should compliance create a rebuttable presumption of proper design? This report contains extended abstracts of the twelve issue papers and summaries of reviewers' comments for distribution to all symposium pre-registrants to stimulate and guide an orderly debate at the August 1980 meeting.

Chapter 1 Introduction

1.1 About the Symposium

1.2 Symposium Opening Remarks

1.1 ABOUT THE SYMPOSIUM

The American Society of Mechanical Engineers (ASME), through its Materials and Fabrication Committee, Pressure Vessels and Piping Division (PVP), is pleased to announce the co-sponsorship(*) of a Critical Issue Symposium in August 1980 as part of the observance of ASME's One Hundredth Anniversary (1880-1980).

The goals of the symposium are:

(a) To identify, through a series of pre-symposium meetings at various laboratories and plants around the country, critical materials and fabrication issues for debate at this symposium as a challenge to all engineers, scientists, applied mathematicians, research managers, and regulatory administrators, as ASME begins its second century of service. The issues are broad enough to encompass all types of engineering materials and fabrication practices.

(b) To seek a broadly based consensus on critical problems through a three-level review process(**) prior to, and an open debate of the issue papers during the two-day symposium. This should lead to a joint commitment to address in the next decade those critical problems so that new solutions may emerge to advance the safe and economical use of pressure vessels, piping, pumps and valves.

To accomplish the above goals, a symposium organizing committee consisting of eighteen (18) individuals(***) from a variety of industrial and governmental organizations was assembled to guide and supervise the selection of critical issues as proposed by the twelve technical subcommittees of the ASME-PVP Materials & Fabrication Committee. The issues, as described in Symposium Bulletin No.2 (March 1980), were grouped in three categories as follows:

Category A - Generic and Standards Issues

- Issue 1 - The Role of Engineering Judgment and the Computer in the Management of Material Property Data
- Issue 2 - Curve-Fitting vs. Modeling for Formulating Design Rules
- Issue 3 - New Material Property Data: Terminal vs. Incremental Tests
- Issue 4 - Variability of Data: Standards for Applications

Category B - Fabrication, Inspection and Operation Issues

- Issue 5 - On-Line Monitoring of Critical Components to Improve Reliability
- Issue 6 - Upgrading Welders' Skill and Educational Level: How and Why?
- Issue 7 - Reliability of Nondestructive Evaluation
- Issue 8 - Characterization of the Subjective Component of Inservice Data

Category C - Failure Analysis, Fracture, Fatigue and Liability Issues

- Issue 9 - Should there be a Methodology for Failure Analysis?
- Issue 10 - Accelerated Development of a More Rational Basis for Nonlinear Fracture Mechanics
- Issue 11 - Safety Factors in Fatigue Design: Arbitrary or Rational?
- Issue 12 - ASME Code and Product Liability: Should Compliance Create a Rebuttable Presumption of Proper Design?

(*)For a complete list of symposium co-sponsors, see Appendix I.

(**)The three-level review process consists of an oral presentation before a technical subcommittee, a peer review of the revised draft by about twenty experts on the specific issue, and a general review by members of the ASME-PVP Materials and Fabrication Committee after all issue papers are edited by the symposium editorial committee.

(***)For a list of the names and affiliations of the organizing committee members, see Appendix II.

The symposium organizing committee has adopted a three-session format to present the above issues for floor discussion. Each session will last about three hours, with forty (40) minutes allotted to each issue paper including its presentation by the issue champion (10 minutes), oral arguments by three official discussers (5 minutes each), questions from the floor (10 minutes) and the final response by the issue champion (5 minutes). The symposium will include a brief opening statement (10 minutes) and a final summary (10 minutes) to be delivered by the two co-chairmen.

To promote a more incisive discussion of all issues during the three-session symposium, the organizing committee initiated the preparation of this publication as a symposium preview. It contains the full texts of an opening statement and extended abstracts of the twelve issue papers. The organizing committee plans to distribute the symposium preview to all pre-registrants one month before the August meeting. Each extended abstract is required to contain the following nine elements to sharpen the symposium discussion:

Outline of the Extended Abstract of an Issue Paper

1. Statement of the Issue
2. Importance of the Issue to ASME and Beyond
3. Availability of New Tools for Resolving the Issue
4. Importance of Multi-Party Collaboration
5. Some Recent Contributions
6. Some Forthcoming Conferences and Publications
7. Some Contacts for More Information
8. Issue Champion's Position
9. Summary of Arguments for the Champion's Position

The organizing committee has made plans to tape the entire proceedings of the symposium. These tapes will be transcribed and edited for verification by the speakers and the discussers. After reviewing the full texts of the position papers to be submitted by the issue champions, together with their response to all questions raised at the symposium, the committee will submit the edited proceedings to the American Society of Mechanical Engineers (ASME) for release as a special publication. It is expected that the proceedings will appear in print approximately nine months following the August 1980 meeting.

1.2 SYMPOSIUM OPENING REMARKS(*)

On behalf of the symposium organizing committee, I would like to welcome you all to this unique symposium on critical issues. To our distinguished visitors from abroad, I would like to bid a special welcome. Dr. Karl Stahlkopf and I are particularly pleased, as co-chairmen of this conference, to see so many of you join the ASME members in celebrating the one-hundreth anniversary and in meeting the challenges of the 1980's.

As you know, this symposium is co-sponsored by four ASME Divisions, the American Society for Nondestructive Testing, the Pressure Vessel Research Committee, the Metal Properties Council, the Electric Power Research Institute, two divisions of the Southwest Research Institute, and three agencies of the U.S. Government. Many of you may wonder about the need to have so many co-sponsors. Some of you may wish to know how the issues and the speakers were selected. Another obvious question to ask is why we limit the discussion to twelve and not twenty issues.

Within the next eight to ten minutes, I hope to share with you some of my thoughts on this symposium and attempt to answer some of these quetions.

PRESSURE VESSELS, PIPING, PUMPS, AND VALVES:
A MULTI-BILLION-DOLLAR INDUSTRY

According to Business Week (March 17, 1980), the 1979 sales of 43 leading companies such as Combustion Engineering, Foster Wheeler, etc., which are classified as General Machinery, is 30.7 billion dollars. The comparable figure for 41 leading chemical companies amounts to 83.7 billion dollars. A fraction of each of the two figures must be taken into account to estimate the annual dollar volume of the U.S. expenditure on pressure vessels, piping, pumps, and valves. A crude estimate of that volume can easily convince you that we are dealing with a multi-billion-dollar industry. To enhance the credibility of our discussion, it is therefore essential to involve as many outstanding groups in both the private and public sectors as are willing to co-sponsor this event. At our latest count, we have 16 such groups acting as our co-sponsors.

MATERIALS AND FABRICATION INFORMATION:
SHORT ON SCIENCE AND LONG ON JUDGMENT

My second thought turns to the nature of the technical information that we are supposed to generate, assess, or simply transmit. It is no secret that engineers and scientists have at least one problem in common; namely, funds are always too tight to do a job right. If you are a scientist, lack of funds simply means no result or a postponed deadline for completing a study, whatever that study may be. Engineers are not so lucky, i.e., whether there are enough funds or not, a decision must be made by a certain deadline to alleviate a problem or to satisfy a client's need. To support such a decision, engineers are paid to dig into their experience on related events and render a judgment. This occurs more frequently on materials and fabrication problems because the field of materials science and engineering was born only about twenty years ago. In short, when it comes to generating, assessing, or transmitting materials and fabrication information, a large part of our product is "engineering judgment."

(*) To be delivered on August 14, 1980 at the opening session of the symposium by Jeffrey T. Fong, Symposium Chairman, National Bureau of Standards, Washington, DC 20234.

AN ENGINEER'S OBLIGATION TO ACCUMULATE EXPERIENCE IN ORDER TO DEFEND HIS/HER JUDGMENT BEFORE THE PUBLIC

As the pace of our technological development quickens, there comes a time when the operating experience of an old system may not be adequate to provide the basis for a sound engineering judgment on a new system. Jolted by a series of highly publicized incidents, impairing the delivery of services to the public and, in some cases, potentially hazardous to the community, the public turned skeptical in the last decade and demanded an examination of the bases for the many critical engineering decisions underlying the design and operation of the facilities involved. Recognizing that engineers are wont at times to hide behind codes and standards on questions of safety and conservation, the public has turned its attention to the technical and judgmental bases of most of these codes, including the ASME Boiler and Pressure Vessel Code. The challenge before us, as ASME enters its second century, is simply this:

> Are we as members of ASME going to sit around and wait for the public to tear our codes and standards system apart, or are we going to identify the critical issues head on, achieve a consensus on their priority and promote a dialogue with the public on the value of our engineering judgment?

THE BIRTH OF A CONSENSUS-MOLDING, FORWARD-LOOKING ISSUE SYMPOSIUM

Clearly, the answer to the question is to accept the challenge. This has led to a unique organizing effort for a non-traditional conference where the speakers do not come with new technical results but with critical issues and convincing arguments why we need to study them in the 1980's. The organizing committee has formulated three criteria for defining an issue as critical, i.e.,

Criterion 1 - The issue must lead to significant economic benefits when resolved

Criterion 2 - The issue must be ripe for resolution due to the availability of new tools or concepts

Criterion 3 - The resolution of the issue depends strongly on a multi-party collaboration through information sharing and critique.

The chairman of each of the twelve technical subcommittees of the PVP Materials and Fabrication Committee was asked to contribute one and only one issue to this consensus-molding and foward-looking symposium. Since April 1978, when the idea of a critical issue was first conceived, numerous discussion meetings have been held at offices, laboratories, plants, and even hotels around the country to bring you the twelve issues as listed in the program. The subsidiary criteria for the selection of issues and speakers were developed as each technical subcommittee deliberated and, at times, argued heatedly over some aspects of one issue or another. The results of our two-year effort in sharpening the issues and in editing the pre-symposium special publication are here for you to judge.

I now declare the symposium on critical issues officially open.

Chapter 2 Generic and Standards Issues

Issue 1 The Role of Engineering Judgment and the Computer in the Management of Material Property Data

Issue 2 Curve-Fitting vs. Modeling for Formulating Design Rules

Issue 3 New Material Property Data: Terminal vs. Incremental Tests

Issue 4 Variability of Data: Standards for Applications

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ISSUE NO. 1

THE ROLE OF ENGINEERING JUDGMENT AND THE COMPUTER IN THE MANAGEMENT OF MATERIAL PROPERTY DATA

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Mr. Schaefer is a Fellow of ASME, Fellow and Honorary Member of ASM and ASTM. He was also awarded the J. Hall Taylor Medal, ASME. He has been with The Metal Properties Council since its founding in 1966 and during this time was also the recipient of the Robert Yarnall Award from the University of Pennsylvania.

Paul M. Brister

Babcock & Wilcox Co., Inc.
Barberton, OH 44203

Mr. Brister has been active in ASME Codes since 1948 in materials properties and power boilers. He served as the Chairman of the Boiler & Pressure Vessel Committee from 1977-1980. He was an organizer of MPC and Chairman of Technical Advisory Committee since its founding. He has been a Fellow Member of ASME since 1972 and ASTM since 1969. He was the recipient of J. Hall Taylor Medal in 1980.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Increasing numbers of methods of testing, improved equipment and facilities for testing and measuring the characteristics of materials, as well as changes in the materials themselves as a result of new sources, new processes and refinements in extraction, and new methods of fabrication, all have their effects on a growing mass of data indicative in some way of the properties of the materials. Information of this type has always required evaluation if it is to be applied to any specific application.

Materials properties, as considered in these remarks, is a comprehensive term including, among other things, strength and toughness characteristics, corrosion and erosion resistance, as well as those physical properties which bear on the fabrication and the use of the materials.

For engineers to use materials property data most effectively, the raw data must be properly organized, classified, analyzed, and made available in a manner that will assure its correct use. Such action is the management of materials property data.

Computers provide an excellent tool for storing, retrieving, processing, and analyzing data. However, the materials engineer must maintain the responsibility for the correct use of the data, and must, therefore, assure that the computer data base is properly designed to give the correct information needed for design. For example, engineers responsible for providing design stresses in codes, or for using the materials in a product such as a boiler or pressure vessel, must use their judgment in recognizing the significance of the variations in properties in the material as supplied; variations that may be caused by manufacturing processes such as forming, welding, and heat treatments; and by the end use requirements such as pressure, temperature, operating environment, and operating conditions. The data base must be designed so the input will receive such pertinent information and the retrieval system will permit access to this information. Further, before inputing the data, it must be appraised by an engineer to assure that the data are verified; are on material representative of a specification; and provide adequate characterization of the material.

The issue is: Should materials engineers and/or metallurgists bring their judgment to bear not only on the analysis and interpretation of data, as traditionally expected of engineers, but also on the design and management of the computer data base to insure that the computer output is meaningful and cost effective.

It is the contention of this paper that the application of computer technology to the evaluation and analysis of materials property data make it critically important that engineering judgment be exercised at all points from the sampling and testing procedures to the final product of the computer analysis, however it may be expressed.

Engineering judgment is human judgment, based on knowledge of engineering principles as well as of the characteristics of materials together with appreciation of the true meaning and the limitations of the sampling and testing methods. Experience can be an important factor, and common sense must be considered as a basic ingredient. Even intuition has its place.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

This issue is of utmost importance to ASME in the Boiler and Pressure Vessel Code and the Code for Pressure Piping.

In preparing the stress tables for the different Code Sections, the criteria for establishing the design stresses for each Section are applied to the basic trend curves or behavior pattern developed for the materials which conform to the acceptable specifications. Most of the data used by the committee are obtained by the Metal Properties Council. They are made available to ASME and to other interested engineers by publications of one of the MPC sponsoring societies, ASME, ASTM, or ASM. Since the MPC data base on materials is quite comprehensive, the ASME Committee must be selective to assure that only those data representative of specifications acceptable to ASME are used in establishing ASME trend curves and design stresses.

In the ASME Boiler Code Committee structure, the Subcommittee on Properties and its various Subgroups currently provide the engineering judgment in the use of the "hard copy" data base from MPC or other sources. There is currently a study being made jointly by MPC and ASME on the use of a computer for storage, evaluation, and analysis of data for establishing Code stresses. A joint task group from ASME and MPC will provide the technical guidance for this study, thus assuring the needed engineering judgment.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

Sophisticated test methods and measurement techniques, which will result in better characterization of structural materials, are becoming available. Significant advances in data base management systems which will accommodate the complexities of structural materials properties are now being made. But, possibly most importantly, the necessary resources are also becoming available--groups within separate organizations are just now beginning to seriously formulate strategies which will involve cooperation among these separate organizations, industry, government, and academia.

It is expected that greater use of computers will be made both by the Metal Properties Council and by ASME in the coming years. MPC has a special committee making a comprehensive study on the use of computers in the management of a data base broader than currently used. As mentioned above, ASME has a joint study committee with MPC to develop the technical and administrative feasibility and impact of greater use of computers in analyzing data for ASME Code use.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

The extension of the utilization of the computer in this field is of great concern to all parties involved. It is desirable that the most broadly based group actively participate in the development of areas of application. All those engaged in such work should be aware of the efforts of others. Symposia and seminars at sufficiently frequent intervals should publish the progress of the work so that unnecessary duplication may be avoided, but necessary efforts may be exerted to the end that the accomplishments of the computer be maximized and the role of engineering judgment in selection of materials and in design be recognized and applied.

A period of development is ahead of us in which it is desirable that participation be on the broadest possible basis. Broad participation may be expected to apply our best engineering judgment which will also be vital to successful design and application.

A commonplace expression is that we need to draw into metallurgical circles the design engineer so that he may express his needs and, therefore, perhaps have them met. It is perhaps more reasonable to say that the metallurgist must continually strive to find better ways to express to the design engineer just what are the characteristics of the material the latter proposes to use. The lines on the designers drawings can seldom be assumed to enclose material which is perfectly homogeneous and which has known characteristics in all directions at all locations.

The remarks of the next three speakers on this panel provide examples of the utilization of property data. It is significant that the importance of engineering judgment is apparent in all cases cited. Cost effective design must be based on adequate information properly evaluated.

5. SOME RECENT CONTRIBUTIONS

A. A. Popov, V. M. Timonin, and E. G. Shckukina, "A System of Assembly and Treatment of Data on the Strength Characteristics of Materials," Central Scientific--Research Institute for Mechanical Engineering Technology, Moscow, 0039-2316/79/1101-0099, Plenum Publishing Co. (1979)

Paul M. Unterweiser, "Computer-Aided Engineering at Deere: A Materials Selection-Data System," Metal Progress (April 1977)

"Critical Survey of Data Sources: Mechanical Properties of Metals," NBS Special Publication 396-1

The most comprehensive list of publications related to material properties is that included in the Annual Report to the Metal Properties Council. The 1979 report is available at MPC Headquarters.

A publication of special interest to this issue is "1977 Design Criteria of Boilers and Pressure Vessels" which is an ASME publication of a Panel presentation in Tokyo at the Third International Conference on Pressure Vessel Technology. One of the papers in this publication is "Code Design Criteria in the U.S.A.--Evaluation of Strength Properties" by P. M. Brister.

An important contribution to the knowledge of the interrelation between creep and fatigue damage has resulted from some of the work of The Metal Properties Council. The present state of knowledge of this relationship includes a very small number of materials. More extensive information on this relationship, which will result from work now in progress, will permit more cost effective design by lowering present safety margins.

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

"Automation of the Materials Selection Process" -- A. A. Watts

September 15-19, 1980--International Conference on "Engineering Aspects of Creep," Sheffield, England

November 17-21, 1980--Symposium on "Effects of Environment on Mechanical Properties of Metal," ASME Winter Annual Meeting, Chicago

"PV&P Division Program for ASME Winter Annual Meeting, November 1980"

7. SOME CONTACTS FOR MORE INFORMATION

American Society for Metals

The Metal Properties Council, Inc.
345 East 47th Street
New York, NY 10017
Attn: A. O. Schaefer

National Bureau of Standards

American Society for Testing and Materials

American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017
Attn: G. Eisenberg, Secretary
Boiler and Pressure Vessel Committee

The National Academy of Sciences
National Materials Advisory Board

Battelle Memorial Institute

Oak Ridge National Laboratory

Nuclear Regulatory Commission
Data Bank at Bethesda

8. ISSUE CHAMPION'S POSITION

The computer is a powerful tool for storage, retrieval, evaluation, and analysis of material property data. However, it is only a tool, and cannot replace the human engineering judgment necessary in the management of materials property data for assuring the proper use of these data in engineering design. Improper use of data can result in the selection of the wrong material and inadequate or unsafe products. With engineering judgment exercised in data generation, and in the use of computers for data storage and retrieval, evaluation, analysis, and application, there is much greater assurance of proper material selection and use on a product adequately designed for its intended use from both the economical and safety standpoints.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

The basis for the opinion expressed here is the complex variety of data available on Mechanical Properties of Materials, not only with respect tot he manner in which it is obtained, but also in consideration of the interpretation to be placed on it in using it.

There are many factors which affect the properties of materials, even when supplied to a standard specification. These factors include, among others, metal processing; chemical composition; product form, size, and thickness; heat treatment; and fabrication operations. The behavior of the material in its end use product is affected by the environment in which it is used and the operating conditions to which it will be subjected. The accumulation and analysis of data representative of the various material specifications and conditions of fabrication and use is a complex activity. A computer can be a very effective tool in aiding the engineer to evaluate and analyze the data for establishing design stresses for Code use or other design use. However, the judgment of the engineer is required in the management of this data to properly determine the appropriate analyses, selection of parameters, and criteria for design stresses suitable for the intended application.

10. CONCLUDING REMARKS

HOW AND WHERE ENGINEERING JUDGMENT ENTERS

New designs and new environments, which are inherent in progress, invariably introduce unknown factors. Common sense, intuition, and experience cannot be programmed into a computer. There is no way to record even a fraction of the experience of an individual into a computer.

As an illustration indicating just some of the many places where engineering judgment is obviously required, we offer the following. These are just some of the steps betweeen planning a test to determine properties and the application of the data produced in design.

1) Is the material tested representative of that which will be utilized? New sources of raw materials, changing process variables with source, condition of equipment, personnel, environment, etc., etc., all affect properties.

2) Is the method of sampling and testing giving us meaningful data? Practically all of our tests are best described as "representative," rather than "actual." Judgment is needed to evaluate a multitude of factors involved.

3) What statistical judgments are appropriate?

4) Are there valid ways to extrapolate and evaluate data?

5) What are appropriate safety factors?

6) May variables in operation by expected? Do they affect properties?

7) What variables will fabrication introduce?

8) What degree of control of materials and processing is cost effective?

This list might well be extended. It illustrates the issue that engineering judgment is essential at all stages of selection of material to design and thereafter.

SUMMARY OF COMMENTS*

Ronald C. Dobbyn, Co-Editor

In addition to the comments now adequately addressed in the authors' final draft, there remain three general areas for which some reviewers want additional information and/or examples:

Criticality of the Issue,

Economic Benefit, and

How do we do it.

Many have agreed that this issue is very critical for the decade before us and is, perhaps, crucial for the future development of reliable pressure vessels, piping systems, pumps, and valves.

Although it can be argued that cost-benefit analyses and specific methodology are beyond the scope of an "issue paper," there was hope that Messrs. Schaefer and Brister could indicate the current "size" of the problem and industry's general attitude toward supporting this type of activity.

However, a majority of reviewers and critics have agreed that the only way to insure the reliability and ultimate utility of materials properties data is to demand that materials engineers and scientists get involved in the design, operation, and management of the data base.

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

*Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division, and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

COMMENTS BY SYMPOSIUM PARTICIPANT(*)

(Use Back Sheet if necessary)

Submitted by______________________________Affiliation____

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Comments (continued)

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ISSUE NO. 2

CURVE-FITTING vs. MODELING FOR FORMULATING DESIGN RULES

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EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

A design engineer has three approaches on which he can rely in analyzing a structural component: mathematical formulation, curve-fitting based on experimental data, and modeling procedure. Mathematical formulation is generally a hypothesis based on assumptions that may or may not properly describe material behavior. It does not have to be verified experimentally. Experimental data is the result of material performance under prescribed and controlled conditions. A curve is then fitted to the experimental data, resulting in an empirical relationship between the controlled testing variables. The curve can be used to predict material performance within the experimental regime. Modeling is a procedure that predicts performance within and beyond the domain of the experimental data. A model starts with experimental data and adopts necessary physical variables that allow prediction and extrapolation beyond the data domain. It is a forecasting tool venturing into the unknown.

Therefore, the ciritical issue here is "Should a designer use curve-fitting in predicting material performance or should he rely on modeling?" To answer this question one has to weigh variables such as the cost of generating the data, cost of developing a model and whether the design involves short-time or long-time predictions, and what types of risks are involved.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

A typical example in the use of curve-fitting is the fatigue curve used in the ASME Code for life prediction. The curve was based on considerable data for a variety of materials, and a technique for scaling down the original data was developed. The scaling in this case includes human factors and laboratory observations that reduced time experience to a design curve for life prediction. In some cases one may argue that the curve is a model, since it has the ability to predict life within and outside the experimental domain if certain procedures are followed. The curve has been applied, for example, to biaxial loading and to high temperature problems. However, the results are not adequate and therefore the curve, according to the modeling definition, does not fit the description of a model.

Basically, most experimentally fitted curves are empirical relations. For example, in fatigue curves, the empirical relation is between stress or strain and life with constants that can be related to the mechanical properties of a specific material. In the case of fracture mechanics, power law relations have been fitted to experimental data, and these laws are very well accepted in design analysis.

Curve-fitting techniques have been favored by designers for their simplicity and predictability, specifically in short-time applications. For example, in fatigue analysis, short-time can be interpreted as 10^5 cycles or less. The cost of developing adequate data is not an exuberant factor and within the reach of most analysts. On the other hand, developing a model is an expensive and a long drawn out affair. A model has to be developed on the basis of the experimental evidence, and has to be fitted with one or more variables that can extend the curve-fitting process to outside the experimental regime. In other words, the variables in a model must be well defined for any extrapolation process. The development of a model, in addition to cost factors, is a time consuming process. It requires the involvement of at least three laboratories to insure that the proposed model is adequate for extrapolating known results into unknown environment. An engineering model can become advantageous over curve-fitting if a long-time prediction is required. For example, in creep analysis, data generation over a period of years is practically impossible; and, in such cases, modeling is a strong tool.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

In modeling techniques, new tools have been developed that can provide the model with an input that describes the load, the required life, the environment, and the time-reference. These tools are not required in curve-fitting techniques since the experimental data is generated under a prescribed environment that accounts for all of the input needed in a model. The curve-fitting techniques adequately answer the question within the experimental domain. The difficulty in curve-fitting is the availability of good data generated by several laboratories and field observations. The data obtained for a specific material can vary considerably due to material structure, heat treatment, and loading procedures. Therefore, new testing practices have to be developed so that more uniform data can be obtained with minimum lab-to-lab variations. This requires the use of common and precise sophisticated instrumentation for accurate measurements. The use of statistical analysis has made curve-fitting a reliable design technique.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

It is extremely important that multi-party collaboration in both curve-fitting and modeling is practiced. The cooperation of metallurgists, chemists, mechanical engineers, and statisticians is a vital element in resolving this issue. Material behavior is an essential and common denominator among these disciplines. A pressure vessel stress analysis under a high temperature environment requires not only a design procedure but also understanding of both the micro-and macro-scopic behavior of the material. The emergence of dislocation theories based on metallurgical observations has generated a greater input to the understanding of engineering theories that are based solely on mechanical properties. Material properties must be well identified and investigated by multi-party researchers so that a unified approach to a safe design can be achieved. Material behavior is a complex problem and requires a multiparty solution.

5. SOME RECENT CONTRIBUTIONS

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Structural Life Prediction/Correlation Program ADAPL-TR-2082

Reproducibility and Accuracy of Mechanical Tests, edited by J. H. Holt, STP 626 (American Society for Testing and Materials, Philadelphia, 1977)

Fatigue of Engineering Materials and Structures, edited by K. J. Miller, Vol. 2, No. 2, 1979

ASME Boiler and Pressure Vessel Code, ASME, NY

J. F. Saltman and G. R. Halford, "Applications of Strainrange Partitioning to the Prediction of MPC Creep-Fatigue Data for 2 1/4 CR-1 Mo Steel," ASME-MPC-3, edited by R. M. Curren (ASME, 1976)

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

Symposium on Mechanical Testing for Deformation Model Development, American Society for Testing and Materials (ASTM), Nov. 1980, Bal Harbour, FL.

[Additional information to be furnished at the August 1980 Symposium.]

7. SOME CONTACTS FOR MORE INFORMATION

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8. ISSUE CHAMPION'S POSITION

At the present time, modeling has not been widely used among designers. It is a topic of discussion since no adequate modeling tools have been proposed and accepted by the majority. On the other hand, curve-fitting is an acceptable design procedure that has been practiced by the majority. In the coming decade, more modeling techniques will be available, but until then, curve-fitting is a good approach even though it lacks physical properties of materials.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

Curve-fitting techniques are advantageous to modeling. They are simple tools that can predict performance with a good degree of reliability, particularly in short-time applications. In the analysis of fatigue, creep, and fracture, curve-fitting techniques have produced power-law relations that are well accepted by the engineering community.

10. CONCLUDING REMARKS

Both curve-fitting and modeling are essentials in formulating design rules. Both methods need improvements, and in the coming decade they will be used simultaneously. However, curve-fitting is a more acceptable procedure.

SUMMARY OF COMMENTS*

Leonard Mordfin, Co-Editor

Several of the comments received on this issue paper suggested that there was some uncertainty regarding the specific uses of curve-fitting and modeling that Dr. Zamrik was addressing. One reviewer, for example, questioned whether the issue applied to the prediction of material properties or to the entire design procedure. He offered the opinion that modeling for overall design is much further advanced than modeling for predicting material properties because the latter requires extensive verification testing. He noted that such testing is also required for curve-fitting of material properties.

Another reviewer felt that the proper focus of the issue should be on the development of design data which would facilitate the implementation of design rules. Still another expressed the view that multi-party collaboration in model development may not be entirely adequate unless different approaches are used.

In spite of these comments there was general agreement that the issue is, indeed, critical and that the engineering community would welcome a lengthier exposition by Dr. Zamrik, clarifying the definitions and the differences between modeling, curve-fitting, and mathematical formulation; elaborating on short-term versus long-term, and microscopic versus macroscopic, aspects of material behavior; and discussing the relative responsibilities of the designer and the design procedure. An assessment of the roles of inservice data and NDT data for curve-fitting would also be welcomed.

In support of the issue champion's position, a reviewer pointed out that for long-term applications modeling is always necessary since it is impossible to generate sufficient long-term laboratory data. He felt that the question should not be whether a model should be used but, rather, which model or models are appropriate and what sort of criteria should be applied in the selection of these models.

Another argument received in support of the champion's position was that curve-fitting is expedited by computers, which permit evaluations of variabilities in the assumed limits of the relevant parameters. Such evaluations enable curves to be extended beyond the upper and lower limits of proper operation to show where the assumptions fail.

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ISSUE NO. 3

NEW MATERIAL PROPERTY DATA: TERMINAL VS. INCREMENTAL TESTS

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Dr. Esztergar received his education at the Technical University of Hungary and came to the United States in 1957. He has been associated with Babcock & Wilcox, Kaiser Engineers, and General Atomic as well as in private practice (since 1971). He has had much experience in the development of new analytical methods and ASME Code requirements.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Traditionally the design codes evolve by a historically iterative process, alternating between design procedures that were deemed overly conservative and inadequate. When no failure occurs for a good length of time, a design code may come under criticism as being too conservative or uneconomical. At the other extreme when too many failures occur, the code is then extensively revised to eliminate any deficiencies associated with costly failures. These two extreme conditions of failure or no failure serve as the bounds within which a design code is fine-tuned. The phenomenon of failure becomes the driving force that causes a change in the design procedure.

The same driving force is also at work in the area of the accumulation of new material property data and the formulation of acceptance standards. Instead of observing the failure of the actual component or structure, a test specimen is usually involved in providing the failure information. For example, many acceptance standards are based on "proof test" methods, which supply data on the material behavior of a component by measuring the tensile strength, creep-rupture strength, total elongation, reduction-in-area, etc., of a series of test specimens. These methods usually call for uniaxial specimens and the data consist of stress, ductility, elapsed time at the terminal failure (separation) of the specimen. Fatigue data are generated in a conceptually similar way: uniaxial specimens are cycled under constant stress or strain amplitudes until a separation of the test piece is observed. For brevity, we shall call these tests "terminal tests."

Because of new safety and economic concerns, current design requirements demand a broader interpretation of what constitutes failure. In addition to physical separation, leakage or collapse of a component, potential hazards caused by partial impairment of function, reduced system availability, and even a lack of predictability of performance have all become part of a new definition of failure. Parallel to safety-related failure conditions, the economic considerations introduce in the design specifications several new items such as (a) long-term durability, (b) reliability, and (c) maintainability, with specific numerical limits that function in the design evaluation as failure conditions.

Consequently, the design procedures must prescribe an evaluation of the stress, deformation, and damage states prior to the so-called terminal failure state of a product. This practice requires the evaluation of incipient or partial damage conditions, since the design has to satisfy not only the maximum loads but also the limits on progressive deformation for a variety of load sequences, transients, intermediate load levels and even unloaded configurations. The emphasis has therefore shifted from a failure due to a single, well-defined "maximum load" to a new "failure condition" corresponding to some specified maximum permissible partial damage. The terminal failure type of tests, or simply, the terminal tests, which supply data on 100% damage for a particular loading sequence, is now inadequate.

Given that shift of emphasis, we observe that the current design methods rely on empirical relations for the evaluation of partial damage. As a rule, partial damage is not physically measured per se, but is defined as an arbitrary fraction of the terminal failure condition, even though it is well known that different loading histories for a fixed test procedure can result in different partial damage states. (This is so because the terminal failure state as well as the stress state at the partial loading conditions are history-dependent). Therefore a large number of tests are required to supply the information for even a partial justification of the empirical damage correlation methods. When the number of tests become prohibitively large, a small number of tests are usually used with the uncertainties reflected in the use of large safety factors. This approach penalizes some designs, imposes the cost and time burden of essentially irrelevant test programs on the designers, and promotes, worst of all, a false sense of security.

The issue therefore is: What test types can be substituted for the costly and inefficient terminal failure tests to supply direct measurements of incremental damage progression? What tests can measure directly the interactions of the incremental damage processes and environmental effects? What tests are adequate to supply proof of safety and reliability of the design procedures for the evaluation of damage accumulation under complex cyclic load and time dependent deformation histories projected for 30-40 years of design life?

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

The ASME Code has been a valuable guide to engineers, designers, regulators, funding agencies, etc. for the manufacturing and operation of pressure vessels, piping, pumps, and valves. The increasing demand by the consumers on long-term equipment reliability and public safety requires a constant updating of the state-of-art of design and fabrication, which in turn requires the extension of the data and available design procedures beyond the proof of adequacy at the time of commissioning the equipment. History dependent analyses for projected service life histories have been added to the traditional design analysis requirements,but corresponding material data are not supplied by the standard proof test methods. Test procedures are to be developed also for the demonstration of the adequacy of the extrapolation methods. It is important that ASME retains the leadership in the process of updating the design standards and develop the material data base that responds to the new requirements.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

Currently available procedures of life prediction can be used reliably for failure evaluation when the flaw evaluation techniques using linear elastic fracture mechanics methodology are applicable. The extension of these techniques to elevated temperatures, environmental effects, and cyclic conditions requires modeling the defect creation, damage interaction and damage accumulation processes, which are needed to define damage threshold, crack growth under inelastic conditions and synergistic interaction effects that are essential for reliable extrapolation. This can be accomplished by isolating the microstructural changes that initiate and promote crack growth through intergranular and transgranular processes.

In addition, theory and testing techniques are available to calibrate the competing thermally and cyclically activated void generation and crack growth rates but these require extension into multiaxial and rotating stress conditions. The available laboratory techniques of non-contacting and dynamic strain measuring methods, assisted by image enhancement and signal processing methods (already routinely used in space technology) need to be adopted for industry-scale testing procedures. These techniques make possible the generation of data that are representative of the "mission" requirements and reduce the overly broad scatter bands of general proof test results. The cost advantage of improved statistical information for long term extrapolation offsets the initial cost of the new testing procedure.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

The standardization and general acceptance amongst designers, analysts, material suppliers, and regulators require extensive quantitative verification of the new test methods of independently generated data to establish the statistical variability and isolation of spurious environmental or systematic equipment effects under routine testing conditions. The necessary inter-laboratory tests, round-robin tests, screening tests, etc., can be accomplished only by cooperative programs under the guidance of committees of professional societies and other forums of impartial evaluation.

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[5] Raj, R., and Min, B.K., "The Effect of Cycle Shape on Creep-Fatigue Interaction in Austenitic Stainless Steels," ASME Paper No. 78-PVP-89, ASME, New York (1978).

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[19] Prof. Symp. on Fracture Mechanics, ONR-G. Washington Univ., Washington, DC, Sept. 1978.

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

Structural Mechanics in Reactor Technology (SMiRT) 6, Paris, 1981.

Fourth International Conference on Pressure Vessel Technology, ASME, London, 1980.

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8. ISSUE CHAMPION'S POSITION

It is the position of the author that a rational design of structures for service life many times longer than the extent of the possibly largest database, requires modeling and extrapolation techniques based on measurable damage rate and damage accumulation theories, that can be tested within reasonable length of time. Incremental damage measurements are needed rather than more test data of the same terminal failure type, that already has been proven inadequate for sound extrapolation of the time and history dependent effects. Instead of relying on undefinable "conservative" safety factors, the new approach should be aimed at the functional isolation of the microstructural damage mechanisms so that the safety factors can be assigned to the damage components on the basis of the relative importance of the interactive processes for the particular application. Often excessive reduction factors are applied to cover all applications and all possible combinations of the damage processes. It is suggested here that new tests and partial damage models be used that are specifically testable and can be adopted for design on the basis of damage rate extrapolation, rather than continuing the reliance on fractions of complete, 100% damage, obtained by acceleration of the tests. These tests reach the terminal failure state within reasonable time limits, but distort the damage processes and obscure the true margins of safety.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

The material database used in the current design practice provides values of the traditional strength properties (tensile, yield, endurance, etc.) which are measures of the terminal failure state, defined as 100% damage. The safety standards and reliability requirements necessitate the evaluation of partial damage states and their extrapolation to long term service conditions that are inaccessible to proof test procedures. Direct measurements of partial damage and reliable damage accumulation models are needed for updating the life evaluation methods. Laboratory techniques to supply the necessary new data are already available and need to be adopted for industrial use.

An example to illustrate the need for new material database is provided by the present state of creep-fatigue analysis. The initiation and propagation of cracks due to cyclic loading combined with time-dependent creep damage is a potential failure mode in many types of structures operating at elevated temperatures. The current design methods separate the total damage into cycle- (strain range) dependent and time- (creep and relaxation) dependent components, on the basis of partial "life fraction" evaluation of the "pure" fatigue tests and "pure" creep tests. The design criteria are defined in terms of limits on the linear sums of the life fractions. This linear summation of fictitious life fractions is a method widely used because of its basic simplicity. The demonstrated inaccuracies of the method due to history and load path dependent interactions of the damage mechanisms are expected to be compensated for by very large safety factors. These are excessive for applications where the interactions are slight and are not safe enough in temperature and loading combinations where the interactions are strong. The relative strength of these processes can be established by measuring the void generation and crack growth rates under loadings comparable to service conditions, rather than terminal failure tests under exaggerated loading and temperature conditions. It is well known that under the latter conditions, damage accumulation is accelerated but the interaction mechanisms are distorted.

10. CONCLUDING REMARKS

Sophisticated constitutive theories and advanced computer methods are routinely used in the design analysis of components in elevated temperature service. The material data used in the life evaluation procedures, however, still have to be extracted from endurance and terminal failure data generated by proof test methods. Incremental damage measurements are more economical than the traditional test methods because the former can provide the new database for developing mathematical models of incremental damage which, in turn, permit a better utilization of the advances in analytical capabilities. Moreover, these models can assist in the verification of the new design procedures for critical components in long-term service.

SUMMARY OF COMMENTS*

Jeffrey T. Fong, Co-Editor

There were many comments on this controversial issue regarding the cost-effectiveness of the champion's position, namely, to supplement terminal failure tests with incremental damage measurements for the purpose of satisfying the incremental damage limits specified in the design codes. It would be useful to the reader, as commented by one reviewer, if the champion would include in his final manuscript the extension of the example detailing the long-range gain of his approach vs. the inadequacies of the present practice. Apparently, several reviewers were not convinced that with more incremental tests, there would be more understanding and less failures. One reviewer complimented the champion for his far-sightedness in proposing a radical change in material testing, and argued that the champion's position would have been stronger had he introduced a parallel development in mathematical modeling.

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ISSUE NO. 4

VARIABILITY OF DATA: STANDARDS FOR APPLICATIONS

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Mr. Swindeman received his B.S. in 1955 and his M.S. in Metallurgy in 1957 from the University of Notre Dame. He worked in the Large Steam Turbine Division of General Electric and joined the Metals and Ceramics Division of Oak Ridge in 1957. From 1957 to 1961 he studied high-temperature creep and fatigue behavior of pressure boundary materials for use in the Molten Salt Reactor and High-Temperature Gas-Cooled Reactor. He was assigned to the Australian Atomic Energy Research Establishment from 1961-1963 after which he returned to ORNL. Since 1970 he has been involved with the development of materials data and constitutive equations needed for the inelastic analysis of breeder reactor components. Recently he has been assisting in the management of materials research programs sponsored by DOE in support of direct coal liquefaction.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Variability is inherent in materials data. The sources for variability are known and can be attributed to chemistry, thermomechanical treatment, and sampling methods including measurement errors. Material specifications are based on the knowledge of the factors that produce variability and are designed to assure that the materials within a grade will exhibit properties within a certain acceptable range. It is possible to produce a material whose properties fall within a desired grade by proper manipulation of the known sources of material variability. However, it is not always clear to the user what factors were manipulated nor where the fabricated material ranks relative to the lot-to-lot distribution of a given property within the material grade.

Those physical properties controlled primarily by chemistry, such as thermal conductivity, elastic moduli, and coefficient of thermal expansion, generally exhibit small coefficients of variation, say 2 percent or less.[1] More than likely, the physical property data used in pressure vessel design represent "average" or "typical" behavior rather than "minimum" properties. Mechanical properties, on the other hand, are very sensitive to the thermomechanical variables associated with fabrication methods and can exhibit large lot-to-lot variations. Further, design data are usually based on minimum rather than average expectations. This leads to problems, since the typical coefficients of variation for such properties as the yield strength and creep-rupture strength may exceed 20 percent.[2,3] As an example, Fig. 1 shows yield stress vs. temperature data for type 304 stainless steel. Included in the figure is a curve that represents the "minimum expected yield strength" for type 304 stainless steel in the mill-annealed condition. Nearly all of the data that fall below the line were derived from tests on reannealed material. This is an acceptable fabrication procedure. Nearly all of the data that exhibit very high strength levels were derived from moderately cold worked material, say an equivalent of 10 percent uniaxial strain. Again, this amount of strain is acceptable in fabrication procedures. This sort of variability creates problems in selecting the data base needed to establish design stress intensity limits. The use of the reannealed data will produce design stresses that are much too low relative to the actual strength of a typical fabricated material. Similar problems occur for other austenitic stainless steels,[3] castings,[4] and for low alloy steels that undergo post weld heat treatment.[5] One method to resolve the problem might be to subdivide the grade and provide a set of

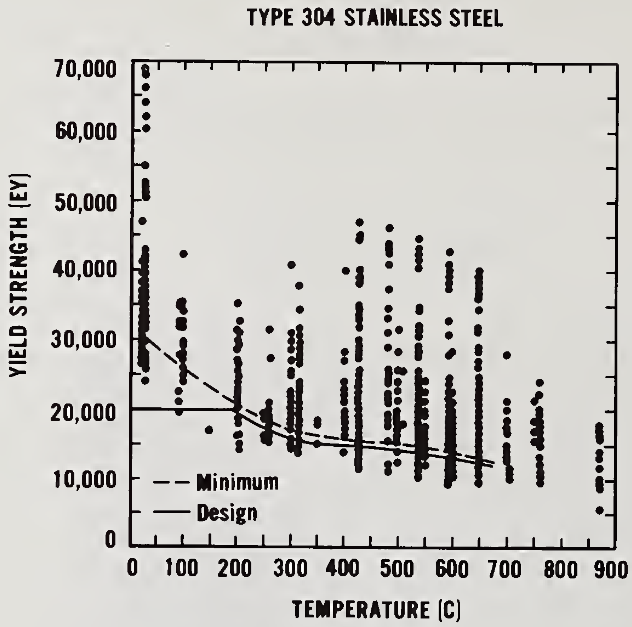

Fig. 1 Yield Strength vs. Temperature for Type 304 Stainless Steel. Data include mill-annealed, laboratory reannealed, and base metal under cladding.

stress limits for each subdivision. However, if this method, or some other method, is chosen, we are faced with the problem of determining the properties of the material in the fabricated condition and can no longer depend solely on relationship between the purchase specification and the published design stress and strain limits for the grade. This dilemma leads us to the critical issue regarding material variability: Is it practical to perform short-time characterization tests on a fabricated material, classify the material relative to the distribution of properties exhibited by the grade, then make a judgment as to what stress and strain limits are most appropriate? To answer this question requires knowledge about the mean and distribution of the property data about the mean. For long-time design the extrapolation of short-time data trends is also required.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

There often exists a strong economic incentive to optimize the material property data developed for design so as to provide a conservative margin of safety yet utilize the full potential of an alloy grade. Generally, as material specifications for a grade become tighter, production costs increase; hence, we can always expect resistance to tight specifications and subsequently, a wide gap between the minimum strength, ductility, or toughness properties provided as design data and the average properties characteristic of a grade. Further, the methods used to establish design data and failure criteria are linked to both materials property and component experience, as shown in Fig. 2, and the use of rigorous statistical methods to establish design data has not been commonplace. Once more, in some design situations a "minimum property" will actually produce a less conservative stress evaluation than will the use of the average property. An example is the use of the minimum stress to describe yielding in a creep-fatigue analysis. For such situations the use of realistic data representing the mean and distribution of properties about the mean can often result in economic benefits derived from the optimization of design procedures, material selection, and fabrication methods.

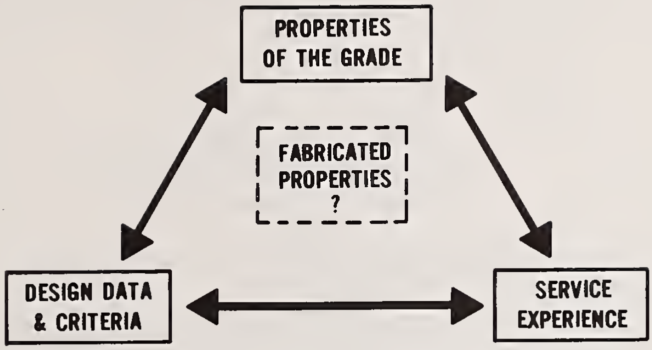

Fig. 2. Should the Actual Fabricated Properties be Used When it is Necessary to Optimize a Design Relative to Economy, Reliability, or Safety?

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

Many new tools, concepts, and methods have developed that will help to resolve the key issues with respect to variability of data. First, melting, fabrication, and other production procedures have become more automated in recent years, and quality assurance has been greatly improved; hence, it may be easier to reduce the lot-to-lot variability. Second, new chemical analysis techniques and material identification methods have been developed that enable the users to identify reasons for variability or predict behavior more accurately. Along the same line we now know more about the role of alloying elements and heat treating procedures in influencing the final material properties. Third, revised and new testing practices have been developed that help to reduce the lab-to-lab variability associated with experimental testing procedures. Fourth, data storage and retrieval centers have been developed that will allow more comprehensive bodies of data to be stored and examined. Further, improved computational procedures have been developed for statistically treating these large bodies of data and statistical theories of decision making have been developed.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

The extent of multi-party collaboration needed to resolve the issue depends to some measure on the specific design situation. A typical problem for example, might be the suitability of a material for long-time high-temperature pressure vessel service under creep-enhanced ratchetting conditions. Studies on this subject were recently performed by Corum and co-workers.[6,7] Mechanical engineers, metallurgists, data processors, and statisticians collaborated to quantitatively establish the variability of the flow stress, creep law, and fatigue resistance for type 304 stainless steel. Predictions were made regarding how the ratchetting rate, creep, and fatigue damage were accumulated as functions of the variability in each mechanical property. It was found that low flow stresses and high creep rates promote creep ratchetting and creep damage but suppress fatigue damage. Fig. 3 represents some typical findings. Depending on the severity of the problem and design limiting property, it may be possible to alter fabrication methods or change the material specifications.

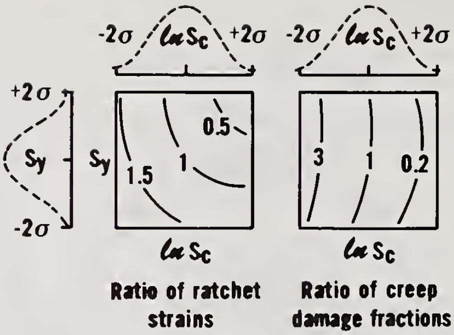

Fig. 3. Contour Maps Showing How the Ratchet Strain and Creep Damage Fraction at 10 cycles are influenced by variability in the yield strength (S_y) and Creep Strength (S_c) in a typical pipe ratchetting situation. Contour lines are normalized relative to "average" material.

5. SOME RECENT CONTRIBUTIONS

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Properties of Austenitic Stainless Steels and Their Weld Metals (Influence of Slight Chemistry Variations), edited by C. R. Brinkman and H. W. Garvin, Spec. Tech. Publ. 679, American Society for Testing and Materials, Philadelphia, 1979.

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V. K. Sikka et al., Residual Cold Work and Its Influence on Tensile and Creep Properties of Types 304 and 316 Stainless Steel, Nucl. Technol. 31: 96-114 (October 1976).

Cast Metals for Structural and Pressure Containment Applications, MPC-6 edited by G. V. Smith, American Society of Mechanical Engineers, NY, 1979.

H. P. Offer et al., The Effects of Remelting and Heat Treatment on 2 1/4 CR-1 Mo Steel Elevated Temperature Tensile Properties, pp. 195-220 in Effects of Melting and Processing Variables on the Mechanical Properties of Steel, MPC-6, edited by G. V. Smith, American Society of Mechanical Engineers, NY, 1977.

W. K. Sartory and W. J. McAffee, Materials Heat-to-Heat Variability Study: Part II--Analysis of the Effect on the Conservation of Current Inelastic High-Temperature Design Procedures, ORNL-5605 (December 1979).

J. M. Corum et al., Thermal Ratchetting Tests of Type 304 Stainless Steel Pipe: Specimens TTT-1 and TTT-2, ORNL-5386 (June 1978).

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

International Conference on Engineering Aspects of Creep, Sheffield, England, September 15-19, 1980.

Symposium on Mechanical Testing for Deformation Model Development, Bal Harbour, Florida, November 1980.

7. SOME CONTACTS FOR MORE INFORMATION

NUCLEAR SYSTEMS MATERIALS HANDBOOK
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8. ISSUE CHAMPION'S POSITION

The need to consider lot-to-lot differences in the design of a structure is a judgment that must be made by the engineer and based on the need for economy, reliability, and safety. Having determined that such a need exists, the issue champion believes that it is possible for the engineers to perform characterization tests on a fabricated material and use this information in conjunction with the known variability for the same grade of material to improve the product from several points of view. There are important problems that must be solved to develop the methodology. These include (1) the development of testing methods and statistically planned test matrices, (2) the development of statistical treatment procedures to charaterize the lot-to-lot distribution of pertinent properties, and (3) the development of suitable models that relate data to experience. In the coming decade it should be possible to develop a methodology that will satisfy these requirements.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

Optimization of design requires knowledge of the important material properties of the specific lot relative to the mean and variability about the mean of the grade. Indeed, data collected on a specific lot are interpretable only if the analyst can relate the data to the behavior of a grade. There is a need to develop a methodology that will enable the user to estimate the performance of a fabricated material from a few laboratory determinations.

SUMMARY OF COMMENTS*

Jeffrey Fong, Co-Editor

This paper generated a large number of comments which may be summarized as follows:

(a) Alternative Issues: Perhaps the issue should be narrowed to a study of QA or some specific test methods. One reviewer wished to address the narrow question of the use of minimum property in design as a legitimate approach to contain variability of data.

(b) Economic Issue: Specific examples on the economic benefit of the champion's position were missing. One reviewer requested that the champion should include an example in the final manuscript to strengthen his argument.

(c) New Tools: One reviewer wised to add the lot-centering analysis technique as a new tool. Another wanted to include current advances in a statistical theory of decision-making.

(d) Institutional Issue: One reviewer wondered out load whether it would be feasible to adopt the champion's position without first checking with members of the ASME Boiler and Pressure Vessel Code Committee. The reviewer agreed with the champion that the time had come for such an initiative, but its implementation would require a strong liaison between the Materials and Fabrication Committee and the ASME Boiler and Pressure Vessel Code Committee.

(e) Measurement Error Reporting and Analysis: One reviewer complained that the champion's analysis of data variabilities excluded a discussion on the measurement errors associated with all laboratory or inspection processes.

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

*Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vesels and Piping Division, and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

COMMENTS BY SYMPOSIUM PARTICIPANT(*)

(Use Back Sheet if necessary)

Submitted by____________________ Affiliation____________________

Address______________________________ Phone_______________

(*) Symposium participants are encouraged to use this sheet to comment on the issue paper as presented in this preview and discussed during the August 1980 meeting. Please send the completed form to: Mrs. Bette Johnson, Managing Editor, Proc. ASME Symp. on Critical Issues, c/o National Bureau of Standards, A302 Bldg 101, Washington, DC 20234, before Sept. 15, 1980.

Comments (Continued):

N O T E S

NOTES

Chapter 3 Fabrication, Inspection, and Operation Issues

Issue 5 On-Line Monitoring of Critical Components to Improve Reliability

Issue 6 Upgrading Welders' Skill and Educational Level: How & Why

Issue 7 Reliability of Nondestructive Evaluation

Issue 8 Characterization of the Subjective Component of Inservice Data

Reprinted from National Bureau of Standards Special Publication 588, Critical Materials and Fabrication Issues for Pressure Vessels, Piping, Pumps, and Valves, Jeffrey T. Fong, Ronald C. Dobbyn, and Leonard Mordfin, Editors. Issued 1980

ISSUE NO. 5

ON-LINE MONITORING OF CRITICAL COMPONENTS TO IMPROVE RELIABILITY

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Dr. Egan is the President and Technical Director of Aptech Engineering Services, a Palo Alto based consulting engineering company. He has a Bachelor of Engineering degree from the University of Canterbury in New Zealand and a Ph.D. from the London University. He spent seven years at the British Welding Institute and Laboratory in Cambridge, England. He spent five years with an engineering consulting company in California. He is a member of the American Society of Mechanical Engineers, the American Welding Society, and the British Institution of Mechanical Engineers.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Current methods of assessing component and structural behavior, particularly for those components that experience a wear-out phase (be it the onset of cracking or material property degradation) are based on predictions made from small, short term, laboratory tests. In some cases account is also taken of the field experience data base. Experience with structural failures indicates that this approach has not been completely successful, particularly where we are required to predict corrosion mechanisms such as stress corrosion cracking, general corrosion and corrosion fatigue.

More recent data on the fracture behavior of irradiated pressure vessel steels also show that we may tend to self-impose uneconomically conservative design limits if a reliable measurement of actual property degradation is not available. A lack of appropriate predictive tests and very conservative property limits can lead to unfavorable economic implications.

As a complement to predictive testing on line monitoring can provide several unique benefits:

More information will be available so that rational decisions on plant operability can be made.

The demand for more information (from both operations engineers and the public) can be satisfied.

In the long term, a better definition of operating conditions (load cycles, etc.) can be obtained which can be fed back into the design specifications. Rational decisions regarding maintenance scheduling, inspection intervals and inventory planning can be made.

In addition to these benefits on-line monitoring can also provide a knowledge of the operational status of plant components such as pumps and valves. The performance of these components can have a marked impact on overall plant integrity and reliability.

Perhaps the benefits of on-line monitoring are obvious and it only remains for us to endorse the use of additional monitoring, and wait for this to happen. Unfortunately, such an ideal state of affairs does not exist. With increasing costs for energy production any additional capital outlay will be viewed by production people as unnecessary. The most useful thing that we can do in the short term is to demonstrate the benefits which drive from increased on-line monitoring of critical components.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

This issue is important to ASME and the engineering profession because the successful implementation of on-line monitoring will provide useful information to aid decision making and back up engineers' judgments.

Since it is a federal requirement in most states for non-nuclear plants that the design of pressure vessels, piping, pumps, and valves is carried out under ASME code rules, this issue is also important to ASME code committees. The necessary feedback to enable code committees to up-date rules, procedures and predictive methods will become readily available through the application of on-line monitoring systems.

In the long term, on-line monitoring and the early flagging of structural distress can result in major economic benefits since for the most part unanticipated failures would be eliminated. In addition, responses to public questions such as "Is it safe?" will be supported by established and credible data bases derived from monitoring systems. For this to be a realization, however, it will be necessary to develop monitoring systems which can identify the particular mechanism which leads to a loss of structural integrity. In addition, more reliable methods of monitoring component status are required. It is the development of these systems which is the focus of this critical issue.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

Standard monitoring systems for such things as strain, pressure, flow rate, etc., are available and are commonly used for on-line monitoring of these basic parameters. Before on-line monitoring of critical components can be achieved to increase plant reliability it will be necessary to define engineering models which describe the failure mechanisms against which we need to design. From these engineering models, the variables which can be measured will be defined. Instrumentation can then be developed to measure these variables and to provide a real time output of the appropriate diagnosis. This means that the work in the 1980's will need to concentrate on (1) development of engineering models to describe .ppropriate failure mechanisms, (2) definition of variables that need to be measured, (3) development of software to evaluate measured variables and to indicate the integrity of the component, structure or system as a function of time, (4) advances in the state-of-the-art in monitoring instrumentation and (5) better description of fault sequence and consequence for operational errors.

As an example, with development of real time X-ray imaging systems, it would be possible to avoid the repair of a defect discovered in service until a convenient outage was reached. If the failure of the component was controlled only by flaw size and shape (that is, with constant toughness and predictable stress levels) the flaw could be monitored to some size less than the critical flaw size to allow an orderly repair scheme to be developed. Further, if a data base of plant transients exists (from on-line monitoring), it would be possible to determine the expected remaining life.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

Multi-party collaboration is of paramount importance in resolving this issue since R & D effort required to resolve the issue has to be balanced against the limitations imposed by production needs. In addition, the cost of such on-line monitoring will have to be taken into account with (1) the cost of providing estimates of structural integrity by predictive testing and (2) the cost of anticipated failure.

Although the benefits of on-line monitoring can be demonstrated in an engineering sense, and we may wonder why much more on-line monitoring is not used, on-line monitoring will only have wide scale applications if it can be demonstrated that an economic benefit will result to plant operators. It will be easier, of course, to demonstrate this benefit for components and systems which have either (1) very high costs of failure or (2) completely unacceptable consequences of failure (such as release of radiation). The question of which critical components would show most benefit if on-line monitoring was applied needs to be addressed.

Much of the future work in this area, in the short term (1-4 years), will be focused on determining which structures, components, etc., could benefit most from fully instrumented on-line monitoring with feedback to flag structural distress and operational malfunctions. As a corollary to this effort it will be necessary to define the reliability of on-line monitoring systems because for large plants, a "false call" can result in costs comparable to a real outage. (Downtime costs from lost production usually outweigh repair costs.)

Multi-party collaboration is also important to establish the credibility of the data base that will result from on-line monitoring systems. To be most effective, these data bases will need to be supported by ASME and the engineering profession.

5. SOME RECENT CONTRIBUTIONS

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Hartman, W. F., Acoustic Monitoring of Relief Valve Position, EPRI Report NP 1313, February 1980

Cross, N. O., Display and Analysis of Real Time Data From Acoustic Emission Tests of Pressure Vessels, Exxon Research and Engineering Company, Florham Park, New Jersey, presented at the Second Acoustic Emission Symposium, Tokyo, Japan, September 1974

Bently, P. G., et al., Acoustic Emission Test on a 25 mm Thick Mild Steel Pressure Vessel with Inserted Defects, Jnl. I. Mech. E., June 1976

Kassen, W. et al., BWR In-Plant Corrosion Measurement, Nuclear Water and Waste Tech. Report, NWT 137-3, February 1979

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

EPRI Research Project RP824 - On-Line Vibration Diagnostics For Power Plant Machinery (to be published in mid-1980)

7. SOME CONTACTS FOR MORE INFORMATION

Gordon Shugars
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Steve Sawochka
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8. ISSUE CHAMPION'S POSITION

At the present time little use is made of on-line monitoring of systems to update structural integrity or to establish a knowledge of component operational status although some limited instrumentation has been employed in the power industry to update cumulative usage factor for evaluating fatigue performance. Process efficiency and transients are also sometimes monitored.

To minimize unanticipated plant outages (which are costly) and to allow orderly planning for maintenance, inspection, repairs and inventory control of parts, more use must be made of on-line monitoring. In addition, errors in the interpretation of the plant condition are eliminated.

It is the Issue Champion's position that: a move to on-line monitoring for optimal control of critical components is already long overdue, and an agressive campaign must be mounted to demonstrate the economic advantages of such monitoring. Furthermore, manpower allocation, training and education will also need to be addressed. As a first step, ASME could undertake the documentation of the existing experience data base.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

A. Critical components, where either (1) the cost of unanticipated failure is very high or (2) the consequences of failure are completely unacceptable by society, will benefit from on-line monitoring since with the correct interpretation and diagnosis unanticipated failures will be eliminated.

B. Since it is the nature of things to wear out and fail, this does not imply that failures will be completely eliminated, but repair and replacement can be planned in an orderly manner ahead of time.

C. For each group of similar components, structures, or systems continued on-line monitoring will provide, in the long term, a statistically significant data base which can be used to avoid failures completely in these systems.(*)

D. Development of theoretical (and often tenuous) predictions of structural integrity will continue; however, the data base which results from on-line monitoring will provide experimental justification for any methods which are proposed. The data could be collected and controlled by ASME.

E. Furthermore, these methods of predicting structural integrity will not become part of an ASME code procedure. Rather, the parameters to be measured and limits at which some action must be taken will be provided as guidance in the code.

F. Maintenance scheduling, definition of inspection intervals and inventory planning will be based on credible data bases which result from on-line monitoring.

SUMMARY OF COMMENTS(**)

Jeffrey Fong, Co-Editor

This paper has generated many favorable comments regarding the timeliness of the subject and the bold claims implied in the champion's position. A central question that was raised by a number of reviewers related to the possibility of false alarms and the associated cost in answer to those alarms. Another reviewer would like to see a concrete example and a cost-benefit analysis before becoming convinced that there would be merit in this expensive undertaking. One reviewer also questioned the notion that the parameters of current measurement technology would indeed be adequate to give a warning with a reasonable degree of accuracy. Perhaps, he added, a demonstration over a three to five year period would be useful.

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

(*)In the practical sense, it is not possible to avoid failures completely; however, experience with risk analysis of critical components suggest that failure rates lower than 1×10^{-6} per year are acceptable to society even if the consequences of failure are high.

(**)Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division, and selected experts invited by the symposium organizing committee to assure a fair and adequate review.

COMMENTS BY SYMPOSIUM PARTICIPANT(*)

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Submitted by__________________________Affiliation____

Address____Phone______________________

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Comments (continued)

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ISSUE NO. 6

UPGRADING WELDERS' SKILLS AND EDUCATIONAL LEVEL: HOW AND WHY

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Mr. Webb received his B.S. in Metallurgical Engineering from Vanderbilt University in 1969 and his M.S. in Metallurgical Engineering from the University of Connecticut in 1974. He is responsible for selection of materials of construction, welding, nondestructive examination, failure analysis and corrosion technology for Badger America, Inc. and is currently a member of ASM, AIME, NACE and ASTM. In 1977 and 1978 he won awards for papers submitted to the Lincoln Arc Welding Foundation.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Welding is a very specialized trade. High quality welding is essential in any welded structure so that the integrity requirements of the applicable design code are fulfilled. Design codes require that most welded joints meet certain strength requirements based on anticipated loading conditions. These strength requirements are normally met by specifying the type of joint design, e.g., fillet or full penetration, and the size of the weld, e.g., size of fillet leg plus length of weld metal deposited. In addition to the type and size requirements, welds must also meet certain quality requirements. Furthermore, recent advancements made in materials, such as HSCA and dual-phase steels, and in welding procedures require an increased level of skill and knowledge on the part of welders to minimize welding defects. These advances, along with greatly improved inspection techniques, make upgrading welders' skills and education level extremely urgent.

The critical issue here is "upgrading welders' skills and education level as it applies to the fabrication of pressure vessels, piping, pumps and valves: how is the upgrading to be accomplished and most importantly, why an upgrading is required."

2. IMPORTANCE OF ISSUE TO ASME AND BEYOND

The primary importance of the issue "Upgrading Welders' Skills and Education Level: How and Why" is that on a national basis the overall quality of welding would improve.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

The major tool for resolving this issue in the 1980's will be the establishment of a working group within a technical organization, such as The American Welding Society, to create a program whereby welders' skills and education levels are upgraded. In addition, improvements in metallurgy, development of new welding procedures and implementation of quality control engineering should be instrumental in the resolution of this issue.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

If the goals of upgrading welders through the establishment of a national program are to be realized, then a cooperative effort between all affected parties is the key element to success. By bringing together representatives that reflect the various engineering concerns such as design, fabrication, inspection, R&D, and professional organizations, program standards and criteria that are both fair and realistic can be established.

5. SOME RECENT CONTRIBUTIONS

Bush, S. A., Zero Weld Repair Is Achievable, Welding Design and Fabrication, Nov. 1979, pp. 64-68

Training, Flux-Cored Wire Get Rail Cars Rolling, Welding Design and Fabrication, Nov. 1979, pp. 78-80

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Bollis, W. H., DeHaven, C., and Baker, R., Training of Oxyacetylene Welders to Join Mild Steel Pipe, Welding Journal, Vol. 56, No. 4, pp. 15-19, April 1977

Dermott, R. G., Goal: Crackfree Welds in High-Strength Steels, Welding Design and Fabrication, Nov. 1976, pp. 61-73

Barckhoff, J. R., Checklist: Better Welds, Higher Productivity, Welding Design and Fabrication, Oct. 1976, pp. 84-88

Procedural Handbook of Arc Welding, 12th Edition, Lincoln Electric Co., June 1973

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

[None known at this time.]

7. SOME CONTACTS FOR MORE INFORMATION

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8. ISSUE CHAMPION'S POSITION

To upgrade welders' skills and education level a national welder certification program should be created. This program would differ from the ASME Section IX welder qualification in that it would emphasize welder education and skill development. This program should be established and administered by The American Welding Society (AWS) and should assign personnel into various levels or categories. The program goals and program criteria for assigning personnel to categories or levels should be defined by AWS in collaboration with other technical organizations, such as ASME, WRC, ANSI, ASTM, and the Welding Institute. Furthermore, the program should contain provisions whereby other organizations, such as contractors or independent consulting laboratories, would be allowed to develop programs to certify welders that meet the AWS requirements.

An example of a welder classification program and the requirements for each category is shown in Table 1. (It should be noted that this is only an example.) In general, each category requires that personnel satisfy certain requirements based on education, training and work experience. These requirements should be flexible in that some substitution, from one area of expertise as partial fulfillment of others, should be allowed. Take for example, a person with an excess of work experience. That person should be allowed to substitute this excess to partially meet the education or training requirements.

TABLE 1

Recommended Training and Experience Minimum Levels

	Training (Hrs)		
	Level A	Level B	Level C
Completion, with a passing grade, of at least 2 years of engineering or science study at a university, college, or technical school.	16	40	80
High school graduation, diploma or its equivalent	24	60	100
Grammar school graduation or demonstrated proficiency or additional training	80	100	140
	Work Time Experience (Months)		
All educational levels as listed above	6	12	24

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

Growing demands for safety, costs, and technology require higher quality welds. Also, recent advances in materials, welding procedures and inspection techniques require that welders have a higher level of skill and knowledge to minimize welding defects. One possible method of producing higher quality welds is to upgrade welders' skills and education level by implementing a national certification program.

Another reason for establishing a national certification program is to provide the welder with a better understanding of welding processes, welding procedures, materials and design codes. Frequently, welders are not even familiar with Section IX of the ASME B&PV Code and often lack a basic understanding of the weldability of various base materials. This lack of fundamental information could be supplied through training programs consisting of formal lectures and applied laboratory/shop experiments.

Finally, by establishing a national qualification program, the variability in welders' ability should be better defined. Many companies establish training programs to fulfill specific in-house welding needs. In addition, various commercial suppliers of welding products conduct excellent training programs. While both of these concerns have programs that are far in excess of Section IX ASME B&PV Code requirements, there is currently no means of recognizing a welder who has been through a training program from one who has not.

Under today's Section IX qualification requirements, a welder obtains the same certification regardless of education, training and work experience. By assigning welders into various levels or categories based on their background, some of the problems of recognizing various levels of ability/ experience should be reduced. In addition, a national certification program should result in welders being trained to a higher and more uniform level of competency.

As with any program of this nature, the costs of implementation can be substantial. While the actual dollar values are difficult to calculate, a significant amount of the costs should be recovered as the quality of the welders is upgraded, thereby reducing rejection rates. In addition, many fabricators already have training programs established which should require little if any modification to comply with program certification criteria.

10. CONCLUDING REMARKS

The requirements for higher quality welds have increased because of demands for safety, costs and technology plus recent advances in materials, welding procedures and inspector techniques. One area that could result in weld defect rejection rate reduction is the upgrading of welders' skills and education level. One vehicle for accomplishing this improvement would be the establishment of a national multi-level certification program based on increasing amounts of education, training and work experience. By creating such a program, welders should receive improved overall knowledge of welding, thereby becoming proficient in producing high quality welds.

SUMMARY OF COMMENTS*

Leonard Mordfin, Co-Editor

Few, if any, of the issue papers generated as much comment and heated discussion, both pro and con, as did this one. Supporters of the issue champion's position made the point that upgrading the skills and the education levels of welders would be beneficial not only for fabrication, but also for repair, which is often carried out under worse conditions than production welding and with poorer planning, control and supervision.

Dissenters, for the most part, accepted the need to upgrade weld quality but disagreed with the champion's proposed approach. One, for example, suggested that a more meaningful issue would be, simply, "Upgrading the Quality of Welding". In support of this view, there were questions raised about whether weld quality can, in fact, be upgraded by upgrading welders. The high costs of upgrading and certifying welders' skills led others to suggest that weld quality could be upgraded more economically through the use of automatic welding, improved weld joint design, improved materials, and/or instruments to help manual welders control welding processes.

Numerous comments indicated a feeling that welders were being singled out unfairly. Some suggested that what is really needed is an upgrading of the knowledge of welding supervisors or a certification program for welding engineers. Engineers, it was felt, could better utilize some of the new advances in metallurgy and QC engineering. A particularly interesting observation was that early suspicion of welds led to the intensive use of radiography and this, in turn, forced welding to its present state where it is recognized for critical applications such as pressure vessels. A reviewer suggested that the audio-visual course by Hobart, McKay et al should be added to the author's list of references.

END OF SUMMARY

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*Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

COMMENTS BY SYMPOSIUM PARTICIPANT (*)

(Use Back Sheet if necessary)

Submitted by ____________________ Affiliation ____________________

Address ____________________ Phone ____________________

(*) Symposium participants are encouraged to use this sheet to comment on the issue paper as presented in this preview and during the August 1980 meeting. Please send completed form to Mrs. Bette Johnson, Managing Editor, Proc. ASME Symp. on Critical Issues, National Bureau of Standards, A302 Bldg 101, Washington, DC 20234, before Sept. 15, 1980.

Comments (continued)

Reprinted from National Bureau of Standards Special Publication 588, Critical Materials and Fabrication Issues for Pressure Vessels, Piping, Pumps, and Valves, Jeffrey T. Fong, Ronald C. Dobbyn, and Leonard Mordfin, Editors. Isued June 1980

ISSUE NO. 7

RELIABILITY OF NONDESTRUCTIVE EVALUATION

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EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Nondestructive evaluation (NDE) is a term used to denote a variety of inspection methods and techniques that assess the quality of materials, structures, and components without impairing their abilities to perform their intended functions. Reliable NDE, performed during fabrication and in service, can enhance safety, increase durability, improve performance, and reduce the life-cycle costs of pressurized systems and structures. These benefits cannot be realized fully, however, unless the inspection reliability is well-defined and quantified. The critical issue, therefore, is the need for intensive and concerted efforts to characterize the reliability of NDE systems as they are applied to pressure vessels, piping, pumps, and valves.*

The issue is a complex one. No inspection methods will detect all potentially serious defects. The term "NDE reliability," as it is often used, can refer to the probability with which defects of a given size can be detected or, given a defect, to the accuracy with which it can be located, sized, or otherwise described. In a safety context, NDE reliability has been defined as a measure of the ability to discover and to define defects having the potential to cause failure.

NDE reliability depends on a great many factors: the NDE method, technique, and procedure; the equipment, instrumentation, and its sensitivity; the geometry of the defect and its relationship to the geometry of the object in which it exists; the material, its surface condition, and its residual stress distribution; the inspectability of the object, including the environment in which it must be inspected and the access to it; the time available for inspection; and a host of other factors too numerous to detail here. In the present state of the art, however, the factors which sometimes exert the greatest influence on NDE reliability are human factors; motivation, training, integrity, visual acuity, and all of the other factors that shape the judgment of the individual performing the inspection.

*While these applications are consistent with the title of the Symposium, the issue is equally applicable to many other technologies.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

NDE is a key element in quality control programs for pressure vessels, piping, pumps, and valves. It is used for detecting defects that could--if undetected--lead to premature failure. NDE is also used for characterizing defects to permit application of fracture-mechanics analyses and, thus, to guide meaningful decisions regarding repair, replacement, or rejection. NDE is, further, used for measuring or monitoring material properties or parameters such as alloy composition, heat treatment, thickness, residual stress, etc.

Changes in NDE practices that increase its reliability are, of course, desirable. But unless the increase can be demonstrated, quantified, and verified in a reproducible manner there is only questionable justification for amending design, fabrication, or maintenance practices to capitalize on the improvement. NDE with well-characterized reliability, on the other hand, can facilitate retirement for cause rather than by schedule, and can enable safety factors and overdesign to be reduced, leading to materials and energy savings without sacrifice of safety, durability, or performance.

The increased confidence in NDE, which well-characterized assessments of reliability will engender, will discourage designers from specifying smaller allowable flaw sizes (i.e., calling for more NDE sensitivity) than are actually warranted and this will contribute to reduced inspection costs and lowered rejection rates. Similarly, assessments that indicate inadequate NDE reliability will encourage the development of improved inspection procedures.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

There is need for a formal and widely accepted methodology for assessing NDE reliability so that the assessments, for a given NDE system, are reproducible. The reliability of an NDE inspection cannot be characterized to a level of certainty exceeding that with which the NDE system itself is characterized. The NDE system must be definitively and restrictively prescribed and the procedures must thereafter be rigidly followed. The establishment of such rules begins (and only begins) with standards. For the conventional NDE methods that are widely used to inspect a pressure boundary, many of the required standards are available or under development. But for the emerging methods (such as acoustic emission testing and residual stress measurement) and for new methods to assure pump and valve operability (such as vibration signature analysis and wear debris analysis), much standardization work remains to be done.

Characterizing an NDE system includes characterization of the idividuals that perform the inspection. Recent research indicates that the human qualities which determine an individual's capabilities for precise NDE work are only poorly understood, and there is urgent need for psychological and human factors research to put this aspect of the NDE system on a firm footing. At this time it may be impossible to characterize inspectors so that their contributions to NDE reliability are more reproducible, and to always use the same few inspectors for a given type of inspection. For some applications it may be advantageous to automate in order to eliminate the inspector, but dependence on people for many crucial inspections will continue for many years.

The methodology should also guide the statistical analyses and the demonstration programs that are used to establish the reliability of the NDE system. Such programs, whether they address flaw detectability, flaw characterization, or property measurement, must include accurate and independent means (e.g., destructive testing or mechanical sectioning) to verify actual flaw or property values. This has been largely absent, to date, in evaluations of residual stress measurement techniques, vibration signature analyses, and other emerging NDE methods.

Most of the tools needed to carry out the recommended research and to develop the required standards and methodology appear to be available. The need in the 1980's is not for breakthroughs but for commitment, at the highest levels of industrial and government management, to a task that is difficult and complex but also worthwhile. It may well be that events of the past two years have provided the motivation toward this commitment.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

This issue, although critical, is not new and some significant progress in characterizing NDE reliability has already been achieved through multi-party collaboration. The PVRC and PISC test programs are noteworthy examples of this, as are other round robins that have been carried out under the auspices of EPRI, the Air Force, and others. Codes and standards, almost by definition, must be widely accepted as well as technically sound in order to be effective. Collaboration among industry, government,and the standards organizations is absolutely necessary to the development of a methodology for assessing NDE reliability and for establishing that reliability.

The recommended research on human factors will, it appears, require multidisciplinary approaches and substantial levels of support, so multi-party collaboration will likewise be beneficial here, too.

5. SOME RECENT CONTRIBUTIONS

Plate Inspection Programme--PISC (Organisation for Economic Co-operation and Development, Paris, France, November 1979).

W. H. Lewis, W. H. Sproat, and B. W. Boisvert, "A Review of Nondestructive Inspection Reliability on Aircraft Structure," Proceedings of the Twelfth Symposium on Nondestructive Evaluation, pp. 1-16 (Southwest Research Institute, San Antonio, TX, 1979).

Periodic Inspection of Pressurized Components--1978, MEP-99 (Mechanical Engineering Publications, London, 1979).

J. C. Herr and G. L. Marsh, "NDT Reliability and Human Factors," Materials Evaluation 36, No. 13, pp. 41-46 (December 1978).

Nondestructive Evaluation in the Nuclear Industry (American Society for Metals, Metals Park, OH, 1978).

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

S. H. Bush, Reliability of Nondestructive Examination (Battelle Pacific Northwest Laboratories, Richland, WA, in preparation).

Proceedings of the 3rd International Conference on NDE in the Nuclear Industry, Salt Lake City, UT, February 1980 (American Society for Metals, Metals Park, OH, in press).

Proceedings of the Symposium on Eddy Current Characterization of Materials and Structures, Gaithersburg, MD, September 1979 (American Society for Testing Materials, Philadelphia, PA, in press).

Symposium on Ultrasonic Measurement of Residual Stress, Philadelphia, PA, April 1981 (American Society for Testing and Materials, Philadelphia, PA).

7. SOME CONTACTS FOR MORE INFORMATION

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8. ISSUE CHAMPION'S POSITION

Establishing the reliability of NDE inspection systems is more critical, at this time, than improvements in NDE systems that foster small but uncharacterized improvements in reliability. The reliability of an NDE system cannot be established in a meaningful way until the system is well characterized. This will require development of a methodology for demonstration and verification programs that is based on standards, well-defined systems, rigorous procedures and appropriate statistical analyses. Standardization of the newer and emerging NDE methods must be pursued, and research to better characterize the contribution of the NDE inspector to the reliability of the system also merits high priority.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

A. NDE is an essential element of quality control programs for pressure vessels, piping, pumps, and valves.

B. Reliable NDE enhances the reliability of pressure vessels, piping, pumps, and valves.

C. The full benefits of reliable NDE cannot be realized unless the reliability is well characterized.

D. The reliability of an NDE system is best established through multi-party demonstration and verification programs involving well-defined components and procedures.

E. A formal methodology for assessing NDE reliability would promote reproducibility and foster confidence in the assessments.

F. Some of the newer NDE methods, which could contribute to enhanced reliability, are inadequately standardized.

G. Human factors sometimes exert great influence on NDE reliability; these are only poorly understood.

10. CONCLUDING REMARKS

The views expressed in this issue paper were shaped by helpful discussions with many people and by the work of many others. It is a pleasure to acknowledge, in particular, Harold Berger, G. J. Dau, D. G. Eitzen, G. M. Jordan, and E. R. Reinhart.

SUMMARY OF COMMENTS*

Jeffrey Fong, Co-Editor

Support for the designation of this issue as critical, and for the issue champion's argument, was almost unanimous. However, several of the comments which were received merit repetition here.

A view was expressed that characterization of entire NDE systems will occur only when we begin taking a systems approach to solving NDE problems. Only then will it be possible to specify optimum systems. The concentration of R & D on specific system components has been at the expense of insufficient attention to system considerations and the attendant trade-off studies.

This reviewer also warned against placing too much emphasis on upgrading inspector performance since we may be reaching a plateau of what any reasonably trained person can accomplish. It was recommended that we concentrate on developing system-wide improvements that will reduce the routine load on the inspector while saving the unique ability of the human mind to resolve unusual situations.

Another reviewer emphasized the need for getting technical understanding to the NDE practitioners and a technical base into codes and standards. Too many requirements are based upon what has traditionally been considered "good" practice rather than on sound technical principles.

Two comments were received which bear upon the importance of the issue. NDE techniques are often used to control welding materials and processes in order to improve the quality, reliablity, and serviceability of welded products. Reliable NDE can also be psychologically effective in influencing management and workers to upgrade the quality of manufacturing and, thereby, to improve product performance indirectly.

A number of comments sought further information, e.g., examples of unreliable NDE and of the inadequacies in current procedures, discussions of cost effectiveness and the economic impact of more reliable NDE, and clarification of the difference between reliability in general and the reliability of NDE. One reviewer felt that the reliability of flaw detection should be addressed separately from the reliability of flaw sizing, and another directed attention to the problem of "false calls" as opposed to "flaws missed."

The following two reports were recommended for addition to the author's list:

W. H. Lewis, W. H. Sproat, B. D. Dodd, and J. M. Hamilton, "Reliability of Nondestructive Inspections--Final Report," SA-ALC/MME 76-6-38-1 (San Antonio Air Logistics Center, Kelly AFB, TX, December 1978).

W. H. Lewis, W. H. Sproat, and W. M. Pless, Proceedings from the Government/Industry Workshop on the Reliability of Nondestructive Inspections, SA-ALC/MME 76-6-38-2 (loc. cit., December 1978).

END OF SUMMARY

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

*Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division, and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

COMMENTS BY SYMPOSIUM PARTICIPANT(*)

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Submitted by__________________________Affiliation____

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(*) Symposium participants are encouraged to use this sheet to comment on the issue paper as presented in this preview and during the August 1980 meeting. Please send completed form to Mrs. Bette Johnson, Managing Editor, Proc.ASME Symp. on Critical Issues, National Bureau of Standards, A302 Bldg 101, Washington, DC 20234, before Sept. 15, 1980.

Comments (continued)

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ISSUE NO. 8

CHARACTERIZATION OF THE SUBJECTIVE COMPONENT OF INSERVICE DATA

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EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

One part in the gathering of inservice piping and pressure vessel data which could result in an inaccurate assessment is the subjective (human) component. Because of the various configurations of systems and piping and the nature of data gathering and examination processes, the subjective component will continue to play a vital role in inservice reporting and analysis technology. Two major areas in the data gathering process which have an impact on the accuracy and reliability of data because of their subjective component are:

(1) Human reliability in the setting up and collection of data, and

(2) Engineering judgement in the inspection and evaluation of data regarding failures, flaw detection, or other vital information.

A number of variables can be identified with each of these factors. Human reliability includes, for example, determining the amount of coupling between a search unit and an examining piece; applying pressure, speed and direction to the search unit; and selecting the amount of coverage in the area under examination. Engineering judgement is not an exact science because of the vast number of interests, levels and backgrounds of investigators who judge data. Therefore, a variety of opinions will continue to surface as to the presence, size and orientation of flaws. Similar examples can easily be applied to inservice failure data reporting.

It is possible, with the right set of circumstances, conditions and individuals, to achieve consistency and repeatability in the collection of the data, and in the interpretation of opinions of data analysis. Experience has shown that consistency does occur with relatively high frequency for certain select groups of individuals; otherwise, a consistent pattern may be rare indeed. Often, a disagreement in opinion as to whether or not a flaw exists results in more cost to the customer (utility) who is striving to satisfy code requirements or proposed rulemaking. Utilities would prefer to use more uniformity across all disciplines involved in inservice inspection, data collection and data evaluation.

Therefore, the critical issue becomes accurate accounting for the subjective component during every step of the data processing cycle, from source to data base, to properly characterize this component of the data base and minimize its negative impact on inservice data. In this way we could minimize the many variables in examination methods and procedures, opinions of inspectors, and masses of information that cause discrepancies in data. As members of a professional society, we must characterize the subjective component of inservice data so that the data convey truthful information, without causing doubt about the status of the source they represent.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

Opinions on acceptance test data for weld examinations or failure reports vary, based on the judgement of the examiner or investigator and compliance with or interpretation of code requirements. This variance in inspectors' opinions regarding acceptance of inservice data results causes an apparent spread in the data. It is this spread in data that seems to put standards and judgement criteria to the test. In UT examinations, for instance, some examiners do go beyond the code requirements (using two angles instead of one for piping examinations) to provide sufficient data on the examinations to confirm the findings of the examiner. Likewise, in reporting failures, the same types of failures (or events) in similar systems, in different reporting units, may be coded and reported differently. In general, the inservice data collection and examination process is highly subjective and, because of this, the issue is important to ASME in revising code requirements and acceptance standards. The issue is also important to investigators and regulators in formulating acceptance criteria for enforcement and in asssuring consistency and high-quality examinations.

For example, Section XI may require one beam angle for UT examinations for certain inspections. Experience has shown that two beam angles provide 100% more data, a 20% increase in overall project costs, 7% more weld flaws detected, and less spread in inspector opinion. Should we inspect strictly by the code (one angle), or should we change the process (to two angles), to produce the output we desire from the input data that measures up to the requirements?

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

Tools available for reducing the subjective component in data gathering include (A) inspection standards and interpretation of standards, (B) specifications for judgement criteria, and (C) computer capabilities to process large masses of data.

A. Inspection Standards and Interpretation of Standards

Inspection standards and interpretation of standards (to reduce the subjective component) would consist of establishing criteria for identifying and collecting specific data representing the information desired. The criteria would include approved inspection methods for observing and recording data, a consensus within the industry as to what constitutes data parameters representing the information desired or required from the source, and the designation of certain documents to be used as the proper sources of data for the information needed.

B. Specifications for Judgement Criteria

The specifications for judgement criteria would be an outgrowth of knowledge about what specific information is needed. Once such criteria are established, decisions made by the data recorder would become more black and white. The goal is to maximize the black and white-type decisions and minimize the gray area decisions. Concise rules and clear instructions need to be provided so that correct and authoritative decisions can be made. The effectiveness of the judgement criteria rests mainly with the experience of the examiners and, more importantly, with feeding this experience back into the information flow process to sharpen the decision-making ability of the individual involved in screening unwanted data from the process.

C. Computer Capabilities

Computer capabilities to process large masses of data include the use of correctly designed forms on which to record data input. The formats specified by these forms help standardize data available to the industry. The growing ability of computer software to edit and check data at the input is a valuable tool in verifying that entries from predesigned tables are correct and properly located; thus, invalid data is screened from the flow process. With the advent of microprocessors and developing software programs, large masses of data can be reduced to provide characterization opinions more quickly and more reliably. Several programs are in development to interrogate raw data in ways not previously possible and through this adaptive learning technology higher confidence in decision-making is achieved, based on more data points than previously possible.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

Correct assessments and opinions on flaw detection require a cooperative effort on the part of government, industry, academia and professional groups. The same can be said for reporting failures. Many groups, such as those involved with failure analysis, code development, rulemaking, compliance with law, and cost to the customer, are concerned with proper opinions and assessments of flaw size and orientation and proper reporting of failures. Failure and flaw detection reports are all subject to interpretation and varying interpretations result in uncertainty. This degree of uncertainty in data gathering has a direct impact on the economics and safety of the profession as a whole, and only by cooperation throughout the profession can such a broad problem be resolved.

As described in Issue No. 1, engineering judgement in the application of computers to data is vital and cannot be ignored.. Also, the current reliability of NDE, as indicated in Issue No. 7, and the present use of failure analysis, as discussed in Issue No. 9, have a direct bearing on the validity and confidence level of inservice data reporting. All of these issues must be addressed if the subjective component is to be effectively reduced.

There is also a need for multi-party agreement on the quantity and quality of data collected in order to make a proper assessment of flaws, failures and other inservice conditions. We need to examine and redefine the rules that we apply to the collection and evaluation of data if we want to achieve an equitable balance for all groups concerned.

5. SOME RECENT CONTRIBUTIONS

C. E. Lautzenheiser, "Utility Requirements for ISI of Nuclear Power Plants", ANS Conference, June 18-23, 1978, San Diego, Library No. 255

C. E. Lautzenheiser, "Effective Application of Inservice Inspection and Reporting", ASME Symposium, Dec. 4, 1978, Library No. 0258

C. E. Lautzenheiser, "Inservice Inspection of Ligh-Water-Moderated Reactor Systems" printed in Atomic Energy Review, 1978, Library No. 293

C. E. Lautzenheiser, "Inservice Inspection of Nuclear Power Plant Pressure Components", printed in Nuclear Safety, Dec. 1976, Library No. 0161

"Inservice Data Reporting and Analysis for Pressure Vessels, Piping, Pumps and Valves," Symposium Proceedings, J. T. Fong, ed., PVP-PB-032, ASME New York 1978

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

[To be furnished at the August 1980 Symposium]

7. SOME CONTACTS FOR MORE INFORMATION

[To be furnished at the August 1980 Symposium]

8. ISSUE CHAMPION'S POSITION

In the information flow process, from source to user, the subjective component (human judgement in obtaining and interpreting data) is determined to be a critical issue. We must look closely at the inservice data flow process. By identifying and examining the processes involved in setting up, collecting, and evaluating inservice data, we can identify where improvements can be made. Once identified, priorities can be established for new methods or alternative approaches to provide the quality of data we, as professionals, know that we require. By dividing the information flow into various processes, certain areas may be identified where resources could be expended to improve the quality of data. The allocation of resources and priorities for improving these areas must be determined from cost-benefit assessment on an individual or combined basis. This should be done in order to establish a balance between the cost of improvement and the confidence level desired. The subjective component cannot be completely eliminated because it is a human condition. However, it can be minimized by instituting some of the techniques and control methods suggested herein and by the ongoing, careful training of individuals involved.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

There are many requirements for data: some are required by law, some are required by economic considerations, and some are required by industrial needs. Data required by law, for example, are the License Events Reports, which are required for conditions that violate technical specification limits and performing inservice inspections of certain welds in pipes and vessels during the operating lifetime of a power plant. Data required by economic considerations include information on performance of systems and equipment for reducing maintenance and maintenance downtime, and for increasing capacity factors and availability of systems and equipment to produce revenue. Data required by industry include materials, components and systems performance information that can be incorporated into mathematical models for analysis and assessment of new designs, as well as engineering input into current designs. By dividing up the data flow process, we can identify parameters which affect the subjective component, deal with it in an objective manner, and judge the degree of improvement made.

10. ADDITIONAL REMARKS

Three groups of people are involved in the data gathering process--the specifier, the recorder and the user. The specifier, who may be a designer, a plant owner, or a government agency, specifies information to be collected at the source that is essential, required by law, or economically important. The recorder, who may be a technician or engineer, collects information by processing data from the source to the data bank. Finally, the user, who may be a plant owner, analyst, or the collective industry, uses data from the data bank to obtain information about the source which conveys its true and accurate status. The discussion in this paper concerns the recorder and the information flow process from the source to the data bank. Discussion about the specifier and user within the topic of the subjective component of data are beyond the intent and scope of this paper.

The passage of information from the source to the data base can be said to take place during several processes in the data flow cycle. Each step in the flow cycle is designed to identify wanted data and unwanted data from all data entering the process at that point. A simple example of a process function is shown in Figure 1. Data enters the process as input. The process acts upon the input to produce the desired output. Controls are placed upon the process to correctly convert the input to obtain thr desired output. The output at each stage in the process must meet specified requirements for it to continue as an input to the next stage (process function). If the requirequirements are not met, that part of the output is fed back to the input and repeated in the process cycle. If the output continues to fail to meet the requirements, then changes may be made in the controls to correct the process function as well as changes to the input.

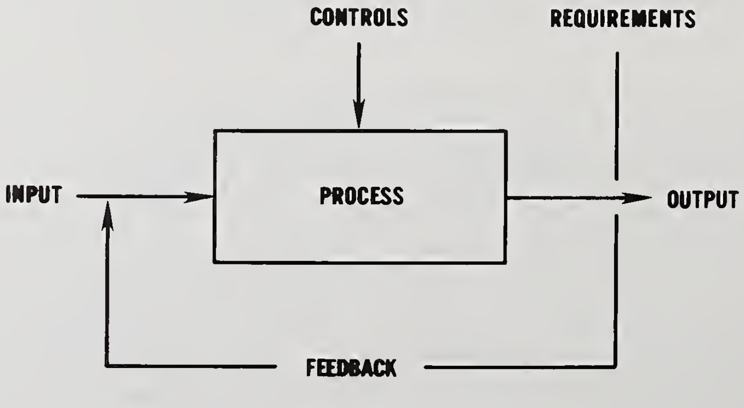

FIGURE 1

The subjective data flow from the source of the data bank could be represented by the illustration in Figure 2. The processing functions are identified in the flow path as identifying, collecting, interpreting, recording and processing data. The unwanted data resulting from the process steps are represented by fallout from the flow path.

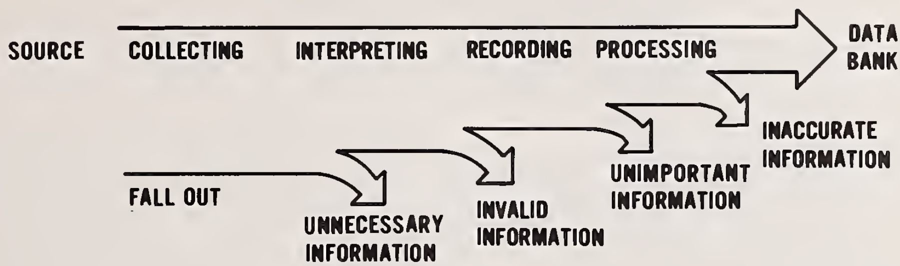

FIGURE 2. SUBJECTIVE INFORMATION FLOW PROCESS

SUMMARY OF COMMENTS*

Ronald Dobbyn, Co-Editor

It is felt by some reviewers that Mr. Tashjian has only touched on part of the stated issue and, although defining the subjective component of inservice data, has failed to characterize it or even suggest how one might begin to do this.

One important group of comments suggest that what is needed is a quantitative characterization of the subjective component of these data - a numerical value assigned to each reporter of inservice data and to each measurement technique employed in gathering inservice data - which are then some measure of the reliability of the raw data, and may be used in automated statistical analyses.

Another reviewer would like this issue brought to the doorstep of industry, for whom much of these data can and will be very helpful in assessing the performance of materials and components, in service, for input into materials conservation program and improved designs.

Finally, we all recognize that there are many sources of prejudiced on incomplete data; the reporter is only one of them. The fostering of a climate similar to that suggested for failure analyses by Professor Roberts (Issue No. 9) may be appropriate for inservice data reporting and analysis, as well.

END OF SUMMARY

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

(*) Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

COMMENTS BY SYMPOSIUM PARTICIPANTS(*)

(Use Back Sheet if necessary)

Submitted by____________________________Affiliation____

Address____Phone______________

(*)Symposium participants are encouraged to use this sheet to comment on the issue paper as presented in this preview and during the August 1980 meeting. Please send completed form to Mrs. Bette Johnson, Managing Editor, Proc. ASME Symp. on Critical Issues, National Bureau of Standards, A302 Bldg 101, Washington, DC 20234, before Sept. 15, 1980.

Comments (Continued)

NOTES

NOTES

Chapter 4 Failure Analysis, Fracture, Fatigue, and Liability Issues

Reprinted from National Bureau of Standards Special Publication 588, Critical Materials and Fabrication Issues for Pressure Vessels, Piping, Pumps, and Valves, Jeffrey T. Fong, Ronald C. Dobbyn, and Leonard Mordfin, Editors. Issued June 1980

ISSUE NO. 9

SHOULD THERE BE A METHODOLOGY FOR FAILURE ANALYSIS?

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Dr. Roberts received his BSME from Drexel University in 1961 and his MSME in 1962 and Ph.D. in 1964 from Lehigh University. He has been Professor of Mechanical Engineering and Mechanics at Lehigh University since 1975. During this time he has conducted research in the areas of fatigue and fracture of metals, design of pressure vessels and fracture of structural welded details.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Failure analysis represents a crucial link in the design process. When properly employed it can provide significant information as to how a particular design functions. It can also produce valuable insights into the suitability and functionality of current designs as well as new directions for future efforts.

To date failure analysis has not received proper recognition as an important design tool. There are many reasons for this. While most engineers know intuitively that the majority of successful engineering designs have produced some failures during their evolution, there still is a reluctance on the part of management and the engineering community in general to recognize failure and failure analysis as a positive and powerful link in the design process. Rather than viewing the failure event as a unique opportunity to learn more about the particular design and the engineering process in general, the failure is usually viewed in a totally negative context. In addition to the negative feelings which, at times, surround a failure event there has been an ever-growing tendency over the last 10 - 15 years to try to resolve difficulties resulting from some failures by litigation rather than at a technical level. This can severely limit the effectiveness of a failure investigation as it restricts the flow of information within the engineering community.

With respect to the question raised by the title of this issue paper, "Should There be a Methodology for Failure Analysis?" the answer is a resounding YES!! The critical issue is to highlight to all sectors of society the following:

1. Failure analysis is a vital part of the engineering design process.

2. A systematic engineering approach is essential to any failure analysis.

3. A forum or forums msut be developed so that issues related to failure events can be freely discussed and analyzed.

With these things accomplished, a strong methodology can be developed for failure analysis. It is recognized that there are many diverse interests which come to bear on most failure analyses. Management wants to get back to work. The analysis team wants more time. The public wants to know. All of these things must be carefully balanced. The object of a sound failure analysis methodology would be to provide all parties with the knowledge needed to make trade-offs and complete the analysis.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

It is quite important to recognize that design failures are a major factor in our learing process. We learn by our mistakes. When a design is put forward and implemented the fact that is is successful does not provide positive proof that the item or system is functioning because of the initial assumptions. Many times, through a series of complex or even simple interactions, all of the wrong reasons provide a satisfactory operation. To assume that one can scale up or down to other design conditions can, in such cases, prove to be disastrous. Thus, it is believed that an engineering failure or malfunction, properly analyzed, provides an important feedback link in the design process.

The importance of a sound methodology for failure analysis to the ASME should be obvious. Such a methodology would provide the ASME membership with a rational basis for dealing with failures and their subsequent analysis. Also ASME has a natural interest in the establishment of a failure analysis methodology based on ASME's long standing commitment to design, education, and the general welfare of its members and the general public.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

While each failure event dictates the individual disciplines needed for a specific analysis, it is clear that a failure analyst must be prepared to call on many diverse areas of science and engineering. Some of these are experimental stress analysis, theoretical stress analysis, fracture mechanics, metallurgy, and chemistry. Within these fields advances are constantly occurring and everyday new tools become available to the failure analyst. As an example of this, consider that 10 - 15 years ago there was not wide and easy access to such things as large finite element stress analysis programs or electron microscopes. Today these are readily available. It is expected that new tools and techniques will continue to develop with time. However, it is believed that rapid utilization of these new tools and even many of the older ones will be greatly enhanced by a sound failure analysis methodology.

4. IMPORTANCE OF MULTI-PARTY COLLABORATIONS

To provide an environment whereby failure analysis can be carried out to the benefit of all parties requires the participation and cooperation of the government, industry and academia. This is principally why this topic is felt to be a key technical issue. Once a framework is provided, such that impartial systematic investigations can be carried out in a manner that provides maximum legal protection to all parties, then failure analysis will grow and become a science unto itself.

5. SOME RECENT CONTRIBUTIONS

While this paper is not intended to address the detailed methodology which may be adopted in a failure investigation, some of the check lists of things to do, etc., can be found in the following books and papers:

Fractography and Atlas of Fractographs, Metals Handbook, Vol. 9, ASM, Eighth Ed.

Failure Analysis and Prevention, Metals Handbook, Vol. 10, ASM, Eighth Ed.

Source Book in Failure Analysis, ASM, 1974.

R. Roberts and A. W. Pense, Failure Analysis of Large Structures, Civil Engineering, May 1980, to be published.

John W. Fisher, Alan W. Pense and Richard Roberts, "Evaluation of Fracture of Lafayette Street Bridge," Journal of the Structural Division, ASCE, Vol. 103, July 1977, pp. 1339-1357.

G. F. Van der Voort, "Conducting the Failure Examination," Metals Engineering Quarterly, May 1975, pp. 31-36.

6. SOME FORTHCOMMING CONFERENCES AND PUBLICATIONS

[To be furnished at the August 1980 Symposium]

7. SOME CONTACTS FOR MORE INFORMATION

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8. ISSUE CHAMPION'S POSITION

It is the position put forward in this note that Failure Analysis is a highly complex science. As of this date it requires many changes to provide a climate in which it can be openly practiced to the benefit of the majority. In addition, it requires that bridges be built among the more traditional engineering sciences so that specialists can be educated and trained to carry out proper failure analyses. For these reasons the need for a failure analysis methodology is critical.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

It is important that effort be put forward to resolve technical difficulties at a technical level rather than relying on one's lawyer to resolve the technical issues. To date, the real benefit of good failure analysis as part of the design loop is not known to the general engineer or management. Forums for open discussion of failures are not currently available. It is firmly believed that if a failure analysis methodology is available, the design process in general will be significantly enhanced.

SUMMARY OF COMMENTS*

Ronald Dobbyn, Co-Editor

All reviewers agreed that this issue is, indeed, critical; yet some question the author's arguments in support of calling for a methodology as a solution to the many problems that attend failure analysis. For example, nowhere does the champion indicate how a methodology would change or improve design. He gives us no hint of the constituents of such a methodology. Although the author describes the milieu in which failure analysis would flourish "to benefit of all," he comes up short on why a "methodology" and not public relations is the solution for the 1980's.

END OF SUMMARY

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

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Comments (continued)

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ISSUE NO. 10

ACCELERATED DEVELOPMENT OF A MORE RATIONAL BASIS FOR NONLINEAR FRACTURE MECHANICS

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Dr. Kanninen received his B.S.M.E. and M.S.M.E. from the University of Minnesota and his Ph.D. from Stanford University. At Stanford he worked in developing an atomic crack propagation model and in dynamic structural analysis. At Battelle he is primarily concerned with dynamic crack propagation and crack arrest, elastic-plastic fracture mechanics, atomic simulation of cracks and dislocations, failure of composite and polymeric materials and fatigue crack propagation.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Fracture mechanics includes all failure processes that involve an identifiable crack-like defect in a material. Crack growth initiation, propagation (stable and unstable), and crack-arrest--regardless of the type of loading, the size and shape of the body and of the kind of constitutive relation obeyed by the material--are all within the domain of fracture mechanics. However, currently available proven techniques exist only for the restricted circumstances under which linear elastic fracture mechanics (LEFM) is valid. These are for the initiation of crack growth under quasi-static conditions in materials and structural geometries where the inelastic deformation attending the crack tip is small enough that a linear elastic continuum mechanics treatment can be used. Generally, where LEFM is not valid, its predictions tend to be highly conservative.

The materials used for pressure vessels and pipes tend to be ductile and tough, at least where fracture is a primary concern. In addition, in the many situations where a catastrophic failure would have very severe consequences and the possibility of crack initiation cannot be precluded, assurance that a rapidly propagating crack will be arrested safely is needed. These features are beyond current LEFM techniques. Accordingly, it is necessary to develop nonlinear fracture mechanics treatments for engineering design and structural integrity assessments. Because this can and will be done by some means, the issue is, should the development of a more rational, fundamentally correct, basis for these treatments be accelerated.

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

The existence of crack-like flaws from manufacturing, fabrication, and service conditions cannot be precluded in any structure. Precise treatment of structural integrity must therefore address these. This requires a fracture mechanics approach.

Fracture mechanics can generally be employed in two main ways. First, through knowledge of the loads that a structural component will be expected to bear, material toughness requirements and NDE limits on flaw sizes can be set. Second, for flaws discovered in installation and service, the safe operating loads can be calculated versus replace decision made. Both of these arise routinely for designers, fabricators and operators of pressure vessel and piping systems.

Since the only generally available techniques are now those of LEFM, in many instances the predictions that can be made are unrealistic. The only feasible approach is to enlarge the present scope of fracture mechanics. Clearly this should be done such that materials can be used in a cost-effective manner without jeopardizing structural reliability.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

The tools required to develop a fundamental basis for the use of fracture mechanics beyond LEFM are just now becoming available. They include:

Elastic-plastic finite element analysis capability (large deformation and strain, thermoplasticity, dynamic contributions)

Computational facility capable of accommodating three-dimensional models of pressure vessel and piping components

Experimental measurements of crack growth and instability

Accurate constitutive relations for elastic/plastic viscous material behavior

Full scale component testing for final verification of the analysis procedure.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

The development of nonlinear fracture mechanics requires fundamental expertise in a wider range of disciplines than are contained within any single institution. In particular, the resolution depends upon:

Finite element analysis for component model development and quantitative results

Metallurgists for mechanical and fracture property measurements

Mechanicians for development of a fundamentally correct picture of the fracture process that lends itself to quantitative treatments

NDE for determination of identifiable flaw sizes, shapes, and locations

Structural analysts for practical implementation of the procedures

5. SOME RECENT CONTRIBUTIONS

Status of Current Research

N. Perrone, et al, editors, Fracture Mechanics, University of Virginia Press, Charlottesville, 1978.

A. R. Luxmoore and D. R. J. Owen, editors, Numerical Methods in Fracture Mechanics, University College of Swansea Press, 1980.

G. T. Hahn and M. F. Kanninen, "Crack Arrest Methodology and Applications," ASTM STP 711, 1980.

J. Landes, et al, "Elastic-Plastic Fracture," ASTM STP 668, 1979.

N. Perrone and S. N. Atluri, editors, Nonlinear and Dynamic Fracture Mechanics, ASME Publication AMD, Vol. 35, New York 1979.

R. W. Nichols, editor, Developments in Pressure Vessel Technology--1. Flaw Analysis, Applied Science Publishers, London, 1979.

Periodicals Providing Current Research Results

H. Liebowitz, editor-in-chief, Engineering Fracture Mechanics, Pergamon Press, New York, published quarterly.

M. L. Williams, editor-in-chief, International Journal of Fracture, Suthoff and Noordhoff Publishers, Alpheen aan den Rijn, The Netherlands, published bi-monthly.

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

Thirteenth ASTM National Symposium on Fracture Mechanics, Philadelphia, PA, June 16-18, 1980. Contact Richard Roberts, Lehigh University, Bethlehem, PA 18015.

International Conference on Analytical and Experimental Fracture Mechanics, Rome, Italy, June 23-27, 1980. Contact G. C. Sih, Lehigh University, Bethlehem, PA 18015.

Numerical Methods in Fracture Mechanics, University College of Swansea, Swansea, Wales, July 6-11, 1980. Contact R. D. J. Owen, Swansea, United Kingdom.

Fracture of Composite Materials, Bethlehem, PA, September 3-5, 1980. Contact G. C. Sih, Lehigh University, Bethlehem, PA 18015.

Fifth International Conference on Fracture, Cannes, France, March 29-April 3, 1981. Contact J. Poirier, 91190 Gif-Sur-Yvette, France.

7. SOME CONTACTS FOR MORE INFORMATION

Dr. T. U. Marston, Electric Power Research Institute, Palo Alto, CA.

Dr. F. Shih, General Electric Company, Schenectady, NY.

Prof. P. Paris, Washington Univeristy, St. Louis, MO

Prof. J. Rice, Brown University, Providence, RI

Prof. G. T. Hahn, Vanderbilt University, Nashville, TN

Dr. J. Lanes, Westinghouse, Pittsburgh, PA

8. ISSUE CHAMPION'S POSITION

Because pressure vessels and pipes are usually made of tough ductile materials which exhibit large scale deformation prior to fracture, and where the consequences of unchecked crack propagation could be catastrophic, it is necessary to develop nonlinear fracture mechanics for engineering design and structural integrity assessments. While such treatments are evolving, a proper fundamental basis does not now exist. The development of such a basis should be accelerated.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

Practical applications using ad hoc empirical procedures are often made because necessity usually precedes the existence of fundamentally-based procedures. Applications of fracture mechanics for conditions in which LEFM is not valid can and will continue to be made in this way. However, because of the severe constraints that are already in evidence with regard to materials and energy availability, the profligate use of these in structural design is unacceptable. Hence, there is a distinct need to rapidly develop a more rational basis through which more effective and efficient utilization of our resources can be accomplished without increasing the risk of fracture.

10. BACKGROUND INFORMATION

General Background on Fracture Mechanics

D. Broek, Elementary Engineering Fracture Mechanics, Noordhoff International Publishing, Leyden, The Netherlands, 1974.

S. T. Rolfe and J. M. Barsom, Fracture and Fatigue Control in Structures: Applications of Fracture Mechanics, Prentice-Hall.

R. W. Hertzberg, Deformation and Fracture Mechanics of Engineering Materials, Wiley, New York, 1976.

J. F. Knott, Fundamentals of Fracture Mechanics, Wiley, New York, 1973.

G. P. Cherepanov, Mechanics of Brittle Fracture, McGraw-Hill, New York, 1979.

V. Z. Parton and E. M. Morozov, Elastic-Plastic Fracture Mechanics, Mir Publishing, Moscow, 1978.

Background and Applications to Pressure Vessel and Pipe Design

J. F. Harvey, Theory and Design of Modern Pressure Vessels, van Nostrand Reinhold, New York, Second Edition, 1974.

R. Chuse, Pressure Vessels, The ASME Code Simplified, McGraw-Hill, New York, Fifth Edition, 1977.

The M. W. Kelloff Company, Design of Piping Systems, Wiley, New York, Second Edition, 1956.

SUMMARY OF COMMENTS*

Ronald Dobbyn, Co-Editor

Virtually all of the comments and suggestions provided by our reviewers and critics were skillfully accommodated in the author's final draft. There was, however, one interesting observation made during our March 1980 meeting: It is the misapplication of linear elastic fracture mechanics to fracture problems in general that is dangerous and should, therefore, be the critical issue. Well, some considered this to be one and the same issue. Dr. Kanninen points out that such misapplications tend to be conservative and, hence, would lead to overdesign which is wasteful of our natural resources.

END OF SUMMARY

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Comments (continued)

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ISSUE NO. 11

SAFETY FACTORS IN FATIGUE DESIGN: ARBITRARY OR RATIONAL?

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Dr. Fong received a B.Sc. in engineering from the University of Hong Kong (1955), an M.S. in mechanics from Columbia (1961), and a Ph.D. in applied mechanics and mathematics from Stanford (1966). From 1955 to 1963, he worked at Ebasco Services in New York as a design engineer on more than 20 power plants built or proposed in the United States and abroad. Following a three-year interdisciplinary study at Stanford, Dr. Fong accepted in 1966 an award of the National Academy of Sciences to continue research at the National Bureau of Standards (NBS) in Washington, DC. Dr. Fong is currently a physicist and technical supervisor at the Center for Applied Mathematics of NBS and has authored or co-authored 40 technical papers and 4 books on subjects ranging from continuum mechanics to fatigue mechanisms. He is a registered professional engineer in the State of New York and in United Kingdom, and is active in professional societies with duties as chairman of two major committees (ASRM E9.01 on fatigue research, and ASME-PVP materials and fabrication committee). From 1975 to 1976, he was awarded a U. S. Department of Commerce fellowship with assignment as a senior policy analyst with the U. S. Nuclear Regulatory Commission in Washington, DC.

John H. Smith

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Dr. Smith received a B.S. in Metallurgical Engr. and an A.B. in Mathematics from Lafayette College, an M.S. in Metallurgy from the University of Missouri at Rolla, and the Sc.D. in Physical Metallurgy from MIT. He has been associated with the NASA-Lewis Research Center and the U. S. Steel-Research Center. He has been with NBS since 1974 and his current responsibilities include development and application of fracture mechanics and mechanical properties of metals test methods, failure analysis investigations of pressure vessels, transportation equipment, and energy production systems. He is a registered Professional Engineer--Metallurgical in the State of Pennsylvania.

EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

Engineers are entrusted by the public to integrate the best available information, in order to design and create a product that the public can afford and safely operate to satisfy a need. For example, when the public needs a bridge to cross a certain river, engineers are called upon to design, fabricate, install, test, and maintain a functional as well as an aesthetically appealing structure which, by prevailing standards, is an "economical" solution to a specific transportation need of the community. The same applies when a utility company orders a pressure vessel for its nuclear reactor, or when a chemical company orders a series of pumps, valves, and piping systems for a new manufacturing facility. In each case, the public looks for a product that is both safe and economical.

Unfortunately, as in many critical applications, a conflict exists between the two objectives the engineer is asked to achieve. To make a product "completely" safe, the engineer may have to prescribe so much laboratory and full-scale testing that the ultimate cost of the product may be several times the price the public is willing to pay. On the other hand, the public's need for an affordable product may be so compelling that a tacit understanding is frequently reached between the engineer and the public whereby a product is judged acceptable if (a) it is safe to operate under carefully prescribed "normal" service loadings, and (b) its resistance to "extreme" loadings is adequate based on the "best" engineering information and judgment.

Strictly speaking, a knowledge of the real performance of a component or a structural system is obtained only from long term operation. In the absence of this knowledge, engineers adopt the practice of prescribing the so-called "safety factors" on all facets of design with the specific goal that the actual life of a product exceeds or at least equals that predicted by the design practice. Such a practice, when restricted to the case of repetitive service loadings as in fatigue design, is illustrated in Fig. 1 where a plot of the stress range S versus the number of cycles to failure N is exhibited with three curves:*

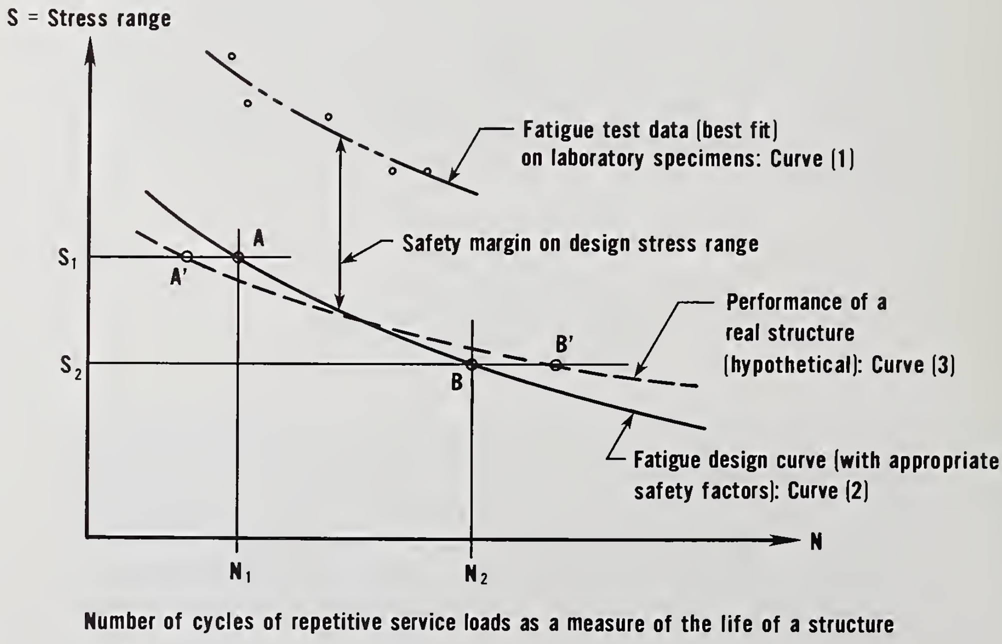

Fig. 1 Hypothetical Fatigue Design Curves (Stress Range versus Life)

(1) A best-fit curve of the fatigue test data on laboratory specimens.

(2) A fatigue design curve with the appropriate safety factors adopted either on the stress-range or the number of cycles to failure, or both; the ASME Boiler and Pressure Vessel Code on fatigue design with a safety factor of two on stress range or twenty on life is an example of this curve.

(3) A hypothetical curve indicating the performance of a real structure.

From a technical viewpoint, this practice of fatigue design raises at least two questions on the choice of safety factors: (a) How well do the test loadings simulate the real ones? (b)Why is the curve independent of scaling? With the availability of the design curve incorporating a recommended factor of safety to cover uncertainties due to measurement errors, material inhomogeneities, fabrication practice, etc., the design engineer in essence defers his/her own judgment in favor of that of a committee which may have long disappeared from the scene. In the case of a premature failure as indicated by points A' and A at stress range S_1 on Fig. 1,* it is difficult for the design engineer to justify the implicitly rational choice of safety factors because they were based on the judgment of others whose experience was seldom documented. A critical issue hence arises:

(a) Should the present practice of fatigue design with the choice of safety factors largely judgmental without explicit documentation be continued at the risk of being labelled "arbitrary" by a suspicious public whenever a fatigue failure occurs?

or,

(b) Should the engineers demonstrate to the public that the process, though imperfect, does rest on a "rational" basis in the sense that the choice of a safety factor can depend logically on the sample size of each set of observed or measured information and that the variabilities of all applicable parameters as estimated from documented laboratory and inservice data constitute necessary input to the numerical determination of such a factor?

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

The issue is important to ASME members for two primary reasons: (a) ASME has pioneered in the development of engineering codes and standards particularly in the area of boiler and pressure vessel design and fabrication; and (b) ASME has also prided itself as a leader in promoting continuing education for its members and in fostering engineering research to advance the state of our knowledge in support of the engineering decision-making process. The fundamental question that underlies the issue is to demonstrate explicitly that the engineering judgment used in the selection of safety factors is rational. This question, if left unanswered, can lead to a loss of confidence by the public in the entire engineering profession. The issue is, therefore, of great importance to both the ASME and the professional community at large.

To discuss the significance of this issue beyond the technical community,(*) it is instructive to examine the lead paragraph of an article in a recent issue of the Washington Post (May 3, 1980, p.A4):

> Harrisburg, Pa. -- The financial fallout from the Three Mile Island nuclear accident was totaled up for the final time here last week, and all that remains is for the Pennsylvania Utility Commission to decide who pays the bill. (by Joanne Omang)

(*)The implication of the issue goes beyond the narrow subject of fatigue design, since most engineers are interested, not only in safety factors per se, but also in the procedure how they are selected.

At issue was "whether what happened at Middletown, Pa., a year ago should be treated as a fluke,..., or something predictable that could, and probably will, happen to any other nuclear utility." Insisting that the design was based on an implicitly rational framework, Samuel Russell, attorney for Metropolitan Edison Co., which owns TMI, argued that "those who get the electric service must pay for its cost. The accident in March 1979 should be treated as another cost, a fluke event,..." On the other hand, Ms. Omang reported that "if it could happen to anyone, anti-nuclear groups argued, then the banks, investors and utilities that boost nuclear power ought to expect -- and therefore pay the costs of -- accidents in the same way they shoulder the risks of other investment." The utility argued that the design which included the use of safety factors was rational. The anti-nuclear groups seemed to argue otherwise. "At stake in the verdict," concluded Omang, "...might well be the financial future of nuclear power -- at least as far as the future depends on Wall Street."

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

To resolve the issue, it is useful to divide the overall uncertainty in modeling the service life of a structure or component into four major categories:

(a) Measurement Science and Statistics. This category includes measurement errors and uncertainties on all aspects of testing and data gathering. In particular, sampling errors are included in this category.

(b) Materials Science and Modeling. This category includes variabilities due to inherent material inhomogeneities as well as the uncertainties associated with the empirical models of numerous mechanisms at the microstructural level.

(c) Scaling. This category includes all uncertainties due to scaling effect in structural geometry and load spectra between real and laboratory configurations.

(d) Human Factors.

Fundamental advances during the last twenty years in computer science and engineering, materials science and quantitative microscopy, statistical theories and decision-making concepts, inservice data reporting and analysis, on-line monitoring of critical structures and components, nondestructive evaluation for quality control and inservice inspection, etc., have yielded an assortment of new tools for a rational estimate of uncertainties of categories (a) and (b). For critical components and structures, uncertainties due to scaling, i.e., category (c) may also be estimated by a careful analysis of the test data on prototypes of design such as the full-scale fatigue testing of the Boeing 747 jumbo jet. It is conceivable that during the next decade, advances in human factor engineering may progress to the point that uncertainty category (d) may also be estimable. The existence of inservice data and failure event reporting systems may lead to an estimate of the overall uncertainty which can be used to determine how the individual uncertainties of the four categories can be combined.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

The technical program outlined in the last section contains an implicit assumption that engineers, scientists, applied mathematicians, etc., are willing to pool their information in an attempt to construct a rational basis for the selection of safety factors. Without the spirit and substance of a multi-party working format, such a program has little chance of success or credibility.

5. SOME RECENT CONTRIBUTIONS

J. T. Fong, "Uncertainties in Fatigue Life Prediction and a Rational Definition of Safety Factors," Nuclear Engineering and Design, Vol. 51, pp. 45-54 (1978).

J. T. Fong, "Inservice Data--The Missing Link in the Exercise of Judgment in Engineering Decision-Making," Proc. International Symp. on Inservice Data Reporting and Analysis, PVP-PB-035, Vol. 2, pp. 153-162, New York: Am Soc of Mechanical Engineers (1979).

J. T. Fong, "Statistical Aspects of Fatigue at Microscopic, Specimen, and Component Levels," Proc. ASTM-NBS-NSF Symp. on Fatigue Mechanisms, Kansas City, May 1978, ASTM-STP 675, pp. 729-758, Philadelphia, PA: Am Soc for Testing and Materials (1979).

J. T. Fong,,"Inservice Data Reporting Standards for Engineering Reliability and Risk Analysis," Bundesanstalt fur Materialprufung (BAM) Tagungsbericht, No. 11, Preprints for 2nd International Seminar on Structural Reliability, Berlin (West), August 20-21, 1979. To appear in Nuclear Eng. & Design, Vol. 59 (1980).

J. T. Fong, and N. E. Dowling, "Analysis of Fatigue Crack Growth Rate Data from Different Laboratories" to appear in Proc. ASTM Symp. on Fatigue Crack Growth Measurement and Data Analysis, Pittsburgh, October 1979.

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

[To be furnished at the August 1980 Symposium.]

7. SOME CONTACTS FOR MORE INFORMATION

[To be furnished at the August 1980 Symposium.]

8. ISSUE CHAMPION'S POSITION

It is our position that the traditional process of selecting safety factors for fatigue design has always been implicitly rational and never arbitrary. Given the appropriate resources in both funds and trained personnel, a program for turning the implicitly rational process into an explicit one for public examination is feasible.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

In support of our position, we wish to summarize our arguments as follows:

(a) The process of choosing safety factors by examining four categories of uncertainties tends to improve the fatigue design practice with a more accurate predictive model and an intrinsic apparatus for fine-tuning the design practice.

(b) The availability of a rational basis for choosing safety factors facilitates the public's entry into the traditional engineering decision-making process where the trade-off between safety and economics on critical structures should be of public concern.

(c) The rejection of the notion that the choice of safety factors is "arbitrary" brings credit to the engineering profession such that it will continue to attract and retain the "best" minds of the country for a sustained growth in our technological development.

SUMMARY OF COMMENTS*

Leonard Mordfin, Co-Editor

There was general agreement among reviewers that the issue is critical. One comment suggested that the scope of the issue may be too far-reaching for a single committee or division of ASME to address exclusively. Another expressed a desire for a concrete example in which some of the tools discussed by Dr. Fong and Dr. Smith were actually used to arrive at a specific value for a safety factor. Several individuals wondered whether the increased costs associated with the establishment of safety factors on a rational basis might not generate resistance among the public. A designer responded to this concern by pointing out that only the most critical components or structures need to be treated in this way; only then will the benefits justify the additionasl costs.

END OF SUMMARY

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

*Comments were received by submitting drafts of issue papers to members of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division, and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

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(*) Symposium participants are encouraged to use this sheet to comment on the issue paper as presented in this preview and during the August 1980 meeting. Please send completed form to Mrs. Bette Johnson. Managing Editor, Proc. ASME Symp. on Critical Issues, National Bureau of Standards, A302 Bldg 101, Washington, DC 20234, before Sept. 15, 1980.

Comments (continued)

Reprinted from National Bureau of Standards Special Publication 588, Critical Materials and Fabrication Issues for Pressure Vessels, Piping, Pumps, and Valves, Jeffrey T. Fong, Ronald C. Dobbyn, and Leonard Mordfin, Editors. Issued June 1980

ISSUE NO. 12

THE ASME CODE AND PRODUCT LIABILITY: SHOULD COMPLIANCE CREATE A REBUTTABLE PRESUMPTION OF PROPER DESIGN?

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EXTENDED ABSTRACT

1. STATEMENT OF THE ISSUE

There are many instances in which a manufacturer's violation of a standard, code, regulation or specification has resulted in liability for injury caused by a product manufactured in violation of the standard, code, etc. Liability may be based upon negligence, breach of warranty, or (under strict liability) upon presumed presence of a design defect as a result of the manufacturer's deviation from a standard. If violation of standards can be used as a basis of liability, it seems equally just that compliance with them should constitute a defense.

While there are compelling reasons for not permitting compliance with a code to be an absolute defense to a claim of defective design, there are equally powerful reasons for the proposition that compliance with code requirements with respect to design, manufacturing or testing of a product should create a rebuttable presumption that the product was not defective.*

2. IMPORTANCE OF THE ISSUE TO ASME AND BEYOND

Nearly every state, city and county in the United States requires that pressure vessels comply with the ASME Boiler and Pressure Vessel Code. The Code has been developed over a number of years with input from professors, engineers, boiler inspectors and others interested in the construction and operation of steam boilers. Many pressure vessel manufacturers depend on meeting Code standards as the method of assuring that boilers and pressure vessels they build can be safely operated for their intended use. By creating a rebuttable presumption that compliance with the ASME Code is evidence of proper design, tremendous impetus is given to further strengthening of Code requirements. Under the rebuttable presumption rule manufacturers could be expected to eliminate potential weaknesses in the Code design requirements so that an injured party could not easily demonstrate the possibility of superior design alternatives. The incentive for developing more stringent Code requirements would come from the greater protection against charges of defective design, and the lower insurance costs to those who build Code vessels. The end result would be a lower probability of injury from defectively designed boilers and pressure vessels.

(*)A presumption is an inference of the truth or falsehood of any proposition of fact. A conclusive presumption is one of which is not permitted to be overcome by any proof that the fact is otherwise; as an example, an infant under seven years is not responsible for his action. A rebuttable presumption on the other hand, is an inference of law which holds good until disapproved. It shifts the burden of proof. For the issue under discussion, creation of the rebuttable presumption would put the burden on the injured party to show that a product designed in accordance with the ASME Code was defective.

3. AVAILABILITY OF NEW TOOLS FOR RESOLVING THE ISSUE

The theory of strict liability for defective design was developed over the past two decades, primarily by state courts. At the core of the strict liability approach was the idea that when a seller places a defective product into the stream of commerce, the loss should fall on that seller, who is in a position to control the danger and to distribute the losses equitably, rather than on the innocent plaintiff who cannot control the danger and who has less ability to distribute the loss.

While this idea may have some validity for the case of consumer products, it is much less persuasive in the case of ASME Code boilers and vessels which are generally owned and operated by sophisticated business entities with resources which equal or surpass those of the seller. A new approach must be considered for resolving problems which arise from use of Code designed vessels. Congress or individual state legislatures rather than state courts are the arenas for resolving the issue of how to weigh evidence of compliance with ASME Code requirements. The evidentiary effect of compliance with the Code should be written into state and federal product liability legislation.

4. IMPORTANCE OF MULTI-PARTY COLLABORATION

To satisfactorily resolve the issue of the evidentiary weight to be given to demonstrated compliance with the ASME Code, input will be required from manufacturers, users, insurers, government officials, inspectors, designers and lawyers. The legislators who must enact appropriate legislation must be convinced that creation of a rebuttable presumption of proper design is the approach which offers the best balance of safety to the public while maintaining utility to the user at a reasonable price.

5. SOME RECENT CONTRIBUTIONS

The Research Group, Inc., Product Liability, Legal Study, U.S. Dept. of Commerce Report No. ITFPL-77102, January, 1977

A. D. Twerski, A. S. Weinstein, W. A. Donaher, and H. R. Piehler, "The Use and Abuse of Warnings in Products Liability - Design Defect Litigation Comes of Age", 61 Cornell Law Rev. 495 (1976)

D. W. Noel, "Manufacturer's Negligence of Design or Directions for Use of a Product", 42 Tennessee Law Rev. 11 (1974)

J. A. Henderson, Jr., "Judicial Review of Manufacturers' Conscious Design Choices" The Limits of Adjudication", 73 Columbia Law Rev. 1531 (1973)

6. SOME FORTHCOMING CONFERENCES AND PUBLICATIONS

Short courses on product safety and product liability are offered regularly by the American Law Institute - American Bar Association Committee on Continuing Professional Education, by various colleges and universities, and by professional organizations.

7. SOME CONTACTS FOR MORE INFORMATION

[To be furnished at the August 1980 Symposium]

8. ISSUE CHAMPION'S POSITION

A rule providing that compliance with the ASME Code creates a rebuttable presumption of proper design would provide the appropriate balance between the needs to design pressure vessels which are both safe and utilitarian.

9. SUMMARY OF ARGUMENTS FOR THE CHAMPION'S POSITION

A. Since the presumption of proper design would be easily rebutted if the Code were weak, manufacturers would be encouraged to strengthen Code requirements.

B. Insurers would be encouraged to lower insurance rates for those who design according to ASME Code requirements, thereby lowering vessel costs.

C. Smaller manufacturers would be provided with a safe design standard, thereby minimizing the danger of entry into the marketplace of defectively designed pressure vessels, while enhancing competition.

D. An injured party is not deprived of his day in court.

E. The rebuttable presumption of proper design does not eliminate a manufacturer's duty to warn, warranty requirements, or claims of negligence on the part of designers, manufacturers and distributors.

F. In ASME Code cases the injured party is unlikely to be an "ordinary consumer".* The purchaser of ASME Code pressure vessels often prescribes tests and specifications which must be met by the manufacturer and is often in an equal bargaining position with the manufacturer.

G. When a basic design is found to be defective the manufacturer may be subject to more extensive liability than is the case where a single item is flawed. Thus, more stringent requirements, and greater protection for those who meet those requirements, is desirable to assure the availability of safe pressure vessels at a reasonable price.

10. CONCLUDING REMARKS

Creation of a rebuttable presumption of proper design for products designed according to ASME Code specifications would be a major incentive for industry to strengthen the Code, would offer smaller designers some measure of protection from product liability suits, would tend to reduce insurance costs and would not deprive an injured party of his day in court.

*Injuries from defective hotwater heaters comprise an exception to this rule.

SUMMARY OF COMMENTS*

Leonard Mordfin, Co-Editor

The relevance of this issue has been particularly evident ever since it was first proposed by the Committee. Each stage of the review process generated considerable discussion, primarily by engineers expressing concerns over the implications of the issue and seeking clarification of legal nuances. Among the many questions raised were, "Do present actions of the courts tend to support or to oppose a rebuttable presumption?", "What are the possibilities of getting action at the Congressional level rather than in state legislatures?", "What are the consequences of a rebuttable presumption to ASME?", and "Does Code compliance imply a state-of-the-art defense?". It seems clear that the interest level in this issue among engineers would justify further ASME attention through appropriate symposia and short courses.

The majority of the reviewers overwhelmingly agreed that this issue is critical and that Dr. Seltzer's argument was clear. A few of the less supportive comments do merit attention, however. One reviewer pointed out that the Code is a safety code for pressure containment and not a product design code which considers the overall design and operation of a product for its intended use. He emphasized that there are many design requirements of a product, to assure its proper operation and suitability for its intended use, which are not covered by the Code.

Another reviewer observed that making compliance with the Code a rebuttable presumption of proper design would encourage the Code to become more conservative so as to reduce even the most remote chances of failure. This, he suggested, would have the undesirable effect of prohibiting innovation in design and materials, leading to inefficient use of materials and energy.

An interesting viewpoint was expressed concerning the buyer's obligation to understand the applicability of a Code-designed product to his specific use or service. Such an obligation, it was felt, would enhance the protection of a manufacturer from designing a product with misunderstanding and misjudgment.

One reviewer expressed concern that the Code does not call for hazard identifications and control analyses, and that failure to perform such analyses is often gross negligence. He offered the following references in support of a system safety engineering approach:

"Hazard Control Through Designer Education," by Leslie W. Ball, National Safety News, August 1973

"Safety Achievement Through Management and Lawyer Education and Action," Fourth International System Safety Conference (July 10, 1979)

END OF SUMMARY

The above is an extended abstract of a full paper to appear, complete with discussions and closure, in an ASME special publication entitled "Critical Materials and Fabrication Issues: An ASME Centennial Challenge."

*Comments were received by submitting drafts of issue papers to member of the Materials and Fabrication Committee, ASME Pressure Vessels and Piping Division and selected experts invited by the Symposium Organizing Committee to assure a fair and adequate review.

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Comments (Continued)

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

As part of its centennial observances in August 1980, the American Society of Mechanical Engineers (ASME) will co-sponsor with the National Bureau of Standards and others a unique symposium entitled "Critical Issues." Through an intensive two-year series of debates, meetings, presentations, and reviews, a total of twelve issues on the materials and fabrication aspects of technical problems in the pressure vessels and piping industry were identified for discussion at the August 1980 meeting. The twelve issues are: (1) The role of engineering judgment and the computer in the management of material property data; (2) Curve-fitting vs. modeling for formulating design rules; (3) New material property data: Terminal vs. incremental tests; (4) Variability of data: Standards for applications; (5) On-line monitoring of critical components to improve reliability; (6) Upgrading welders' skill and educational level: How and why; (7) Reliability of nondestructive evaluation; (8) Characterization of the subjective component of inservice data; (9) Should there be a methodology for failure analysis? (10) Accelerated development of a more rational basis for nonlinear fracture mechanics; (11) Safety factors in Fatigue Design: Arbitrary or Rational? (12) The ASME Code and product liability: Should compliance create a rebuttable presumption of proper design? This report contains extended abstracts of the twelve issue papers and summaries of reviewers' comments for distribution to all symposium pre-registrants to stimulate and guide an orderly debate at the August 1980 meeting.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

ASME Boiler Code; data; fabrication; failure analysis; fatigue; fracture; materials science; nondestructive evaluation; piping; pressure vessels; product liability; pumps and valves; standards; statistical modeling; welding.

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DIMENSIONS/NBS—This monthly magazine is published to inform scientists, engineers, business and industry leaders, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing. Annual subscription: domestic $11; foreign $13.75.

NONPERIODICALS

Monographs—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

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Special Publications—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

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National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS under the authority of the National Standard Data Act (Public Law 90-396).

NOTE: The principal publication outlet for the foregoing data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St., NW, Washington, DC 20056.

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NBS Interagency Reports (NBSIR)—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Services, Springfield, VA 22161, in paper copy or microfiche form.

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