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Vol. 3

Research Program Plan

Piping

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

M. Vagins, J. Strosnider

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Washington, D.C. 20555

FOREWORD

This document presents a plan for research in Piping to be performed by the Materials Engineering Branch, MEBR, Division of Engineering Technology, (DET), Office of Nuclear Regulatory Research. It is one of four plans describing the ongoing research in the corresponding areas of MEBR activity, which are being published simultaneously in four volumes as follows: Vol. 1 Reactor Vessels, Vol. 2 Steam Generators, Vol. 3 Piping, and Vol. 4 Non-Destructive Examination. These plans have been updated and are more detailed expansions of those originally published as part of the Long Range Research Plan for the Office of Nuclear Regulatory Research in NUREG-1080 Vol. 1; for more complete information on background, interfaces, and utilization, the above cited report should be consulted.

These plans were originally written as internal NRC working documents to cover the five year period from FY 1985 through FY 1989, to foster better coordination between the offices of Nuclear Regulatory Research and Nuclear Reactor Regulation, and improve the understanding of the derivation, approach and scope of the research programs. The plans have also been very useful for expanding that circle of understanding of the programs to other parts of the NRC staff, to the ACRS, and to contractors as an important information source and planning base. It is therefore hoped that the readers will benefit from these more clearly delineated objectives, needs, programmatic activities, and interfaces together with the overall logical structure within which these exist.

Publication of these plans will make visible to industry and other interested individuals what our objectives are and how we are approaching the work in these important areas. It is noted that reports of progress in all the areas of MEBR research are published annually in the series of reports "Compilation of Contract Research for the Materials Engineering Branch, Division of Engineering Technology," NUREG-0975 (Vol. 3 Annual Report for FY 1984). It is intended that these plans will periodically be updated; therefore, comments on these plans are welcomed from all quarters. Comments need not be restricted to activities for the five year period covered, but may include comments on omissions or what might be considered for the longer term. Please address comments directly to me.

Charles Z. Serpan, Jr., Chief
Materials Engineering Branch

Approved by:

Guy A. Arlotto, Director
Division of Engineering Technology
Office of Nuclear Regulatory Research

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Introduction

Regulatory issues related to piping can be divided into the three areas of pipe cracking, postulated design basis pipe breaks, and design of piping for seismic and other dynamic loads. The first two of these issues are in the domain of the Materials Engineering Branch (MEBR), while the last of the three issues is the responsibility of the Mechanical/Structural Engineering Branch. This volume of the MEBR Research Plan defines the critical aspects of the pipe cracking and postulated design basis pipe break issues and identifies those research efforts and results necessary for their resolution. In general, the objectives of the MEBR Piping Research Program are to provide experimentally validated analytic techniques and appropriate material properties characterization methods and data to support regulatory activities related to evaluating and ensuring piping integrity.

1.0 Definition of Issues and Needs

1.1 Pipe Cracking

The potential for cracking in critical LWR piping systems raises several difficult regulatory issues. These include defining adequate inservice inspection (ISI) programs and techniques, determining the appropriate corrective actions for cracks detected in service, and determining the adequacy of proposed fixes for eliminating or reducing the incidents of cracking.

Inservice inspection is one of the most important problem areas related to piping integrity. The reliable detection and accurate sizing of cracks is important to ensuring the integrity of the reactor coolant pressure boundary. Results of ISI are the starting point for crack growth and fracture mechanics analyses which are conducted to determine the appropriate corrective actions. NUREG-1153, Vol. 4 addresses the subject of ISI in depth while this program plan concentrates mainly on the area of piping fracture mechanics, including crack growth rate and failure models.

If a crack is detected in service, there are several courses of action. Generally, an evaluation is first performed to determine if the flaw is acceptable for continued operation. To perform this evaluation requires a reasonably accurate knowledge of the applied and residual stress states; the relation of crack growth to stress, environment, and time; and the ultimate loading capacity of the pipe. Improved models and data are needed in all these areas to improve on the current analyses and to allow realistic evaluations of the significance of detected cracks. If a flaw cannot be demonstrated to be acceptable for continued operation, the main corrective actions are weld repair, weld overlay, or pipe replacement. There currently exist no standards governing the weld repair of stainless steels. Research to support the development of such standards is an important effort. Weld overlay is a relatively new repair technique which requires evaluation to determine its suitability as more than a short term fix. Of particular interest are the strength of the weld overlay as well as its ability to stop or slow crack growth. Analytical studies and long-term laboratory tests are necessary to ensure that the weld overlay can stop not only stress corrosion cracking but also crack growth by other non-stress assisted mechanisms such as crevice corrosion.

Continuing research is necessary on the suitability of proposed long-term fixes such as pipe replacement with more resistant materials, induction heating stress improvement (IHSI), last pass heat sink welding, and hydrogen water chemistry. This research requires short-term efforts to support the decisions which must be made in the near-term and also longer-term efforts to identify any potential problems that might arise with these fixes after extended operating times.

Finally, since there is the possibility that some cracks may go undetected, it is desirable to understand the conditions under which leak-before-break will prevail. Research is needed to better define the magnitude of the leak rates expected from different types of cracks under various operating conditions and to determine the amount of time between detection and pipe failure. The subject of leak-before-break is also important to the issue of postulated pipe breaks as discussed in the following section.

1.2 Postulated Design Basis Pipe Breaks

The double-ended guillotine break (DEGB) was originally postulated for the purpose of sizing containment and emergency core cooling systems. But, historically, the DEGB has also been used in the U.S. for evaluating the postbreak consequences of pipe ruptures. The mechanical loads resulting from the postulated DEGB, together with other loads such as seismic loads, are used for designing component supports and other structural members, while the postbreak consequences resulting from the postulated DEGB result in the need for massive pipe whip restraints and jet impingement shields. These pipe whip restraints and jet impingement shields can reduce the reliability of inservice inspections, increase the radiation exposure associated with ISI and maintenance operations, and are very expensive to design and install. The postulated DEGB creates significant difficulties for old as well as new plants. For example, the postulated guillotine break at the reactor pressure vessel nozzle led to the Asymmetric LOCA Load issue and postulated breaks have created complications in the Systematic Evaluation Program of older operating plants.

The key issue to be resolved is whether or not leak-before-break can be accepted as the actual failure mode in nuclear piping systems. Research is needed to determine under what conditions pipe cracks will be reliably detected by leakage prior to their reaching the critical size under normal or postulated accident conditions. Necessary areas of investigation include studies on crack growth characteristics, residual stress distributions, leak rate magnitudes, leak detection reliability, and fracture mechanics models to predict pipe failure.

2.0 Program Description

In order to address the issues identified in the previous section, the MEBR Piping Research Program is organized into the three main areas of flaw evaluation procedures, repair and mitigation techniques, and pipe break criteria. A description of the research activities in each of these areas is given below. These activities are being conducted by many different contractors, including Argonne National Laboratory (ANL), Battelle Columbus Laboratories (BCL), Materials Engineering Associates, Inc. (MEA), the David Taylor Naval Ship

Research and Development Center (DTNSRDC), the United States Naval Academy (USNA), Westinghouse, and Pacific Northwest Laboratories (PNL). The following discussion identifies the efforts of each of these organizations in the three main subject areas identified above and describes how the efforts are integrated.

2.1 Flaw Evaluation Procedures

2.1.1 Crack Initiation and Growth

Investigations being performed at ANL on Intergranular Stress Corrosion Cracking (IGSCC) crack growth rates focus on the effect of loading history, specimen geometry, and water purity on crack growth in sensitized Type 304 and other alternative stainless steel alloys. Constant load tests using compact tension specimens are being conducted to provide baseline data on IGSCC growth rates and for subsequent tests under alternating loads. The alternating load tests are being conducted for high R ratios simulating normal constant operating loads with small amplitude transient loads superimposed. Low R ratio tests are also being performed for comparison with crack propagation data generated in EPRI/GE pipe tests. Crack growth rate experiments to quantify the influence of water chemistry (oxygen, hydrogen, and anion concentration) are also being performed for Type 304 stainless steel and other alternative piping materials such as Type 316 LN and Type 347 stainless steels. Tests are being conducted to quantify the effects of transient, off-normal to normal water chemistry conditions and to evaluate possible "memory" effects. The effect on crack growth rates of impurity anions ($CO_3^{=}$, Cl, $S_2O_3^{=}$) at low concentration are also being investigated. The information obtained in this task will be used to determine the potential degree of improvements in the SCC resistance of piping materials through implementation of more stringent control of water chemistry. In addition, the effects of hydrogen addition to the water on crack growth rates in irradiated and unirradiated materials are also being investigated. Crack growth rate data developed in this program will provide an independent basis for evaluating proposed crack growth laws to be used in evaluating flaws discovered in service. Furthermore, an attempt will be made to develop a mechanistic understanding of stress corrosion cracking of piping alloys in nuclear reactor environments which will aid in assessment and extrapolation of laboratory data to field application and in the evaluation of proposed environmental and metallurgical corrective actions and modified reactor operating procedures.

2.1.2 Corrosion Assisted Fatigue

In addition to propagation by stress corrosion cracking (SCC), crack propagation by fatigue or environmentally assisted fatigue is also a concern in performing flaw evaluations. This area will be addressed through the Phase II of the Structural Integrity of Light Water Reactor Boundary Components Program, being conducted by Materials Engineering Associates, Inc. (MEA) and Westinghouse as a subcontractor to the HSST program at Oak Ridge National Laboratory (ORNL). Related tasks in this program include the development of S-N curves for nuclear grade steels in light water reactor environments, investigation of "real" crack geometry on fatigue crack growth, development of data defining the effect of cladding on environmentally assisted fatigue crack growth, and development of an effective cumulative damage or usage factor for

environmentally assisted fatigue crack growth. Initial efforts will concentrate on ferritic materials. The data developed in this program will be used to propose appropriate modifications or additions to the ASME Boiler and Pressure Vessel Code. Much of this work is also applicable to pressure vessel integrity. This element of the research program is developed in more detail in "Environmentally Assisted Fatigue and Fatigue Crack Growth," in the section on Reactor Vessels described in NUREG-1153, Vol. 1.

The research efforts described above will provide data on the rate of crack growth as a function of the stress state and environment. In order to perform a flaw evaluation, information on the state of stress (particularly residual stresses for SCC) and criteria defining the critical flaw size at which failure of the piping will occur must be defined. Work is being conducted at ANL to better define the magnitude and distribution of weld residual stresses and their influence on SCC crack growth in original weldments and in weldments that have been mitigated with a stress related fix. This work involves both experimental and analytic evaluations.

2.1.3 Degraded Piping Program - Phase II

The major effort in determining the ultimate loading capacity of cracked pipes will be conducted under Phase II of the Degraded Piping Program. The objectives of this program are to determine the capacity of cracked pipes to withstand normal and postulated accident loads and to validate the application of elastic-plastic fracture mechanics techniques for use in predicting the loading capacity and failure mode of cracked pipes. These objectives will be accomplished through a comprehensive experimental program supported by an extensive analytic effort. The experimental portion of the program involves performing a large matrix of full scale pipe fracture tests. The matrix includes a spectrum of crack geometries and modes of loading and materials including carbon steel, stainless steel, Inconel, and weldments typical of those in operating light water reactor plants. Piping diameters range from approximately 4 inches to 30 inches. The main focus of the program is not the theoretical validation of the tearing instability concept, which has already been demonstrated in numerous experimental programs, but rather the demonstration of the application of tearing instability and other failure criteria, such as net section collapse, to real world situations considering the influence of welds and complicated crack geometries. An important consideration is also the determination of how to extrapolate from small laboratory specimens to full scale pipes.

2.1.4 Supporting Fracture Programs

In addition to the Degraded Piping Program, research efforts are underway at NSRDC, USNA, and MEA to develop testing techniques and data on the fracture toughness of piping materials. The work at NSRDC and USNA focuses primarily on developing and standardizing test techniques and methods for evaluating load and environmental history effects on ductile fracture toughness. Tasks in this program include developing J-R curve test methods using potential drop techniques for crack growth measurements, evaluating effects of loading history on J-R curves, evaluating the effects of crack morphology on fracture toughness, and evaluating effects of crack geometry on fracture toughness. In addition, NSRDC will conduct intermediate size pipe tests to evaluate ductile fracture

analysis techniques and the application of small specimen fracture toughness data to real piping geometries. The program at MEA is directed at developing a comprehensive fracture toughness data base. The end product from the MEA program will be a computerized data base of fracture toughness and tensile property data for all the piping materials used in light water reactors. This component of the MEA program is part of the Reactor Vessel Research Program and is described in detail in NUREG-1153, Vol. 1.

2.1.5 Aging of Cast Austenitics

Finally, a program was initiated at ANL in the last quarter of FY-1984 to study the long-term aging effects on cast duplex stainless steels. In this program, aging experiments will be conducted on cast alloys with ferrite contents ranging from 2% to 30% and interstitial (C+N) contents of about 0.04% to .20%. Examination of the microstructure and impact and J-R curve testing will be performed on aged specimens. Service aged as well as laboratory aged specimens are being examined in this program.

2.2 Repair and Mitigation Techniques

The objective of the research efforts being conducted in this area is to provide experimentally validated methods and experimental data for evaluating the susceptibility of piping materials to crack initiation and crack propagation. Stress corrosion cracking, one of the main causes of pipe cracking in operating LWRs, generally results because of a combination of a susceptible material (because of its chemistry and fabrication history), an aggressive environment, and relatively high tensile stresses. The SCC phenomenon can be countered through control of any of these elements or combination of these elements. Accordingly, the research program plan includes investigations in all of these areas.

2.2.1 Sensitization Studies

Research to evaluate the susceptibility of various stainless steel alloys to initiation of stress corrosion cracking (SCC) is being conducted under programs at ANL and PNL. The objective of this research is to evaluate alternative piping materials by developing an understanding of the effect of thermomechanical history on the nature and degree of sensitization and by developing techniques for estimating the degree of sensitization and susceptibility to crack initiation.

At ANL, the effect of thermomechanical history on the degree of sensitization and susceptibility to crack initiation is being studied for Type 304 SS and various alternative alloys. Tests are conducted in both CERT and constant load SCC facilities. Weld specimens fabricated from the various piping materials and subject to various stress improvement remedies (heat sink welding, induction heating stress improvement, and corrosion resistant cladding) are being subjected to low temperature sensitization for various time-temperature combinations, and then EPR, ASTM A262-A and -E, and CERT tests will be performed. Investigations are being performed into the correlation between the path dependence of different thermomechanical histories, IGSCC susceptibility and sensitization tests such as EPR. Slow strain rate tests in oxygenated water (0.2ppm O_2) with minor impurity additions (chlorides and sulfate) are

also being conducted on alternative piping materials. These tests are conducted at temperatures from 100 to 289°C and applied strain rates from 10^{-8} to 10^{-5} sec^{-1}. Heat to heat variation in susceptibility to IGSCC will also be investigated. In addition, tests on bolt loaded fracture mechanics type specimens will be initiated to assess the susceptibility of piping materials to cracking in the presence of tight crevices. All of the above studies are intended to provide data and techniques for judging the susceptibility of various piping materials to crack initiation.

2.2.2 Weld Repairs

Work is also being performed at PNL to develop a method for evaluating welded and/or repair welded stainless steel piping with respect to the degree of sensitization and level of IGSCC susceptibility. The program involves experimental and analytic determination of the thermomechanical history of stainless steel pipe welds and the correlation of the thermomechanical history and alloy chemistry with the degree of sensitization. The thermomechanical history will be determined as a function of heat input for each pass for the underlying weld and subsequent repair welds. The degree of sensitization and IGSCC resistance will be evaluated by the EPR technique and by CERT testing.

The final product of this work will be a model for predicting the degree of sensitization and IGSCC resistance for various stainless steel alloy compositions and weld repair procedures.

2.2.3 Stress Redistribution

In addition to studying the performance of alternative piping materials, studies are also being conducted at ANL on stress redistribution techniques such as induction heating for stress improvement (IHSI), weld overlay, and last pass heat sink (LPHS) welding. Finite element studies to determine the range of crack lengths for which IHSI and the weld overlay procedures will be effective in producing compressive residual stresses and negative stress intensity values will be performed. Experimental measurements of the residual stresses in pipe weldments with overlays are being performed to benchmark the finite element analyses. Pipe tests on precracked pipe to which an overlay has been applied will be conducted in realistic BWR environments. The pipe tests will evaluate both the effectiveness of the residual stresses produced by the overlay and the crack arrest capability of the weld metal with a deeply creviced configuration in an environment containing realistic levels of impurities.

2.2.4 Water Chemistry

In addition to the above, investigations of the merits of improved water chemistry control (including hydrogen additions), as described in the section on flaw evaluation, will also provide information necessary for evaluating proposed fixes to the SCC problem in BWRs.

2.3 Postulated Pipe Break Criteria

Postulated pipe break criteria are keyed to the issue of leak-before-break. The objective is to determine under what conditions a cracked pipe will be reliably detected by leakage prior to a catastrophic failure or under what conditions

failure of a pipe, which is not detected by leakage, will result in undesirable but acceptably small leakage. Of particular interest is the ability to determine when full double-ended guillotine breaks are a justifiable design basis accident and when they are not. The necessary elements to address this issue are validated piping fracture mechanics models for predicting the failure load and failure mode of cracked piping, data on leak rates as a function of crack size, and data on the sensitivity and reliability of leak detection. The MEBR Piping Research Program addresses all of these areas.

As stated previously (under Flaw Evaluation Procedures), a primary objective of Phase II of the Degraded Piping Program is to develop and experimentally validate ductile fracture analysis models for predicting crack instability and piping failure modes (leak-before-break versus guillotine failure). Although the majority of the experiments to be conducted in the program are low energy (unpressurized or pressurized with a relatively incompressible medium such as oil) a number of high energy tests (pipes pressurized with water at LWR pressure and temperature conditions) will also be conducted if they can be achieved in a cost effective manner. The primary objectives of the high energy tests would be to demonstrate the validity of the ductile fracture and to study the run/arrest crack phenomena and postbreak phenomena under prototypical conditions. These tests are, however, very expensive to perform due to the facility requirements. Therefore, MEBR is currently seeking cooperative efforts with EPRI and other domestic and foreign organizations which will allow such tests to be conducted at a reasonable cost within currently foreseen budget constraints.

The second major area requiring work is that of leak rate measurements and leak detection capabilities. Work is underway at ANL to develop and assess acoustic techniques for leak detection in reactor coolant systems. Acoustic leak detection is being studied in a laboratory pipe run capable of simulating leaks from IGSCC and fatigue cracks as well as valves and seals as a function of pressure and temperature. Leaks from throughwall field-induced and graphite wool grown IGSCC, thermal fatigue cracks, and fabricated slots as small as 25 micrometer width have already been examined. In the future, data acquisition will be continued on acoustic leak detection (effect of pressure, temperature, and flow rate on frequency spectra) for various crack types. Estimates of background noise have been obtained and a value for the minimum detectable leak rate determined. Finally, a field demonstration of acoustic leak detection technology will be performed at an operating plant.

Limited experimental data is currently available on leak rates as a function of crack size and crack morphology. In addition, no comprehensive evaluation of the reliability of leak detection systems as they currently exist in operating plants has been performed. Both these issues have been identified as areas requiring additional effort in the MEBR Piping Research Program. The reliability of leak detection systems is being performed at ANL in conjunction with their current efforts on evaluation of leak detection systems and development of continuous leak monitoring. Additional leak rate studies will also be conducted. This effort which is currently being planned will involve developing experimental data to confirm the ability of analytic models to accurately determine leak rate as a function of crack size. Finally, an effort will be required to integrate the above information and establish criteria for determining the validity of leak-before-break under various conditions. This

effort will be closely coordinated in the near term with work being performed by the NRC Piping Review Committee and in the longer term will provide necessary data and information for the effective review of license submittals on the subject of leak-before-break.

3.0 Schedule

A network showing major milestones and tasks to be completed by fiscal year is enclosed as Table 1.0. Milestone charts for specific programs can be provided upon request.

4.0 Coordination

Coordination within NRC is viewed as extremely important to the success of the subject research program in meeting the needs of the user offices. In order to ensure and improve upon this type of coordination MEBR will establish a Piping Integrity Group (PIRG) similar to the Vessel Integrity Review Group (VIRG) which has operated effectively for several years. The PIRG will be made up of knowledgeable representatives from all of the interested NRC Offices and will provide a forum where the user needs can be effectively identified to RES and where the research program can be reviewed to ensure that they are providing the required information.

Coordination has also been pursued with organizations outside of NRC. These efforts include information exchanges and the development of cooperative efforts such as that discussed earlier for conducting high energy pipe tests. Review meetings are conducted periodically with EPRI and other research organizations to compare research results and ensure that duplication of effort is not occurring. Cooperative efforts including cost sharing type agreements are considered extremely important in the face of declining budgets and will be pursued vigorously by the MEBR staff.

5.0 Capabilities of NRC Staff

MEBR staff members acting as managers for the piping programs are Mr. Milton Vagins, Dr. Joseph Muscara, and Mr. Alfred Taboada.

Mr. Vagins received his B.A. and B.M.E. degrees in Mechanical Engineering (1952 and 1960 respectively) from the City College of New York. During the 3 years (1963-1966) that Mr. Vagins taught courses in the Engineering Mechanics Department of the Ohio State University, he completed all requirements for and entered into candidacy for the Ph.D. degree in Engineering Mechanics. Mr. Vagins was employed by the Battelle Memorial Institute, both at the Columbus and Richland laboratories where he was sequentially, research scientist, program manager and line manager from 1960 to 1979. He joined the Materials Engineering Branch, RES in April 1979 and has had the responsibility for the direction of the HSST program and other fracture mechanics related programs. He was instrumental in bringing the P.T.S. problem to the attention of the NRC and played a key role in the timely achievement of the interim resolution to USI-A49. He acts as the resident expert in fracture mechanics for RES. He currently directs the HSST program, the Structural Integrity of Light Water Reactor Boundary Components program, the Degraded Piping Program, Piping related research programs at the DTNSRDC, and the Naval Academy, and controls the activities of MEBR's Resident Engineer in Germany.

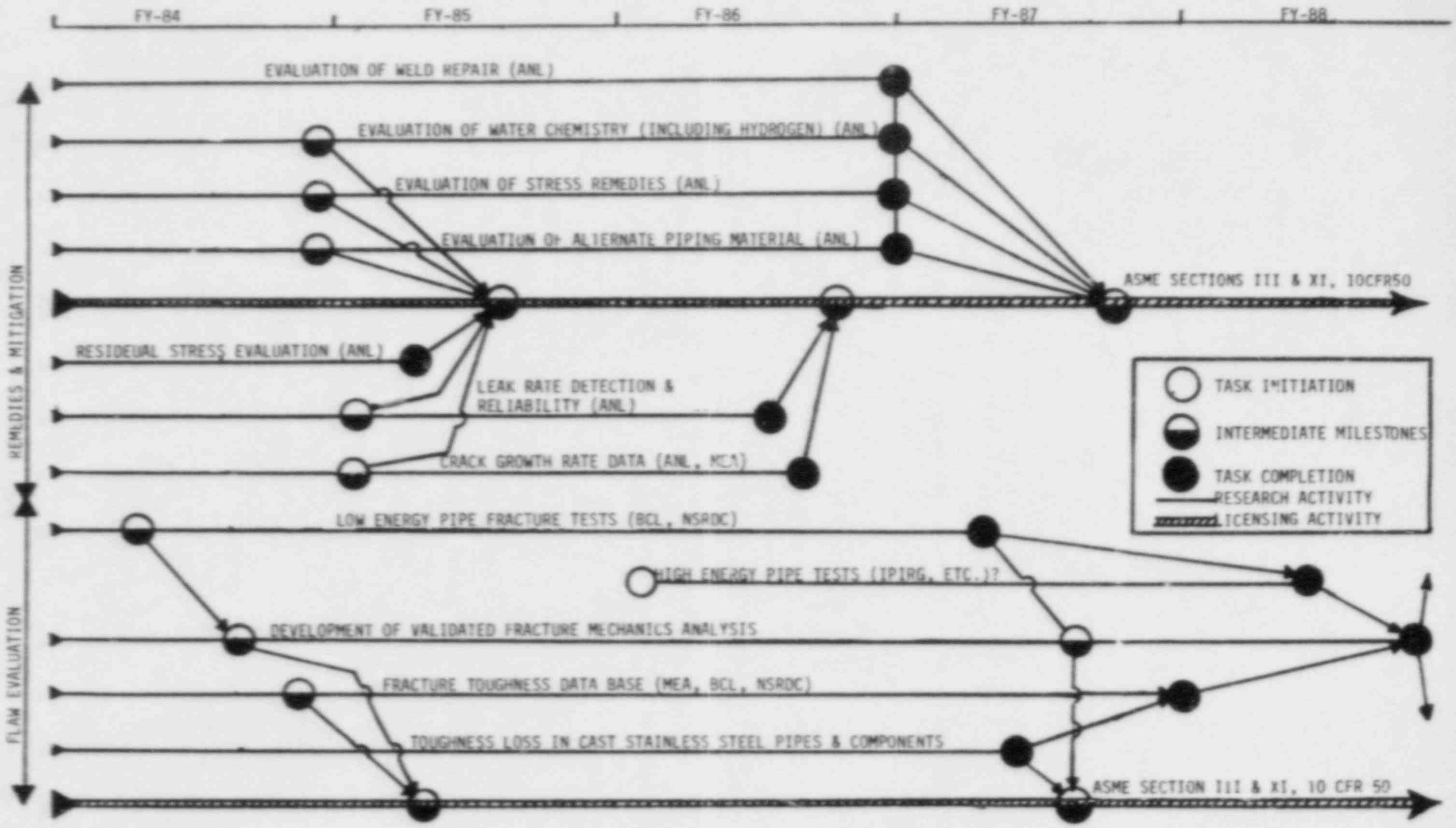
Dr. Muscara received a Ph.D. from the University of Michigan in 1971. Dr. Muscara has been a research program manager in AEC and NRC for nearly nine years; for one year previously, he was on the Standards Development Staff. He has foreseen the need for many research programs and has guided them through the planning, review, approval and program management processes. He has been named as a member of the NRC Pipe Crack Study Groups and as a member of the EPRI Corrosion Advisory Committee. He developed and, until recently, managed the "Environmentally Assisted Cracking in LWR Systems" program at ANL. He is currently manager of the programs on Evaluation and Acceptance of Welded and Weld-Repaired Stainless Steels for LWR Service (PNL) and Long-Term Embrittlement of Cast Duplex Stainless Steels in LWR Systems (ANL). In addition, Dr. Muscara manages the MEBR programs in the area of NDE and Steam Generators.

Mr. Taboada received his B. Chem. Eng. degree from Newark College of Engineering and his M. Met. Eng. degree from Renssalaer Polytechnic Institute. He has worked in the NRC for the past 9 years as a Program Manager, Standards Development staff; and Operating Reactor Reviewer, and in the A.E.C. for 9 years as a Senior Materials Engineer, managing engineering materials development work for advanced reactors. Prior to that he worked at ORNL for 12 years as a Group Leader and Project Metallurgist in the design, development, fabrication, and NDE of the following reactor programs: ANP, MSRP, HFIR, HRP, and SNAP-8. He is a member of the ASME B&PV Code Committee, Subgroup on Materials and ASTM-E10 Executive Committee, and has participated in the NRC Pipe Crack Study Groups and the NRC Piping Review Committee. He is currently managing the SCC of PWR Steam Generator Tubing Program at BNL, the Materials Engineering Program at ORNL, the RV Thermal Annealing Program at INEL and the Dosimetry Programs at HEDL, NBS and ORNL.

6.0 Closure of Technical Issues

The most important issues to be closed through research validation of positions and analysis methods during the FY 1985-89 time period are techniques for evaluation of pipe cracks found inservice and leak-before-break as applied to elimination of the double-ended guillotine break criterion. The basis for the original formulation of the licensing positions on these issues came partly from research data, and the validation will derive from completion of the elastic-plastic and ductile fracture mechanics development plus low and high energy testing of cracked and degraded piping under pressure, bending and seismic loading. Tests will be conducted on carbon and stainless steel pipe, nozzles and elbows. To be closed in the FY 1986-87 time frame are the issues of evaluation and validation of the short-term pipe crack fixes as well as the efficacy of the weld clad overlay for multiple cycle service. Other issues which complement those noted above and are necessary to be resolved are the development of a materials property data base for LWR piping, and a standardized fracture toughness testing procedure for piping materials in the ductile temperature range. Both of these are scheduled for the FY 1987 time frame. These issues are important because the staff must know how properties should be measured so they can be confidentally applied to piping integrity evaluations, and the staff must know if the measurements submitted are reasonable within the range of properties characteristic of that material. These issues arise constantly during regulatory actions on plant submission for all types of actions, including leak-before-break, and pipe crack evaluations.

FIGURE 1 PIPING RESEARCH PROGRAM PLAN



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This document presents a plan for research in Piping to be performed by the Materials Engineering Branch, MEBR, Division of Engineering Technology, (DET), Office of Nuclear Regulatory Research. It is one of four plans describing the ongoing research in the corresponding areas of MEBR activity, which are being published simultaneously in four volumes as follows: Vol. 1 Reactor Vessels, Vol. 2 Steam Generators, Vol. 3 Piping, and Vol. 4 Non-Destructive Examination. These plans have been updated and are more detailed expansiens of those originally published as part of the Long Range Research Plan for the Office of Nuclear Regulatory Research in NUREG-1080 Vol. 1.

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