ORNL/HSSI (W6953)/MLSR-2004/6

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

Monthly Letter Status Report

March 2004

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HEAVY-SECTION STEEL IRRADIATION PROGRAM

JCN W6953

MONTHLY LETTER STATUS REPORT FOR

March 2004

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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
March 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 NRC Program Monitor informed the HSSI Program Manager that funding would be reduced in FY 2004. Without additional funding, the program will stop all work before the end of the August 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 the removal of specimens and the disposal of irradiated waste. The control panels for the HSSI IAR and HSSI UCSB irradiation facilities were shipped from the FNR, received, inspected, and placed into storage at ORNL. Final arrangements for returning the irradiated specimens are expected to be completed during the next reporting period. (See Task 6 for details).

D. E. McCabe, a former employee, has agreed to return as a consult to the HSSI Program. Mr. McCabe will focus on the bias term added to T_0 values determined from pre-cracked Charpy specimens.

K. R. Thoms has agreed to serve as a consultant to the HSSI Program following his retirement at the end of this reporting period.

(Milestone 1.2.A) A revised test plan for investigating the bias term added to T_0 values determined from pre-cracked Charpy specimens has been developed. (Please see Milestone 2.7A for details.)

During this reporting period, the Paul Scherrer Institute (PSI) informed the HSSI Program Principal Investigator that funding is not available for continuation of the TEP experiments. R.K. Nanstad will meet with Dr. Niffenegger in the latter part of May to discuss potential options for conducting TEP experiments with the specimens sent by ORNL. (Please see Milestone 3.2.C for more details)

(Milestone 1.3.A) The microstructure of several high-Ni steels were characterized by a Atom Probe Tomography during this reporting period. This effort fulfilled an NRC Office of Research operational milestone. (Please see Milestones 2.2.G and 5.1.C 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 March 19- 31, R. K. Nanstad, K. R. Thoms, (travel supported by the DOE Gen IV Program) and T. M. Rosseel traveled to Rez, Czech Republic, Studsvik Sweden, and Mol, Belgium, to discuss and evaluate the possible use reactors for a future materials irradiation program. The reactors evaluated included: (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 the Studie Centrum Voor Kernenergie - Centre D'etude De L'Energie Nucleaire SCK-CEN, 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.

Presentations of programmatic needs and site capabilities for the low-flux irradiation facility were made at all three facilities. Detailed discussions were held regarding the draft statement of work and the list of specific questions provided by ORNL prior to the visits. Each facility invested considerable time and manpower, not only during the visit (typically eight to ten staff members in the room for the presentations and discussions), but also in the detailed preparation for the visit. The result was an extremely productive visit that set the stage for a potentially productive collaboration.

Discussions (e-mail and telephone) continued with representatives of the University of Missouri, 10 MW, Missouri University Research Reactor (MURR) and the Massachusetts Institute of Technology MITR reactor. Several challenges must be overcome for these facilities, but both appear to be promising candidates as the future location of the HSSI Program's RPV steel irradiation site.

Task 2: Fracture Toughness Transition and Master Curve Methodology (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.

Subtask 2.1: Fracture Toughness Transition Temperature Shifts (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 8.0×10^{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 1.6×10^{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 $\sim 0.8 \times 10^{19}$ 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 analyses have 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 $0.5 \times 0.5 \times 10$ 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 was prepared and examined during this reporting period. The prepared sample was superior to the previous one and yielded a significant number of atoms with a concomitantly superior tomographic profile (see Section 5.1).

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.

Subtask 2.5: Sub-sized Specimens (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.

Subtask 2.6: Dosimetry and Fluence Analysis of the IAR Irradiation Capsules (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 revised 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 (W/B=2), some with the standard ligament (a/W~0.5) and some with half the standard ligament (a/W~0.8) to provide a comparison with the ligament of a standard precracked Charpy specimen (a/W~0.5). HSST Plate 13B 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. 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.

During this reporting period, a cutting plan was developed and drawings have been prepared for cutting of the plate and machining of test specimens.

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_o 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.

Subtask 3.1: HAZ embrittlement (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 completed aging earlier and those designated for an aging time of 2000 h completed aging during this reporting period. Testing of the aged specimens will begin in April.

(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 has been completed in the Metals and Ceramics Division LAMBDA facility. Atom probe "toothpicks" of both VVER-1000 specimens and the JRQ samples have been made into atom-probe needles and atom probe tomography is underway. Preliminary results in the irradiated, thermally annealed, and reirradiated conditions have been obtained during this reporting period.

(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.

During this reporting period, Dr. Kalkhof stated that the TEP equipment they had previously used was borrowed from Electricite de France (EdF) and is apparently no longer available. Moreover, he acknowledged that funding is not available for continuation of the TEP experiments nor for procurement of a TEP system. R.K. Nanstad will meet with Dr. Niffenegger in the latter part of May to discuss potential options for conducting TEP experiments with the specimens sent by ORNL.

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) The 73W CVN specimens reirradiated in the Ford Reactor will be packaged and sent to ORNL in April or May.

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 □2 x 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 by the technician and preliminary atom probe experiments have been conducted. The results will be analyzed and reported in April.

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. HSSI Program staff members, including M. K. Miller, R. K. Nanstad, M. A. Sokolov, and R. E. Stoller, gave presentations.

(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 $\sim 1.6 \times 10^{19}$ 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, 2003 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, 2003. 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 were included in the ORNL final report to the IAEA CRP. 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 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 experiments have been conducted and the analyses will be completed in April.

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, including Chapter 4, "Radiation Damage Mechanisms," primarily authored by Dr. Jean-Claude Van Duysen of EDF in France. 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.

On November 25-28, 2003, 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." A foreign trip report, ORNL/FTR-205181, was prepared and distributed on 30 December. 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 was held at the IAEA on March 15-17, 2004 to organize and begin to prepare the TECDOC report for the CRP. During that same week, R.K. Nanstad attended the final meeting of the IAEA CRP-5 on "Surveillance Programmes Results Application to Reactor Pressure Vessel (RPV) Integrity Assessment." He has completed a draft of Chapter 9, "Non-mandatory Studies – Additional Tests and/or Evaluations on JRQ Steel and National Materials."

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. The NRC Project Manager will identify specific activities on an as-needed basis. 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 post-weld heat treatments and irradiated in the University of Michigan Ford Reactor, testing of the irradiated sub-size 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, thermal-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.C4) The microstructures of several high-nickel content pressure vessel steels have been characterized by atom probe tomography as part of an Office of Research Operational Milestone. The milestone was completed as required during this reporting period. The objectives of this study were to investigate the influence of high-nickel levels on the response to neutron irradiation of high and low-copper pressure vessel steels and to establish whether any additional phases were present after neutron irradiation. The nickel levels in these steels were at least twice that typically found in Western pressure vessel steels.

Two different types of pressure vessel steels with low- and high-copper contents were selected for this study. The first set of alloys was low copper (~0.05% Cu) base (15Ch2NMFAA) and weld (12Ch2N2MAA) materials used in a VVER-1000 reactor. The composition of the lower nickel VVER-1000 base material was Fe- 0.17 wt% C, 0.30% Si, 0.46% Mn, 2.2% Cr, **1.26% Ni**, **0.05% Cu**, 0.01% S, 0.008% P, 0.10% V and 0.50% Mo. The composition of the higher nickel VVER-1000 weld material was Fe- 0.06 wt % C, 0.33% Si, 0.80% Mn, 1.8% Cr, **1.78% Ni**, **0.07% Cu**, 0.009% S, 0.005% P, and 0.63% Mo. The VVER-1000 steels were irradiated in the HSSI Program's irradiation facilities at the University of Michigan, Ford Nuclear Reactor at a temperature of 288°C for 2,137 h at an average flux of 7.08 x 10^{11} cm^{-2} s^{-1} for a fluence of 5.45 x 10^{18} n cm^{-2} (E >1 MeV) and for 5,340 h at an average flux of 4.33 x 10^{11} cm^{-2} s^{-1} for a fluence of 8.32 x 10^{18} n cm^{-2} (E >1 MeV). Therefore, the total fluence was 1.38 x 10^{19} n cm^{-2} (E >1 MeV). The second type of pressure vessel steel was a high copper (0.20% Cu) weld from the Palisades reactor. The average composition of the Palisades weld was Fe- 0.11 wt% C, 0.18% Si, 1.27% Mn, 0.04% Cr, **1.20% Ni**, **0.20% Cu**, 0.017% S, 0.014% P, 0.003% V and 0.55% Mn. The Palisades weld, designated weldment "B" from weld heat 34B009, was irradiated at a temperature of 288°C and a flux of ~7 x 10^{11} cm^{-2} s^{-1} to a fast fluence of 1.4 x 10^{19} n cm^{-2} (E >1 MeV). These three alloys were characterized with the new ORNL local electrode atom probe (LEAP).

Atom probe tomography revealed nickel-, manganese-, and silicon-enriched precipitates in both the VVER 1000 base and weld materials after neutron irradiation. A high number density of copper-, nickel-, manganese-, silicon- and phosphorus-enriched precipitates were observed in the Palisades weld after neutron irradiation. Atom probe tomography also revealed high levels of phosphorus segregation to the dislocations in all three materials.

<u>Subtask 5.2: Embrittlement Data Base</u> (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.B Update surveillance data in the PR-EDB for the Reg Guide 1.99Rev3

(Milestone 5.2.B) In collaboration with Ernie Easson, several data sets were reviewed, as part of the effort to ensure a comprehensive database that all parties involved can agree is sufficient to complete the re-evaluation of the embrittlement trend model for Reg Guide 1.99Rev3.

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) The focus of the efforts during this reporting period to build a Windows-based PR-EDB included the following two categories.

1. The "File Manipulation" features of PR-EDB utility.

   All the available file manipulation features of DOS version of PR-EDB were successfully converted into Windows environment. The work on building an interface to export the EDB plot and EDB fitting procedure will be completed in the next month effort pending available funding.

2. EDB Database Structure Overhaul

   The new EDB structure, which has true relational database characteristic, was designed during this reporting period. The new structure, with the sample database, will be illustrated in "View EDB Database" feature of the upgrade EDB software for demonstration purposes. After reviewing this new structure, the conversion of PR-EDB into this new EDB structure will be completed.

It is estimated that it will require one more man-month to complete the beta version of EDB upgrade software package. The beta version will be distributed to NRC for public comments.

<u>5.3.D Transfer Surveillance Reports to Electronic Storage:</u> 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.

Subtask 6.1: Investigate Alternative Test Irradiation Facilities (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 March 19 -31, R. K. Nanstad, K. R. Thoms, and T. M. Rosseel traveled to traveled to Prague/Rez, Czech Republic, Stockholm/Nykoping, Sweden, and Brussels/Mol, Belgium, to discuss and evaluate the possible use reactors for a future materials irradiation program. In cooperation with the DOE Gen IV Materials Program, the three European reactors evaluated included: (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-CEN, 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.

Presentations of programmatic needs and site capabilities for the low-flux irradiation facility were made at all three facilities. Detailed discussions were held regarding the draft statement of work and the list of specific questions provided by ORNL prior to the visits. Each facility invested considerable time and manpower, not only during our visit (typically eight to ten staff members in the room for the presentations and discussions), but also in the detailed preparation for our visit. The result was an extremely productive visit that certainly set the stage for a potentially productive collaboration.

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 NRI, Studsvik and SCK-CEN staff presentations will be forwarded to the NRC HSSI Program monitor.

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 IAR instrumentation shipped from FNR was received and inspected at ORNL. The equipment is temporarily stored in the complex occupied by the HSSI-IAR Task Leader. It is hoped that with slight modification the instrumentation can be used at another reactor site as soon as a suitable site for future materials irradiation experiments has been identified.

The last specimens to be irradiated in the IAR facilities are stored and are being monitored in the FNR hot cells to decay for a period of time. The arrangements to send an empty shielded shipping cask to FNR to retrieve the first of the remaining 2 groups of irradiated specimens from the FNR hot cells are continuing. This work was delayed slightly due to a new DOT requirement that the casks, normally used for such shipment, be fitted with an additional liner inside to contain the material. The new liner has been procured and delivered to FNR. The FNR staff will load the specimens into the new liner and see that everything is prepared for arrival of the shipping cask early in the next reporting period.

(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.

<u>Subtask 6.3: Operate the HSSI-UCSB Irradiation Facility</u> (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 HSSI-UCSB instrumentation shipped from FNR was received and inspected at ORNL. The equipment is temporarily stored in the complex occupied by the HSSI-IAR Task Leader. It is hoped that with slight modification the instrumentation can be used at another reactor site as soon as a suitable site for future materials irradiation experiments has been identified.

<u>Subtask 6.4 Shutdown irradiation facilities and dispose of irradiated material from the IAR and IVAR facilities</u> (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 March 15-19, R.K. Nanstad attended two IAEA CRP meetings in Vienna, Austria.

On March 19-31, R. K. Nanstad, T. M. Rosseel, and K. R. Thoms traveled to Prague/Rez, Czech Republic, Stockholm/Nykoping, Sweden, and Brussels/Mol, Belgium, to discuss and evaluate the possible use of the NRI, LV-15 reactor, the Studsvik R2(0) reactor and the SCK-CEN BR2 reactor. The DOE paid for travel expenses for Nanstad and Thoms, since they were also representing the DOE-NE Gen IV Program.

4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:

T. M. Rosseel, "HSSI Program and ORNL Overview," presented to the Nuclear Research Institute staff, NRI, Rez Czech Republic, March 22, 2004.

T. M. Rosseel, "US NRC Overview," presented to the Nuclear Research Institute staff, NRI, Rez Czech Republic, March 22, 2004.

T. M. Rosseel, "HSSI Program and ORNL Overview", presented to the Studsvik Nuclear staff, Studsvik, Sweden, March 25, 2004.

T. M. Rosseel, "US NRC Overview," presented to the Studsvik AB Staff, Studsvik Nuclear staff, Sweden, March 25, 2004.

T. M. Rosseel, "HSSI Program and ORNL Overview," presented to the BR2 staff, Studie Centrum Voor Kernenergie - Centre D'etude De L'Energie Nucleaire, SCK-CEN, Mol, Belgium, March 29, 2004.

T. M. Rosseel, "US NRC Overview," presented to the BR2 staff, Studie Centrum Voor Kernenergie - Centre D'Etude De L'Energie Nucleaire, SCK-CEN, Mol, Belgium, March 29, 2004.

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: 2/23/04-03/28/04

		Current Month	Fiscal Year to Date	Cumulative Project to date
I.	Direct Staff Effort	7 MM	2.4 MY	45.0 MY
II.	A. Direct Lab Staff Effort ($)			
	Direct Salaries	141,464	487,667	6,362,752
	Materials and Services	2,799	5,839	563,295
	ADP Support	77	232	3,284
	Subcontracts	10,819	26,665	1,162,182
	Travel	719	19,031	237,300
	Other: NRC-PO Tax	4,929	28,191	369,237
	General and Administrative	73,760	254,532	3,078,308
	Total UT-Battelle Costs	234,567	822,157	11,776,358
	B. DOE Federal Admin. Costs	7,037	24,665	191,585
	TOTAL PROJECT COSTS	241,604	846,822	11,967,943

Percentage of available cumulative funds costed	93
Percentage of available current FY funds costed	50
Funds Remaining	867,557
Commitments:	20,083
BA Remaining	847,474
BA Remaining Less Projected FAC	822,206

III. Funding Status

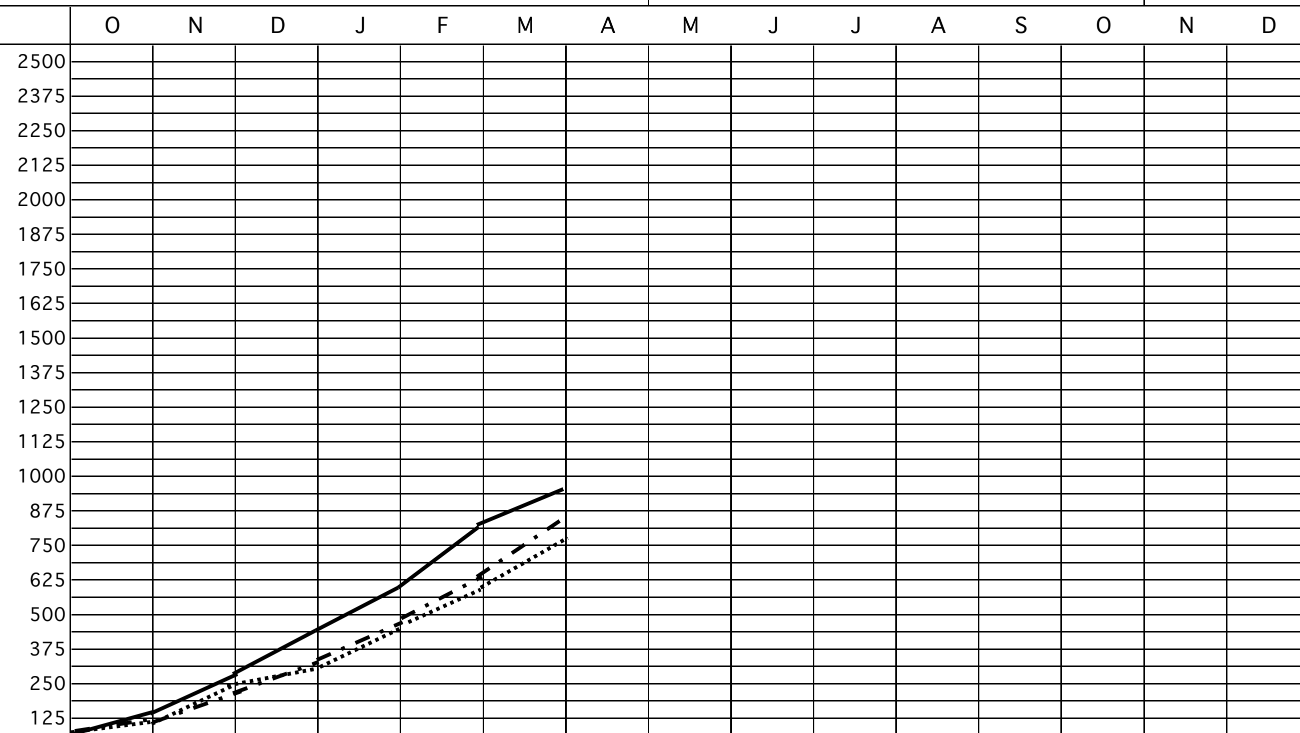
Prior FY Carryover	FY 04 Projected Funding Level	FY 04 Funds Received to Date	FY 04 Funding Balance Needed	Cumulative Amt. Obligated	Cumulative Amt. Costed
693,569	2,430,000	1,000,000	1,430,000	12,835,500	11,967,943

Comments: The Federal Administration Charge of 3% is applied to monthly costs.

1. CONTRACT REPORTING ELEMENT HSSI - Heavy-Section Steel Irradiation Program		2. REPORTING PERIOD 2/23/2004 - 3/28/2004	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)



PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

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	182									
ACTUAL	110	139	65	95	178	235									
EARNED	112	118	86	128	184	196									
CUM. PLANNED	141	300	440	610	804	986	986	986	986	986	986	986	986	986	986
CUM. ACTUAL	110	249	314	409	587	822	822	822	822	822	822	822	822	822	822
CUM. EARNED	112	230	316	444	628	824	824	824	824	824	824	824	824	824	824

11. REMARKS

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

1. CONTRACT REPORTING ELEMENT HSSI - 1. Program Management	2. REPORTING PERIOD 2/23/2004 - 3/28/2004	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

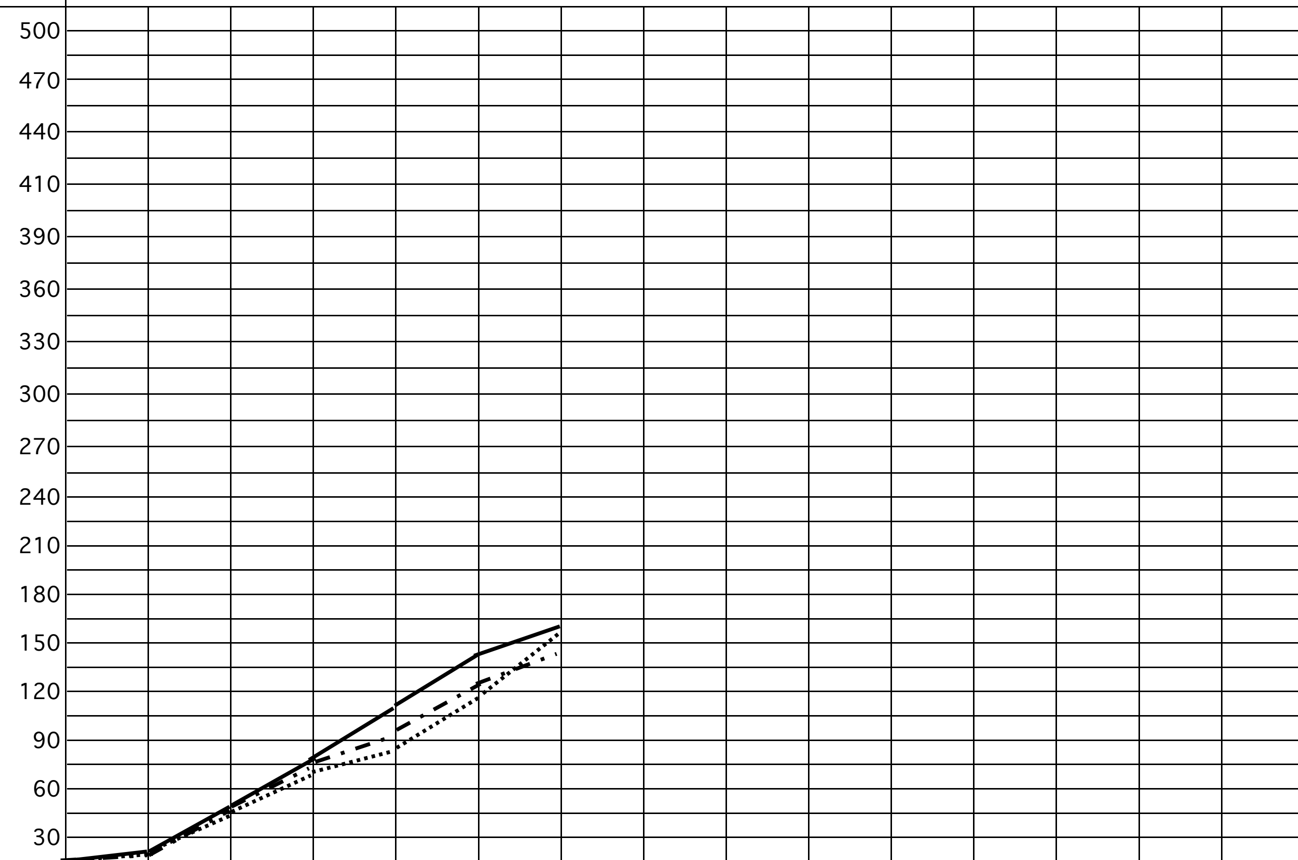
9. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)

PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)



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	35									
EARNED	21	25	21	24	24	29									
CUM. PLANNED	27	55	78	104	134	159	159	159	159	159	159	159	159	159	159
CUM. ACTUAL	22	49	64	86	121	156	156	156	156	156	156	156	156	156	156
CUM. EARNED	21	46	67	91	115	144	144	144	144	144	144	144	144	144	144

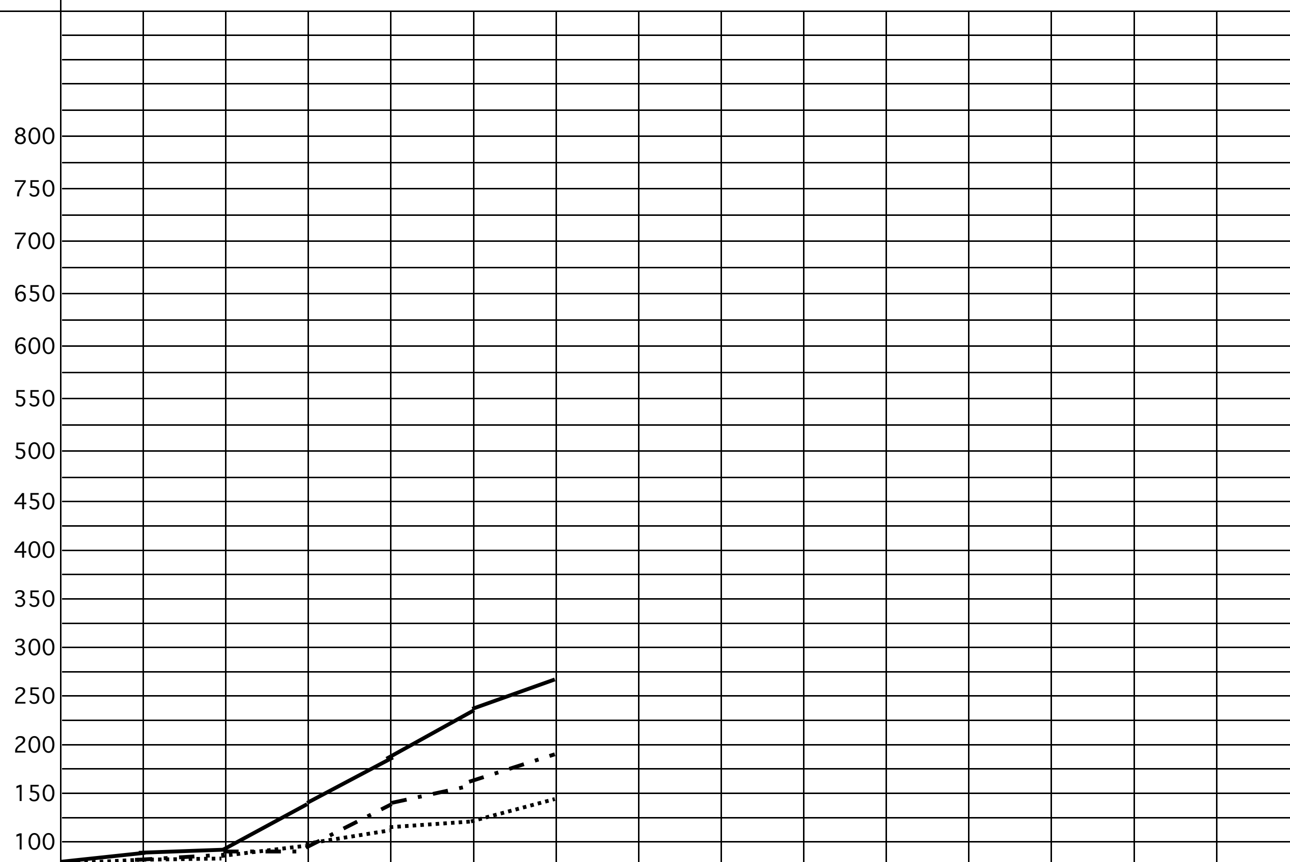
11. REMARKS

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 2/23/2004 - 3/28/2004	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)



PLANNED COSTS (BCWS) — solid line

ACTUAL COSTS (ACWP) — dotted line

EARNED VALUE (BCWP) — dash-dot line

COST PLAN DATES: 10/01/03

PLANNED COSTS FOR ELEMENT ($K): 689

ELEMENT COSTS FOR PRIOR FYS ($K): 131

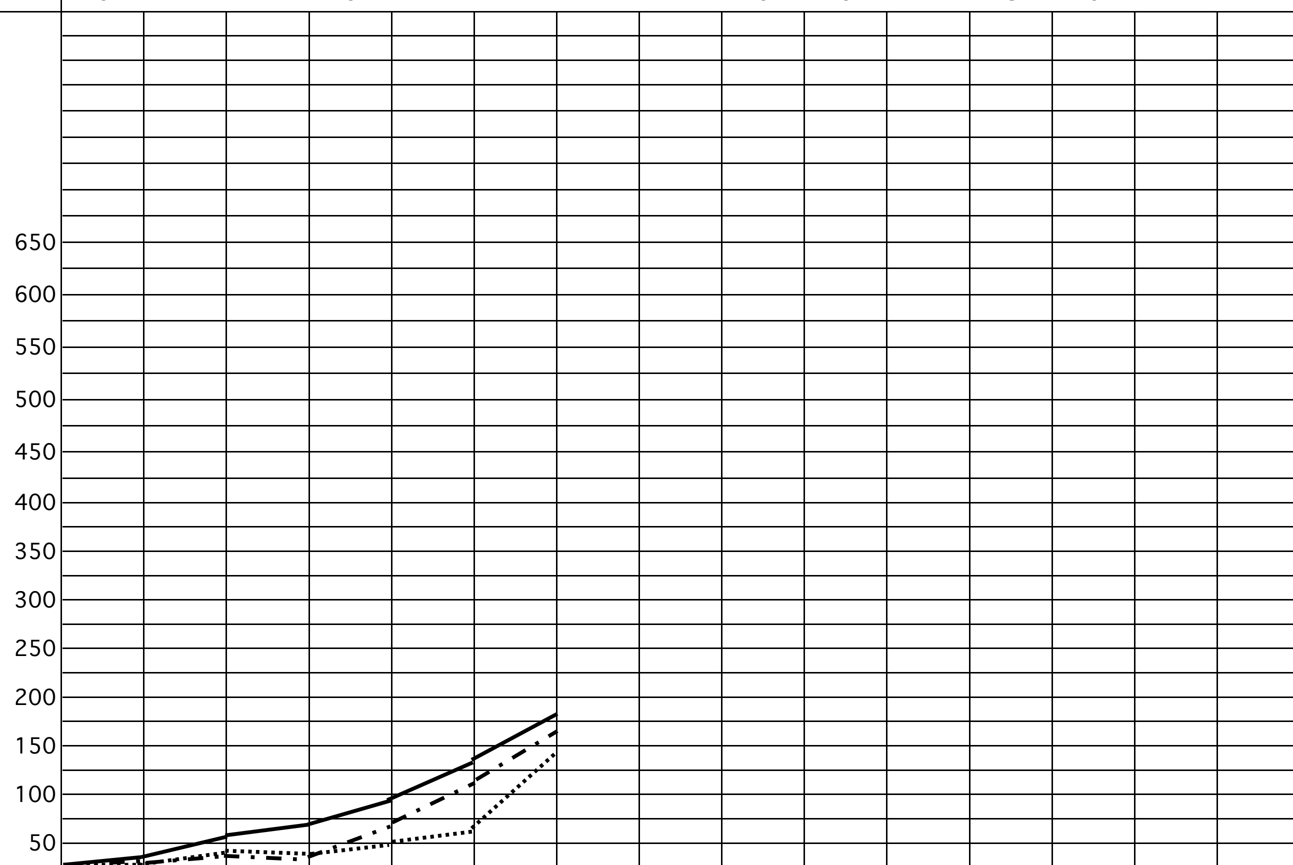
ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	51	42	45	50	43	34									
ACTUAL	31	26	31	19	17	23									
EARNED	31	28	35	35	28	29									
CUM. PLANNED	51	93	138	188	231	265	265	265	265	265	265	265	265	265	265
CUM. ACTUAL	31	57	88	107	124	147	147	147	147	147	147	147	147	147	147
CUM. EARNED	31	59	94	129	157	186	186	186	186	186	186	186	186	186	186

11. REMARKS

1. CONTRACT REPORTING ELEMENT HSSI - 3. Irradiation Embrittlement of RPV Steel	2. REPORTING PERIOD 2/23/2004 - 3/28/2004	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)



PLANNED COSTS (BCWS) — solid line

ACTUAL COSTS (ACWP) — dotted line

EARNED VALUE (BCWP) — dash-dot line

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	79									
EARNED	12	15	6	29	42	50									
CUM. PLANNED	23	55	74	91	132	188	188	188	188	188	188	188	188	188	188
CUM. ACTUAL	10	44	38	49	61	140	140	140	140	140	140	140	140	140	140
CUM. EARNED	14	29	35	64	106	156	156	156	156	156	156	156	156	156	156

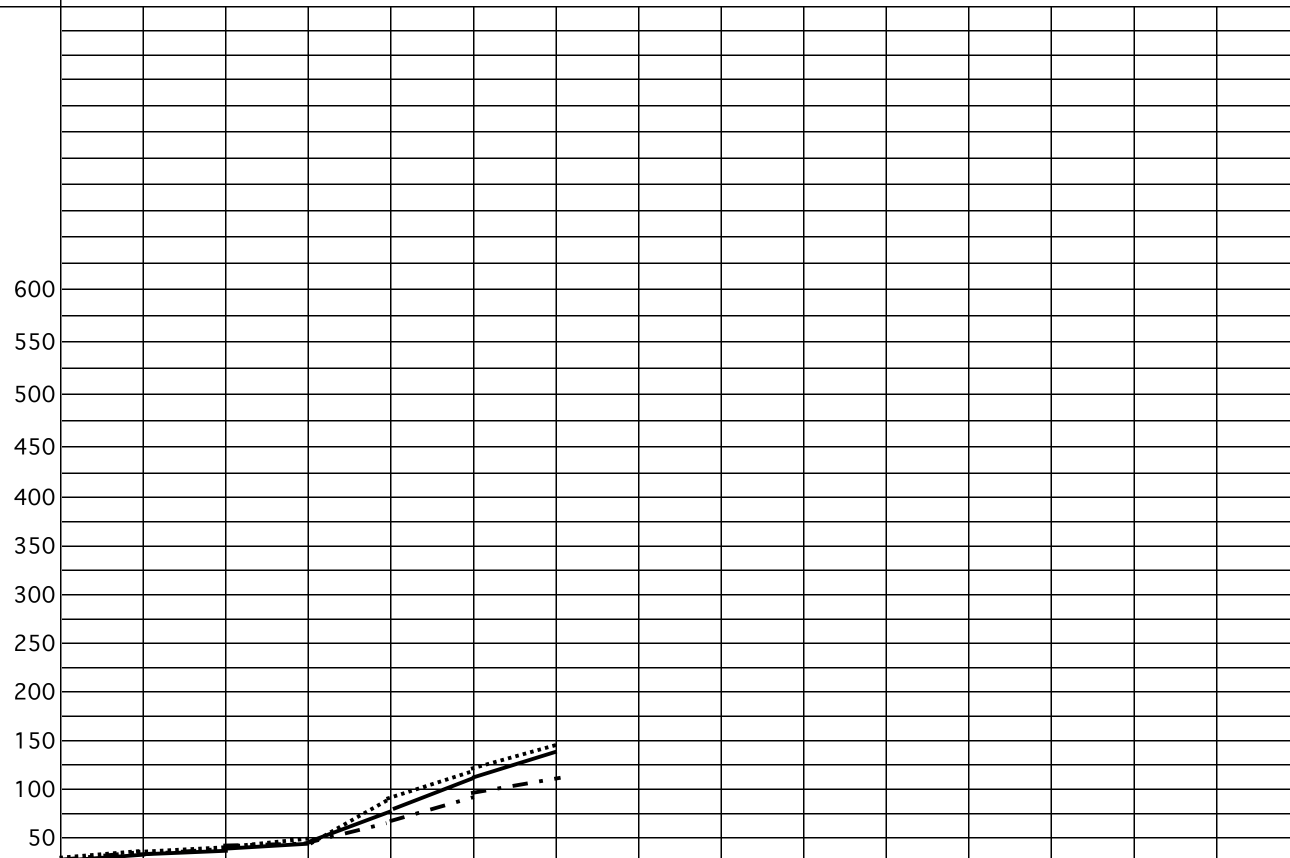
11. REMARKS

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 2/23/2004 - 3/28/2004	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)



PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

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	28									
EARNED	15	15	17	25	19	13									
CUM. PLANNED	7	24	44	76	107	144	144	144	144	144	144	144	144	144	144
CUM. ACTUAL	15	28	48	84	118	146	146	146	146	146	146	146	146	146	146
CUM. EARNED	16	31	48	73	92	105	105	105	105	105	105	105	105	105	105

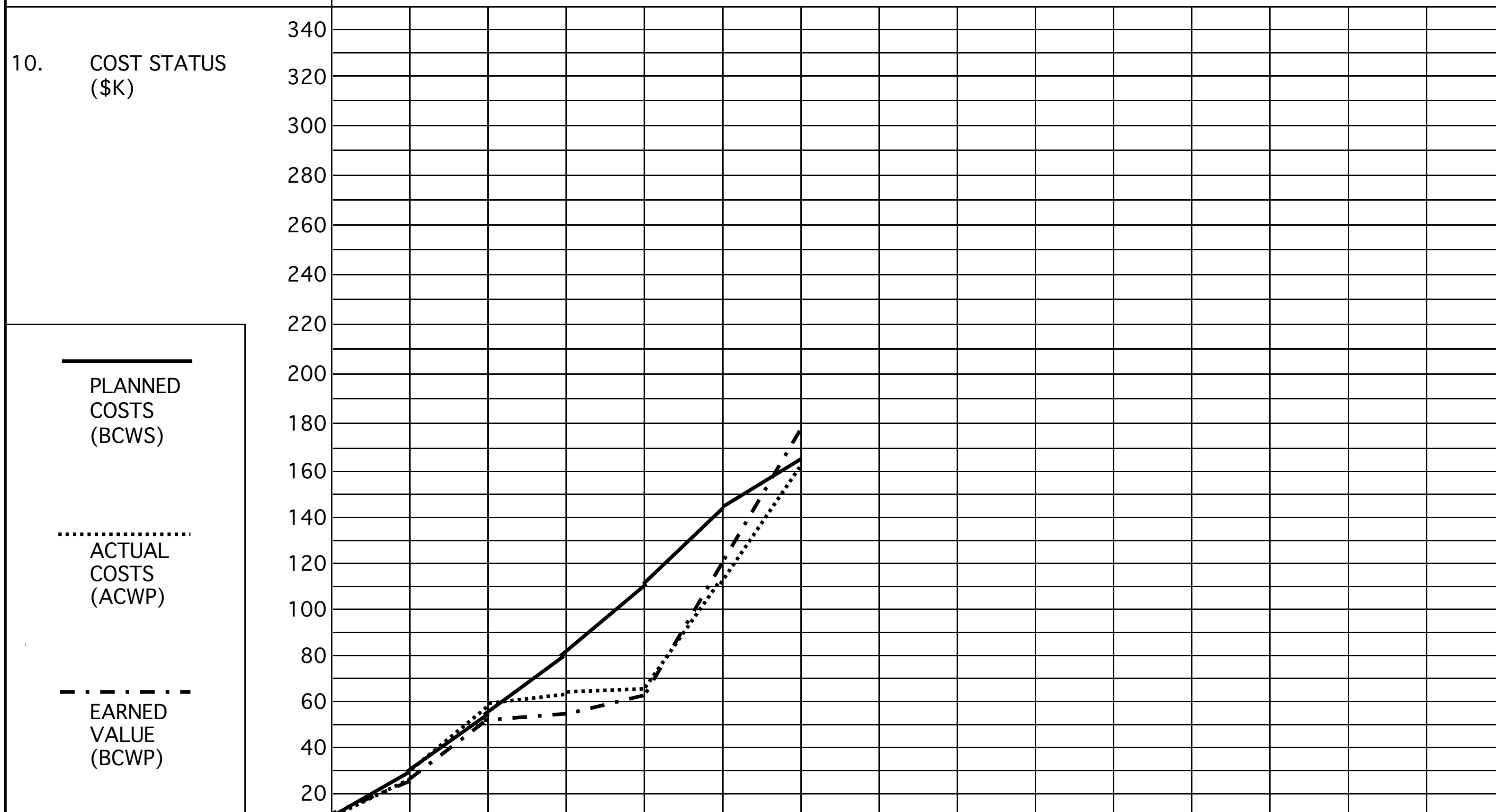
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT HSSI - 5. Modeling and Microstuctural Analysis	2. REPORTING PERIOD 2/23/2004 - 3/28/2004	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 7. NRC B&R NO. 860 15 21 20 05	6. ACTIVITY NUMBER W41 W5 85 3W 1 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)

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	47									
EARNED	23	28	3	8	58	59									
CUM. PLANNED	30	55	80	115	145	165	165	165	165	165	165	165	165	165	165
CUM. ACTUAL	27	59	61	65	116	163	163	163	163	163	163	163	163	163	163
CUM. EARNED	23	51	54	62	120	179	179	179	179	179	179	179	179	179	179

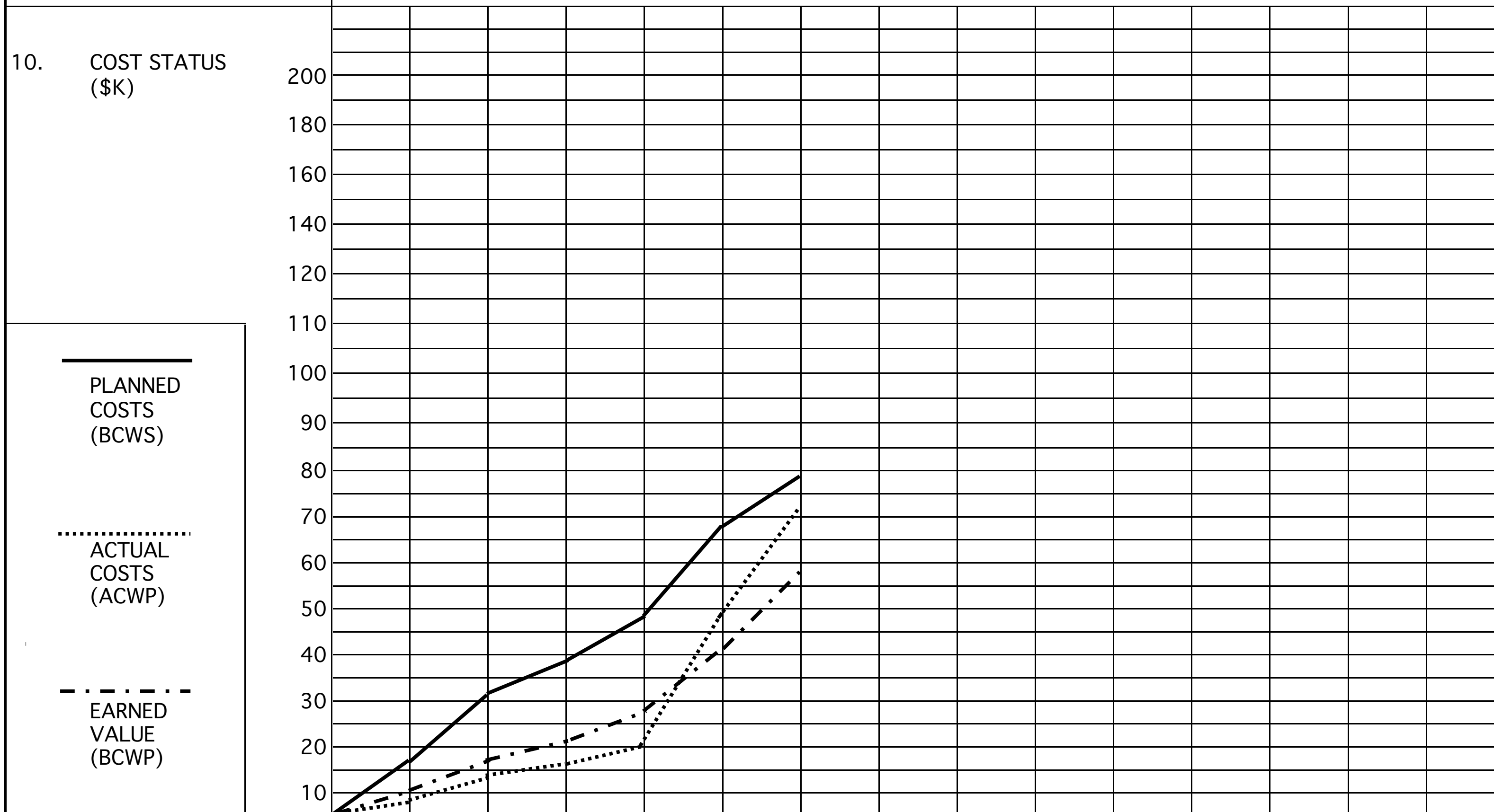
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT HSSI - 6. Irradiation Coordination	2. REPORTING PERIOD 2/232004 - 3/28/2004	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 7. NRC B&R NO. 860 15 21 20 05	6. ACTIVITY NUMBER W41 W5 85 3W 1 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)

149

ELEMENT COSTS FOR PRIOR FYS ($K)

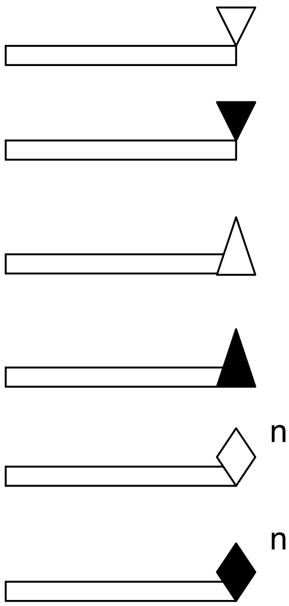
87

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	22									
EARNED	10	7	4	7	13	16									
CUM. PLANNED	16	31	39	49	68	78	78	78	78	78	78	78	78	78	78
CUM. ACTUAL	6	13	16	20	49	71	71	71	71	71	71	71	71	71	71
CUM. EARNED	10	17	21	28	41	57	57	57	57	57	57	57	57	57	57

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

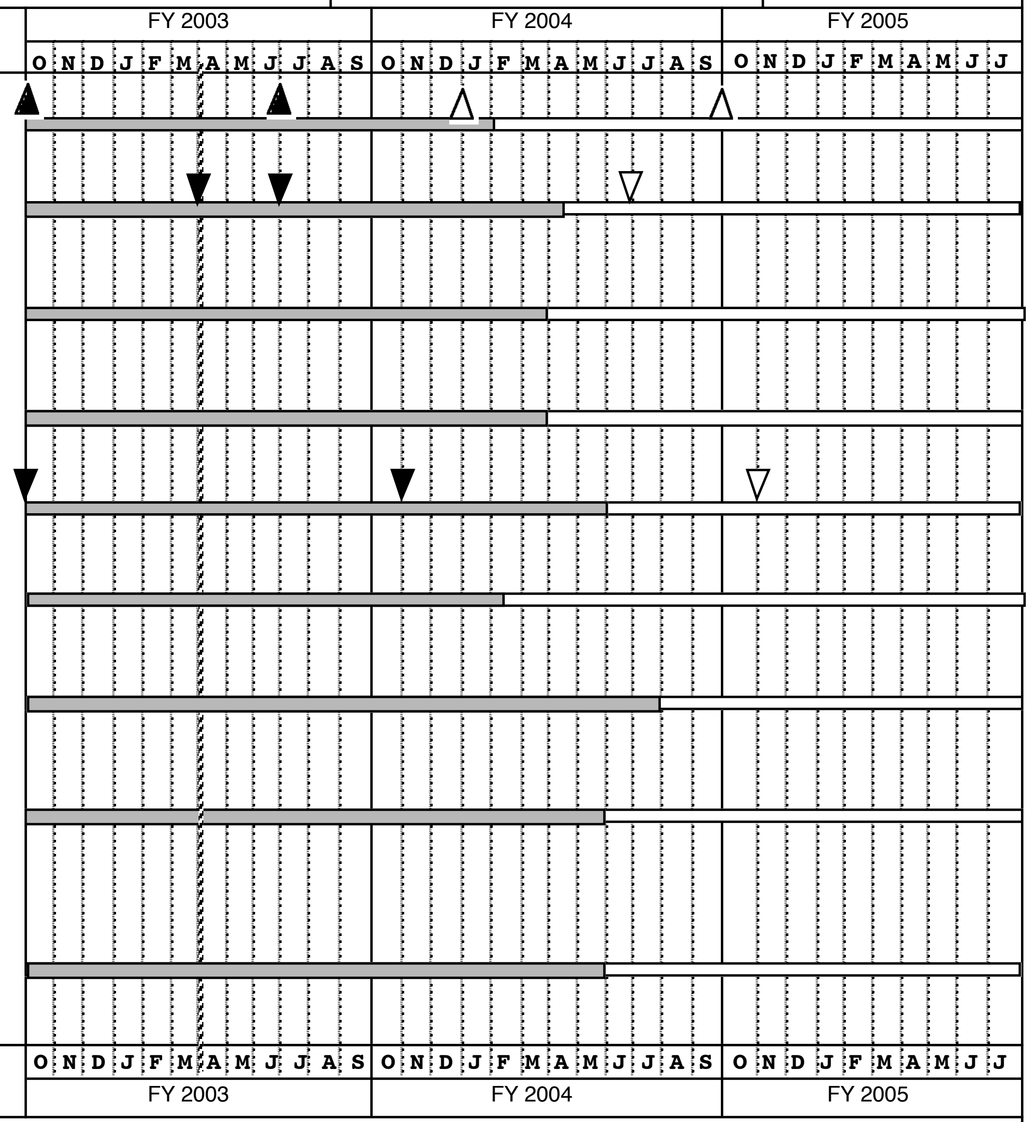
Rescheduled milestone planned

Rescheduled milestone completed

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

1. CONTRACT REPORTING ELEMENT **HSSI - 1. Program Management**	2. REPORTING PERIOD **2/23/2004 - 3/28/2004**	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** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **41 W6 95 3W 1** 8. DOE B&R NO. **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

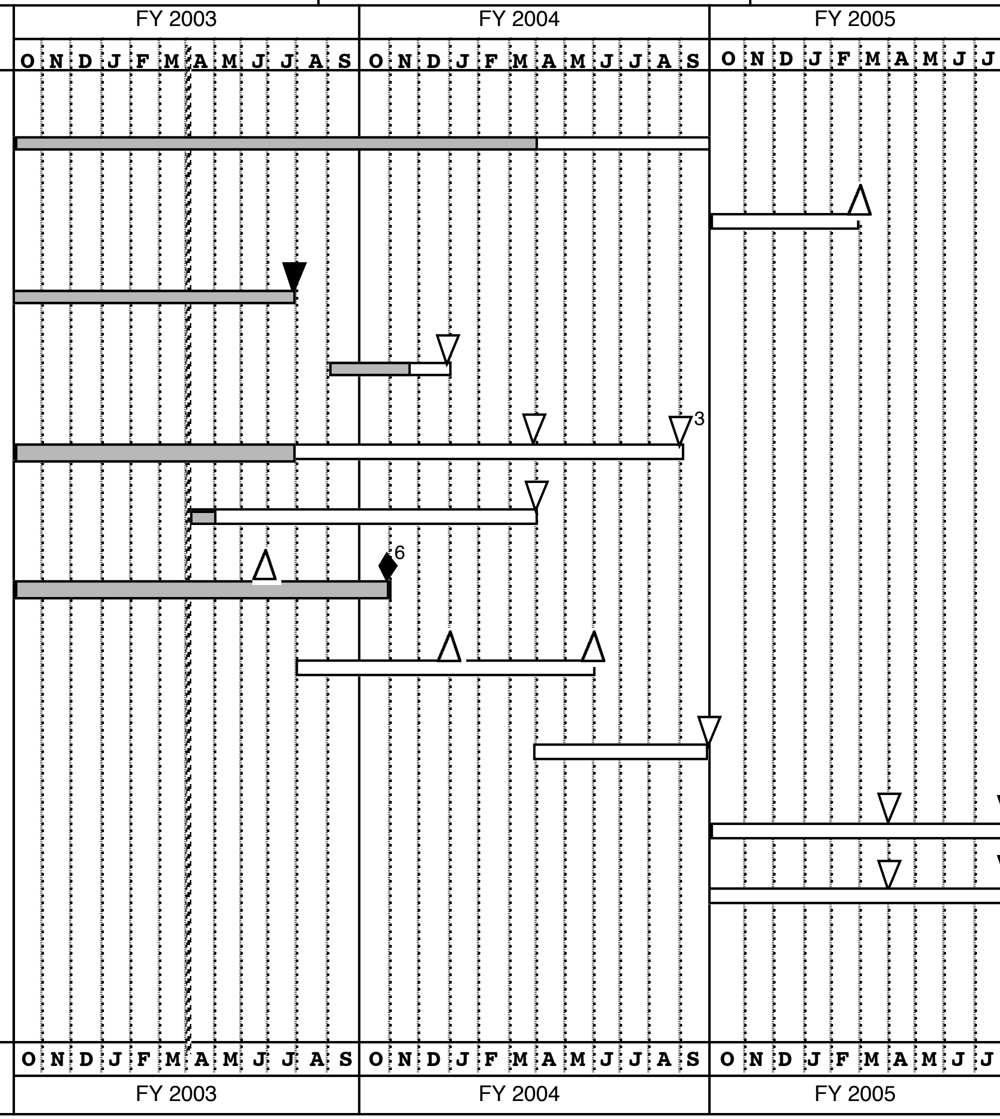


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 2. Fracture Toughness Transition & MC Methodology	**2/23/2004 - 3/28/2004**	**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**

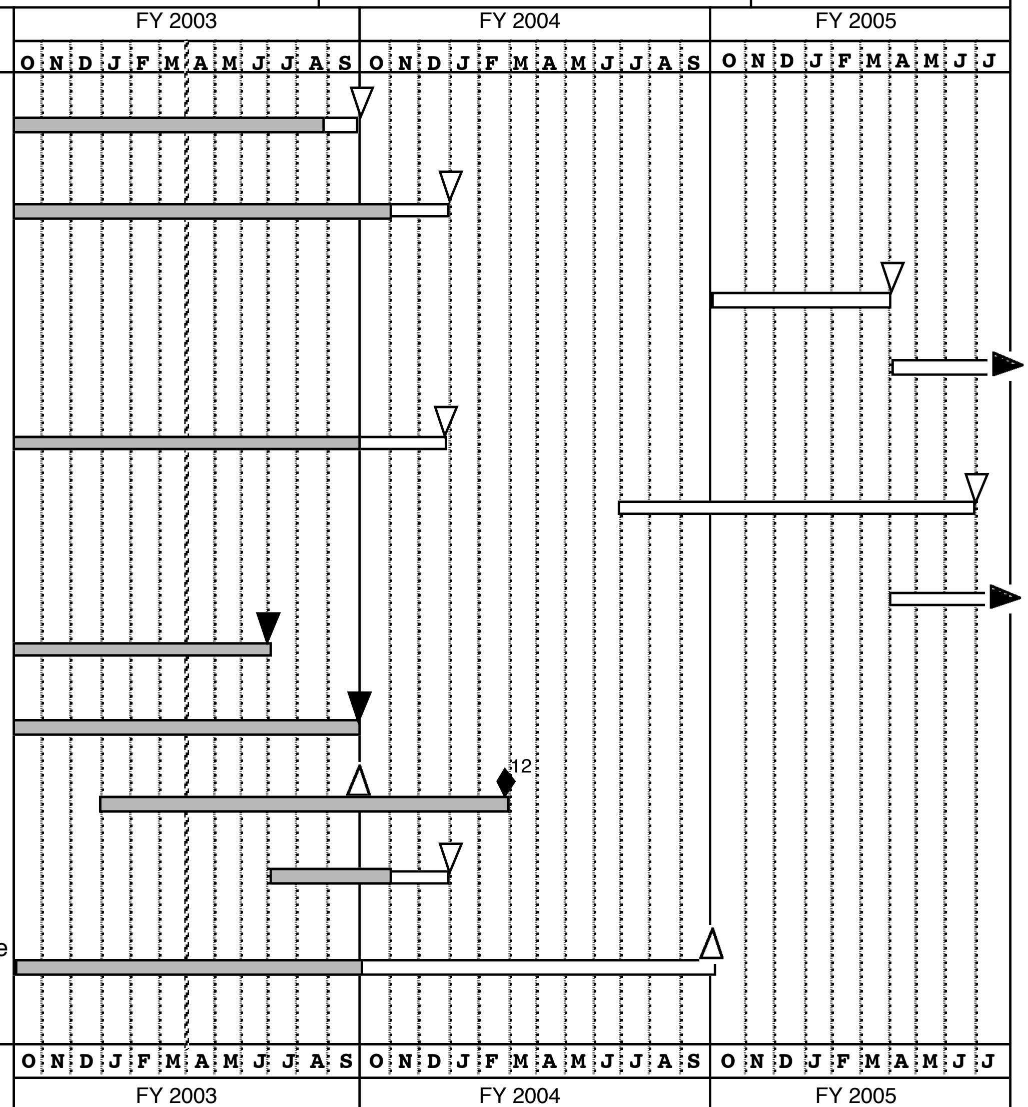
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.1.A.	Continue to accumulate data on comparison of CVN and fracture-toughness shifts
2.1.B.	Update NUREG/CR-6009
2.2.A.	Irradiate Midland and Hi-Ni specimens
2.2.B.	Ship and receive specimens
2.2.C.	Machine 0.4 KS-01 specimens and test
2.2.D.	Test subsize 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 **2/23/2004 - 3/28/2004**	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** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **41 W6 95 3W 1** 8. DOE B&R NO. **40 10 01 06**

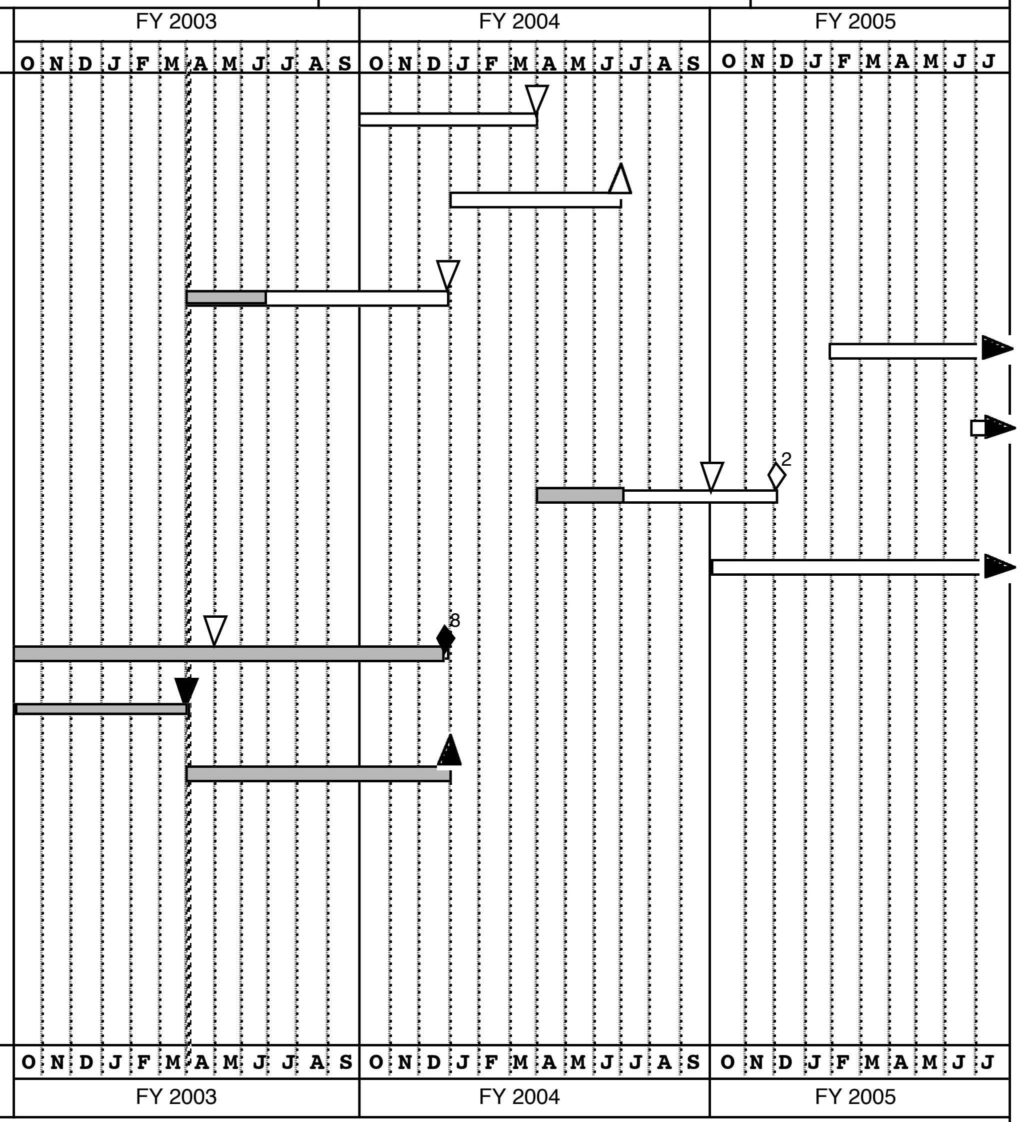
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.3.A.	Complete review of dynamic effects
2.3.B.	Develop testing plan for dynamic fracture toughness effects on MC
2.3.C.	Complete dynamic fracture-toughness tests
2.3.D.	Prepare NUREG report
2.4.A.	Develop test plan for IGF assessment with <100% IGF
2.4.B.	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 **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **2/23/2004 - 3/28/2004**	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**

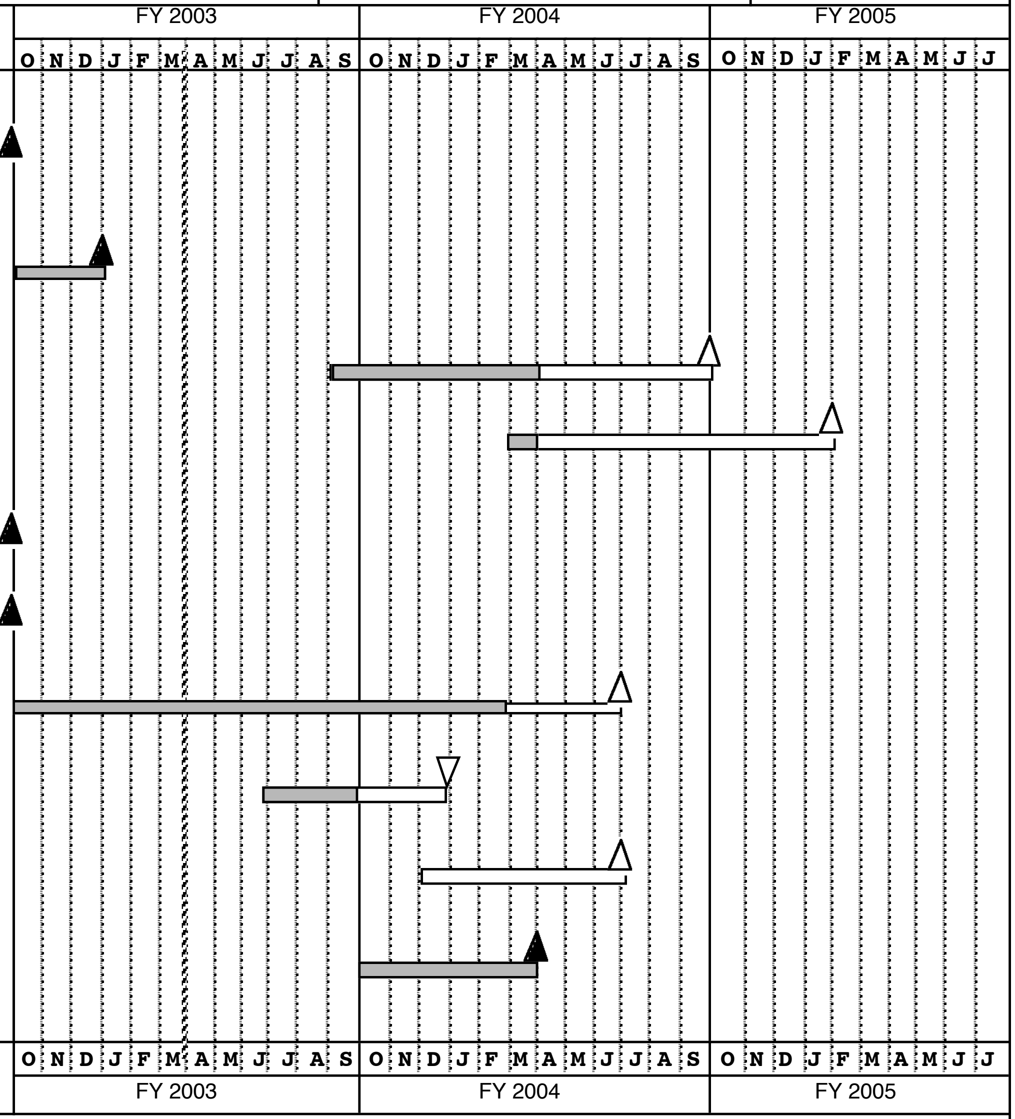
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.6.A.	Complete dosimetry/fluence measurements of 2nd IAR Series
2.6.B.	Complete report on 2nd IAR dosimetry/fluence measurements
2.6.C.	Update code to Linux
2.6.D.	Complete dosimetry/fluence measurements for 3rd IAR Series
2.6.E.	Complete letter report 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 **2/23/2004 - 3/28/2004**	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**

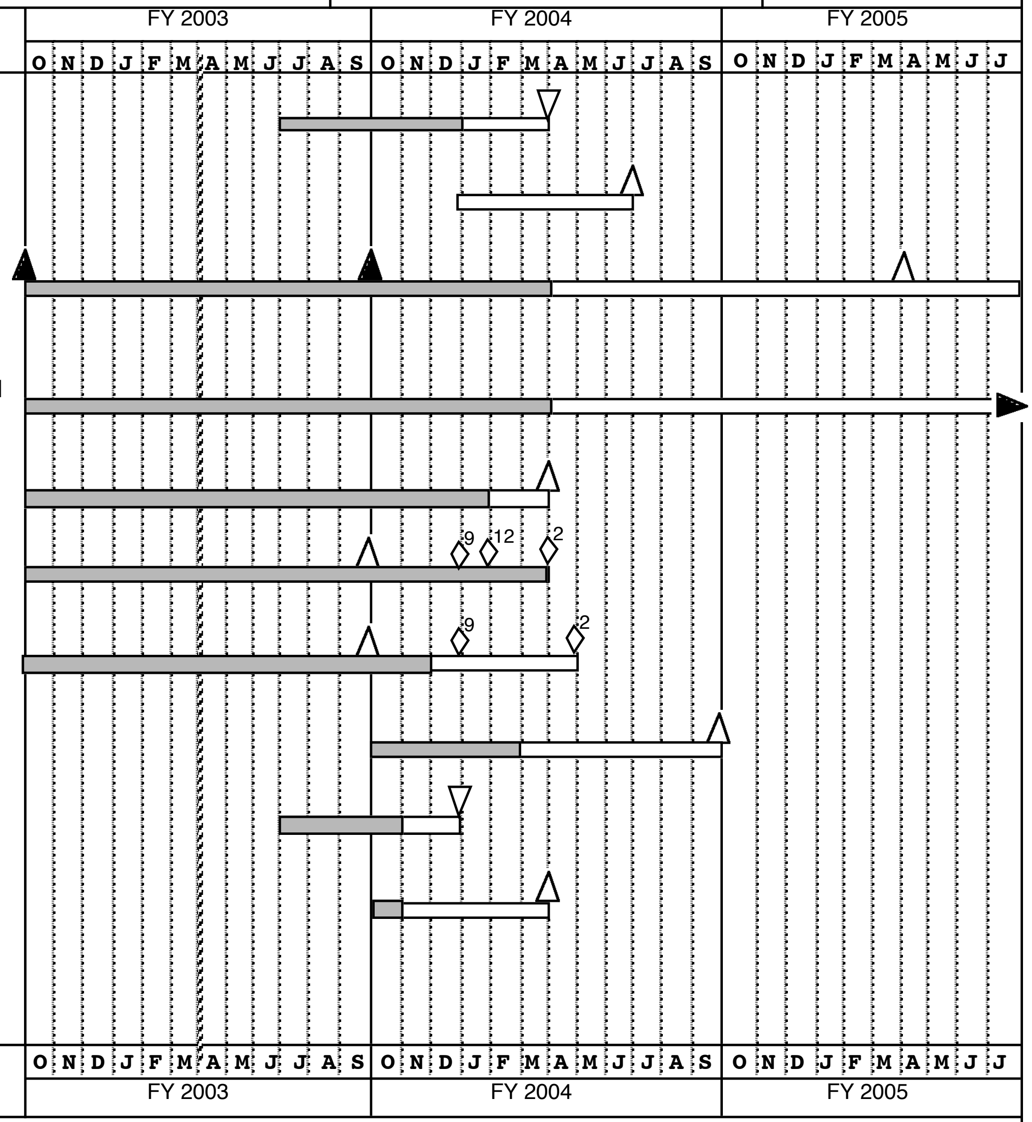
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
3.1.A.	Complete letter report on IA effects on HAZ Phase I
3.1.B.	Fabricate and heat treatment CVN specimens of A302B with slow cool after PWHT. Initiate irradiations in IAR Phase II
3.1.C.	Receive and test IA HAZ specimens from Phase II
3.1.D.	Complete 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 **HSSI - 4. Validation of Irradiated and Aged Materials**	2. REPORTING PERIOD **2/23/2004 - 3/28/2004**	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** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **41 W6 95 3W 1** 8. DOE B&R NO. **40 10 01 06**

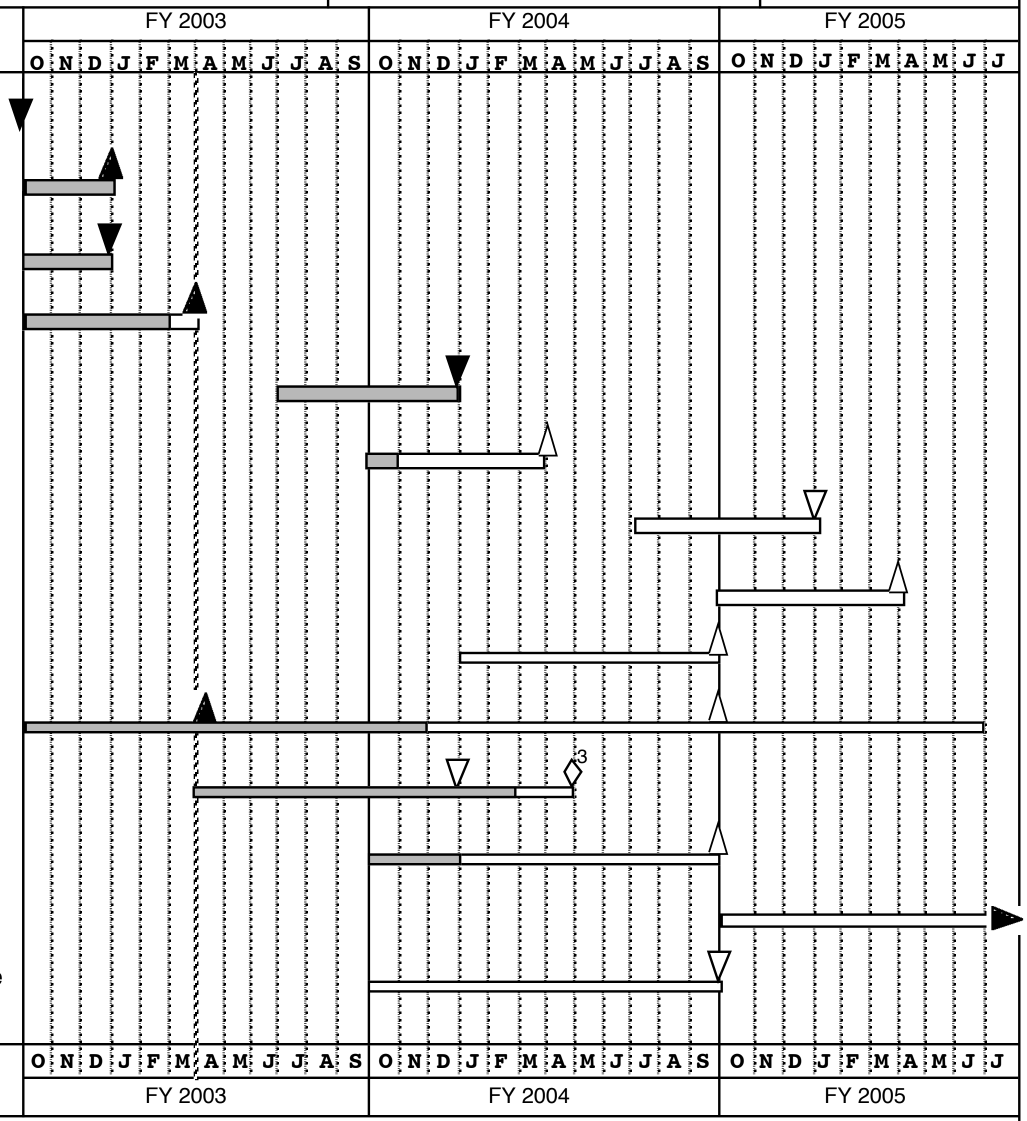
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
4.1.A.	Complete fracture toughness tests of irradiated SS cladding
4.1.B.	Complete letter report on irradiation effects on SS cladding
4.2.A.	Participate in periodic IGRDM meetings
4.2.B.	Participate in international meetings as scheduled
4.3.A.	Draft 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 **HSSI - 5. Modeling & Microstructural Analysis**	2. REPORTING PERIOD **2/23/2004 - 3/28/2004**	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** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **41 W6 95 3W 1** 8. DOE B&R NO. **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
2/23/2004 - 3/28/2004

3. JCN NO.
W6953

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

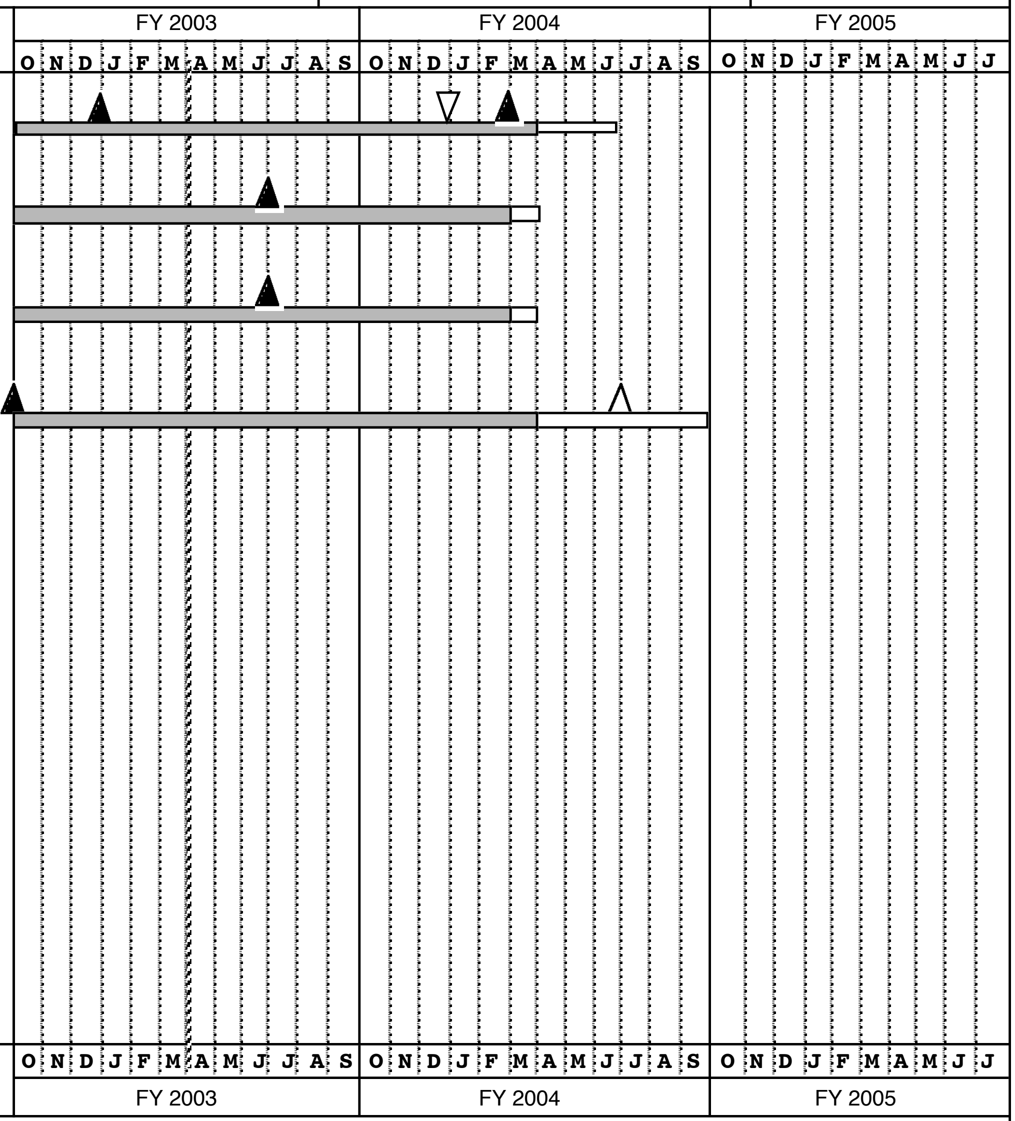
5. CONTRACT PERIOD
FY 2003--2005

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