ORNL/HSSI (W6953)/MLSR-2004/5

HEAVY-SECTION STEEL IRRADIATION (HSSI) PROGRAM (W6953)

Monthly Letter Status Report

February 2004

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HEAVY-SECTION STEEL IRRADIATION PROGRAM

JCN W6953

MONTHLY LETTER STATUS REPORT

FOR

February 2004

Submitted by

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managed by
UT-Battelle, LLC.
for the
U. S. DEPARTMENT OF ENERGY
Under DOE Contract No. DE-AC05-00OR22725

PREFACE

This report is issued monthly by the staff of the Heavy-Section Steel Irradiation (HSSI) Program (JCN:W6953) to provide the Nuclear Regulatory Commission (NRC) staff with summaries of technical highlights, important issues, and financial and milestone status within the program.

This report gives information on several topics corresponding to events during the reporting month: (1) overall project objective, (2) technical activities, (3) meetings and trips, (4) publications and presentations, (5) property acquired, (6) problem areas, and (7) plans for the next reporting period. Next the report gives a breakdown of overall program costs as well as cost summaries and earned-value-based estimates for performance for the total program and for each of the six program tasks. The six tasks, including a project management task, correspond to the 189, dated August 29, 2003. The final part of the report provides financial status for all tasks and status reports for selected milestones within each task. The task milestones address the period from October 2003 to July 2005, while the individual task budgets address the period from October 2002 to December 2003.

Beginning in October 1992, the monthly business calendar of the Oak Ridge National Laboratory was changed and no longer coincides with the Gregorian/Julian calendar. The business month now ends earlier than the last day of the calendar month to allow adequate time for processing required financial reports to the Department of Energy. The precise reporting period for each month is indicated on the financial and milestone charts by including the exact start and finish dates for the current business month.

Thomas M. Rosseel, Manager
Heavy-Section Steel Irradiation

MONTHLY LETTER STATUS REPORT
February 2004

Job Code Number:	**W6953**
Project Title:	**Heavy-Section Steel Irradiation Program**
Period of Performance:	**4/1/98 to 12/31/05**
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1. PROJECT OBJECTIVE:

The primary goal of the Heavy-Section Steel Irradiation (HSSI) Program is to provide a thorough, quantitative assessment of the effects of neutron irradiation on the material behavior, and in particular the fracture toughness properties, of typical pressure vessel steels as they relate to light-water reactor pressure vessel (RPV) integrity. The program includes studies of the effects of irradiation on the degradation of mechanical and fracture properties of vessel materials\ augmented by enhanced examinations and modeling of the accompanying microstructural changes. Effects of specimen size; material chemistry; product form and microstructure; irradiation fluence, flux, temperature, and spectrum; and post-irradiation mitigation are being examined on a wide range of fracture properties. This program will also maintain and upgrade computerized databases, calculational procedures, and standards relating to RPV fluence-spectra determinations and embrittlement assessments. Results from the HSSI studies will be incorporated into codes and standards directly applicable to resolving major regulatory issues that involve RPV irradiation embrittlement such as pressurized-thermal shock, operating pressure-temperature limits, low-temperature overpressurization, and the specialized problems associated with low upper-shelf welds. Five technical tasks and one for program management are now contained in the HSSI Program.

2. TECHNICAL ACTIVITIES:

TASK 1: Program Management (T. M. Rosseel)

This task is responsible for managing the program to ensure that the overall objectives are achieved. The management responsibilities include three major activities: (1) program planning and resource allocation; (2) program monitoring and control; and (3) documentation and technology transfer. Program planning and resource allocation includes: (a) developing and preparing annual budgetary proposals and (b) issuing and administrating subcontracts to other contractors and consultants for specialized talents not available at Oak Ridge National

Laboratory (ORNL) or that supplement those at ORNL. Program monitoring and control includes: (a) monitoring and controlling the project through an earned-value, project-management system; (b) ensuring that quality assurance (QA) requirements are satisfied; and (c) issuing monthly management reports. Documentation and technology transfer includes: (a) participating in appropriate codes and standards committees; (b) preparing briefings for the NRC; (c) coordinating NRC and internal ORNL review activities; (d) coordinating domestic and foreign information exchanges approved by NRC; and (e) documenting the activities of the program through letter and NUREG reports.

(Milestone 1.1.A) The second increment of FY 2004 funds was received, approved by DOE and transferred to the HSSI Program at the beginning of this reporting period.

(Milestone 1.1.B) During this reporting period, discussions with the staff of the University of Michigan Ford Nuclear Reactor (FNR) continued concerning removal of specimens, return of control panels and disposal of irradiated waste. It is anticipated that the control panels will be shipped to ORNL in the second week of March. Final arrangements for returning the irradiated specimens are expected to be completed during the next reporting period. (See Task 6 for details).

(Milestone 1.3.C) Site visits and planning for reactor site evaluations for future irradiation experiments, in cooperation with the DOE Gen IV Program, continued during this reporting period.

On February 2 –4, R. K. Nanstad, K. R. Thoms, D. W. Heatherly, and T. M. Rosseel traveled to Columbia, Missouri, to discuss and evaluate the possible use of the University of Missouri, 10 MW, Missouri University Research Reactor (MURR). Several challenges must be overcome, but it appears that this could be a very promising candidate as the future location of the HSSI Program's RPV steel irradiation site.

On February 17-19, R. K. Nanstad, K. R. Thoms, D. W. Heatherly, W. R. Corwin, and T. M. Rosseel traveled to Cambiradge, Massachusetts to discuss and evaluate the possible use of the Massachusetts Institute of Technology (MIT), 4.9 MW MITR II tank-type reactor. Like the MURR, several challenges must be overcome, but it too appears to hold promise as a suitable RPV steel irradiation site.

In cooperation with the DOE Gen IV Materials Program, planning for March site visits and evaluations of three European reactors: (1) the LV-15 reactor at the Nuclear Research Institute (NRI), Rez, Czech Republic, Dr. Milan Brumovsky, point of contact; (2) the BR2 reactor at SCK, Mol, Belgium, Dr. Eric van Walle, point of contact; and (3) the R2(0) reactor at Studsvik Nuclear, Studsvik, Sweden, Dr. Mikael Karlsson, point of contact, was nearly completed. The dates for the visits have been set for March 19 – March 30, while local arrangement details will be finalized during the first week of March.

(Milestone 1.3.D) The following technical letter reports were completed and published:

M. A. Sokolov and R. K. Nanstad, *An Evaluation of the Performance of Precracked Charpy and Subsize Specimens in Determining T_o* (ORNL/NRC/LTR-04/10). Please see Task 2.5 for details.

R. K. Nanstad, *Comparison of Fracture Toughness Reference Temperatures for the First and Second Batches of HSSI Weld 72W*, (ORNL/NRC/LTR-04/8). Please see Task 2.8 for details.

Task 2: <u>Fracture Toughness Transition and Master Curve Methodology</u> (M. A. Sokolov)

Fracture-toughness transition and master-curve (MC) methodology will be broadly explored for pressure-vessel applications through a series of experiments, analyses, and evaluations in eight Subtasks. The effects of irradiation on fracture-toughness curve shape for highly embrittled RPV steels, dynamic effects, crack arrest, intergranular fracture, and subsized specimens will also be explored. Additionally, the fluence received in the HSSI irradiation experiments will be determined.

<u>Subtask 2.1: Fracture Toughness Transition Temperature Shifts</u> (M. A. Sokolov)

The purpose of this subtask is to collect and statistically analyze pertinent fracture-toughness data to assess the shift and potential change in shape of the fracture-toughness curves due to neutron irradiation. The MC methodology will be applied to provide a statistical analysis of the fracture-toughness data and Charpy data will be fitted by hyperbolic tangent function. The resulting reference fracture-toughness temperature, T_o, shifts are compared with Charpy shifts determined by various indexing methods.

(Milestone 2.1.A) The report by M. A. Sokolov and R. K. Nanstad, *Comparison of Irradiation-Induced Shifts of K_{Jc} and Charpy Impact Toughness for Reactor Pressure Vessel Steels*, NUREG/CR-6609 (ORNL/TM-13755), was published by the NRC in November 2000. There was no significant progress during this reporting period. However, as they become available, additional data sets will be analyzed and a revised database assembled.

<u>Subtask 2.2: Fracture Toughness Characterization of Highly Embrittled Materials</u> (M. A. Sokolov)

The purpose of this subtask is to evaluate the assumption of constant shape for the MC for highly embrittled RPV steels and to determine the effect of the interaction of low-energy ductile crack initiation with cleavage in the transition region for highly embrittled materials. The evaluation will be performed through the testing of pressure-vessel steels that have been irradiated to a neutron fluence sufficient to produce a fracture-toughness transition-temperature shift (T_o) of about 150°C (270°F). Other materials to be irradiated and examined for the curve shape effects study include a highly embrittled low upper-shelf RPV steel that exhibits onset of stable ductile tearing at relatively low fracture toughness and a high-nickel weld.

(1) A specially fabricated, radiation-sensitive, weld was selected to perform a pilot study on the ability of a highly embrittled material to maintain the master-curve shape. This weld, which was fabricated and studied in Germany, was supplied to ORNL by MPA, Stuttgart through a Memorandum of Agreement (MOA). Capsules, loaded with 21 1T compact specimens and a larger number of smaller specimens of Weld KS-01, were irradiated to a target fluence of 8.0 x 10^{18} n/cm^2 at the FNR during the first HSSI-IAR irradiation campaign. Evaluation of the fracture-toughness transition curve shape has been performed with 1T compact specimens, 1T C(T). Additionally, 0.5T C(T), and pre-cracked Charpy V-notch (PCVN) specimens were tested to investigate the use of more practical surveillance-size specimens. Tensile specimen testing was also completed to determine the irradiation-induced hardening. Evaluation of the mechanical properties of the unirradiated weld has been completed. Sixteen 0.4T C(T) specimens from the previously irradiated and tested KS01 1T C(T) specimens will be prepared and tested for fracture toughness. These data will be compared with results from small and large compact specimens as well as pre-cracked Charpy specimens from the same material in the unirradiated and irradiated conditions.

(2) Specimens of the Midland belt line weld were fabricated and placed into the IAR facility at the FNR for irradiation to a fluence of at least 3 x 10^{19} n/cm^2 (>1 MeV). This irradiation is being conducted to evaluate the assumption of constant shape for the master curve with highly embrittled low upper-shelf RPV steels that exhibit onset of stable ductile tearing at relatively low fracture toughness.

(3) A high nickel weld from the Palisades steam generator will also be examined. Not only will this material provide additional information on curve shape effects, it will permit experimental validation of an assumption of 1:1 relationship between Charpy 41J and fracture toughness shifts for highly embrittled materials. Eight 0.5C(T) and twelve Charpy specimens were irradiated to the intermediate fluence of 1.6x10^{19} n/cm^2 (>1 MeV) and these specimens shall be tested. These results will be compared to the small specimens data from the UCSB program where this weld was also characterized after a similar dose of irradiation.

(Milestone 2.2.A) Irradiation of the Midland beltline weld and a high-nickel weld from the Palisades steam generator has been completed with shutdown of the University of Michigan FNR on July 3, 2003. Following an appropriate cool-down period, the specimens have been removed from the IAR facility and preparations are underway for shipping the specimens to the ORNL hot cells for testing. Please also see Task 6.2.

(Milestone 2.2.B) Some of the Palisades steam generator specimens irradiated to an intermediate fluence were removed previously and were received at the ORNL hot cells. These specimens were sorted and identified in preparation for testing, as discussed below (Milestone 2.2.G).

(Milestone 2.2.C) As reported previously, programming of the computer numerically controlled (CNC) milling machine system and the design of fixtures has been completed. Preparations for machining of the 0.4T compact specimens from the broken irradiated 1T compact specimens of KS-01 is under way with evaluation of the CNC machine operational status, design and fabrication of special fixtures for remote change-out of tools, remote lubrication of moving parts, etc. The machine has been exercised, various issues have been identified, and the issues are being resolved. A number of practice specimens have been machined and measured for comparison with established tolerances. This practice machining has identified a number of issues relevant to machining of compact specimens and the issues have been largely resolved, including the machining of new specimen holder fixtures from steel, as opposed to aluminum.

Following machining of the irradiated specimens, these 0.4T specimens will be tested in the same general temperature range as the 1Ts described in Task 2.2 to expand the database further for this material, and will provide for a comparison of compact specimen results with those from the similar size pre-cracked Charpy specimens. This comparison is directed at the bias indicated in some precracked Charpy data that results in somewhat lower determinations of T_o relative to compact specimens.

(Milestone 2.2.D) As noted previously, 21 1T and six additional 0.5T compact specimens of the submerged-arc weld KS-01, irradiated to ~0.8×10^{19} n/cm^2 (>1 MeV), were successfully tested. The results have been evaluated relative to the shape of the master curve. The occurrence of intergranular fracture in the test specimens was suspected to influence the deviation from MC shape observed. However, for a number of reasons also discussed previously, the contribution of IGF is not clear and the nonconformance of the KS-01 irradiated fracture toughness data may be predominantly due to the high degree of irradiation embrittlement. Further statistical analysis has been performed with these data and have been included in the draft NUREG report. Three additional tensile tests, as noted previously, were expected to shed light on the effects of the intergranular fracture observations relative to expected irradiation-induced hardening. The yield and ultimate strengths for these tests exhibited the expected irradiation-induced strengthening, indicating that intergranular fracture was not the dominant fracture mechanism.

Testing of 12 irradiated precracked Charpy KS-01 specimens has been completed and the results have been analyzed. The draft NUREG report has completed technical review and incorporation of the reviewers' comments, and was submitted to the NRC for publication in December. The KS-01 results were also included in a presentation on nickel effects at the IGRDM-11 meeting in San Diego in September. Please see Section 4.

(Milestone 2.2.G) Charpy impact tests of the Palisades unirradiated specimens and specimens irradiated to ≈1.38×10^{19} n/cm^2 (>1 MeV) were performed. The material exhibited a Charpy 41-J shift of 101ºC. Using the assumed fluence, this is considerably less than the predicted shift of 148ºC by *Regulatory Guide 1.99* (Rev. 2) and the predicted shift of 137ºC by the Eason, Wright, Odette (EWO) equation. Both predictions are, of course, dependent on the chemical composition variables used. The chemical composition used was an average of values available for the weld. Additional analyses will be conducted with the tested specimens to verify those values and will be compared with subsequent results from testing of the specimens irradiated to a higher fluence when they become available.

One broken half of a tested CVN specimen was submitted for atom-probe needle preparation. The fracture surface was cut from the specimen and a 0.5-mm-thick slice was cut from the remainder of the specimen. That slice was then cut into 0.5-mm-thick blanks with approximate dimensions of 0.5 x 0.5 x 10 mm. The blanks were stored in a lead pig and transported to the atom probe preparation facility. Atom probe needles were prepared and atom probe tomography

(APT) was conducted. The APT examinations revealed copper-enriched precipitates also enriched with manganese and nickel. This result was also incorporated into the presentation on nickel effects at the IGRDM-11 meeting in San Diego in September. However, because the number of atoms obtained from that group of needles was substantially less than desired, another group of needles will be prepared and examined during March.

Additional testing of the Palisades weld will be conducted following reception of the high fluence specimens from the FNR. Preparations are underway for shipping the specimens to the ORNL hot cells for testing, with receipt of the specimen anticipated in March. Charpy V-notch tests will be performed followed by cutting of atom probe needles for atom probe tomography examination.

Subtask 2.3: Dynamic Fracture Toughness (R. K. Nanstad, post doc)

The purpose of this subtask is to evaluate the applicability of the MC to dynamic fracture toughness of RPV steels. There are data available that suggest reasonable applicability of the master curve to dynamic fracture toughness data; however, a review of the available data under high-rate loading conditions is needed. There are also data available that indicate a significant effect of loading rate within the limits prescribed in ASTM E1921. Previous plans within the HSSI Program included the evaluation of data from precracked Charpy specimens tested under impact conditions. Although the development of such techniques and resulting data are desirable, the first recommended step in evaluation of the master curve will be a review of the available data mentioned above. The conduct of high-rate loading experiments under elastic-plastic conditions with compact specimens under non-impact conditions will be dependent on the results of that review.

(Milestone 2.3.A and 2.3.B) If the review discussed above results in a recommendation for additional testing, compact specimens (either 0.5T or 1.0T) will be machined from a material with a Master Curve pedigree, such as HSST Plate 02, HSST Plate 13A, or HSSI Welds 72W/73W, and tested at a rate consistent with the dynamic elastic-plastic fracture toughness annex in ASTM E-1820-2001. This will allow for a direct comparison between T_o from quasi-static and dynamic tests. As mentioned above, a variation of loading rates within the E-1921 allowable range will also be considered following a review of the recently recommended changes regarding loading rates in the E-1921 standard. This issue has been identified as a potential area of investigation in a proposed Cooperative Research Program at the International Atomic Energy Agency (IAEA). Additionally, a review of instrumented impact testing of precracked Charpy specimens will be conducted to assess the potential inclusion of that technique in the project.

Subtask 2.4: Intergranular Fracture (R. K. Nanstad)

This subtask will address the issue of whether the MC technique can be applied to materials that experience brittle fracture by an intergranular mechanism. Specifically, it will be determined whether steels that experience intergranular fracture can be correctly characterized by the MC To temperature and whether the transition-curve shape can be changed by different fracture modes.

Complete intergranular fracture from temper embrittlement occurs only at lower-shelf temperatures. As it is with transgranular cleavage, the transition to upper shelf is marked by an increased volume percentage of ductile rupture mixed with the lower-shelf, brittle-fracture mechanism. Since the onset of crack instability is most likely triggered in the brittle zones, the critical issue becomes one of understanding the influence of the triggering mechanism on the distribution of K_{Jc} values obtained. This information can be obtained on the lower shelf and, in part, into the transition range.

The proposed approach is to determine if there is an operational weakest-link effect when instability is triggered within an intergranular region. If an effect is observed, there should also be a measurable specimen-size effect on K_{Jc}. It will also be determined if the temper-embrittled materials exhibit a change in the J-R fracture toughness since such steels do not show a significant change in upper-shelf CVN energy.

The modified A302 grade B steel selected to evaluate intergranular-fracture effects on the universal MC shape assumption was specially heat treated to temper embrittle the material, and fracture-toughness testing was performed. In the analysis of the data, however, it became clear that additional testing was deemed necessary to allow for a more definitive conclusion regarding the relationship between the intergranular fracture results and the Master Curve. A letter report describing this work was submitted in December 2002.

Additional 0.5TC(T) specimens were fabricated and tested, demonstrating that materials that fail with 100% intergranular fracture are not appropriate for MC characterization. This result compares with observations of materials that have failed with 10 to 20% intergranular fracture and which appear to behave in a manner consistent with MC characterization.

(Milestone 2.4.A) A test plan for intergranular fracture (IGF) assessment for conditions that produce less than 100% IGF is being developed.

<u>Subtask 2.5: Sub-sized Specimens</u> (M. A. Sokolov, guest/post doc)

The purpose of this subtask is to evaluate the applicability of the weakest-link theory-based size-adjustment procedure in the MC methodology to specimen sizes that are the most likely to be present in surveillance capsules. The MC methodology will be applied using precracked Charpy-size or smaller specimens to test the lower-size limit applicability. Testing will be performed at two or more temperatures with at least six specimens at each temperature. The exact number of temperatures and specimens will be determined following analysis of initial results. The testing of these subsize specimens will also satisfy the HSSI Program test matrix within the New Coordinated Research Program (CRP) of the International Atomic Energy Agency (IAEA).

(Milestone 2.5.A) As reported previously, the testing and analysis of specimens has been completed. These specimens were machined from three blocks of materials into 1TC(T) and precracked Charpy specimens for the size effect study. Two of the blocks are broken halves of 4TC(T) specimens of two A302B plates previously tested by the HSSI Program. The third block of material is the well-characterized Plate 13A. This study is specifically designed as an evaluation of the precracked Charpy specimen.

(Milestone 2.5.B) A series of subsize specimens of JRQ steel has also been completed. The specimens are 0.2TC(T) and 0.4TC(T), and 5 by 5 mm and 5 by 10 mm SE(B) specimens.

(Milestone 2.5.C) The letter report, M. A. Sokolov and R. K. Nanstad, *An Evaluation of the Performance of Precracked Charpy and Subsize Specimens in Determining* T_o (ORNL/NRC/LTR-04/10), was completed and submitted to the NRC Program Monitor.

Report Summary:

The applicability of small specimens to characterize the transition fracture toughness of pressure vessel steels has been examined by the testing of precracked Charpy and other type of subsize specimens from five different plates. The main focus of this study was to examine the ability of PCVN and smaller size specimens to exhibit the same reference transition fracture toughness temperature, T_o, as larger specimens.

The main results are summarized as follows:

1. When T_o is determined from PCVN specimens with W/B=1, on average, it is lower than T_o determined from compact specimens with W/B=2. This observation agrees with recently published results from different laboratories.
2. At the same time, 5x10x55 mm three-point bend specimens with W/B=2 exhibited T_o values that were very similar to T_o values derived from compact specimens. Additional experimental data with larger thicknesses (10 mm and 25.4 mm for example) are needed to confirm this observation
3. The present results indicate that there is a need for further experimental and analytical work to resolve the issue of the observed differences between compact and PCVN specimens from both constraint and J-integral formulas points of view.

<u>Subtask 2.6: Dosimetry and Fluence Analysis of the IAR Irradiation Capsules</u> (C. A. Baldwin, I. Remec, and T. M. Rosseel)

The purpose of this task is to measure and analyze the dosimeters used during the HSSI-IAR irradiation campaigns and to obtain accurate fluence determinations.

(Milestone 2.6.A) As reported previously, the set of four Fissionable Radiometric Dosimeters (FRDs), removed from the IAR facilities in April 2001, and shipped to counting lab, will be used to verify the fluence estimates for the high-Nickel specimens and re-irradiation specimens removed from the FNR in 2001.

(Milestone 2.6.C) – (I. Remec and E. D. Blakeman) Final conversion of the LSL-M2 code package from DOS to Linux will be completed during the second quarter of the new fiscal year. A report, previously prepared under JCN 6164, will be issued as an ORNL technical report.

The report entitled, *Characterization of the Neutron Field in the HSSI/UCSB Irradiation Facility at the Ford Nuclear Reactor*, by I. Remec, E. D. Blakeman, and C. A. Baldwin, NUREG/CR-6646 (ORNL/TM-1999/140) was submitted to the NRC in September 1999.

Subtask 2.7: Investigate the Bias Term Added to T_o Values Determined from Pre-Cracked Charpy Specimens (R. K. Nanstad)

The purpose of this task is to perform a systematic study of the bias term added to T_o values determined from pre-cracked Charpy specimens, such as that used in the Kewaunee evaluation. The approach would utilize both analytical and experimental methods. Either HSST Plate 02 or HSST Plate 13A will be used since extensive C(T) data on these materials are available.

(Milestone 2.7.A) Planning for this task has continued and a test plan has been developed. The experimental phase of the bias term project will include 1T three-point bend specimens (both W/B=1 and W/B=2), precracked Charpy specimens with and without side-grooves and with W/B=1 and W/B=2, Charpy thickness [10 mm (0.394 in.)] compact specimens, some with the standard ligament (W/B=2) and some with half the standard ligament (W/B=1) to provide a direct comparison with the precracked Charpy specimen. The issue of two different materials is also under consideration. HSST Plate 13 is the primary material of choice because of the extensive compact specimen-derived fracture toughness database available for HSST Plate 13A. HSST Plate 13B currently resides at the ORNL site and will be used for the bulk of the testing. A set of "calibration" tests will be conducted to evaluate the normalized load vs normalized plastic displacement curves with the different specimen geometries prior to the conduct of the test matrix.

One important aspect of such testing is the number of specimens needed to provide a statistically reliable estimate of the difference in T_o for each specimen geometry. There are various methods for such a calculation that will not be discussed here. However, if one desires to know T_o within ±10°C (±2 standard deviations) using the equation provided in E1921, the number of specimens needed is 13. If a two standard deviations variation of 5°C is desired, the number of specimens needed is 52. Similarly, a monte carlo analysis of the Weibull distribution and a student's t analysis indicates that no advantage is obtained after 20 specimens. Thus, statistical considerations will play a strong role in the test matrix. The draft will be discussed with appropriate and interested reviewers outside of ORNL. R. K. Nanstad visited SCK-CEN, Mol, Belgium, and discussed this issue with Eric Van Walle and his staff. Additionally, presentations and discussions from the ASTM E-08 Workshop on Constraint are being evaluated relative to planning of the experimental and analytical needs. A literature review is in progress, including a review of linear elastic fracture mechanics (LEFM) results that may provide information regarding specimen configuration differences observed as the result of specimen fractures under predominantly elastic loading. The use of the T-stress based constraint adjustments have received considerable discussions within the technical community and a comparison of such LEFM data may shed light on that specific subject.

Subtask 2.8: Verify the 72W T_o Value (R. K. Nanstad)

The purpose of this subtask is to verify the T_o value for HSSI weld 72W. The ASME Materials Properties Council conducted a round robin testing program a few years ago with pre-cracked Charpy specimens of two RPV steels, one of which was HSSI Weld 72W. The specimens were machined from the "second batch" of weld 72W. The results showed a disparity in the T_o values of about 20ºC between that determined from the pre-cracked Charpy specimens and that from the extensive base of fracture toughness data using the "first batch" of 72W.

(Milestone 2.8.A) A block of HSSI Weld 72W (second batch) was located, drawings were prepared, and 13 1T compact specimens were machined, fatigue precracked and tested without side-grooves, the same condition as in the HSSI Fifth Irradiation Program. Specimens were tested at –80, -50, and –30°C.

(Milestone 2.8.B) Using the multi-temperature equation in E-1921, the T_o for the group of specimens described above from the "second batch" is –53.4°C. This compares with a T_o from the "first batch" of –56.6°C. The overall T_o for the combined database is –54°C. Thus, the results indicate no significant difference between the first and second batches. Therefore, the T_o result of –75°C from the Materials Properties Council (MPC) round robin program with PCVN specimens points to a difference of 21°C between the 1TC(T) and PCVN specimen for HSSI Weld 72W.

(Milestone 2.8.C) A letter report, "Comparison of Fracture Toughness Reference Temperatures for the First and Second Batches of HSSI Weld 72W," by R. K. Nanstad, has been completed and will be distributed in March. Additionally, a summary of the results was prepared and submitted to the MPC for inclusion as an annex in a Welding Research Council (WRC) Bulletin entitled "Indexing Fracture Toughness Data." The WRC Bulletin includes a paper based on the results of the MPC round robin test program with the uncertainty of the T_0 value for the second batch of HSSI Weld 72W. Thus, the annex was provided to show resolution of that uncertainty. (Please see Section 4). The abstract from that letter report (ORNL/NRC/LTR-04/08) is provided below:

ABSTRACT

The Heavy-Section Steel Irradiation Program at Oak Ridge National Laboratory conducted the Fifth Irradiation Series with two submerged-arc welds, HSSI Welds 72W and 73W. The weld wires for these welds were fabricated from a split-melt of steel with additional copper added to one half, such that the chemical compositions of the two weld wires are the same, except for the copper contents. About 15 m of weldment were fabricated for each weld and, for each weld in the unirradiated condition, a large number of compact type fracture toughness specimens, from 25.4 to 203.2 mm [1T to 8TC(T)], were tested at different temperatures. To accommodate the material needs for the Sixth Irradiation Series on crack-arrest toughness, additional welds were fabricated with the same weld wires and the same lot of welding flux as for the first batch. Because the same fabricator made the second batch of each weld from the same weld wire and the same lot of flux as the first batch, only Charpy V-notch impact specimens from

the second batch were tested to verify the similarity of the two batches. Subsequently, the Materials Properties Council conducted a cooperative testing program with pre-cracked Charpy specimens of two RPV steels, one of which was HSSI Weld 72W. The specimens of weld 72W were machined from the second batch. The results showed a disparity in the T_0 values of about 20° C between that determined from the precracked Charpy specimens of the second batch and that from the fracture-toughness data using the first batch of 72W. These results raised the issue of similarity of the two batches of HSSI Weld 72W. To verify the similarity of the two batches, thirteen 1T compact specimens from the second batch of Weld 72W were machined and tested to provide a T_0 value comparable to that for the first batch. The T_o for this group of 1T specimens from the second batch is –53.4°C. This compares with a T_o for the first batch of –56.6°C. The overall T_o value for the combined database is –54°C. Thus, the test results indicate no significant difference in T_o values between the first and second batches. Therefore, the T_o result of –75°C from the MPC round robin program, with PCVN specimens, points to a difference of 21°C between the 1TC(T) and PCVN specimen for HSSI Weld 72W.

Task 3: Irradiation Embrittlement of RPV Steel (R. K. Nanstad)

The issues affecting vessel lifetime extensions including the application of mitigation procedures to RPVs and embrittlement saturation effects at high fluence will be examined. Specifically, (1) the effects of temper embrittlement on the coarse-grained HAZ in RPV steels; (2) the effects of reirradiation on K_{Jc} and J_{Ic} in order to evaluate the relative changes in the recovery and reembrittlement between CVN and fracture-toughness properties and a detailed examination of reembrittlement rates; and (3) late-blooming phases in high-nickel steels, will be evaluated.

<u>Subtask 3.1: HAZ embrittlement</u> (R. K. Nanstad and E. T. Manneschmidt)

The purpose of this subtask is to determine the susceptibility of RPV heat-affected-zones (HAZ) to irradiation/thermal aging-induced temper embrittlement. Research conducted to date by ORNL and AEA-Technology (UK) on temper embrittlement of the coarse-grain materials in HAZs of RPV steel multi-pass welds has revealed the potential for substantial embrittlement under some conditions. AEA-Technology discovered that using high-temperature austenitization to produce very coarse grains, followed by thermal aging resulted in large transition-temperature shifts. Further, post-irradiation thermal annealing of such material resulted in an even greater increase of the transition temperature. Subsequent research at ORNL under the previous HSSI Programs used five commercial RPV steels to investigate potential temper embrittlement. Since the amount of intergranular fracture observed was unexpected following irradiation and thermal annealing, further studies are required to resolve the issue. A letter report on the results of Phase I was published in December 2001.

The objective of this follow-on study is to prepare and test simulated heat-affected-zone (HAZ) material under typical RPV cooling conditions to study the effect of temper embrittlement. This work will be compared to the first HAZ irradiation experiment that was conducted with Gleeble-simulated HAZ material, which used a fast cooling rate after the post-weld heat treatment. Although a fast cooling rate likely enhances the probability of irradiation-induced phosphorus segregation to grain boundaries, it is not prototypic of RPV treatment.

(Milestone 3.1.A) The letter report by R. K. Nanstad, D. E. McCabe, M. A. Sokolov, C. A. English, and S. R. Ortner, *Comparison of Effects of Thermal Aging, Irradiation, and Thermal Annealing on Propensity for Temper Embrittlement on an RPV Submerged-Arc Weld HAZ*, ORNL/NRC/LTR-01/07, was published and distributed.

(Milestone 3.1.B) As noted previously, to investigate the effect of cooling rate following postweld heat treatment, additional material would be treated in the Gleeble system to simulate the coarse-grain HAZ as accomplished previously. This would then be followed by thermal aging, as well as by irradiation and post-irradiation thermal annealing. The A302 grade B (modified) steel in the previous study (designation Z-7) has a phosphorus content of 0.07 wt %. A second steel, A302 grade B (modified) with phosphorus content of 0.14 wt % (designation Z-5) is also included in this study for comparison. Excess material of each heat from the original investigation was identified and Gleeble specimens [(rods of about 75 mm (3 in.) long and 14.3 mm (0.562 in.) in diameter] were machined.

Gleeble treatment was performed with the same procedure used for the previous study and has now been completed for all the specimens. Following Gleeble treatment, the Gleeble specimens were postweld heat treated at 615ºC (1140ºF) for 24 h, then furnace cooled at ~15ºC/h. Charpy and tensile specimens were machined from the Gleeble specimens, notched and some were fatigue precracked for testing as precracked Charpy (PCVN) specimens. A total of 50 CVN (20 of Z-5 and 30 of Z-7), 20 PCVN (all of Z-7), and 16 tensile (4 of Z-5 and 12 of Z-7) specimens were packaged in two specially-fabricated steel boxes and were inserted into the IAR facility at the Ford Reactor. The unirradiated/unaged Charpy specimens have been tested and the specimens to be aged were enclosed in glass tubes, evacuated, backfilled with helium, and sealed in preparation for thermal aging. A furnace was identified for the thermal aging exposures and aging began in December. The specimens designated for aging of 168 h have completed aging. Immediately following aging of those specimens, those designated for an aging time of 2000 h were inserted into the furnace and will complete aging in early March. Testing of the aged specimens will begin in March.

(Milestone 3.1.C) The irradiation of these specimens was completed on July 3, 2003, with shutdown of the FNR. Arrangements are underway for shipment of the specimens to the ORNL hot cells in February. Please also see Task 6.2. Following receipt of those specimens, a decision will be made regarding testing and thermal annealing dependent on the neutron fluence achieved in the IAR. Consideration is also being given to reirradiation of the remaining specimens from the initial series, dependent on availability of an irradiation facility.

<u>Subtask 3.2 Evaluation of Reirradiated JRQ Specimens</u> (R. K. Nanstad, E. T. Manneschmidt, and T. M. Rosseel)

The purpose of this subtask is to examine the fracture-toughness behavior of an RPV steel that has been irradiated, annealed, and re-irradiated. The specimens, which were fabricated from a heat of A533 grade B class 1 steel identified as JRQ, were prepared by the Paul Scherrer Institute (PSI) as part of the IAEA CRP 3. This steel has been used for several studies sponsored by the IAEA and is under consideration as a reference material for various RPV evaluation projects, including surveillance programs. This subtask is collaboratively conducted under a Memorandum of Agreement (MOA) between ORNL and PSI. Charpy impact, pre-cracked Charpy, and tensile specimens are available in the irradiated, and in the irradiated/annealed/re-irradiated conditions. Thermal annealing and testing of Charpy impact and precracked Charpy specimens has been completed.

(Milestone 3.2.B) During June 2002, the precracked Charpy specimens were tested in the irradiated condition, in the irradiated/annealed condition, and in two different IAR conditions. A presentation on the preliminary results from this work was made by R. K. Nanstad at the ASTM Symposium on Radiation Effects in Materials in Tucson, Arizona, in June. Photographs of specimen fracture surfaces have been made, crack lengths have been measured, and final analyses have been completed. During the hot cell testing, it was discovered that many of the specimens have relatively shallow flaws, with a/W ratios of about 0.3. Results from these specimens do not, of course, satisfy the requirements of E 1921 for valid fracture toughness data. There are some results in the literature indicating no significant effect of a/W ratios as low as 0.3 and this will be further pursued. Thus, the data will be evaluated giving consideration to the potential loss of constraint on the results. An initial comparison of the test results in the irradiated and the irradiated/annealed conditions, both of which included specimens with both short and long cracks, provided mixed results. In one case, the average K_{Jc} values were about the same, while in the other case they were substantially different. Moreover, neither comparison is based on a statistically strong database in that the subsets comprise only 4 or 5 test results.

A paper entitled, "Irradiation and Post-Annealing Reirradiation Effects on Fracture Toughness of RPV Steel Heat JRQ," by R. K. Nanstad, P. Tipping, and R. D. Kalkhof, was submitted to ASTM for review and publication in the STP for the Tucson meeting. The reviewer comments were received and incorporated in the final paper, and the paper has been sent to ASTM for publication. Additionally, R. K. Nanstad made a presentation of the fracture toughness test results and the TEP Seebeck Coefficient results at the IGRDM-11 meeting in San Diego in September.

A work package was prepared for cutting of pieces of selected JRQ specimens to be submitted for atom-probe examination. The same work package included packaging and transport of selected irradiated specimens to PSI for their thermoelectric power (TEP) testing. The selected specimens were retrieved from the storage cans and identified. They were packaged and were shipped to PSI in early September. They were received at PSI in mid-September. The cutting of specimens for atom-probe examination is underway in the Metals and Ceramics Division LAMBDA facility. Atom probe "toothpicks" of both VVER-1000 specimens have been delivered to the technician for preparation of atom probe needles. The JRQ samples will be delivered in early February.

(Milestone 3.2.C) R. K. Nanstad visited PSI during the last week of July to discuss the various aspects and progress of the collaborative project that is conducted under a Memorandum of Agreement between ORNL and PSI. He met with Dr. Dietmar Kalkhof, the lead scientist for the

PSI portion of the project, and Dr. Niffenegger of PSI, the researcher responsible for conduct and analysis of the TEP experiments. They have completed TEP measurements with both unirradiated and irradiated CVN specimens that had been previously tested at PSI. Comparison of the results with the Charpy impact results indicates the probability of a reasonable correlation between results from the two tests. Nanstad and Kalkhof discussed and agreed on the selection of broken CVN and PCVN specimens for shipment to PSI for additional TEP testing (see 3.2.B). A joint NUREG report and technical papers will be prepared following completion of all the experiments and analyses. A foreign trip report, ORNL/FTR-200785, *Report of Foreign Travel for R. K. Nanstad*, was prepared and distributed.

Subtask 3.3: Evaluation of reirradiated 73W specimens (R. K. Nanstad)

The purpose of this subtask is to examine the effects of reirradiation on HSSI Weld 73W to a higher fluence than previously obtained. The previous data showed relatively low transition temperature shifts compared with the lateral shift methodology in Regulatory Guide 1.162. Moreover, reirradiation results for Weld 73W from the Kurchatov Institute during the JCCCNRS cooperation were substantially different than those obtained by ORNL.

(Milestone 3.3.A) No significant progress during this reporting period.

Subtask 3.4: Evaluation of High Nickel Steels (R. K. Nanstad, M. A. Sokolov, and A. M. Murphy)

The purpose of this subtask is to investigate the effects of high nickel content on irradiation embrittlement of RPV steels at relatively high neutron fluences (above $\approx 2 \times 10^{19}$ n/cm^2 (>1 MeV). A large body of data shows a strong nickel effect and indicates a strong synergistic interaction with copper and manganese. This has been observed with both Western type RPV steels and WWER steels. It is also applicable to concerns of "late-blooming phases" (e.g., MnNi) at high fluences, effects on development of copper-rich precipitates, and effects of post-weld heat treatment. These phases are predicted to nucleate at relatively high fluences with the potential to cause an increase in embrittlement after the onset of the so-called "embrittlement saturation" associated with most embrittlement predictive formulas. There are examples in the surveillance database with such behavior but the materials have not been examined. This subtask will be conducted in close collaboration with UCSB, whose program has developed a large amount of information regarding nickel effects.

(Milestone 3.4.A) Cutting of atom probe "toothpicks" from the Palisades weld and the VVER-1000 weld and base metals has been completed. Atom probe needles have also been prepared and preliminary atom probe analyses have been conducted. These analyses will be completed in March.

Task 4: Validation of Irradiated and Aged Materials (R. K. Nanstad)

The purpose of this task is to validate the assessment of the effects of neutron irradiation on the fracture-toughness properties of typical RPV materials obtained in the previous HSSI (L1098)

Program, Tasks 2 and 3 of this program, and retired RPVs. This will be accomplished through the examination of the effects of neutron irradiation on the fracture toughness (ductile and brittle) of the RPV stainless steel cladding and of typical plate materials used in RPVs. The irradiated materials from retired RPVs will be machined and tested in the Irradiated Materials Examination and Testing (IMET) hot cells. Other issues to be addressed include foreign interactions, thermal aging, evaluation of pressure vessel heads, and technical assistance to the NRC.

Subtask 4.1: Fracture Toughness of Irradiated Stainless Steel Cladding (R. K. Nanstad)

The purpose of this subtask is to evaluate the effects of irradiation on fracture toughness of irradiated stainless-steel weld-overlay cladding specimens at 288°C. This will complete the testing of the matrix from the HSSI (L1098) 7th Irradiation Series. The PCVN specimens were irradiated in HSSI Capsule 10.06.

(Milestone 4.1.A) No significant progress during this reporting period.

Subtask 4.2: Foreign Interactions (R. K. Nanstad)

The purpose of this subtask is to provide technical support and continued collaboration for a number of cooperative relationships with foreign institutions in the area of radiation effects on RPV steels. Collaborative relationships may be developed during the course of this program and will be developed with the cognizance of NRC. Current relationships are:

1. Collaboration with MPA-Stuttgart in Germany regarding applicability of the master curve to highly embrittled RPV steels.

2. Collaboration with PSI in Switzerland on evaluation of reirradiation effects.

3. Collaboration with AEA-Technology in the United Kingdom regarding fracture toughness testing, temper embrittlement, and work hardening of RPV steels.

4. Participation in three coordinated research programs (CRPs) sponsored by the International Atomic Energy Agency (IAEA), informally designated CRP-5, CRP-6, and CRP-7. These CRPs will investigate: the use of PCVN specimens to determine fracture toughness of RPV steels, effects of nickel on irradiation-induced embrittlement of RPV steels, and the bias effect on T_0 determined with PCVN specimens, respectively.

5. Participation, including membership on the Executive Committee, in the International Group on Radiation Damage Mechanisms (IGRDM).

6. Collaboration with CIEMAT in Spain on dynamic fracture toughness and subsize specimens in support of MC evaluations.

7. Collaboration with institutes in the Czech Republic, Germany and Finland on fracture toughness with small specimens in support of MC evaluations.

8. Cooperation with SCK-CEN in Belgium regarding the supply of well-characterized materials and comparison of test results, including dynamic PCVN testing for development of RPV testing standards.

9. Collaboration with NRI, Rez (Czech Republic) in the area of microstructural evolution in RPV steels as a consequence of reirradiation.

10. Information and data exchange with all of the above and other countries, especially regarding RPV surveillance data and comparisons of fracture toughness and Charpy impact data.

(Milestone 4.2.A) The 11th meeting of the International Group on Radiation Damage Mechanisms (IGRDM) was held in San Diego on September 10-16, 2003. R. K. Nanstad, as secretary of the IGRDM, has updated the membership list, prepared a revision of the charter, and worked with the local host for the meeting (R.G. Carter of the Electric Power Research Institute) and the IGRDM Chairman (T.J. Williams of Rolls-Royce, U.K.) to organize the meeting. Presentations were given by HSSI Program staff members, including M. K. Miller, R. K. Nanstad, M. A. Sokolov, and R. E. Stoller.

(Milestone 4.2.B) R. K. Nanstad attended the meeting of the IAEA Cooperative Research Program "Mechanisms of Nickel Content on Irradiation Embrittlement of RPV Steels," in Pamporovo, Bulgaria, 2-4 December 2002. He made a presentation entitled "Comparison of Nickel Effects on Embrittlement Mechanisms in Prototypic WWER-1000 and A533B Steels," by Randy K. Nanstad, Mikhail A. Sokolov, Michael K. Miller, and G. Robert Odette. The presentation included a summary of HSSI Program activities in the area of nickel effects, the test results and atom-probe analysis results of the KS-01 weld, preliminary results of testing of the irradiated [to ~1.6×10^{19} n/cm^2 (>1 MeV)] high-nickel submerged-arc weld from the Palisades steam generator, and the Charpy impact test results for the CRP-supplied high-nickel forging and high-nickel weld (VVER-1000) in the unirradiated condition. The VVER-1000 specimens inserted in the IAR facility in April 2001 were removed in January at the behest of the CRP and transported to ORNL for testing as soon as practicable. A trip report, ORNL/FTR-164584, has been submitted.

The irradiated VVER-1000 Charpy impact specimens were tested in the ORNL hot cells in May. Twelve specimens each of a base metal (forging) and a weld were tested at various temperatures, with lateral expansion measurements and photographs of fracture surfaces made subsequent to testing. The forging contains about 1.2 wt% nickel, while the weld metal contains about 1.7 wt% nickel. The results have been analyzed and are in preparation for transmittal to the IAEA CRP committee members for inclusion in the committee database for those two materials. Following submittal of these data, the committee will complete the final analysis of all the data on the two materials and a final report for the CRP will be prepared.

Slices of the VVER-1000 steels were cut in the ORNL hot cells, put in lead pigs, and shipped to to the LAMDA facility in the Metals and Ceramics Division for cutting of atom probe blanks. Cutting of the blanks has been completed and atom probe needles were prepared for atom probe tomography analysis. Preliminary analyses have been conduted and will be completed in March.

R. K. Nanstad attended the meeting of the IAEA CRP "Surveillance Programmes Results Application to Reactor Pressure Vessel (RPV) Integrity Assessment," and an IAEA consultancy meeting on development of a new CRP on "Bias Terms for Master Curve application," in Vienna, Austria, 24-28 February 2003. R. K Nanstad is an author of a chapter on "Fluence Projection and Attenuation" for the IAEA guidelines document on application of the fracture toughness master curve, now in preparation. A trip report, ORNL/FTR-167446, has been prepared and submitted.

R. K. Nanstad attended a consultancy meeting at the IAEA in Vienna, Austria from July 31 through August 4. The meeting was held to edit and complete the IAEA Technical Report Series (TRS), "Neutron Irradiation Embrittlement of RPV Steels." The book has languished with the death of the previous chief editor (Myrddin Davies) earlier in the year. Also, the former IAEA Technical Secretary responsible for the book, V. Lyssakov, completed his term in April and was replaced as Technical Secretary by Dr. Ki-Sig Kang. Dr. Kang set up and coordinated the consultancy meeting in Vienna. R. K. Nanstad is the author of Chapter 3, "Irradiation Effects on Mechanical Properties," of the TRS and is also one of the three editors, including Mr. William Server of ATI Consulting in the United States and Dr. Milan Brumovsky of the Nuclear Research Institute in Rez, Czech Republic. All the chapters have now been written and edited with the exception of Chapter 4, "Radiation Damage Mechanisms," primarily authored by Dr. Jean-Claude Van Duysen of EDF in France. Dr. Van Duysen has committed to submit his chapter in mid-October. The meeting in Vienna was very productive in that significant progress was made towards publication of the TRS. Such progress would not have happened without such a meeting.

Additionally, as a result of discussions during the consultancy meeting, the IAEA representative subsequently asked R. K. Nanstad to assume the duties as chairman of the CRP on Nickel Effects discussed earlier. A meeting of selected members of the CRP will be asked to attend a meeting at the IAEA in March 2004 to prepare the TECDOC report for the CRP.

On November 25-28, R. K. Nanstad attended an IAEA consultancy meeting in Vienna, Austria. The meeting was entitled "Joint Consultant Meeting to Develop the Strategic Plan on Nuclear Power Plant Life Management with European Commission/Institute of Energy." He also met with Dr. Ki-Sig Kang, the IAEA representative, to discuss detailed planning for finalizing the IAEA CRP on Nickel Effects. It was decided to schedule a meeting of selected members of the CRP in Vienna during the week of 15 March 2004, with the goal to finalize the TECDOC (the IAEA report that presents the results of the CRP). Contact was made with the three members, all of whom indicated their willingness to serve and their availability during that week. A foreign trip report, ORNL/FTR-205181, was prepared and distributed on 30 December.

Subtask 4.3: Technical Assistance (R. K. Nanstad and M. A. Sokolov)

The purpose of this subtask is to provide special analytical, experimental, and administrative support to the NRC in resolving various regulatory issues related to irradiation effects. Specific activities will be identified on an as needed basis by the NRC Project Manager. Examples of such activities include: 1) providing support for the NRC on issues related to irradiation effects,

2) evaluation of the effects of post-weld heat treatment (PWHT) on the copper solubility and fracture toughness of unirradiated RPV steels; 3) machining of material removed from retired irradiated RPVs for evaluation of through-thickness attenuation of irradiation embrittlement; 4) reporting on the results of testing crack-arrest toughness specimens; and 5) evaluating embrittlement and 6) identify issues associated with material variability and establish associated uncertainties for use in statistics based fracture toughness assessments.

(Milestone 4.3.A) For the weld previously given a series of postweld heat treatments and irradiated in the University of Michigan Ford Reactor, testing of the irradiated subsize Charpy specimens in the ORNL hot cells has been completed. A letter report will be prepared following completion of all analyses. Additionally, M.A. Sokolov presented a preliminary summary of the results at the IGRDM-11 meeting in San Diego in September. The presentation was authored by M. A. Sokolov, R. K. Nanstad, and M. K. Miller, and was entitled "Effect of Radiation on Embrittlement and Matrix Cu Content of an RPV Weld with Different PWHT Conditions." A paper, for which M. K. Miller was the lead author, including the unirradiated Charpy results and the atom probe tomography results, was presented at the Tenth International Conference on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, August 5-9, 2001, in Lake Tahoe, Nevada. R. K. Nanstad attended the meeting and presented the paper. A paper by M. K. Miller, S. S. Babu, M. A. Sokolov, R. K. Nanstad, and S. K. Iskander, "Effect of Stress Relief Temperature and Cooling Rate on Pressure Vessel Steel Welds," *Mater. Sci. Eng. A 327*, 76-79 (2002) was also published. A letter report is in preparation.

(Milestone 4.3.B) The NUREG report, *Detailed Results of Testing Unirradiated and Irradiated Crack-Arrest Toughness Specimens from the Low Upper-Shelf Energy, High Copper Weld, WF-70,* by S. K. Iskander, C. A. Baldwin, D. W. Heatherly, D. E. McCabe, I. Remec, and R. L. Swain, NUREG/CR-6621 (ORNL/TM-13764), was submitted to the NRC Program Monitor for review. It is anticipated that it will be submitted for publication during the next reporting period.

(Milestone 4.3.C) Irradiated, annealed, and reirradiated specimens of HSSI Weld 73W were reinserted into the IAR facility at the FNR to accumulate additional fluence. The results obtained from tests of some of the reirradiated specimens showed a much lower transition temperature shift than expected. The target total fluence for the final group of specimens which was about 4×10^{19} n/cm^2 was obtained. Dosimeters associated with the experiment are waiting to be counted and analyzed (see Task 2.5). The specimens will be scheduled for testing at the ORNL hot cells during the second quarter of 2004.

(Milestone 4.3.E.1) The NUREG report (ORNL/TM-2000/343), *Attenuation of Charpy Impact Toughness Through the Thickness of a JPDR Pressure Vessel Weldment*, by S. K. Iskander, J. T. Hutton, L. E. Creech, M. Suzuki, K. Onizawa, E. T. Manneschmidt, R. K. Nanstad, T. M. Rosseel, and P. S. Bishop, was submitted to the NRC in January 2001 as part of an Office of Research Operational Milestone.

(Milestone 4.3.E.2) The NUREG report entitled *Evaluation of Neutron Energy Spectrum Effects Based on Primary Damage Simulations in Iron,* NUREG/CR-6643, (ORNL/TM-1999/334) was submitted to the NRC in July 2000.

Subtask 4.4: Review of thermal aging effects in RPVs (R. K. Nanstad and R. E. Stoller)

The purpose of this subtask is to evaluate the role of thermal aging in the potential embrittlement of RPV steels. Although there are data at relatively high aging times in an actual RPV that indicate minimal effects to about 140,000 h, there are other data that do indicate embrittlement due to thermal aging under typical RPV operating conditions. Thus, the existing data provide conflicting results. For life extension of RPVs, the total operating time will exceed 400,000 h. This issue is closely linked to neutron flux and will be performed in collaboration with UCSB.

(Milestone 4.4.A) The report, *The Effect of Aging at 343°C on the Microstructure and Mechanical Properties of Type 308 Stainless Steel Weldments*, by D. J. Alexander, K. B. Alexander, M. K. Miller, and R. K. Nanstad, NUREG/CR-6628 (ORNL/TM-13767), was published in November 2000.

Task 5: Modeling & Microstructural Analysis and Embrittlement Data Base (T. M. Rosseel)

This task shall determine the microstructural basis for radiation-induced property changes in RPV materials to aid in understanding and applying the experimental results obtained in Tasks 2 through 4. The two proposed subtasks will comprise: (1) experimental investigations of the microstructure and, (2) maintaining and updating the Embrittlement Data Base (EDB). The experimental component will focus on detailed microstructural characterization of RPV materials in relevant conditions, including long-term, thermally-aged and high-fluence irradiated materials. The information obtained from the experiments and microstructural characterization will be used to support validation of the theoretical models. Further model verification will be carried out through use of the mechanical property data contained in the EDB, and data generated in other experiments coordinated by this task. Updated versions of the EDB will be issued as appropriate.

The modeling and experimental research will be coordinated with complementary activities carried out by other NRC contractors and the international community. Work and milestone schedules will be contingent on available funding.

Subtask 5.1: Microstructural Characterization (M. K. Miller and K. F. Russell)

APFIM characterization will be used to determine whether additional radiation-induced phases are forming especially at longer times and higher fluence. In addition, the methods of APFIM, SANS, and field-emission scanning transmission electron microscopy (FEGSTEM) have been used to determine the matrix copper content and the chemical composition of radiation-induced precipitates in RPV materials. Although there is qualitative agreement between the three methods, some significant inconsistencies exist. Comparisons among the techniques will be performed so as to resolve the apparent inconsistencies.

(1) Atom probe tomography (APT) will be used to characterize the thermal surveillance capsule from the EBR-II, if material can be obtained. Attempts were made previously to perform

characterization of a sample of the thermal surveillance capsule that was aged at 371°C was for ~18 years. Unfortunately, little data was obtained due to low quality of the specimens that could be prepared from the extremely small size of the sample supplied and the presence of carbides in the A533B material.

(2) APT will be used to study of Mn and high Ni in the so-called late blooming phases. Characterization of model alloys using APT will be compared with the results obtained by University of California-Santa Barbara (UCSB) to determine the influence of manganese on the thermal stability of supersaturated iron-copper alloys.

(3) In collaboration with UCSB, the microstructure of a series of neutron irradiated model (Fe-0.05% Cu-1.6% Mn-1.6% Ni [OV5] and Fe-0.10% Cu-1.6% Mn-1.6% Ni [OV7]) pressure vessel steels will also be characterized by APT to investigate the presence of fine scale phase decomposition.

(4) Palisades high-nickel steel that has been irradiated to fluences of 1.6 and ~4 x 10^{19} n cm-^{2} (E > 1 MeV) will be characterized using APT (see also Task 3.4). Since Ni-rich phases in low Cu steels may contribute to hardening and embrittlement at high fluences, this evaluation is critical to developing an understanding of the so-called late blooming phases that may appear at long irradiation times. When available in FY2003, low fluence broken Charpy specimens will be sliced in the hot cell, prepared for the APT, and examined.

(5) High fluence, broken Charpy specimens will be sliced in the hot cell, prepared for the APT and examined. In addition, the APT will be used to characterize the high fluence ~4 x 10^{19} Midland weld and JRQ specimens in the I, IA, IAR, IARA and possibly IARAR conditions will be initiated. This series of materials is designed to look at extending lifetime issues out to a projected 40-year license time frame.

(Milestone 5.1.C1) A study of the precipitation in Neutron-irradiated Fe-Cu-Mn-Ni Model Alloys in collaboration with G.R. Odette (Department of Chemical Engineering, University of California - Santa Barbara, Santa Barbara) and B. D. Wirth (Nuclear Engineering Department, University of California, Berkeley) was completed. The microstructures of a systematic series of Fe-Cu-Ni-Mn model alloys have been characterized by atom probe tomography (APT) and small angle neutron scattering (SANS). The primary aims of this study were to determine whether any precipitation occurs in low (0.05%) and copper-free alloys during neutron irradiation and to determine the influence of nickel.

This OV series of alloys contained 0, 0.05 or 0.1% Cu, 0.8 or 1.6% Ni and 1.6% Mn. An Fe-0.05% Cu, 1.6% Mn, 1.6% Ni, 0.025% P, 0.5% Si was also characterized to investigate the effects of phosphorus and silicon. These model alloys were neutron irradiated to a fluence of ~1.3 x 10^{23} n m^{-2} (E > 1 MeV) at a temperature of 290°C. The microstructures of these model alloys were characterized in the Oak Ridge National Laboratory's local electrode atom probe and by small angle neutron scattering.

After neutron irradiation, the hardness of the alloy was found to increase with the copper content for the same nickel and manganese levels. The hardness increased with nickel content at same manganese level for both low (0.05%) and high (0.1%) copper alloys. The hardness was higher in both high (0.1%) copper alloys. The hardness also increased with silicon plus phosphorus additions. SANS indicated that small features were present in all alloys. The radius <R> of these features was between 0.5 and 1 nm, and increased with Cu and Ni levels and decreased with the silicon plus phosphorus additions. The number density was between 0.5 and 1.8 x 10^{24} m^{-3}, and increased with the silicon plus phosphorus additions. The M/N was between 0.4 and 1. APT also detected solute-enriched precipitates in all alloys. Some precipitates were enriched in Ni and Mn and some were enriched in Cu, Ni and Mn. In the silicon plus phosphorus alloy, the precipitates were enriched in Cu, Ni, Mn, Si and P. Copper-enriched precipitates were observed in the 0.05% Cu alloys indicating that 0.05% Cu is above the solubility limit under these neutron irradiation conditions. The Cu, Ni and Mn atom distributions were not located at the same center of mass possibly due to the different atomic sizes of the elements and a strain field around the precipitates.

Subtask 5.2: Embrittlement Data Base (J.-A. Wang)

Nuclear radiation embrittlement information from radiation embrittlement research on nuclear RPV steels and from power-reactor surveillance reports will be maintained in a database to be published on a periodic basis. The information will assist the Office of Nuclear Reactor Regulation and the Office of Nuclear Regulatory Research to effectively monitor current procedures and databases used by vendors, utilities, and service laboratories in the pressure vessel irradiation surveillance program.

5.2.A Maintain and update the EDB: This subtask was, until March 1, 1999, part of the Embrittlement Data Base (EDB) and Dosimetry Evaluation Program, JCN: 6164. The objectives of the subtask have been reduced but the focus remains the same. Nuclear radiation embrittlement information from radiation embrittlement research on nuclear RPV steels and from power-reactor surveillance reports will be maintained in a database to be published on a periodic basis. The information will assist the Office of Nuclear Reactor Regulation and the Office of Nuclear Regulatory Research to effectively monitor current procedures and databases used by vendors, utilities, and service laboratories in the pressure vessel irradiation surveillance program. Specifically, this activity will maintain and update the EDB by evaluating surveillance reports, entering the data into the EDB, and providing an update to the NRC by the end of the fiscal year if more than four reports have been received. If there are fewer than four reports, an update will be delayed for another six months.

(Milestone 5.2.A) No significant progress during this reporting period.

5.2.C Move PR-EDB from DOS to Windows: The purpose of this activity is to integrate and transform DOS-base EDB Utility into a WINDOWS operating platform. All fields shall be reconfigured in a user-friendly Windows environment.

The current version of the software package EDB-Utilities has been written in the Clipper language, which allows compilation of dBASE procedures and has facilities for menu and help screens. The dBASE and related software, such as Clipper, lack the ability for extensive mathematics/statistics calculations and scientific graphs. Instead, plotting and Charpy fitting programs are written in FORTRAN using the IMSL and GRAFMATIC libraries and require ASCII files as input. To convert the current EDB utilities from DOS base to WINDOWS base program, three major tasks are needed, (1) converting file manipulation procedures utilizing Visual FoxPro or MS ACCESS program; (2) converting the plotting procedures utilizing WINDOWS compatible plotting package; and (3) converting the Charpy fitting procedures utilizing Visual FORTRAN program. The deliverable products of the proposed EDB-Utilities upgrade will cover the features described below.

1. Converting all the present information into a "windows" type format;
2. Maintaining all search and analysis capabilities;
3. Adding "help" features;
4. Demonstrating a "beta" version;
5. Compiling a final version instruction and demonstration;
6. Developing an installation procedure for PCs;
7. Providing some maintenance and trouble-shooting support; and
8. Preparing a detailed, indexed electronic manual.

The upgrade EDB (Windows version) will pave the way for the future development of the Analytical Program Library for the NRC. The EDB upgrade is an important step in a broader goal to develop an integrated EDB program, which would include “Generate Common Databases and Application Programs,” “Build Networks, Intellectual Interfaces, to carry out Data Sharing and Data Exchange,” and “Develop Long Term Archive Methodology.” Therefore, the continuation of improving EDB methodology on structuring, grouping, linking, and processing data are critical to successfully develop an integrated EDB program.

(Milestone 5.2.C) User-friendly software to evaluate the embrittlement data base is essential to improve the efficiency of the decision making process for regulatory related issues, and to increase the performance on reactor pressure vessel aging research among the technical community. The objective of this subtask is to upgrade the PR-EDB package to a Windows environment so as to provide a user-friendly interface with functional extensions to the existing PR-EDB Version 2.0.

PR-EDB Version 2.0 is a DOS-based package, which was developed in 1993 using Clipper, Dbase and plotting tools. Since DOS has limited extendibility, a decision was made to upgrade the package to a Windows-based environment to enable the extension of the capabilities of Power Reactor Embrittlement Data Analysis and keep up-to-date with the current software trends.

PR-EDB is being upgraded to the Windows environment by rebuilding the entire package from scratch while capturing the raw data used in the earlier Version 2.0, and using Visual Basic.NET and Access 2002 from Microsoft Inc.

Visual Basic.NET is a cutting edge technology that features many improvisations on package development and deployment. Its features range from versatile Graphical User Interfaces (GUI), prepackaged data structures, easy and efficient database processing, client/server architecture and distributed computing. Visual Basic.NET is appropriate for building PC-based applications that can be seamlessly integrated with the Intra/Internet. Another very important feature of Visual Basic.NET, which is vital to the project, is the language/platform independence. This feature will enable the PR-EDB to become a highly versatile Analysis Tool that can be deployed across a wide variety of platforms and also enable future upgrades to be done more efficiently and for less cost.

This first phase of the project is focusing on moving the PR-EDB across the platforms while the second phase will concentrate on revamping the basic PR-EDB Architecture and on the functionality extensions. The new version will continue to use the existing PR-EDB Charpy impact data fitting procedure for the time being, but could be rebuilt if the sponsor requests a change. Hence, it will involve building interfaces and generating ASCII file based data to enable the old fitting procedures (which were built upon FORTRAN language) to streamline with the new version.

The detailed approach to perform the initial work was planned in February, which includes the possibility of the EDB data structural overhaul. This investigation was initiated due to the concern of the inefficiency of the original PR-EDB data structure. The PR-EDB data structure is a simulated relational database structure; this structure is not a true relational database structure, which is commonly used across the database management system. The original PR-EDB structure was constructed primarily so as to archive the data extracted from the RPV surveillance report. After the initial investigation, it was determined that this structural overhaul will not be an easy task since the original 14 data files will need to be broken up into at least 40-45 data files to fully incorporate a true relation database structure. This break-up effort will include rebuilding key identifiers, separating irradiated data and baseline data, building data one-to-one relation with respect to key identifiers, and installing foreign keys for linking relational database, etc. Therefore, a decision was made that at this initial stage that instead of tackling the overall EDB structure, the focus will be on converting the DOS PR-EDB into the WINDOWS platform. However, this data structure overhaul will be an on going task for EDB Upgrade program development.

The main flaw uncovered in the DOS-based PR-EDB is that it works well only for single processing Operating Systems (OS) and is not suited for multiprocessing OS. The underlying problem was the use of a never-ending loop in a batch file to link the various executable files. This methodology, when used with multi processing OS like Windows, stole the CPU cycles and stalled all other processes running. This flaw will be rectified in the new version by providing a single executable file and replacing the loop to link various executable files by “user-friendly” menus to link various functions of the PR-EDB provided inside the same single executable file.

The file manipulation feature of PR-EDB was the main focus of the February EDB upgrade work. It’s also interesting to note that a few inconsistencies in the database have been found during program testing that range from missing decimals points to placing of blanks before special symbols.

5.3.D Transfer Surveillance Reports to Electronic Storage: The purpose of the activity is to copy all paper surveillance reports to CDs by October 2004.

(Milestone 5.2.D) There was no significant progress during this reporting period.

<u>Task 6: Test Reactor Irradiation Coordination</u> (K. R. Thoms)

This task provides the support required to supply and coordinate irradiation services needed by NRC contractors, such as the UCSB and the ORNL HSSI programs at the University of Michigan FNR until it shuts down. These services include the design and assembly of irradiation facilities (and/or capsules), as well as arranging for their exposure, periodic monitoring by remote computer access and interaction with the FNR staff, and return of specimens to the originating research organization. For the HSSI irradiation experiment it includes determining the fluence received during a given campaign. This task also provides the support required to coordinate the shut down of irradiation facilities at the FNR following the end of reactor operations on July 3, 2003. All salvageable equipment shall be transported to ORNL. All irradiated and hazardous materials/equipment/supplies shall be disposed of in accordance with Federal, State, and Local laws and regulations.

<u>Subtask 6.1: Investigate Alternative Test Irradiation Facilities</u> (K. R. Thoms. T. M. Rosseel, and D. W. Heatherly)

During fiscal year 2003 and 2004, it is proposed that staff investigate alternative test irradiation facilities including, as necessary and with NRC approval, site visits. The results of these evaluations will be reported to the US NRC.

(Milestone 6.1.A) On February 2 –4, R. K. Nanstad, K. R. Thoms, D. W. Heatherly, and T. M. Rosseel traveled to Columbia, Missouri to discuss and evaluate the possible use of the University of Missouri, 10 MW, Missouri University Research Reactor (MURR). Several challenges must be overcome, but it appears that this could be a very promising candidate as the future location of the HSSI Program's RPV steel irradiation site. Electronic copies of the MURR staff presentations were forwarded to the NRC HSSI Program monitor.

On February 17-19, R. K. Nanstad, K. R. Thoms, D. W. Heatherly, W. R. Corwin, and T. M. Rosseel traveled to Cambiradge, Massachusetts to discuss and evaluate the possible use of the Massachusetts Institute of Technology (MIT), 4.9 MW MITR II tank-type reactor. Like the MURR, several challenges must be overcome, but it too appears to hold promise as a suitable RPV steel irradiation site. When they become available, electronic copies of the MIT staff presentations will be forwarded to the NRC HSSI Program monitor.

In cooperation with the DOE Gen IV Materials Program, planning for March site visits and evaluations of three European reactors: (1) the LV-15 reactor at the Nuclear Research Institute (NRI), Rez, Czech Republic, Dr. Milan Brumovsky, point of contact; (2) the BR2 reactor at SCK, Mol, Belgium, Dr. Eric van Walle, point of contact; and (3) the R2(0) reactor at Studsvik Nuclear, Studsvik, Sweden, Dr. Mikael Karlsson, point of contact, was nearly completed. The dates for the visits have been set for March 19 – March 30, while local arrangement details will be finalized during the first week of March.

Subtask 6.2: Operate the HSSI Irradiation (IAR) Facility (K. R. Thoms and D. W. Heatherly)

This subtask provides the necessary monitoring, control, supervision, and maintenance of the HSSI reusable irradiation capsules in the dual-capsule irradiation facilities at the University of Michigan FNR until it shuts down.

(Milestone 6.2.A) As reported previously, all of the irradiated specimens in the IAR-1 and IAR-2 facilities were removed and placed in dry storage in the FNR hot cell. The facilities were shut down and the instrumentation controlling them was shut off. The facilities are currently suspended at the side of the FNR pool. All operating records, specimen-transfer records, and videotapes of specimen transfers have been forwarded to ORNL.

During this reporting period, the ORNL HSSI instrumentation and controls staff traveled to the FNR site and prepared all of the fragile IAR control instrumentation for shipment back to ORNL where it will placed in a temporary storage area. The equipment is scheduled to arrive at ORNL at approximately the middle of the next reporting period. It is hoped that with slight modification, the instrumentation can be used at another reactor site as soon as a suitable site for materials irradiation experiments has been identified.

The FNR staff is continuing to monitor the activity of the irradiated specimens to determine the decay rate and schedule a suitable time for shipping the specimens to ORNL. Arrangements are being made to send an empty shielded shipping cask to FNR to retrieve the first of the remaining two groups of irradiated specimens from the FNR hot cells. This work has been delayed due to a new DOT requirement that the casks, normally used for such shipment, be fitted with an additional liner to contain the material. A new liner has been ordered and delivery is expected soon.

(Milestone 6.2.B) The NUREG report, D. W. Heatherly, K. R. Thoms, M. T. Hurst and G. E. Giles, UT-Battelle, LLC, Oak Ridge, Tenn., *Heavy-Section Steel Irradiation Program's Reusable Irradiation Facility,* USNRC NUREG/CR-6779, (ORNL/TM-2002/77) was submitted to the NRC in March 2002.

Subtask 6.3: Operate the HSSI-UCSB Irradiation Facility (K. R. Thoms and D. W. Heatherly)

This subtask includes supervision of the overall operation and provides assistance to the reactor personnel in the routine operation and maintenance of the HSSI-UCSB irradiation facilities at the University of Michigan FNR until it shuts down.

(Milestone 6.3.A) As reported previously, all of the irradiated specimens in the HSSI-UCSB facility were removed and placed in dry storage in the FNR hot cell. The facility was shut down and the instrumentation controlling it was shut off. The facility is currently suspended at the side of the FNR pool. All operating records, specimen-transfer records, and videotapes of specimen transfers have been forwarded to ORNL.

During this reporting period, the ORNL HSSI instrumentation and controls staff traveled to the FNR site and prepared all of the fragile control instrumentation for shipment back to ORNL where it will placed in a temporary storage area. The equipment is scheduled to arrive at ORNL at approximately the middle of the next reporting period. It is hoped that with slight modification, the instrumentation can be used at another reactor site as soon as a suitable site for materials irradiation experiments has been identified.

The activity of the specimens stored in the FNR hot cell was allowed to decay for a period of time. After monitoring the activity of the irradiated specimens to determine the decay rate, the FNR staff has prepared the final 14 remaining specimen packages for shipment to the UCSB experimenters.

Subtask 6.4 Shutdown irradiation facilities and dispose of irradiated material from the IAR and IVAR facilities (D. W. Heatherly)

The purpose of this subtask is to coordinate the orderly shutdown of irradiation facilities at the FNR, return the monitoring and control instrumentation to ORNL, and dispose of the irradiated materials generated during the operation of HSSI experiments at the FNR.

(Milestone 6.4.A) The FNR staff in cooperation with the HSSI staff is continuing to develop a plan for the disposal of all the irradiation facilities and irradiation capsules.

3. MEETINGS AND TRIPS:

On February 2 – 4, D. W. Heatherly, R. K. Nanstad, T. M. Rosseel, and K. R. Thoms traveled to Columbia, Missouri to discuss and evaluate the possible use of the University of Missouri, 10 MW, Missouri University Research Reactor (MURR).

On February 17-19, W. R. Corwin (representing the DOE-NE Gen IV Program), D. W. Heatherly, R. K. Nanstad, T. M. Rosseel, and K. R. Thoms, traveled to Cambridge, Massachusetts to discuss and evaluate the possible use of the Massachusetts Institute of Technology (MIT), 4.9 MW MITR II tank-type reactor.

4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:

T. M. Rosseel, "HSSI Program and ORNL Overview", presented to the University of Missouri Research Reactor, University of Missouri, Columbia, MO, February 3, 2004.

T. M. Rosseel, "HSSI Program and ORNL Overview", presented to the Nuclear Research Laboratory, Massachusetts Institute of Technology, Cambridge, MA, February 18, 2004.

M. A. Sokolov and R. K. Nanstad, *An Evaluation of the Performance of Precracked Charpy and Subsize Specimens in Determining* T_o (ORNL/NRC/LTR-04/10)

R. K. Nanstad, *Comparison of Fracture Toughness Reference Temperatures for the First and Second Batches of HSSI Weld 72W*, (ORNL/NRC/LTR-04/8)

5. PROPERTY ACQUIRED:

Items listed in this section include all nonconsumable project purchases that were actually paid for during this reporting period. They do not include either accruals or accrual reversals and hence may not accurately reflect total material procurement charges within this period.

Item	Cost ($)
None	

6. PROBLEM AREAS:

None

7. PLANS FOR THE NEXT REPORTING PERIOD:

The plans for the next reporting period are described in Section 2

FINANCIAL STATUS for W6953 — Reporting Period: 1/26/04-02/22/04

		Current Month	Fiscal Year to Date	Cumulative Project to date
I.	Direct Staff Effort	6 MM	1.8 MY	44.4 MY
II.	A. Direct Lab Staff Effort ($)			
	Direct Salaries	105,787	346,203	6,221,288
	Materials and Services	2,959	3,040	560,496
	ADP Support	31	155	3,207
	Subcontracts	0	15,846	1,151,363
	Travel	8,626	18,312	236,581
	Other: NRC-PO Tax	5,622	23,262	364,308
	General and Administrative	55,215	180,772	3,004,548
	Total UT-Battelle Costs	178,240	587,590	11,541,791
	B. DOE Federal Admin. Costs	5,347	17,628	184,548
	TOTAL PROJECT COSTS	183,587	605,218	11,726,339

Percentage of available cumulative funds costed	91
Percentage of available current FY funds costed	36
Funds Remaining	1,109,161
Commitments:	30,695
BA Remaining	1,078,466
BA Remaining Less Projected FAC	1,066,362

III. Funding Status

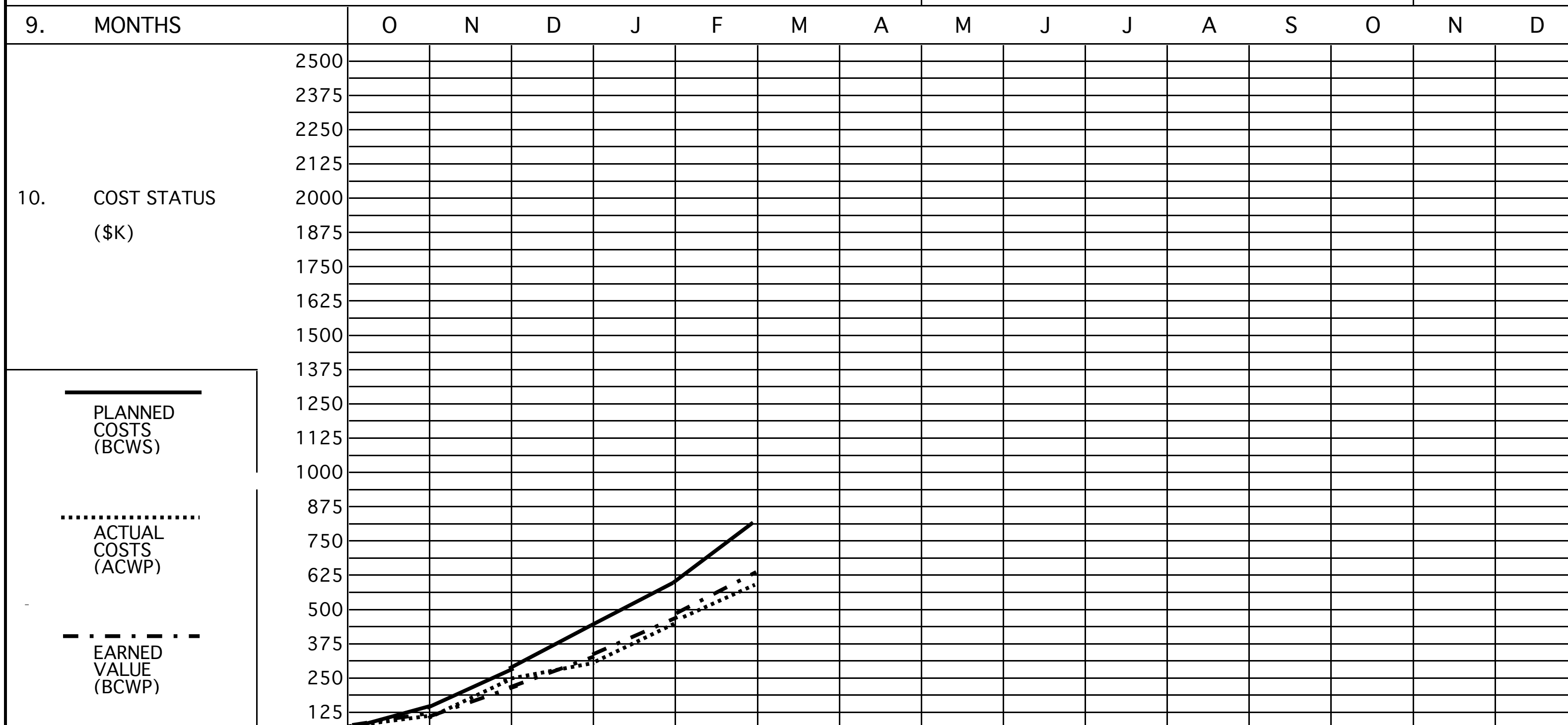
Prior FY Carryover	FY 04 Projected Funding Level	FY 04 Funds Received to Date	FY 04 Funding Balance Needed	Cumulative Amt. Obligated	Cumulative Amt. Costed
693,569	2,430,000	1,000,000	1,430,000	12,835,500	11,726,339

<u>Comments</u>: The Federal Administration Charge of 3% is applied to monthly costs.

1. CONTRACT REPORTING ELEMENT HSSI - Heavy-Section Steel Irradiation Program	2. REPORTING PERIOD 1/26/2004 - 2/22/2004
	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831	5. CONTRACT PERIOD FY 2003 - 2006
	6. ACTIVITY NUMBER W41 W5 85 3W 1
	7. NRC B&R NO. 860 15 21 20 05
	8. DOE B&R NO. 40 10 01 06

9. MONTHS

10. COST STATUS ($K)



COST PLAN DATES
10/01/03

PLANNED COSTS FOR ELEMENT ($K)
2462

ELEMENT COSTS FOR PRIOR FYS ($K)
693

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	141	159	140	170	194										
ACTUAL	110	139	65	95	178										
EARNED	112	118	86	128	184										
CUM. PLANNED	141	300	440	610	804	804	804	804	804	804	804	804	804	804	804
CUM. ACTUAL	110	249	314	409	587	587	587	587	587	587	587	587	587	587	587
CUM. EARNED	112	230	316	444	628	628	628	628	628	628	628	628	628	628	628

11. REMARKS

Total/Planned Cost reflects reduction in funds received due to FAC.

1. CONTRACT REPORTING ELEMENT HSSI - 1. Program Management		2. REPORTING PERIOD 1/26/2004 - 2/22/2004	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831		5. CONTRACT PERIOD FY 2003 - 2006	6. ACTIVITY NUMBER W41 W5 85 3W 1
		7. NRC B&R NO. 860 15 21 20 05	8. DOE B&R NO. 40 10 01 06

9. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)

COST PLAN DATES: 10/01/03

PLANNED COSTS FOR ELEMENT ($K): 377

ELEMENT COSTS FOR PRIOR FYS ($K): 77

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	24	28	23	26	30	25									
ACTUAL	22	27	15	22	35										
EARNED	21	25	21	24	24										
CUM. PLANNED	27	55	78	104	134	159	159	159	159	159	159	159	159	159	159
CUM. ACTUAL	22	49	64	86	121	121	121	121	121	121	121	121	121	121	121
CUM. EARNED	21	46	67	91	115	115	115	115	115	115	115	115	115	115	115

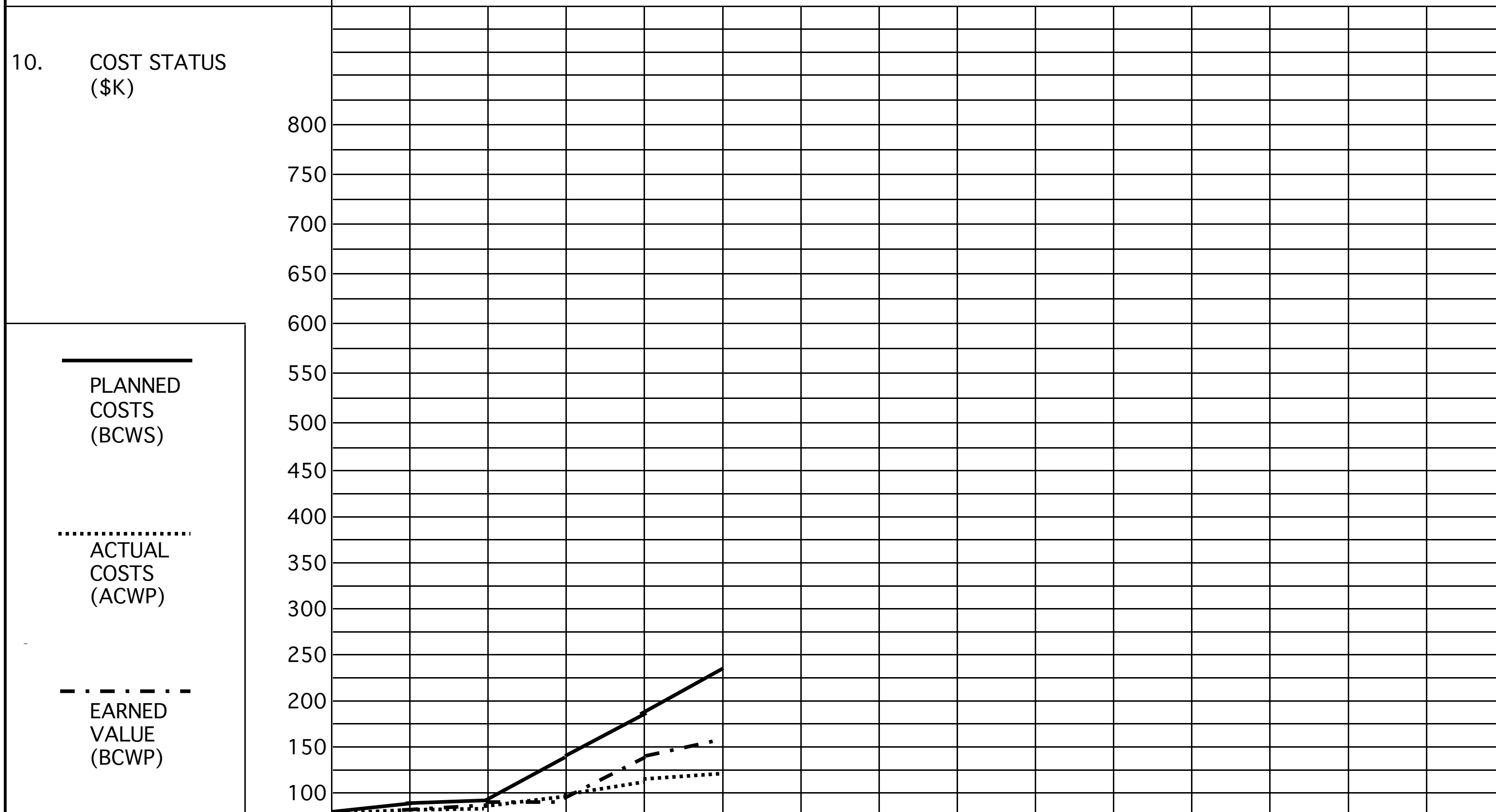
11. REMARKS

Total/Planned Cost reflects reduction in funds received due to FAC.

1. CONTRACT REPORTING ELEMENT HSSI - 2. Fracture Toughness Transition and MC Methodology		2. REPORTING PERIOD 1/26/2004 - 2/22/2004	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831		5. CONTRACT PERIOD FY 2003 - 2006	6. ACTIVITY NUMBER W41 W5 85 3W 1
		7. NRC B&R NO. 860 15 21 20 05	8. DOE B&R NO. 40 10 01 06

9. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)



COST PLAN DATES

10/01/03

PLANNED COSTS FOR ELEMENT ($K)

689

ELEMENT COSTS FOR PRIOR FYS ($K)

131

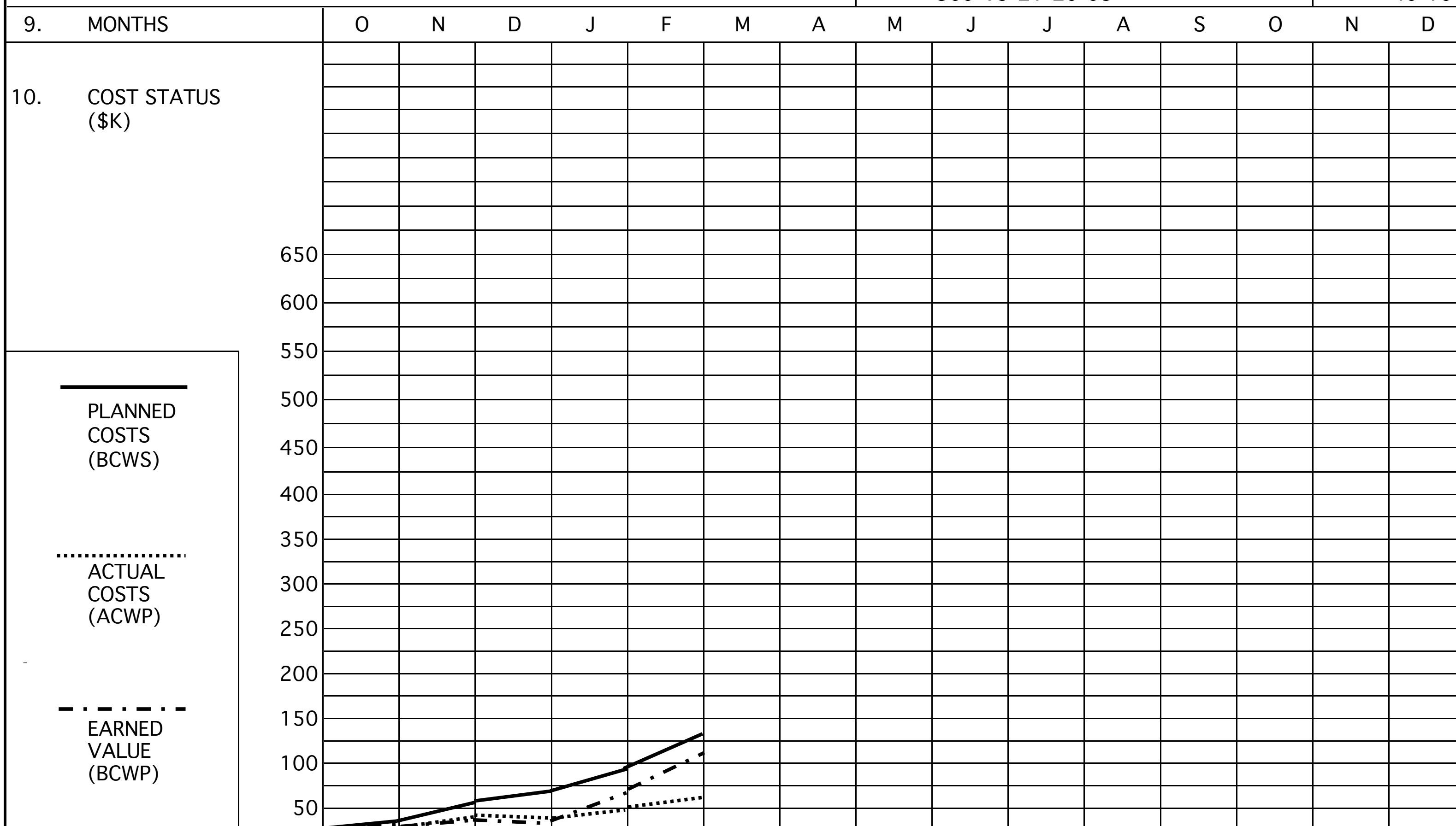
ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	51	42	45	50	43										
ACTUAL	31	26	31	19	17										
EARNED	31	28	35	35	28										
CUM. PLANNED	51	93	138	188	231	231	231	231	231	231	231	231	231	231	231
CUM. ACTUAL	31	57	88	107	124	124	124	124	124	124	124	124	124	124	124
CUM. EARNED	31	59	94	129	157	157	157	157	157	157	157	157	157	157	157

11. REMARKS

1. CONTRACT REPORTING ELEMENT HSSI - 3. Irradiation Embrittlement of RPV Steel		2. REPORTING PERIOD 1/26/2004 - 2/22/2004	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831		5. CONTRACT PERIOD FY 2003 - 2006	6. ACTIVITY NUMBER W41 W5 85 3W 1
		7. NRC B&R NO. 860 15 21 20 05	8. DOE B&R NO. 40 10 01 06

9. MONTHS

10. COST STATUS ($K)



COST PLAN DATES

10/1/03

PLANNED COSTS FOR ELEMENT ($K)

617

ELEMENT COSTS FOR PRIOR FYS ($K)

131

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	20	32	19	17	41	56									
ACTUAL	10	34	-6	11	12										
EARNED	12	15	6	29	42										
CUM. PLANNED	23	55	74	91	132	188	188	188	188	188	188	188	188	188	188
CUM. ACTUAL	10	44	38	49	61	61	61	61	61	61	61	61	61	61	61
CUM. EARNED	14	29	35	64	106	106	106	106	106	106	106	106	106	106	106

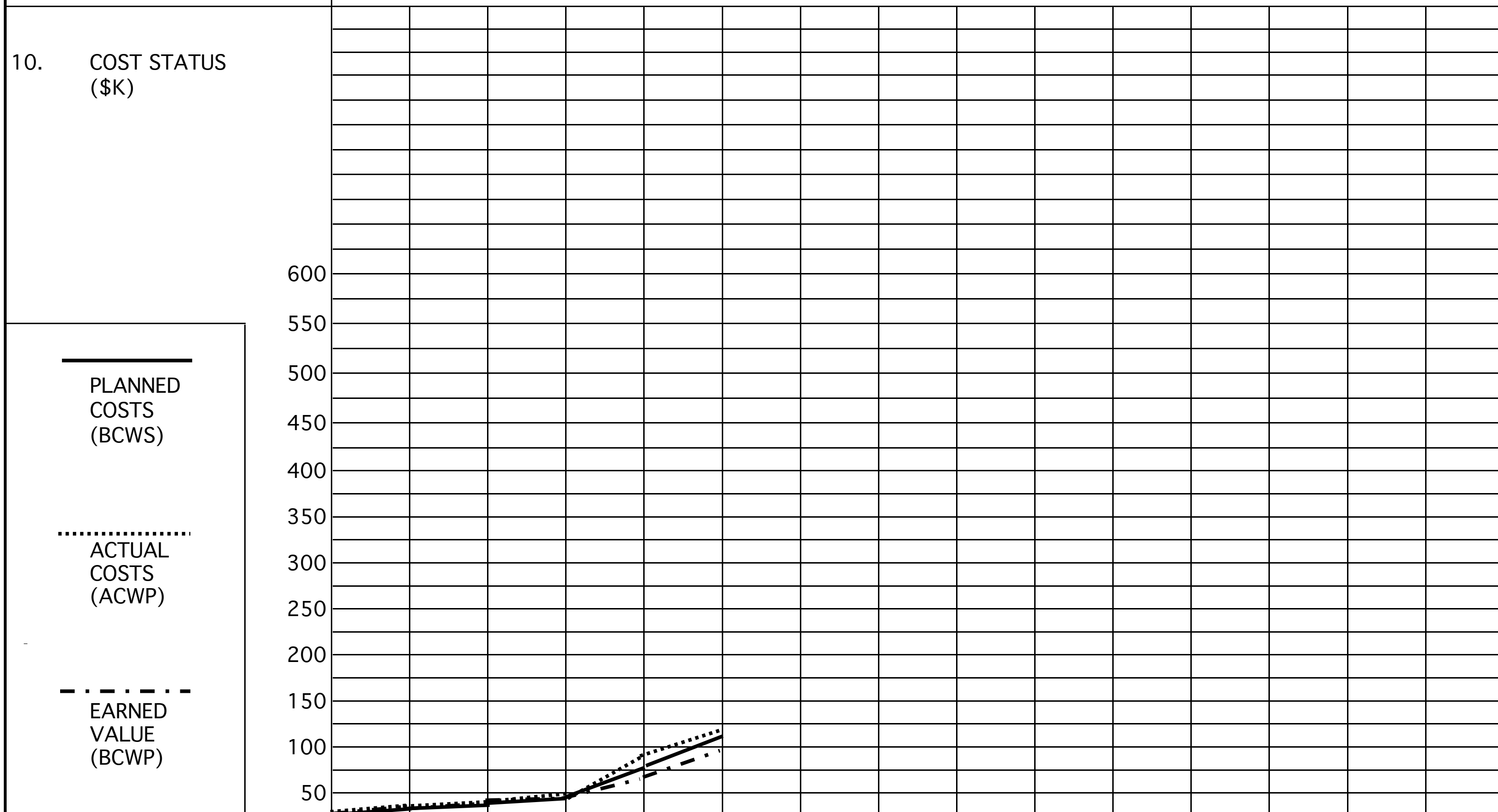
11. REMARKS

Total/Planned Cost reflects reduction in funds received due to FAC.

1. CONTRACT REPORTING ELEMENT HSSI - 4. Validation of Irradiated and Aged Materials		2. REPORTING PERIOD 1/26/2004 - 2/22/2004	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831		5. CONTRACT PERIOD FY 2003 - 2006	6. ACTIVITY NUMBER W41 W5 85 3W 1
		7. NRC B&R NO. 860 15 21 20 05	8. DOE B&R NO. 40 10 01 06

9. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)



COST PLAN DATES

10/01/03

PLANNED COSTS FOR ELEMENT ($K)

420

ELEMENT COSTS FOR PRIOR FYS ($K)

36

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	7	17	20	32	31	37									
ACTUAL	15	13	20	36	34										
EARNED	15	15	17	25	19										
CUM. PLANNED	7	24	44	76	107	144	144	144	144	144	144	144	144	144	144
CUM. ACTUAL	15	28	48	84	118	118	118	118	118	118	118	118	118	118	118
CUM. EARNED	16	31	48	73	92	92	92	92	92	92	92	92	92	92	92

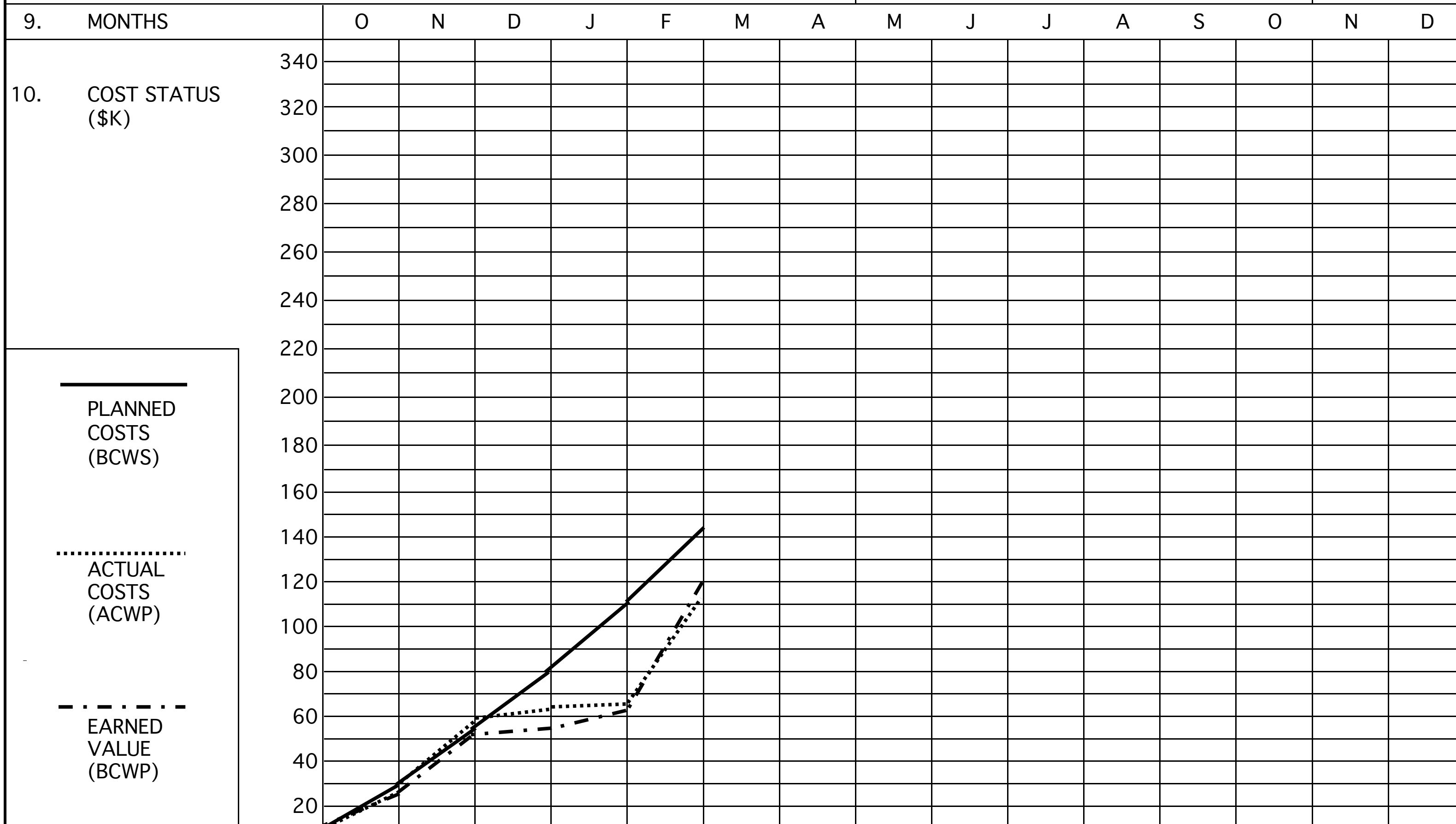
11. REMARKS

Total/Planned Cost reflects reduction in funds received due to FAC.

1. CONTRACT REPORTING ELEMENT HSSI - 5. Modeling and Microstuctural Analysis		2. REPORTING PERIOD 1/26/2004 - 2/22/2004	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831		5. CONTRACT PERIOD FY 2003 - 2006	6. ACTIVITY NUMBER W41 W5 85 3W 1
		7. NRC B&R NO. 860 15 21 20 05	8. DOE B&R NO. 40 10 01 06

9. MONTHS

10. COST STATUS ($K)



COST PLAN DATES

10/01/03

PLANNED COSTS FOR ELEMENT ($K)

210

ELEMENT COSTS FOR PRIOR FYS ($K)

35

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	30	25	25	35	30	20									
ACTUAL	27	32	2	4	51										
EARNED	23	28	3	8	58										
CUM. PLANNED	30	55	80	115	145	165	165	165	165	165	165	165	165	165	165
CUM. ACTUAL	27	59	61	65	116	116	116	116	116	116	116	116	116	116	116
CUM. EARNED	23	51	54	62	120	120	120	120	120	120	120	120	120	120	120

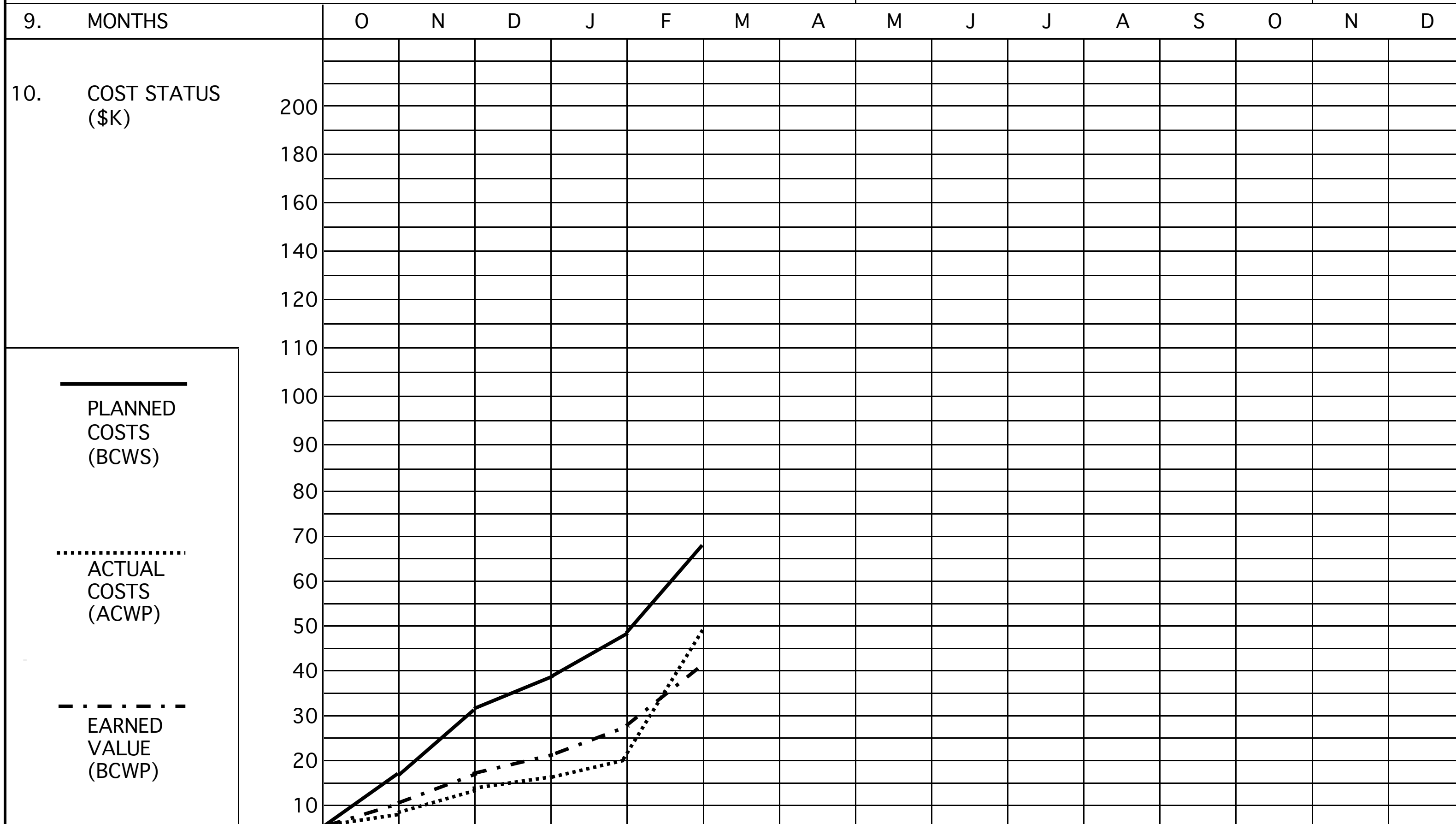
11. REMARKS

Total/Planned Cost reflects reduction in funds received due to FAC.

1. CONTRACT REPORTING ELEMENT HSSI - 6. Irradiation Coordination		2. REPORTING PERIOD 1/26/2004 - 2/22/2004	3. JCN NO. W6953
4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831		5. CONTRACT PERIOD FY 2003 - 2006	6. ACTIVITY NUMBER W41 W5 85 3W 1
		7. NRC B&R NO. 860 15 21 20 05	8. DOE B&R NO. 40 10 01 06

9. MONTHS

10. COST STATUS ($K)



COST PLAN DATES

10/01/03

PLANNED COSTS FOR ELEMENT ($K)

149

ELEMENT COSTS FOR PRIOR FYS ($K)

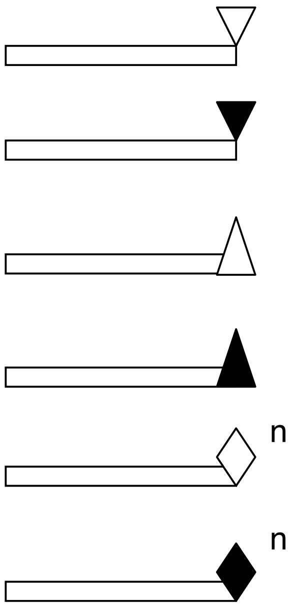
87

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	9	15	8	10	19	10									
ACTUAL	6	7	3	4	29										
EARNED	10	7	4	7	13										
CUM. PLANNED	16	31	39	49	68	78	78	78	78	78	78	78	78	78	78
CUM. ACTUAL	6	13	16	20	49	49	49	49	49	49	49	49	49	49	49
CUM. EARNED	10	17	21	28	41	41	41	41	41	41	41	41	41	41	41

11. REMARKS

Total/Planned Cost reflects reduction in funds received due to FAC.

Milestone Symbology



Intermediate milestone planned

Intermediate milestone completed

Major milestone planned

Major milestone completed

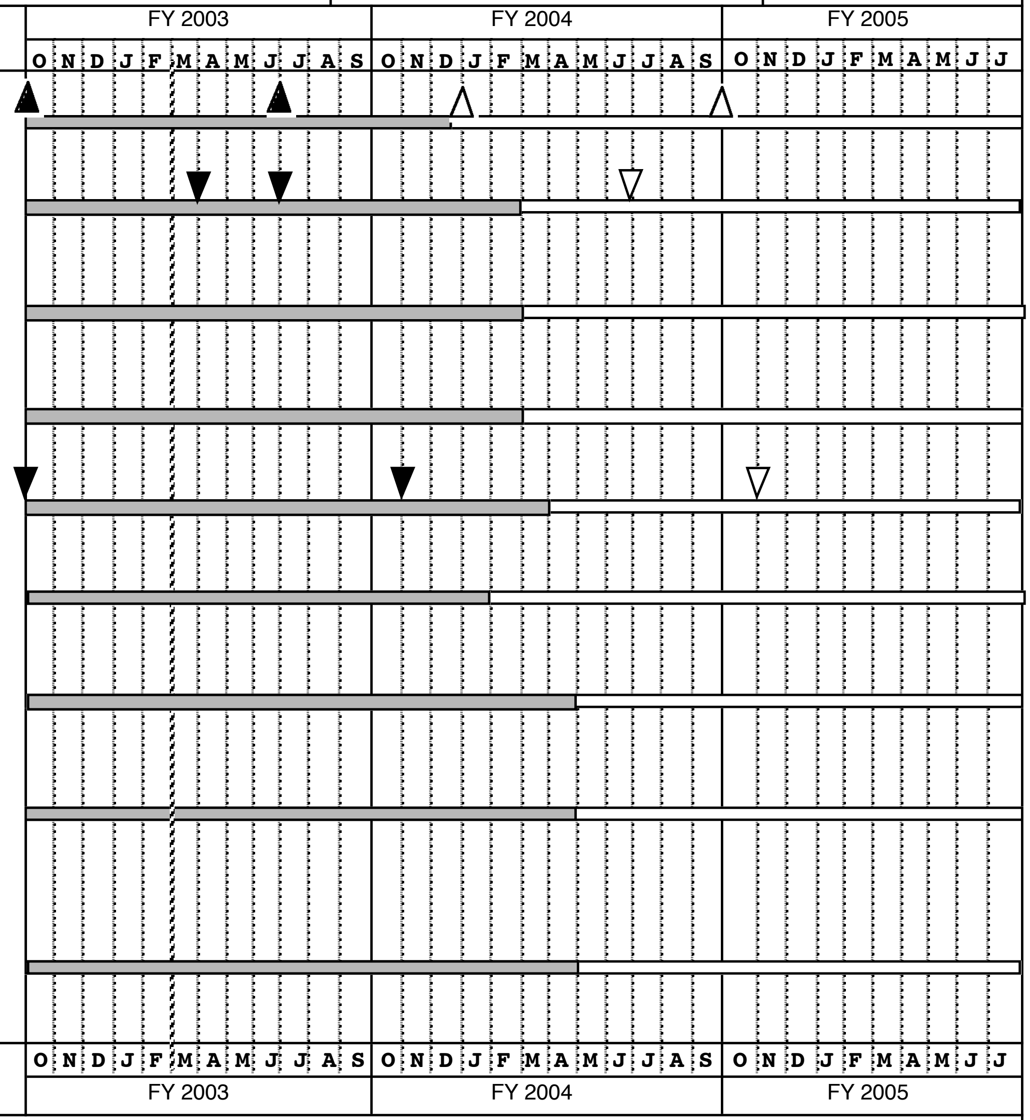
Rescheduled milestone planned

Rescheduled milestone completed

n = number of calendar-year month in which milestone was rescheduled

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 1. Program Management	**1/26/2004 - 2/22/2004**	**W6953**
4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NUMBER
OAK RIDGE NATIONAL LABORATORY **P. O. BOX 2008** **OAK RIDGE, TN 37831**	**FY 2003--2005**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

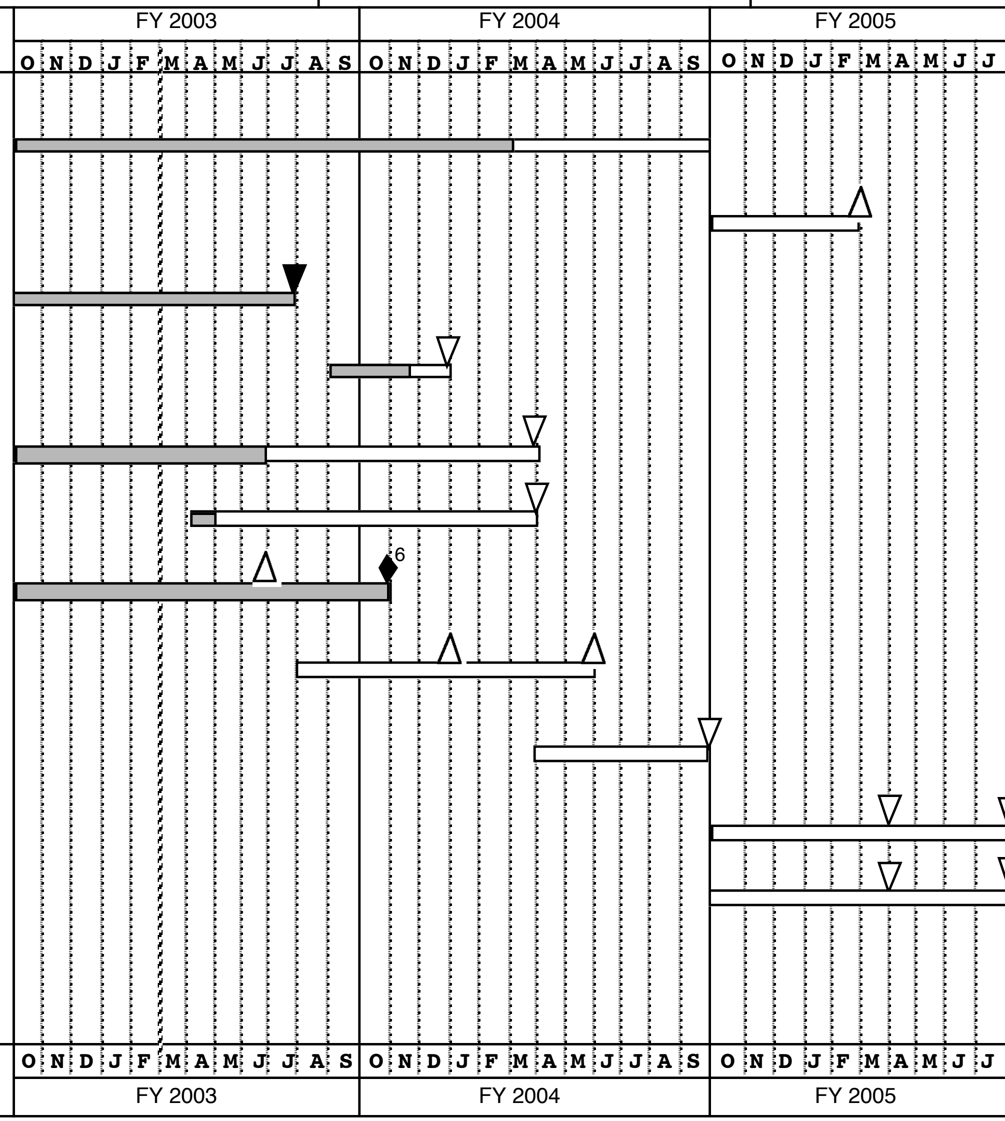
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
1.1.A.	Issue Project & Budget Proposal
1.1.B.	Select and administer subcontracts
1.2.A.	Issue earned value-based monthly reports (by the end of subsequent month)
1.2.B.	Ensure QA requirements are met
1.3.A.	Participate in NRC-sponsored meetings and discussions
1.3.B.	Coordinate NRC and internal reviews
1.3.C.	Coordinate domestic and foreign information exchange as approved by NRC-RES
1.3.D.	Coordinate HSSI Letter and NUREG Reports
1.3.E.	Document the historical information generated by the old HSSI Program



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **1/26/2004 - 2/22/2004**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003--2005**	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.1.A.	Continue to accumulate data on comparison of CVN and fracture-toughness shifts
2.1.B.	Update NUREG/CR-6009
2.2.A.	Irradiate Midland and Hi-Ni specimens
2.2.B.	Ship and receive specimens
2.2.C.	Machine 0.4 KS-01 specimens and test
2.2.D.	Test subsize PCVN KS-01 specimen
2.2.E.	Submit NUREG Report on KS-01 test results
2.2.F.	Submit letter report on small specimens results from KS-01
2.2.G.	Test unirradiated & irradiated Hi-Ni and Midland weld specimens
2.2.H.	Draft letter/NUREG Report for Midland welds
2.2.I.	Draft letter/NUREG Report for Hi-Ni welds



11. REMARKS

1. CONTRACT REPORTING ELEMENT
HSSI - 2. Fracture Toughness Transition & MC Methodology

2. REPORTING PERIOD
1/26/2004 - 2/22/2004

3. JCN NO.
W6953

4. CONTRACTOR (NAME AND ADDRESS)
OAK RIDGE NATIONAL LABORATORY
P. O. BOX 2008
OAK RIDGE, TN 37831

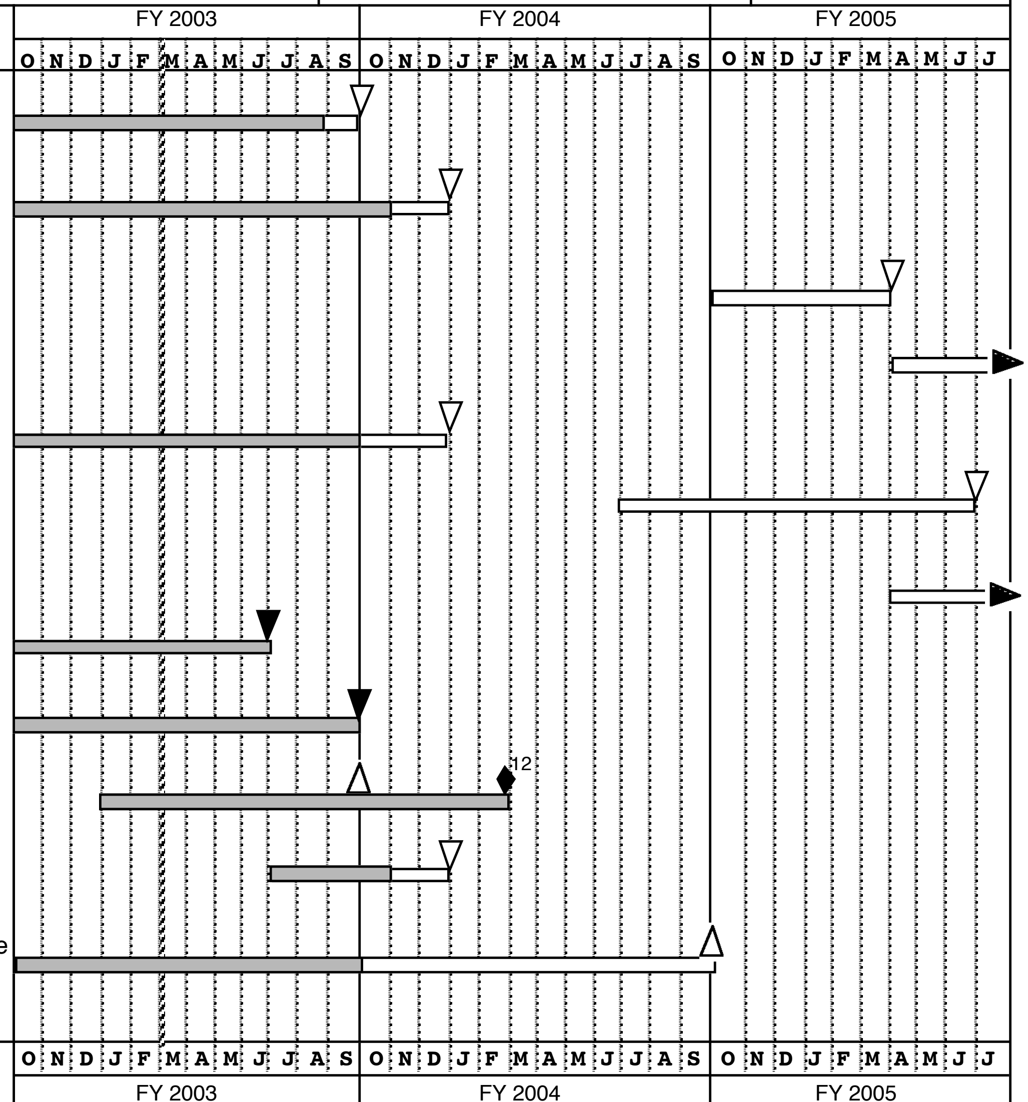
5. CONTRACT PERIOD
FY 2003--2005

6. ACTIVITY NUMBER
41 W6 95 3W 1

7. NRC B&R NO.
860 15 21 20 05

8. DOE B&R NO.
40 10 01 06

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.3.A.	Complete review of dynamic effects
2.3.B.	Develop testing plan for dynamic fracture toughness effects on MC
2.3.C.	Complete dynamic fracture-toughness tests
2.3.D.	Prepare NUREG report
2.4.A.	Develop test plan for IGF assessment with <100% IGF
2.4.B.	Complete testing of all materials
2.4.C.	Submit draft report
2.5.A.	Complete testing and analysis of A302B PCVN
2.5.B.	Initiate testing of JRQ plate sub-size specimen
2.5.C.	Prepare letter report on PCVN and 1(T)CT specimens
2.5.D.	Complete testing of unirradiated and irradiated specimens of JRQ plate
2.5.E.	Submit NUREG Report on assessment of sub-size specimen fracture toughness

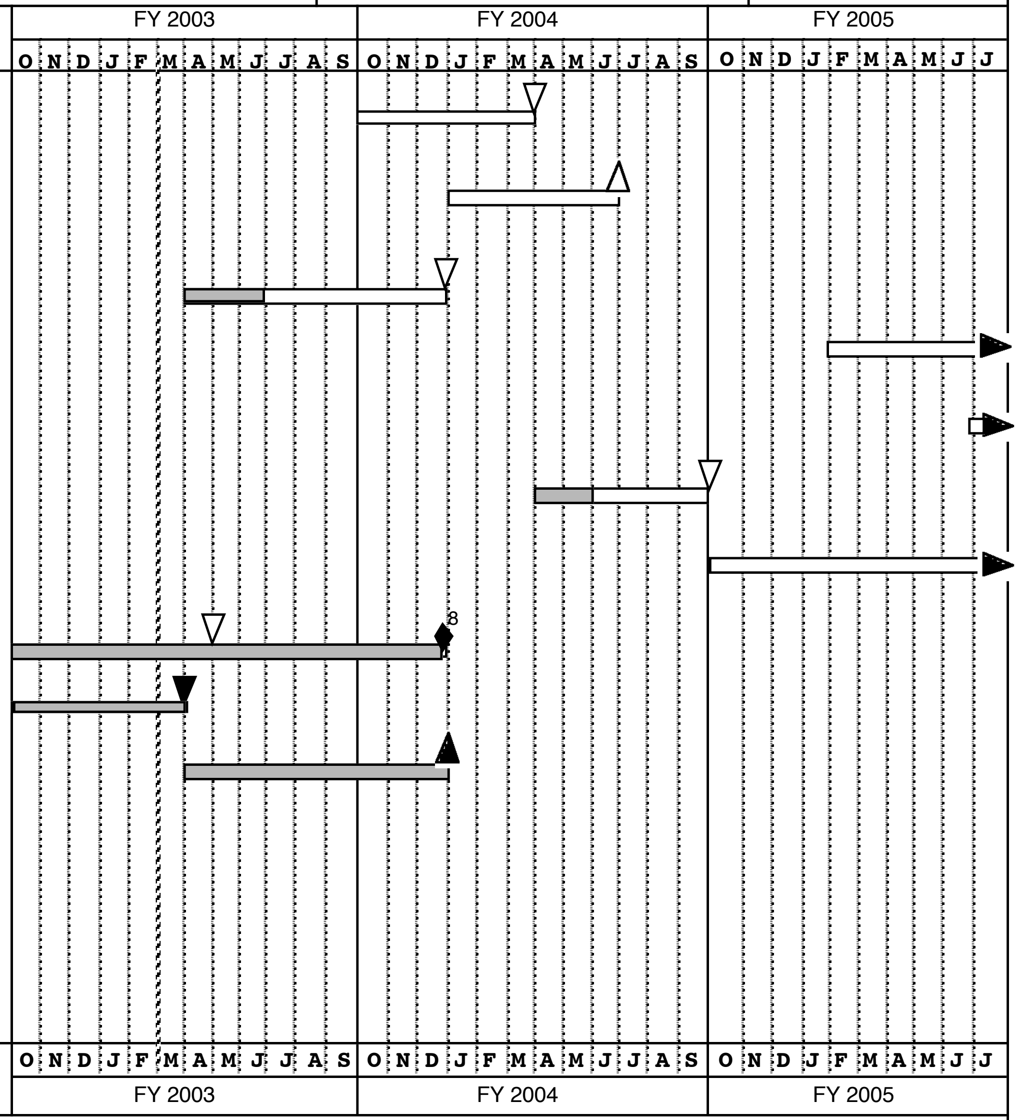


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 2. Fracture Toughness Transition & MC Methodology	**1/26/2004 - 2/22/2004**	**W6953**

4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NUMBER
OAK RIDGE NATIONAL LABORATORY **P. O. BOX 2008** **OAK RIDGE, TN 37831**	**FY 2003--2005**	**41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

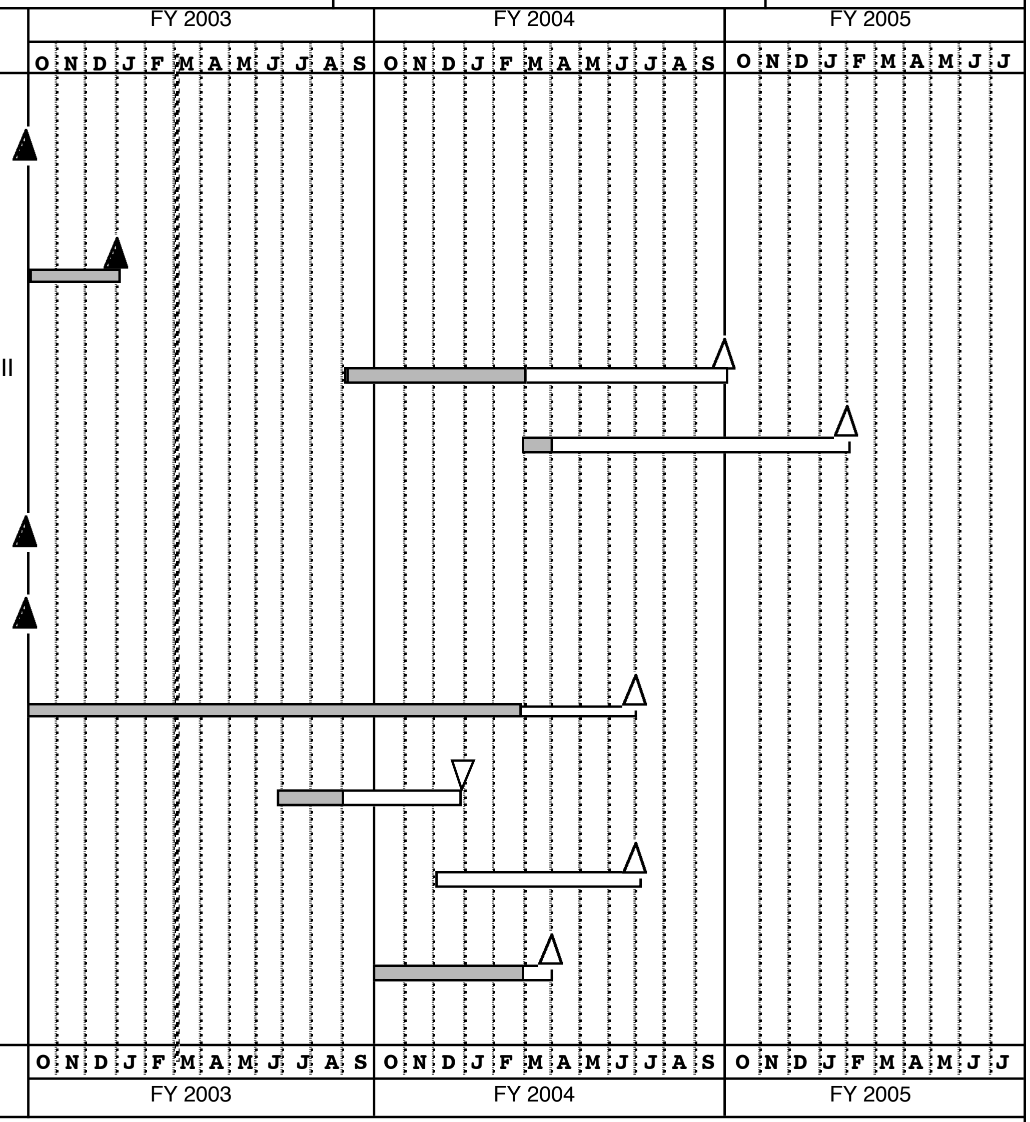
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.6.A.	Complete dosimetry/fluence measurements of 2nd IAR Series
2.6.B.	Complete report on 2nd IAR dosimetry/fluence measurements
2.6.C.	Update code to Linux
2.6.D.	Complete dosimetry/fluence measurements for 3rd IAR Series
2.6.E.	Complete letter report on 3rd IAR
2.7.A.	Test 3-point bend and PCVN specimens
2.7.B.	Prepare NUREG Report
2.8.A.	Machine and test second batch 72W specimens
2.8.B.	Compare first and second batch
2.8.C.	Prepare a letter report



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 3. Irradiation Embrittlement of RPV Steel**	2. REPORTING PERIOD **1/26/2004 - 2/22/2004**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003--2005**	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
3.1.A.	Complete letter report on IA effects on HAZ Phase I
3.1.B.	Fabricate and heat treatment CVN specimens of A302B with slow cool after PWHT. Initiate irradiations in IAR Phase II
3.1.C.	Receive and test IA HAZ specimens from Phase II
3.1.D.	Complete NUREG Report on HAZ irradiation effects
3.2.A.	Complete Charpy testing of PSI-supplied JRQ specimens
3.2.B.	Complete PCVN testing of PSI supplied JRQ specimens
3.2.C.	Submit NUREG Report on results of JRQ testing
3.3.A.	Test and analyze 73W specimens
3.3.B.	Submit a draft NUREG Report
3.4.A.	Complete atom probe and TEM examination of Hi-Ni welds

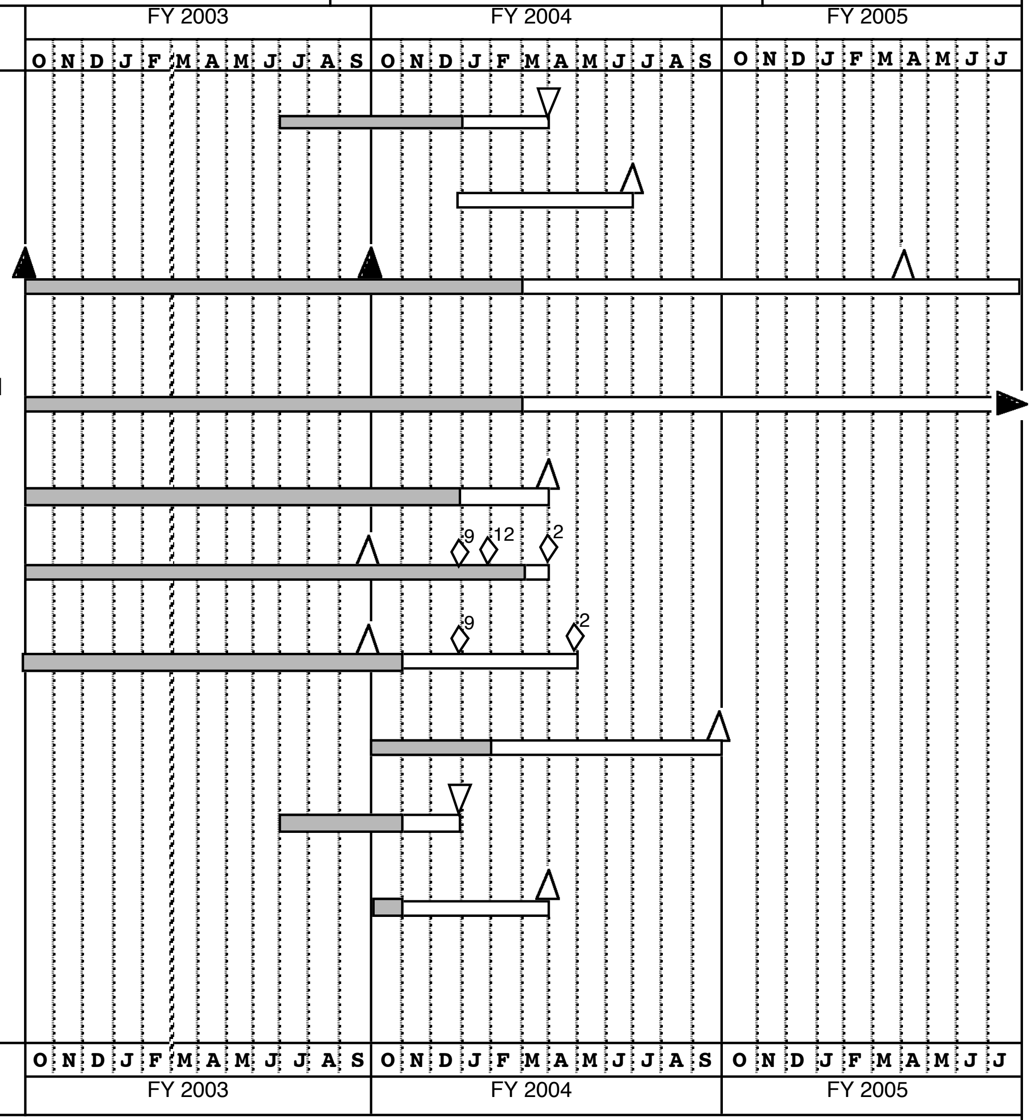


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 4. Validation of Irradiated and Aged Materials	**1/26/2004 - 2/22/2004**	**W6953**

4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NUMBER
OAK RIDGE NATIONAL LABORATORY **P. O. BOX 2008** **OAK RIDGE, TN 37831**	**FY 2003--2005**	**41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
4.1.A.	Complete fracture toughness tests of irradiated SS cladding
4.1.B.	Complete letter report on irradiation effects on SS cladding
4.2.A.	Participate in periodic IGRDM meetings
4.2.B.	Participate in international meetings as scheduled
4.3.A.	Draft report on effects of PWHT on copper solubility and toughness of RPV steels
4.3.B.	NUREG Report on crack arrest tests of irradiated Midland Weld WF-70
4.3.C.	NUREG Report on re-embrittlement rate (IAR) of HSSI 73W material
4.3.D.	Draft report on material variability
4.4.A.	Complete literature review
4.4.B.	Submit draft NUREG Report

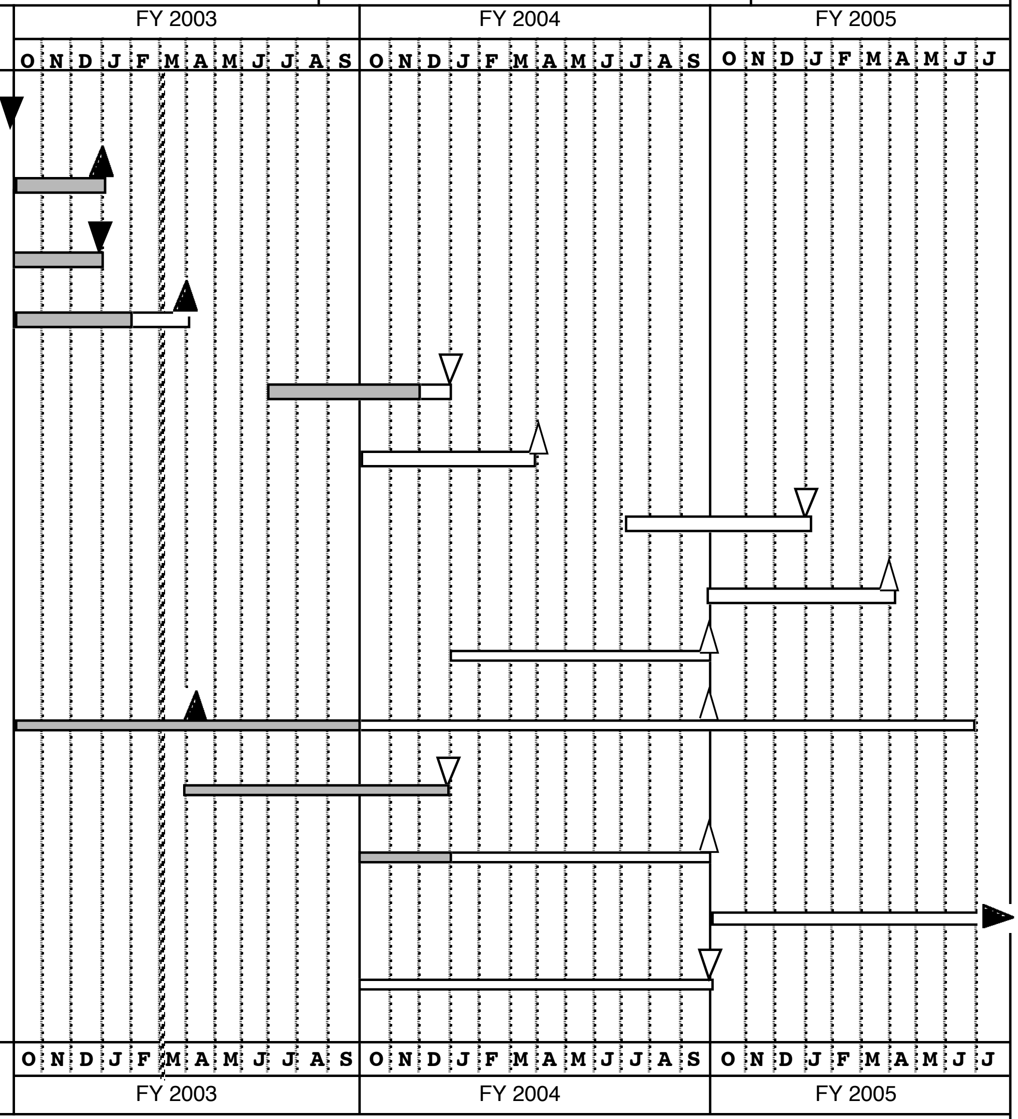


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 5. Modeling & Microstructural Analysis	**1/26/2004 - 2/22/2004**	**W6953**

4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NUMBER
OAK RIDGE NATIONAL LABORATORY **P. O. BOX 2008** **OAK RIDGE, TN 37831**	**FY 2003--2005**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

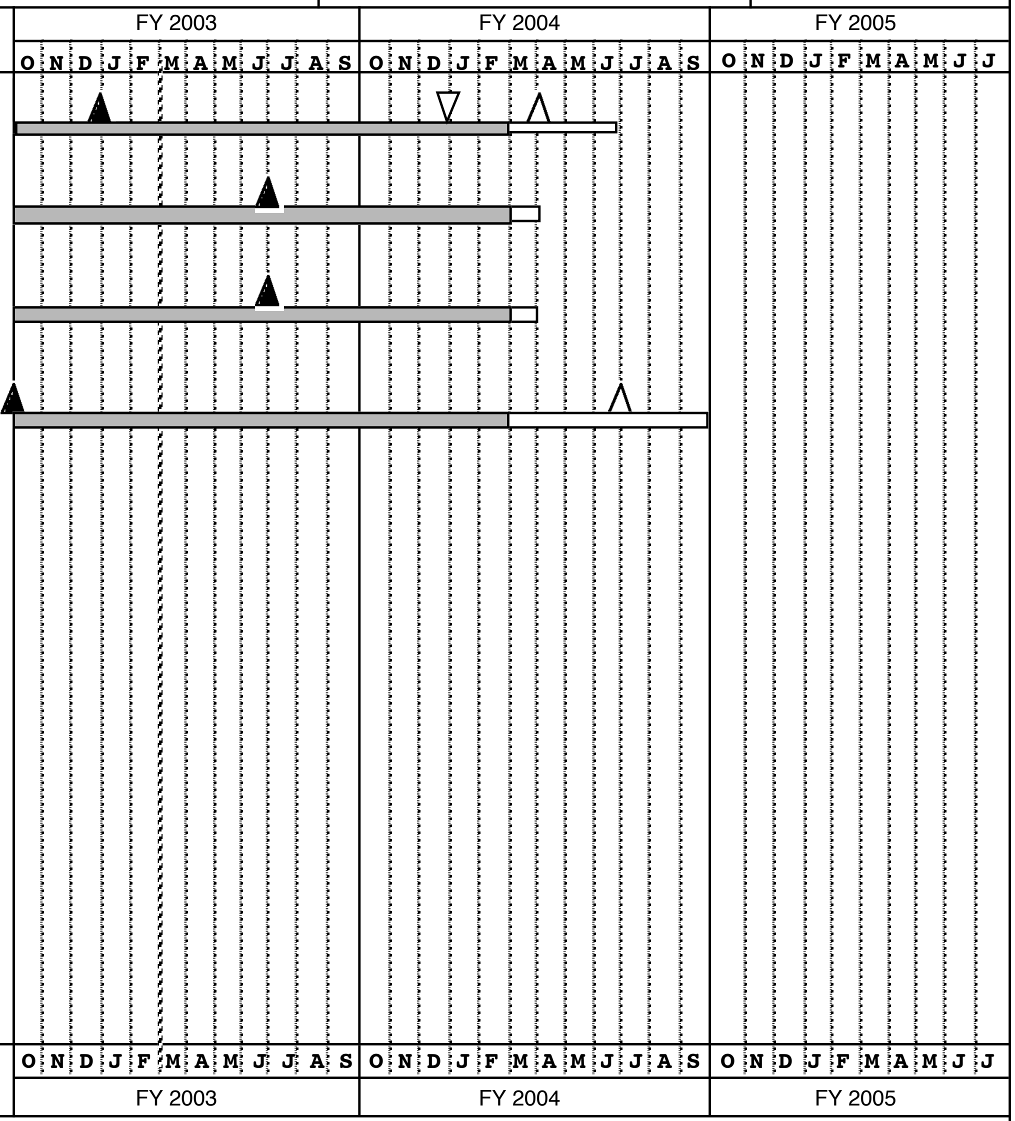
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
5.1.A.1.	APFIM characterization of late blooming phases
5.1.A.2.	Submit report
5.1.C.1.	APT of model steels to study phase decomposition in collaboration with UCSB
5.1.C.2.	Submit report
5.1.D.1.	APT of Palisades Hi-Ni steel
5.1.D.2.	Submit report
5.1.E.1	APT examination Midland and IARAR conditions
5.1.E.2.	Submit report
5.1.F.	Submit NUREG Report on late blooming phases
5.3.A.	Maintain and update EDB (Update 12 and 13)
5.3.B.	Verify data for embrittlement equation
5.3.C.	Move PR-EDM from DOS to Windows (Alpha)
5.3.D.	Move PR-EDM from DOS to Windows (Beta)
5.3.E.	Transfer surveillance reports to electronic storage



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 6. Irradiation Coordination**	2. REPORTING PERIOD **1/26/2004 - 2/22/2004**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003--2005**	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
6.1	Investigate alternative test irradation facilities
6.2.A.	Coordinate the operation, data collection, and maintenance of the HSSI IAR facility through shut down
6.3.A.	Coordinate the operation, data collection, and maintenance of the UCSB irradiation facility
6.4.	Dispose of irradiated materials from the HSSI-IAR and HSSI-IVAR



11. REMARKS