CATEGORY A TECHNICAL ACTIVITY NO. A-11

PROPOSED REVISION 1

Title: Reactor Vessel Materials Toughness

Lead Responsibility: Division of Operating Reactors

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1. Problem Description:

Because the possibility of failure of nuclear reactor pressure vessels designed to the ASME Boiler and Pressure Vessel Code is remote, the design of nuclear facilities does not provide protection against reactor vessel failure. Prevention of reactor vessel failure depends primarily on maintaining the reactor vessel material fracture toughness at levels that will resist brittle fracture during plant operation. At service times and operating conditions typical of current operating plants, reactor vessel fracture toughness properties provide adequate margins of safety against vessel failure; however, as plants accumulate more and more service time, neutron irradiation reduces the material fracture toughness and initial safety margins.

Results from reactor vessel surveillance programs indicate that up to approximately 20 operating PWR's will have beltline materials with marginal toughness, relative to the requirements of Appendices G and H of 10 CFR Part 50, after comparatively short (approximately 10 EFPY) periods of operation. To ensure adequate toughness margins for operating plants it will be necessary to (1) establish a suitable safety criterion for low toughness materials, (2) define and identify critical materials in reactor vessels and (3) monitor and evaluate operational materials surveillance program results relevant to establishing a suitable generic toughness criterion. For those facilities not yet licensed for operation, current licensing criteria are adequate to ensure suitable safety margins throughout design life with the materials currently employed for reactor vessel fabrication. However, the need exists to reconsider these current criteria in light of new methods that may be developed in the evaluation of low toughness materials and to appropriately augment or refine these present criteria to include these new aspects and maintain NRC licensing consistency.

2. Plan For Problem Resolution:

The determination of an appropriate licensing criterion for low toughness reactor vessel materials in currently licensed plants and the evaluation of material degradation resulting from neutron irradiation demands a broad, integrative effort encompassing several aspects

of materials and fracture technology. To successfully establish a suitable licensing criterion for low toughness reactor vessel materials in currently licensed plants and to enable an accurate assessment of neutron irradiation damage, the following tasks need be completed.

A. Development of Advanced Fracture Mechanics Methods

The measurement of fracture toughness for reactor vessel and other materials at temperatures corresponding to the upper shelf region is complicated by the presence of material plastic flow. Current toughness testing and analytical methods based on linear elastic fracture mechanics are not adequate to account for plastic flow. New testing and analytical techniques must be developed to allow evaluation of low toughness in reactor vessel materials for normal operating and faulted conditions.

B. Fracture Toughness Evaluation For Postulated Accident Conditions

In addition to normal operating conditions, the generic criterion for low toughness materials must be sufficiently comprehensive to include postulated accident conditions. To ensure that adequate material fracture toughness is available during postulated accident conditions, the following conditions must be reviewed.

1. Thermal Shock: It has been postulated that the thermal shock to the reactor vessel caused by ECCS operation could, near end of life where accumulated radiation damage is significant, cause the vessel to fail in such a manner that it could not hold the cooling water.

2. Effect of Main Steam Line Break: A main steam line rupture could produce a repressurization of the reactor vessel following initiation of the ECCS. The NRC staff has been advised by various NSSS vendors that this repressurization would produce a significant temperature and stress transient and could, near end of life where accumulated radiation damage is significant, result in significantly reduced safety margins for the reactor vessel.

C. Transient Thermal Analysis For Postulated Accident Conditions

To assess the resistance of the reactor vessel to flaw induced fracture during postulated accident conditions, the transient thermal conditions associated with the postulated accident conditions must be defined. Transient thermal and stress analyses for these conditions previously submitted by licensees and NSSS vendors will be reviewed and used as input for assessing the

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resistance to flaw induced fracture of marginal toughness beltline materials. Appropriate results from the proposed Category A Technical Activity A-22, "Main Steamline Break Outside Containment," will also be used as they become available. 1

D. Radiation Damage Technology Improvements

The amount of radiation damage incurred by the reactor vessel must be predicted and the checked by extrapolation of the results from the surveillance program during the service life. Uncertainties in the predicting methodology can be significant. The variables that are relevant to this study are steel chemical composition and microstructure, neutron spectra variations, uncertainties in dosimetry and dose rate. As older vessels become more highly irradiated, our capability to predict the associated, apparent reduction in toughness must improve. During this time, more information will be available from the surveillance programs. We must develop better ways to evaluate this information to improve our predictive capability.

E. Reactor Vessel Annealing Feasibility

Because the possibility exists that severe material toughness degradation due to neutron irradiation damage may eventually preclude some reactor vessels from meeting fracture toughness licensing criteria, it may be necessary to anneal these vessels to regain the required toughness levels. A reactor vessel annealing feasibility study will be conducted to define the annealing time and temperature parameters necessary to ensure that adequate safety margins are regained and maintained.

F. Reactor Vessel Annealing Licensing Criteria

Environmental, structural and mechanical criteria will be defined to ensure that effluents and personnel exposure are maintained within acceptable limits during an annealing operation and that the reactor vessel and other safety systems maintain their integrity subsequent to an annealing operation. 1

G. Identification and Evaluation of Reactor Vessel Welds

It has recently been determined that the welds in various reactor vessels are not always represented by identical welds in the surveillance program associated with any given plant. This makes accurate evaluation of the surveillance data, relative to the toughness degradation for any given operating plant, difficult. Consequently to obtain sufficient comprehensive information for a generic evaluation, each reactor vessel and surveillance program weld material must be identified, located and categorized to

ensure effective utilization of the surveillance program and effective evaluation of the reactor vessel material fracture toughness. Letters requesting information relevant to this task have been sent to PWR licensees.

H. Development of Surveillance Information System

Because of the large number of possible combinations of reactor vessel and surveillance materials and the large number of variables involved in evaluating these materials, it is necessary to develop an information system for the storage and retrieval of these data. This system will be utilized particularly to maintain up-to-date, accurate data for the generic and plant specific evaluation of operating facilities.

3. NRR Technical Organizations Involved:

A. Engineering Branch, Division of Operating Reactors. Has overall lead responsibility in the identification of relevant reactor vessel material in licensed plants, evaluation of operating experience with neutron irradiation damage, determination of the associated degradation in reactor vessel material toughness and the evaluation and determination of an appropriate safety criterion for low toughness reactor vessel materials. The Engineering Branch also has lead responsibility for evaluating the structural, mechanical and materials aspects of reactor vessel annealing operations, should annealing be requested to restore reactor vessel beltline material toughness.

Manpower Estimates: 0.3 manyears FY 1977, 2.5 manyears FY 1978, 2.5 manyears FY 1979

B. Materials Engineering Branch, Division of Systems Safety. Has lead responsibility for the review of information developed during the evaluation of material toughness in licensed facilities for possible inclusion into material toughness criteria currently used for facilities not yet licensed for operation, where appropriate.

Manpower Estimates: 0.1 manyear FY 1977, 1 manyear FY 1978, 1 manyear FY 1979.

C. Reactor Systems Branch, Division of System Safety. Has lead responsibility for reviewing transient thermal analyses previously submitted by various licensees and NSSS vendors for postulated accident conditions. The Reactor Systems Branch also has lead responsibility for the proposed Category A Technical Activity A-22, "Main Steamline Break Outside Containment," and will provide appropriate results from this activity as input to the Engineering Branch for fracture toughness analyses of postulated accident conditions. 1

Manpower Estimates: 0.1 manyear FY 1978, 0.1 manyear FY 1979.

D. Environmental Evaluation Branch, Division of Operating Reactors. Has lead responsibility for defining licensing criteria related to effluent and personnel exposure control during reactor vessel annealing operations. 1

Manpower Estimates: 0.1 manyear FY 1978, 0.1 manyear FY 1979.

4. Technical Assistance Requirements

Technical assistance from organizations outside the NRC will be required to complete tasks 2A, Development of Advanced Fracture Mechanics Methods; 2B, Fracture Toughness Evaluation During Faulted Conditions; 2C, Radiation Damage Technology Improvements and 2D, Reactor Vessel Annealing Feasibility. The contractors assisting in these tasks are as follows:

A. Contractor: Washington University,(EB/DOR)

Funds Required: $120K FY 1977, $50K FY 1978, $50K FY 1979.

This program is directed specifically at tasks 2A, Development of Advanced Fracture Mechanics Methods and 2B, Fracture Toughness Evaluation During Faulted Conditions. The results of the program will allow advanced fracture mechanics techniques to be used to establish a technical basis for NRC's development of a suitable licensing criterion for low toughness materials. Associated with this is the determination of simplified analytical techniques to evaluate normal operating conditions, postulated accident conditions and assistance in plant specific analyses.

B. Contractor: Naval Research Laboratory, (EB/DOR, MTEB/DSS)

Funds Required: $140K FY 1977, $75K FY 1978, $75K FY 1979.

This program will investigate neutron irradiation of reactor vessel steels and is directed specifically at tasks 2C, Radiation Damage Technology Improvements and 2D, Reactor Vessel Annealing Feasibility. The results should provide improved means to quantitatively describe the effects of material microstructure, chemical composition, neutron spectra and dose rate and allow suitable evaluation, prediction and monitoring of irradiation damage to reactor vessel steels. Included in this program is a study of the feasibility of in-place annealing of reactor vessels to restore fracture toughness to levels that will provide adequate safety margins should the material toughness degradation be sufficient to preclude meeting licensing requirements. Funding for this program is now shared by DSS and DOR.

5. Interaction With Other Outside Organizations:

A. Licensees

Intermittent interaction with licensees is expected for the purpose of obtaining required materials data.

B. NSSS Vendors

Some plant specific analyses have been conducted by the NSSS Vendors. Review of the portions of these analyses relevant to completion of the generic task will be required. Some NSSS Vendors have first hand knowledge of fabrication and materials data relevent to low material toughness; review of these data will be required.

C. EPRI

EPRI is currently funding a number of programs related to reactor vessel materials toughness. These programs include studies for neutron irradiation damage of pressure vessel steels and the development of fundamental failure criteria based on elastic plastic fracture mechanics. Interaction with EPRI to remain informed on the direction and results of these programs and to ensure that appropriate NRC licensing concerns are addressed will be required.

D. ACRS

This task is closely related to one of the generic items identified by the ACRS and, accordingly, will be coordinated with the Committee as the task progresses.

6. Assistance Requirements from Other NRC Offices

A. Office of Nuclear Regulatory Research, Division of Reactor Safety Research, Metallurgy and Materials Branch

RES is funding a major experimental research program (Heavy Section Steel Technology, HSST) through Oak Ridge National Laboratory to determine the fracture toughness of reactor vessel steels and the safety margins for reactor vessels. At the request of NRR, RES recently modified this program to include materials with low toughness that are representative of those at operating facilities.

At the request of NRR, RES is currently considering the initiation of a program to verify experimentally the application of the tearing stability concept as a failure criterion for beltline materials with marginal fracture toughness. 1

RES has just initiated a comprehensive research program to experimentally validate neutron irradiation damage in pressure vessel steels and the associated calculational schemes used to predict radiation damage. This effort is to be part of an overall program being conducted in cooperation with research groups in the US and Europe.

B. Office of Standards Development, Division of Engineering Standards, Structures and Components Standards Branch

SD has assisted NRR in the study of the effects of neutron irradiation and the evaluation of low toughness reactor vessel steels over the past year by providing the services of Dr. P. N. Randall, who is on loan to the Engineering Branch, DOR.

C. Office of Management Information and Program Control, Division of Regulatory Information Systems, Processing and Programming Branch.

MIPC has been assisting NRR in establishing a computer based information system for the storage and retrieval of materials surveillance data.

7. Schedule for Problem Resolution

The major milestones for the Reactor Vessel Materials Toughness Program are:

A. Determination of a preliminary engineering fracture toughness criterion for low toughness reactor vessel materials and appropriate operating conditions, (Tasks 2A and 2B). - December 1977.

B. Obtain information from licensees concerning neutron irradiation surveillance materials, (Part of Tasks 2G and 2H). - December, 1977.

C. Complete initial analysis of HSST model pressure vessel test data, (Part of Task 2A). - June, 1978. | 1

D. Complete review of available licensee and NSSS vendor transient thermal analyses for postulated accident conditions, (Part of Task 2C) - July, 1978. | 1

E. Complete generic evaluation of licensee surveillance materials, (Part of Task 2G). - October, 1978.

F. Complete phase 1 (HSST 2) of the experimental program to determine the fracture toughness of irradiated, low toughness reactor vessel beltline materials, (RES Task) - October, 1978.

G. Define neutron irradiation effects for reactor vessel materials, (Task 2D) - January, 1979.

H. Determination of the feasibility of reactor annealing, (Tasks 2E and 2F) - January, 1979.

I. Complete experimental verification of tearing stability failure criterion for reactor vessel beltline materials (RES task) - March, 1979. | 1

J. Complete second phase (HSST 3) of the experimental program to determine the fracture toughness of irradiated, low toughness reactor vessel beltline materials, (RES Task) - May 1979.

K. Complete development of NRC criterion for low toughness reactor vessel materials for operating facilities and revise, if appropriate, the fracture toughness criterion for facilities not yet licensed for operation. Complete NUREG report presenting results and conclusions of program including management review. - July, 1979.

8. Potential Problems

Critical path items for the development and implementation of a licensing criterion for low toughness reactor vessel materials include completion of the fracture mechanics toughness criterion analysis, the definition of appropriate experimental techniques for testing irradiated materials and the subsequent completion of the HSST experimental program for irradiated low toughness materials.

Because the experimental techniques required for completion of the HSST irradiation materials testing have not been used previously for this type testing, there is reason to expect that short periodic delays will be encountered during this program.

Information supplied by some PWR NSSS vendors indicate that because of neutron irradiation damage some reactor vessels will not satisfy current NRC fracture toughness criteria for the postulated main steam line break accident after approximately 20 years of operation. If the results from the analyses described in Tasks 2A and 2B indicate that newly proposed criteria cannot be satisfied, then additional analyses will be necessary and a new task will be defined to consider equipment modifications for certain operating reactors. These equipment modifications will be employed to mitigate the impact of the postulated main steam line break accident and ensure that NRC fracture toughness requirements are satisfied for the postulated accident conditions.

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