ORNL/HSSI (W6953)/MLSR-2001/7

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

Monthly Letter Status Report

April 2001

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HEAVY-SECTION STEEL IRRADIATION PROGRAM

JCN W6953

MONTHLY LETTER STATUS REPORT

FOR

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Submitted by

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Submitted to
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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 eight program tasks. The seven tasks correspond to the 189, dated March 23, 1998, and modified by the inclusion of the former "Embrittlement Data Base and Dosimetry Evaluation" Program, JCN 6164 in March 1999. 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 2000 to March 2003, while the individual task budgets address the period from October 2000 to November 2001.

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

Thomas M. Rosseel, Manager
Heavy-Section Steel Irradiation

MONTHLY LETTER STATUS REPORT
April 2001

Job Code Number:	**W6953**
Project Title:	**Heavy-Section Steel Irradiation Program**
Period of Performance:	**4/1/98 to 4/1/03**
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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. Six 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) At the direction of the US NRC, the HSSI Program has prepared two position papers on research reactor and facility options and the needs and benefits of an NRC-sponsored reactor-pressure-vessel (RPV) irradiation program. A draft white paper entitled, “Issues Regarding Irradiation Effects on Reactor Vessel Steels,” by Randy K. Nanstad (Oak Ridge National Laboratory), G. Robert Odette (University of California, Santa Barbara), Glenn E. Lucas (University of California, Santa Barbara) was submitted at the end of January.

The other draft paper entitled, “Options Regarding Facilities for Irradiation of Reactor Pressure Vessel Steels,” by K. R. Thoms, was submitted during this reporting period. This manuscript provides a detailed description of the current HSSI IAR and UCSB IVAR reusable irradiation facilities at the University of Michigan Ford Nuclear Reactor (FNR), including the issues that led to the design of these facilities. Potential North American and European reactor options were also reviewed and summarized in a series of tables that will permit a comparison of the costs and advantages and disadvantages of each facility option.

(Milestone 1.1.B) A revised statement of work and requisition to procure a new subcontract with the University of Michigan for collaborative irradiation work at the Ford Nuclear Reactor (FNR) for the next two years was submitted. We anticipate that the existing subcontract will be extended one month through May 31 to permit sufficient time for the University to respond to the new proposal/statement of work that will extend the collaboration to 4/01/03 and incrementally fund the work through 11/30/01.

(Milestone 1.2.B) A number of planned and unplanned events took place at the FNR during this reporting period that limited the operation of the HSSI irradiation facilities to only 60 additional EFPH (effective full power hours). These events described in Task 6.1 and 6.2 included specimen replacements and shuffles, control board and moisture probe failures, replacement of damaged gas lines, and a procedural error by an operator.

(Milestone 1.3.C) On April 2, 2001, Dr. Roy Faulkner, Professor of Physical Metallurgy, University of Loughborough, UK visited ORNL. In addition to presenting a seminar on “Grain Boundary Segregation and Precipitation in Nuclear Reactor Steels,” discussions were held with HSSI staff concerning modeling of precipitates. A possible summer 2002 sabbatical was also discussed.

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. For example, pertinent fracture-toughness data needed to assess the shift and potential change in shape of the fracture-toughness curves due to neutron irradiation will be collected and statistically analyzed. 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. Finally, guidelines for the application of "surrogate materials" to the assessment of fracture toughness of RPV steels will be evaluated.

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 functions. The resulting reference fracture-toughness temperature, T_0, shifts will be 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.

As they become available, additional data are added to the database.

Subtask 2.2: Irradiation Effects on Fracture-Toughness Curve Shape (M. A. Sokolov)

The purpose of this subtask is to evaluate the assumption of constant shape for the MC even for highly embrittled RPV steels. The evaluation will be performed through irradiation of a pressure-vessel steel to a neutron fluence sufficient to produce a fracture-toughness transition-temperature shift (T_0) of about 150°C (270°F). Evaluation of the MC shape will be determined with sufficient numbers of 1T compact specimens, 1T C(T), to allow for testing at three temperatures in the transition-temperature region. Additionally, 0.5T C(T), and precracked Charpy V-notch (PCVN) specimens, for both quasi-static and dynamic tests, will be irradiated and tested to investigate the use of more practical surveillance-size specimens. Tensile specimens will also be included to determine the irradiation-induced hardening. A comprehensive test program with unirradiated material will be included to provide the necessary baseline data for comparison.

(Milestone 2.2.A) Twenty-one (21) 1T compact specimens of the submerged-arc weld KS-01, irradiated to ~0.8 (10^{19} n/cm^2 (>1 MeV), were successfully tested with six at 125°C, six at 150°C, five at 175°C, and four at 200°C. Following testing, the unbroken specimens were broken open and photographs were made of the fracture surfaces. The photographs were used to document the fracture surface appearance and used to measure the crack length parameters needed for analysis of the tests. Analysis of the test records were completed and the results were combined with those from the previously tested 0.5T specimens for analysis to provide the basis for a decision regarding testing of the remaining six 0.5T specimens. Following such analysis and discussions with other researchers outside of ORNL, the decision was made to test the 0.5T specimens at 100°C.

The servohydraulic machine in the hot cell has been repaired and is now back in service. The machine was evaluated during the first week of March to ensure calibration and proper operation prior to conduct of the KS-01 testing. During testing of the final group of 0.5T compact specimens, excessive electrical noise from the machine actuator displacement transducer was observed. Preliminary diagnostic examination of the machine has not determined the exact reasons for the noise problem. However, movement of the machine crosshead and actuator position reduced the noise sufficiently to allow for testing of the remaining 0.5T specimens.

At the end of this reporting period, four of those specimens had been tested. Testing of the remaining specimens will be completed during early May. Photographs of the broken 0.5T specimens, additional scanning electron fractography, and analyses of all the data will be performed during the following two months.

Irradiation of the Midland beltline weld and a high-nickel weld from the Palisades steam generator is under way and proceeding on schedule in the University of Michigan FNR.

Subtask 2.3: Dynamic Effects, Including Precracked Charpy V-Notch Testing (R. K. Nanstad)

As reactors age, the operating window between the startup or shutdown K_a curve, generated from the allowable pressures and temperatures, and the K_{Ia} curve becomes smaller, making it difficult for plants to startup and shut-down. Dynamic testing of relatively small specimens will be evaluated as an alternative method to determine a lower bound to fracture toughness. Results from Subtask 2.5 (crack-arrest), which measures dynamic properties, will also be used in this subtask.

(Milestone 2.3.A) No significant activity during this reporting period.

Subtask 2.4: Irradiation Effects on Fracture Toughness of Midland RPV Weld (R. K. Nanstad)

The purpose of this subtask is to determine the transition-temperature shift and to evaluate transition-toughness curve shape for a low Charpy upper-shelf weld metal at a relatively high neutron fluence that will produce greater embrittlement damage than previously obtained with irradiations at lower fluences. This subtask will evaluate the assumption of constant shape for the MC with highly embrittled low-upper-shelf RPV steels that exhibit onset of stable ductile tearing at relatively low-fracture toughness. The evaluation will be performed through irradiation of the beltline weld from the Midland Unit 1 RPV to a fluence of about 2.5 to 5 x 10^{19} n/cm^2 (>1 MeV) for which a substantial database of unirradiated and irradiated results to a fluence of 1 x 10^{19} n/cm^2 (>1 MeV) already exists. This research is needed to assess the fracture-toughness behavior of such a weld at high-embrittlement levels. Evaluation of the MC shape will be determined with sufficient numbers of 0.5T C(T) to allow for testing at three temperatures in the transition-temperature region. Additionally, PCVN specimens, for both quasi-static and dynamic tests, will also be irradiated and tested to investigate the use of more typical surveillance-size specimens, and tensile specimens will be included to determine the irradiation-induced hardening. A comprehensive-test program with unirradiated material was previously completed under the first HSSI Program (L1098) 10th Irradiation Series, except for dynamic testing of PCVN specimens, which will be included to provide the necessary baseline data for comparison.

(Milestone 2.4.D) The final report, *Evaluation of WF-70 Weld Metal from the Midland Unit 1 Reactor Vessel*, by D. E. McCabe, R. K. Nanstad, S. K. Iskander, D. W. Heatherly, and R. L. Swain, NUREG/CR-5736 (ORNL/TM-13748), was published by the NRC in November.

Further evaluation of the Midland beltline weld will be performed under Subtask 2.2.

Subtask 2.5: Crack-Arrest including Midland (R. K. Nanstad)

In this subtask, the low-temperature operating pressure regulatory concerns will be addressed through testing of the 15 irradiated, Midland crack-arrest specimens. This evaluation will provide an excellent opportunity to determine whether the lower bounds of crack initiation and arrest toughness coincide for this very important class of irradiated LUS welds. These specimens, which were produced and irradiated as part of the previous HSSI (L1098) program, will be used to evaluate the lower and transition arrest-toughness values.

(Milestone 2.5.A) The draft 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), is finished, but completion of the final report and submission to the NRC for publication will be delayed until about September due to personnel reductions.

Subtask 2.6: Intergranular Fracture (R. K. Nanstad and J. G. Merkle)

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 T_O 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 is 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.

(Milestone 2.6.B) As reported previously, five remaining 0.5T compact specimens will be tested at a higher temperature than the previously tested specimens, and a multi-temperature master curve analysis will be conducted and included in the final letter report. Those tests have been delayed due to personnel reductions; it is anticipated they will be conducted in June.

Additional scanning electron fractography will also be performed to evaluate the fracture mode of the specimens previously tested at the highest temperatures (room temperature and above). This fractographic evaluation will specifically evaluate the presence of so-called ductile intergranular fracture. This is an important aspect of the evaluation as it relates to the relationship between the master curve shape, which is used to describe unstable cleavage fracture in the ductile-brittle transition region, and unstable fracture by intergranular fracture. It is anticipated this SEM examination will also be conducted in June.

Subtask 2.7: Subsized Specimens (M. A. Sokolov)

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 suggested testing matrix within the New Coordinated Research Program (CRP) of the International Atomic Energy Agency (IAEA). Subsized specimens will be fabricated from previously characterized materials within the HSSI Program, such as HSST Plate 02, HSSI Welds 68W through 73W, the Midland beltline weld and plate JRQ.

(Milestone 2.7.A) As reported previously, three blocks of materials were machined into 1T C(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. The testing of these specimens is well under way, although delayed due to priority of testing in the hot cell while it remains open, and completion is expected in June.

Subtask 2.8: Quantification of Surrogate Materials for use in a Statistics-Based Fracture Toughness Assessment (R. K. Nanstad and J. G. Merkle)

The purpose of this subtask is to establish guidelines for the use of "surrogate materials" in the assessment of fracture toughness of RPV steels. A plan will be developed to describe the information acquired and the means of collecting it, the method of evaluating the information, and the methods for using the information. Analyses will be performed to provide a methodology for determining limits for predicting fracture toughness of one material, i.e., a surrogate material, with measured fracture toughness of similar materials.

(Milestone 2.8.B) A draft NUREG report, *Considerations for Use of Surrogate Materials Data for Reactor Pressure Vessels*, by R. K. Nanstad, J. G. Merkle, and J. Galt, was previously prepared and sent to the NRC technical monitor for review.

Further review of data, both unirradiated and irradiated, is continuing, which will eventually result in the preparation a table of uncertainties that could be utilized for evaluating the application of surrogate materials. This work is intended to be included in the final NUREG report on this subject.

Subtask 2.10: Dosimetry and Fluence Analysis of the IAR Irradiation Capsules from the First IAR Campaign (C. A. Baldwin, I. Remec, and T. M. Rosseel)

The purpose of this task is to measure and analyze the dosimeters used during the first IAR Campaign and to obtain accurate fluence determinations.

(Milestone 2.10.A) Data files containing the activity information calculated from the analyzed, HSSI-IAR, first-series dosimeters were prepared in the format used in all past HSS-IAR experiments, including the use of the previously defined coordinate system. From this data, the 3-D model, fuel changes and reshuffling, and the original dosimetry experiment results, the exposure parameters for these metallurgical specimens will be calculated. Calculations have not been initiated.

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

The purpose of this task is to examine two important issues affecting the application of mitigation procedures to RPVs. The first addresses the effects of temper embrittlement on the coarse-grained HAZ in RPV steels. The second examines the effects of reirradiation on K_{Jc} and K_{Jac} 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. These questions will be addressed using the IAR facility designed, fabricated, and installed as part of the previous HSSI (L1098) program and with a matrix of irradiated and tempered specimens supplied by the Swiss Paul Scherrer Institut (PSI). Further data on reirradiation embrittlement will be obtained through reconstitution and reirradiation of previously irradiated specimens at the RRC-KI.

Subtask 3.1: HAZ Embrittlement (M. A. Sokolov and R. K. Nanstad)

Research conducted to date on temper embrittlement of the coarse-grain materials in HAZs of RPV steel multi-pass welds has revealed the potential for such 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 mitigation of such material resulted in an even greater increase of the transition temperature. Subsequent research at ORNL under the previous HSSI Program (L1098) used five commercial RPV steels to investigate potential temper embrittlement. The first phase simulated the AEA-Technology heat treatment and observed large transition-temperature shifts, although not as large as those from AEA-Technology. The second phase of the ORNL study used the same five RPV steels, but used the Gleeble system (an electrical-resistance heating device) to produce material deemed representative of the coarse-grain region in RPV welds. These materials revealed very high toughness in the initial condition (i.e., from the Gleeble). After thermal aging at about 454°C for 168 hours the materials exhibited only modest transition temperature increases, however, after aging at the same temperature for 2000 hours, significant transition temperature increases were observed. Of course, 2000 hours is much in excess of the time that RPV steels would be exposed to mitigation cycles, but potential synergistic effects of irradiation and thermal aging are unknown. Moreover, questions also remain regarding other time-temperature effects, such as post-irradiation mitigation at somewhat lower or higher temperatures.

(Milestone 3.1.B) The letter report, by R. K. Nanstad, D. E. McCabe, M. A. Sokolov, C. A. English, and S. R. Ortner, "Preliminary Investigation of Temper Embrittlement in Reactor Pressure Vessel Steels Following Thermal Aging, Irradiation, and Thermal Annealing," is in preparation. A technical paper, which discusses the preliminary results, was presented at the ASTM 20th International Symposium on Radiation Effects on Materials and has been submitted in final form to ASTM for publication in *Effects of Radiation on Materials: 20th International Symposium, ASTM STP 1405*. The abstract of that paper was provided in the previous progress report.

As noted in the previous progress report, 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 thermal annealing. Excess material from the original investigation has been identified, and the proposed study will be discussed with the NRC technical monitor with consideration of funding needs. Consideration is also being given to reirradiation of the remaining specimens from the initial series.

Subtask 3.2: Embrittlement Rate of Reirradiated Steel (R. K. Nanstad, I. Remec, E. D. Blakeman, and C. A. Baldwin)

This subtask will examine the effects of reirradiation on K_{Ic} and K_{Ia} toughness of RPV steel so as to evaluate the relative changes in recovery and reembrittlement between CVN and fracture-toughness properties and to provide a detailed examination of reembrittlement rates. This will be accomplished using the HSSI IAR and the University of California Santa Barbara (UCSB) irradiation facilities at the University of Michigan, Ford Nuclear Reactor (FNR), and through the reirradiation of previously irradiated specimens at RRC-KI, if funding is available. Emphasis will also be placed on completing dosimetry calculations for the new IAR facility.

(Milestone 3.2.B) Neutronics Analysis of the IAR/UCSB Irradiation Capsules (I. Remec, E. D. Blakeman, and C. A. Baldwin). 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.

Milestone 3.2.C) As noted, previously 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 specimens is about 4×10^{19} n/cm^2.

Subtask 3.3: Evaluation of Reirradiated JRQ Specimens (R. K. Nanstad, E. T. Manneschmidt, and T. M. Rosseel)

The purpose of this subtask is to examine the fracture-toughness behavior of a model steel that has been irradiated, tempered, and re-irradiated. The specimens, identified as JRQ, will supplied by the Swiss PSI from a terminated research program.

(Milestone 3.3.A) The testing of the JRQ specimens from the Paul Scherrer Institute, previously placed on hold primarily due to the need for repair of the servohydraulic machine, was initiated in March. A total of 46 Charpy V-notch impact specimens were tested:

15 specimens irradiated at 290°C to 5.0×10^{19} n/cm^2 (>1 MeV),

14 specimens in the condition IAR (0.50): Irradiated-Annealed-Reirradiated to the target total fluence of 0.50×10^{19} n/cm^2 (>1 MeV). This means that the specimens thermally

annealed at 460°C for 18 h when 50% of their target fluence had been reached. The procedure was irradiation to 0.25 x 10^{19} n/cm^2 (>1 MeV), followed by annealing, followed by reirradiation to the end fluence of 0.50 x 10^{19} n/cm^2 (>1 MeV), and

17 specimens in the condition IAR (1.70), with the same procedure as above, except annealing was conducted at 0.85 x 10^{19} n/cm^2 (>1 MeV).

The absorbed energy data were analyzed and hyperbolic tangent curve fits were performed to determine various transition temperatures and the upper-shelf energy. The results were compared relative to the unirradiated results provided by PSI. For the specimens irradiated to 5.0 x 10^{19} n/cm^2 (>1 MeV), the 41-J shift was 97°C. For the IAR (0.5) and IAR (1.70) conditions, the 41-J shifts were 27 and 56°C, respectively. These results have been provided to the researchers at PSI and compare favorably with results obtained previously. When completed, these Charpy impact results will allow for completion of a series of experiments with the JRQ plate comprising four different fluence levels and four different IAR conditions. During April, lateral expansion measurements were completed on the tested specimens and discussions were held with the PSI researchers regarding testing of the remaining specimens. For the remaining specimens of the two IAR groups, it was agreed that some specimens will be thermally annealed and some reirradiated. This will then provide two datasets to evaluate the effectiveness of IARA and two datasets to evaluate the response of the material to IARAR conditions. Due to hot cell scheduling issues, a testing schedule for the precracked Charpy specimens is unknown at this time.

A presentation on this work, to include previous work by PSI, will be presented by R. K. Nanstad at the International Atomic Energy Agency (IAEA) Specialists' Meeting on Radiation Embrittlement and Mitigation in Gloucester, U.K., 14-17 May 2001. The presentation is co-authored by Ph. Tipping (Swiss HSK), G. Waeber (PSI), and Kalkhof (PSI).

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 HAZ of welds 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. The feasibility of reconstitution for CVN and 0.5T C(T) and aging of stainless steel welds will also be explored in this task. Other issues to be address include foreign interactions and technical assistance to the NRC.

Subtask 4.1: Examination of Materials from Retired RPVs (R. K. Nanstad, and J. T. Hutton)

This subtask will examine the issue of neutron-irradiation-induced damage attenuation through the RPV wall. The damage will be related to measurements of received dose, such as displacements per atom (dpa) through the wall. The HSSI program will obtain suitable-size trepans of materials from previously decommissioned RPVs, because these materials would incorporate conditions from actual operating reactors such as the effects of irradiation on stressed material. A sufficient number and size of trepans will be obtained to permit use of the MC approach to relate measures of damage to the fracture toughness. Specimens will be machined on the CNC milling machine located in Cell 6 of the IMET facility. Depending upon availability and appropriateness, trepans from the Japan Power Demonstration Reactor (JPDR) project, Trojan, Maine Yankee or other RPVs may be examined.

(Milestone 4.1.2.B) 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 with major contributions from 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 as part of an Office of Research Operational Milestone.

Subtask 4.2: Reconstitution of Irradiated Toughness Specimens (R. K. Nanstad)

Feasibility studies for reconstitution of CVN, PCVN, and 0.5T bend bar specimens will be prepared. To adequately survey the state-of-the-art capabilities, on-site evaluations of U.S. and international facilities will be required. A letter report that includes the estimated costs of either using existing and available facilities or implementing a reconstitution facility at ORNL will be prepared at the completion of this task.

No work is currently funded in this subtask.

Subtask 4.3: Toughness Changes in Aged Stainless Steel Welds (R. K. Nanstad)

The purpose of this subtask is to evaluate the effects of irradiation and thermal aging on stainless-steel weld metals. Two projects are incorporated in this subtask. The first involves completion of fracture-toughness testing on irradiated stainless-steel weld-overlay cladding specimens at 288°C to complete the testing of the matrix from the HSSI (L1089) 7th Irradiation Series. The PCVN specimens were irradiated in HSSI Capsule 10.06. The second project involves completion of a NUREG report on thermal aging of stainless-steel welds for nuclear piping, a project that began before the inception of the HSSI (L1098) Program and involved thermal aging at 343°C for up to 50,000 hours.

(Milestone 4.3.B) 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. However, ORNL has not received sufficient copies to distribute the report to the internal list.

Subtask 4.4: 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. U.S.-Russia Joint Coordinating Committee for Civilian Nuclear Reactor Safety (JCCCNRS) Working Group on Radiation Embrittlement and Aging of Components.

2. 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.

3. Collaboration with AEA-Technology in the United Kingdom regarding fracture toughness testing of intergranular embrittlement of RPV HAZs.

4. Collaborative studies on fracture properties of high-copper RPV materials with Korean institutes such as KAERI.

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

6. Collaboration with PSI in Switzerland on reirradiation.

7. 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.

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

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

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

11. Collaboration with the University of Lille (France) in the area of primary radiation damage simulation.

(Milestone 4.4.B) R. K. Nanstad, as secretary of the International Group on Radiation Damage Mechanisms (IGRDM) in Pressure Vessel Steels, is updating the IGRDM membership list and (with assistance from R. E. Stoller) is revising the IGRDM charter. The next meeting of the IGRDM will be held in Japan in the Spring of 2002, most probably during the first half of May.

<u>Subtask 4.5: Technical Assistance</u> (R. K. Nanstad and M. A. Sokolov)

The purpose of this subtask is to provide special analytical, experimental, and administrative support to the NRC in resolving various regulatory issues related to irradiation effects. Specific identified activities are incorporated in this subtask, while other activities may be included through modification to the task by the NRC. The currently identified activities involve evaluation of the irradiated specimens contained in capsules previously irradiated at the University of Michigan FNR by Materials Engineering Associates (MEA), evaluation of highly irradiated high-nickel weld surveillance specimens from the Palisades Reactor, evaluation of the effects of post-weld heat treatment (PWHT) on the copper solubility and fracture toughness of unirradiated RPV steels, and compilation of available materials at ORNL and elsewhere for studies of irradiation effects on RPV steels.

(Milestone 4.5.F) Testing of unirradiated specimens has continued with the high-copper weld given varying time/temperature postweld heat treatments. A series of specimens in the as-welded condition were completed during this reported period. A Charpy impact energy versus temperature curve has now been obtained for each condition to evaluate toughness as a function of PWHT. Some Atom Probe Tomography (APT) has been conducted by Dr. Michael K. Miller through Department of Energy Basic Energy Sciences funding and will be used to determine the matrix copper contribution as a function of PWHT. A presentation of progress on this study was made at the IGRDM meeting in September in Leuven, Belgium, and will also be made at the IAEA Specialists' Meeting on Radiation Embrittlement and Mitigation in Gloucester, U.K., 14-17 May 2001. Depending on hot cell scheduling, testing of the irradiated sub-size Charpy specimens is anticipated for May. A letter report will be prepared following completion of all testing and evaluation. An abstract has been submitted and accepted for the Tenth International Conference on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, to be held August 5-9, 2001, in Lake Tahoe, Nevada.

Task 5: Modeling & Microstructural Analysis (R. E. Stoller and 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 subtasks comprise two major components: (1) theoretical modeling and data analysis, and (2) experimental investigations. The modeling work focuses on the development of an improved description of primary-damage formation in irradiated materials, and the further development and use of predictive models of radiation-induced microstructural evolution and its impact on the mechanical behavior of RPV materials. The experimental component consists of special-purpose irradiation experiments to isolate particular irradiation variables (neutron-flux level and energy spectrum), and detailed microstructural characterization of RPV materials in relevant conditions using atom probe and transmission electron microscopy techniques. These conditions include: long-term, thermally-aged, irradiated, post-irradiation mitigation (IA), and reirradiated (IAR). 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 extensive use of the commercial-reactor surveillance data and test-reactor data contained in the NRC-funded Embrittlement Database (EDB), and data generated in other experiments coordinated by this task.

The major areas of inquiry will be: (a) the effects of chemical composition; (b) the role of displacement rate (neutron flux level); (c) the impact of differences in neutron-energy spectrum; (d) potential differences in hardening and embrittlement behavior at very high fluence; and, (e) the response of materials that are reirradiated following a post-irradiation mitigation. Damage modeling will also address such questions as attenuation through the RPV wall. The overall goal of the task is to provide an embrittlement model that can be used in a predictive way to anticipate the response of RPV materials at high fluences near or slightly beyond their nominal end-of-life, and to provide support to the NRC for related safety or licensing questions. The tools developed in this task will also be used to support the analysis of experimental results obtained in other program tasks. Both the modeling and experimental research will be coordinated with complementary activities carried out by other NRC contractors.

Subtask 5.1: Modeling of Damage Evolution (R. E. Stoller)

The modeling and analysis work will include completion of the development required to incorporate alloying effects in the embrittlement model. Additional thermodynamic components are needed to account for chemical effects, particularly for the simulation of high-fluence effects and thermal mitigation. Enhancements to the code used for simulating displacement cascades will permit the investigation of the effects of alloying elements on primary damage formation.

(Milestone 5.1.A) The NUREG report entitled *Evaluation of Neutron Energy Spectrum Effects Based on Primary Damage Simulations in Iron*, NUREG/CR-6670, (ORNL/TM-1999/334) was submitted to the NRC in July.

Subtask 5.2: Microstructural Analysis (M. K. Miller)

Round-Robin studies, using atom probe field-ion microscopy (APFIM), small angle neutron scattering (SANS), and field-emission scanning transmission electron microscopy (FEGSTEM), will be coordinated to resolve the inconsistencies between these techniques that have been used to determine the matrix copper content and the chemical composition of radiation-induced precipitates in RPV materials. Additionally, APFIM characterization will be used to determine whether additional radiation-induced phases are forming.

(Milestone 5.2.A) The NUREG report entitled, *Atom Probe Tomography Characterization of the Solute Distributions in a Neutron-Irradiated and Annealed Pressure Vessel Steel Weld*, NUREG/CR-6629, (ORNL/TM-13768), was published by the NRC in November. A draft NUREG report entitled, *Effect of Reirradiation Rate on The Charpy Properties of an Irradiated/Annealed High Copper Reactor Pressure Vessel Weld HSSI 73W*, that incorporates the atom probe tomography results on weld 73W specimens, has been prepared in draft form.

Subtask 5.3: Experimental Verification of Neutron Flux and Energy Spectrum Effects (R. E. Stoller and T. M. Rosseel)

An experimental examination of neutron-flux level (displacement rate) and neutron energy spectrum effects (thermal-to-fast-flux ratio) will be conducted in collaboration with other NRC contractors.

No significant activity occurred in this subtask during this reporting period.

Task 6: Test Reactor Irradiation Coordination (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 Program) at the University of Michigan FNR. 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.

Subtask 6.1: Operate the HSSI Irradiation (IAR) Facility (K. R Thoms and D. W. Heatherly)

With the fabrication, installation, and initial testing of the HSSI IAR facility at the University of Michigan FNR completed as part of the previous (L1098) HSSI program, the activities associated with the new program include supervising the irradiation of the reusable irradiation capsules in the dual-capsule irradiation facility at FNR. A NUREG report on the design, assembly, installation, and operation of the HSSI IAR facility will be prepared.

(Milestone 6.1.A) A number of planned and unplanned events took place during the month of April that limited the operation of the HSSI irradiation facilities to only 60 additional EFPH (effective full power hours).

After a planned electrical power outage late in the last reporting period (see Milestone 6.2.A) all of the HSSI-IAR irradiation facility control system seemed to function properly. The ORNL Experimenter requested that specimen shuffles/rotations be performed in both the IAR-1 and IAR-2 capsules.

The IAR-1 irradiation facility was transferred to the FNR hot cell on Monday, April 2, and a shuffle of Midland weld specimens was performed. The original cell 1 content was moved to cell 3. The original cell 2 content was left undisturbed. The original cell 3 content was moved to cell 1. The original cell 4 content was moved to cell 5 and the original cell 5 content was moved to cell 4. The IAR-1 irradiation capsule was then placed back into the IAR-1 facility in the reverse (rotated 180 degrees) position. The IAR-1 facility was then placed back into the south, or low flux, irradiation position on the experiment grid.

On Tuesday, April 3, the IAR-2 irradiation facility was raised to the specimen transfer rack for a specimen insertion and rotation. As the facility was being lowered into the rack at the surface of the pool a low-pressure alarm was received. Investigation showed that the gas inlet line, which provides sweep gas to the facility, had broken at the top of the facility. The gas inlet and exit purge lines on the IAR facilities are 1/4 inch diameter plastic lines inside a protective stainless steel braid. It was determined that the gas line had failed due to too much bend stress on it when the facility was raised to the surface of the pool. Further investigation by the FNR staff revealed that the ends of the plastic lines in the reactor pool had become embrittled in the low radiation field when compared to the opposite end of the lines connected to the instrumentation. As a safety precaution, it was decided to replace the plastic inlet and exit gas lines on both facilities with all metal bellows tubing having a stainless steel protective braid. Four new lines were immediately procured.

While waiting for shipment of these lines, the IAR-2 irradiation capsule was transferred to the FNR hot cells so that a new group of high-nickel Charpy specimens could be installed into cell 2 of the capsule in place of dummy specimens. The capsule was then placed back inside the IAR-2 irradiation facility in the reverse (rotated 180 degrees) position.

The new lines were installed onto the IAR-2 irradiation facility on Friday, April 13, which was placed into the high flux position. The new lines were installed onto the IAR-1 Irradiation facility on Tuesday, April 17. Both IAR facilities were purged of moisture obtained when they were opened to replace the gas flow lines. On Thursday, April 19, the IAR and UCSB irradiation facilities were deemed ready and operation resumed at 1415 hours that same day.

On Sunday morning, April 22, approximately 60 hours after startup, the IAR-1 moisture probe malfunctioned and the facilities had to be shut down. Several diagnostic tests indicated that one side of the dual readout and power supply for both the IAR-1 and IAR-2 moisture probes had become defective causing the IAR-1 moisture probe to fail. A new dual readout/power supply and two new moisture probes were shipped to FNR and installed approximately three days later. The moisture probes in both facilities returned to normal operation with all alarms cleared.

During the three day wait for the new moisture probes from ORNL, a momentary power failure occurred at FNR. Ordinarily the UPS (uninterruptable power supply) on the UCSB and IAR instrumentation would provide power to the instrumentation for such momentary outages. It was discovered during the momentary power outage that the UPS to the IAR computer was defective, resulting in the IAR computer shutting down. A new UPS was shipped from ORNL and installed on the IAR control system. On Friday, April 27, all systems on both the IAR and UCSB facilities were back to normal and awaiting reactor startup on 5/1/01.

At the beginning of this reporting period, the second group of specimens to be irradiated in the new IAR facilities had been irradiated for a total of 5859 EFPH. At the end of this reporting period the second group of specimens had been irradiated for a total of 5859 EFPH. The facilities themselves had been in service for a total of 10,187 EFPH.

(Milestone 6.1.B) The draft white paper entitled, “Options Regarding Facilities for Irradiation of Reactor Pressure Vessel Steels,” by K. R. Thoms, was submitted during this reporting period. This manuscript provides a detailed description of the current HSSI IAR and UCSB IVAR reusable irradiation facilities at the University of Michigan Ford Nuclear Reactor (FNR), including the issues that led to the design of these facilities. Potential North American and European reactor options were also reviewed and summarized in a series of tables that will permit a comparison of the costs and advantages and disadvantages of each facility option.

The draft NUREG report on the reusable irradiation facilities has been delayed in order to complete the evaluation of other test reactor options as possible alternatives for using the FNR.

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

This subtask includes supervising the overall operation and providing assistance to the reactor personnel in the routine operation and maintenance of the HSSI-UCSB irradiation facility. A NUREG report on the design, assembly, installation, and operation of the UCSB facility will be prepared.

(Milestone 6.2.A) A number of planned and unplanned events took place during the month of April that limited the operation of the HSSI irradiation facilities to only 60 additional EFPH (effective full power hours).

On March 30, 2001, the HSSI-UCSB and HSSI-IAR computers and control systems were shut down prior to a planned two-hour power outage at the FNR. After electrical power to Phoenix Memorial Laboratory was restored, all of the computers and instruments involved in operation of the HSSI facilities were turned on. Following reboot of the HSSI-UCSB computer, it was discovered that three back-plane boards in the computer were defective resulting in loss of 48 of the 49 thermocouple readouts from the facility. The moisture monitor in the facility was also not responding properly, which according to ORNL instrument technicians could also have been related to the faulty back-plane boards. However, because only one replacement board was available at FNR and because the vendor had no new boards in stock, the defective boards were removed and shipped overnight to the vendor for repair on Friday, March 30. Although the repaired boards were expected to be returned to FNR in four days, due to multiple errors by the vendor's customer service representative, the boards did not arrive at FNR until Wednesday, April 11, a week later than promised.

The newly repaired back-plane boards were installed and all thermocouples responded correctly. The moisture probe, however, did not respond correctly after the boards were installed. Further tests on the HSSI-UCSB moisture probe indicated that the probe had lost its program during the two-hour power outage. After the moisture probe was reprogrammed, it functioned properly. All control and monitoring systems on the HSSI-UCSB facility were ready for startup on April 13, 2001. However, startup did not occur until Thursday, April 19, due to operational problems with the gas inlet lines of the HSSI-IAR facilities. (See Milestone 6.1.A)

The HSSI-UCSB and IAR facilities were heated up and cranked into the reactor face to resume operation on April 19. The facilities were shut down on Sunday, April 22, at ~2:30 a.m., approximately 60 hours after restart, due to a faulty moisture probe in one of the IAR facilities. The FNR operator who shut down the facilities was distracted during the process and failed to completely shut everything down. The operator had correctly pushed the "shutdown" button on the HSSI-IAR screen which, under normal circumstances, shuts off all the IAR and instructs the UCSB computer to shut off the UCSB electrical heaters. The procedure also instructs the operator to open all electrical breakers supplying heater power the UCSB and IAR heaters as a secondary precaution. This step, however, was not completed. Due to a brief network communication breakdown between the IAR and UCSB computers at the very moment the operator pushed the shutdown button, the IAR computer could not instruct the UCSB computer to shut down the UCSB heaters. The UCSB heaters continued to maintain the normal operating temperature in the UCSB facility (even though the facility was cranked away from the reactor) for approximately 11 hours after the shutdown process began.

While performing weekend checks via the web pages, the ORNL Task Leader noted that the UCSB facility was still heated and immediately called the FNR to instruct the staff to shut off the electrical power to all heaters in the facilities. The UCSB facility remained shut down and cranked away from the reactor for the remainder of the reporting period while the moisture probes and associated power supplies were replaced and calibrated in both the HSSI-IAR facilities. To minimize the possibility of this type of event occurring, the HSSI-IAR shutdown program was changed so that the operator who pushes the shutdown button will observe a flashing red message indicating the need to shut down the UCSB facility manually if the IAR computer is unable to communicate the shutdown message to the UCSB computer. Additionally, the FNR has instructed its operator staff to read and record the average facility operating temperatures twice per eight-hour shift. Thus even if the new program change fails, the temperature check and recording operation would signal the need for additional operator action within four hours of a shutdown event.

The HSSI-UCSB irradiation facility received only 60 EFPH during this reporting period. At the beginning of this reporting period, the UCSB facility and original specimen compliment had been irradiated for a total of 17,612 EFPH. At the end of this reporting period, the UCSB facility and original specimen compliment had been irradiated for a total of 17,672 EFPH. The latest irradiation plan received from the UCSB experimenters indicated that the final specimens would be removed from the UCSB facility after 13,500 EFPH. Additional specimen irradiation's have been added to the original plan and at the end of this reporting period the UCSB irradiation program had obtained 131% of the original desired irradiation time.

Task 7: Embrittlement Data Base and Dosimetry Evaluation (T. M. Rosseel)

This task was until March 1, 1999, the Embrittlement Data Base (EDB) and Dosimetry Evaluation Program, JCN: 6164. The objectives of the two subtasks listed below 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 data base 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 data bases used by vendors, utilities, and service laboratories in the pressure vessel irradiation surveillance program. It will also provide technical expertise and analysis to the NRC regarding dosimetry and transport calculations and methodologies.

Subtask 7.1: Embrittlement Data Base (J.-A. Wang)

The purpose of the subtask is to maintain and update the EDB. This includes evaluating surveillance reports, entering the data into the EDB, and providing an update to the NRC by the end of the fiscal year.

(Milestone 7.1.B) The completed UPDATE-11 of PR-EDB was transmitted to the US NRC technical program monitor in July 2000. No new surveillance reports have been received.

Subtask 7.2: Dosimetry Evaluation (I. Remec)

Technical expertise and analysis regarding dosimetry and transport calculations and methodologies will be provided as needed to the US NRC. Specifically, work will be performed to complete the review of, and hold final discussions with the NRC concerning, the dosimetry guide, DG-1053.

This activity was eliminated as directed by SOEW 60-99-356.

3. MEETINGS AND TRIPS:

On April 2, 2001, Dr. Roy Faulkner, Professor of Physical Metallurgy, University of Loughborough, UK visited ORNL. In addition to presenting a seminar on "Grain Boundary Segregation and Precipitation in Nuclear Reactor Steels," discussions were held with HSSI staff concerning modeling of precipitates.

4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:

None

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:

The IMET hot cell facility is currently scheduled for standby from June 1, 2001, until the end of the fiscal year.

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: 3/26/01-4/22/01

		Current Month	Fiscal Year to Date	Cumulative Project to date
I.	Direct Staff Effort	8 MM	5.3 MY	35.1 MY
II. A.	Direct Lab Staff Effort ($)			
	Direct Salaries	74,736	507,975	3,523,680
	Materials and Services	3,212	5,764	381,720
	ADP Support	21	314	2,099
	Subcontracts	0	18,453	380,871
	Travel	0	12,493	129,102
	Indirect Labor Costs	0	0	0
	Other: NRC-PO Tax	4,000	20,000	158,500
	General and Administrative	31,573	212,239	1,591,461
	Total UT-Battelle Costs	113,542	777,238	6,167,433
B.	DOE Federal Access Costs	3,406	23,317	23,317
	TOTAL PROJECT COSTS	116,948	800,555	6,190,750

Percentage of available cumulative funds costed	87
Percentage of available current FY funds costed	47
Funds Remaining	914,250
Commitments:	59,837
BA Remaining	854,413
BA Remaining Less Projected FAC	827,784

III. Funding Status

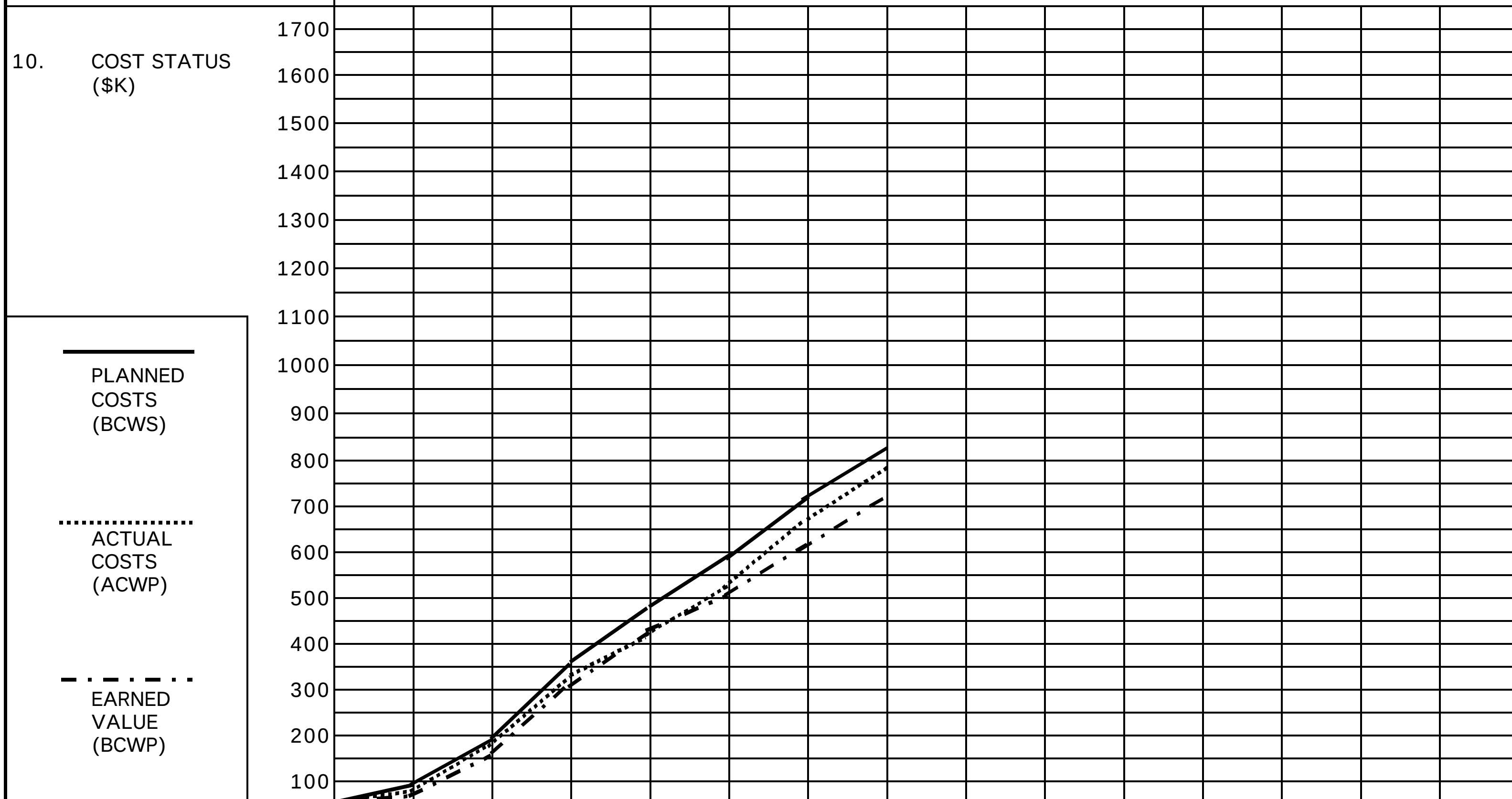
Prior FY Carryover	FY 01 Projected Funding Level	FY 01 Funds Received to Date	FY 01 Funding Balance Needed	Cumulative Amt. Obligated	Cumulative Amt. Costed
279,802	1,435,000	1,435,000	0	7,105,000	6,190,750

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

1. CONTRACT REPORTING ELEMENT **HSSI - Heavy-Section Steel Irradiation Program**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998 - 2003** 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: 04/20/01

PLANNED COSTS FOR ELEMENT ($K): 1546

ELEMENT COSTS FOR PRIOR FYS ($K): 280

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	98	98	155	119	128	129	103	112	107	97	82	117	113	93	
ACTUAL	77	113	134	85	110	145	113								
EARNED	74	78	156	105	92	111	86								
CUM. PLANNED	98	196	351	470	598	722	825	937	1044	1141	1223	1340	1453	1546	
CUM. ACTUAL	77	190	324	409	519	664	777								
CUM. EARNED	74	152	308	413	505	616	702								

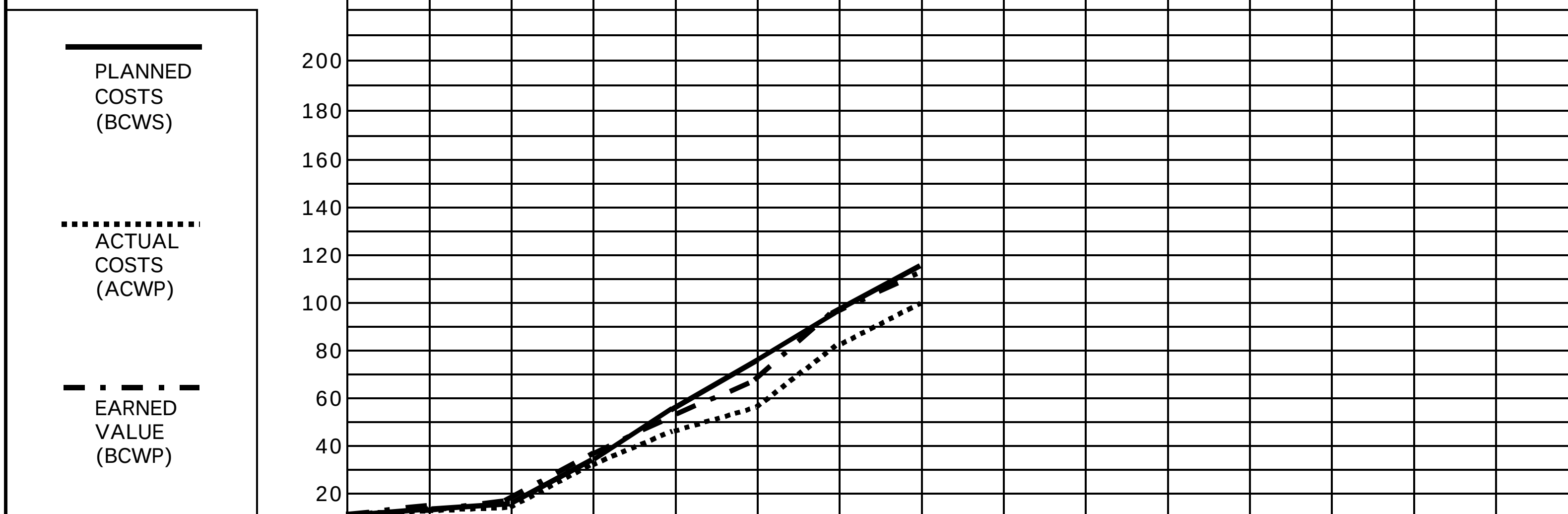
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 1. Program Management**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998 - 2003**	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES: 04/20/01

PLANNED COSTS FOR ELEMENT ($K): 189

ELEMENT COSTS FOR PRIOR FYS ($K): 10

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	4	10	20	20	22	19	18	13	11	12	8	12	11	9	
ACTUAL	4	10	20	11	10	26	19								
EARNED	5	9	20	17	16	31	14								
CUM. PLANNED	4	14	34	54	76	95	113	126	137	149	157	169	180	189	
CUM. ACTUAL	4	14	34	45	55	81	100								
CUM. EARNED	5	14	34	51	67	98	112								

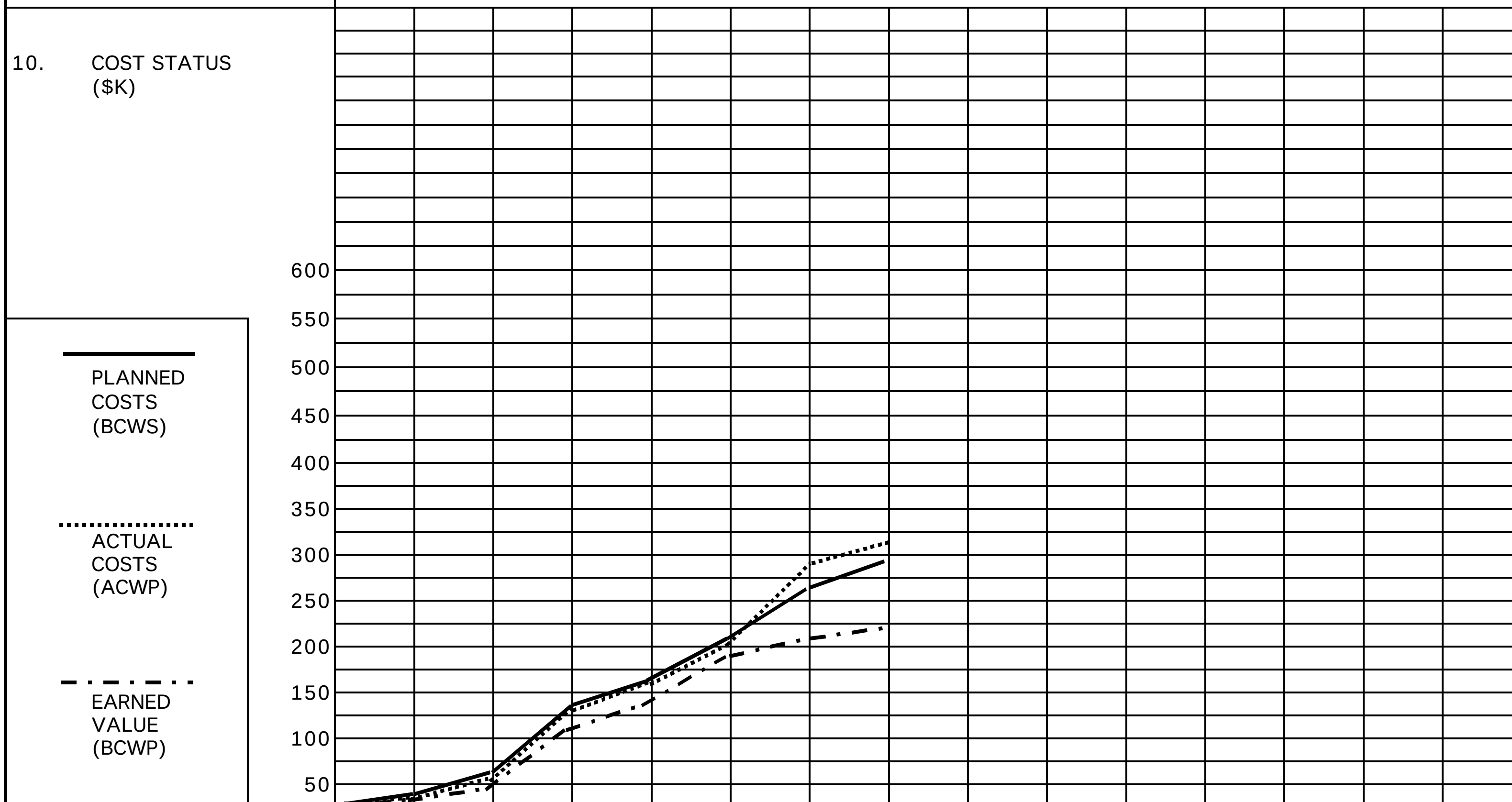
11. REMARKS

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 **03/26/01 - 04/22/01**	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 1998 - 2003**	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
		7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES: 04/20/01

PLANNED COSTS FOR ELEMENT ($K): 509

ELEMENT COSTS FOR PRIOR FYS ($K): 117

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	25	33	73	37	47	46	28	35	32	29	27	33	32	30	
ACTUAL	20	33	75	40	47	78	13								
EARNED	19	22	74	27	28	34	15								
CUM. PLANNED	25	58	131	168	215	261	289	324	356	385	412	447	419	509	
CUM. ACTUAL	20	53	128	168	215	293	306								
CUM. EARNED	19	41	115	142	170	204	219								

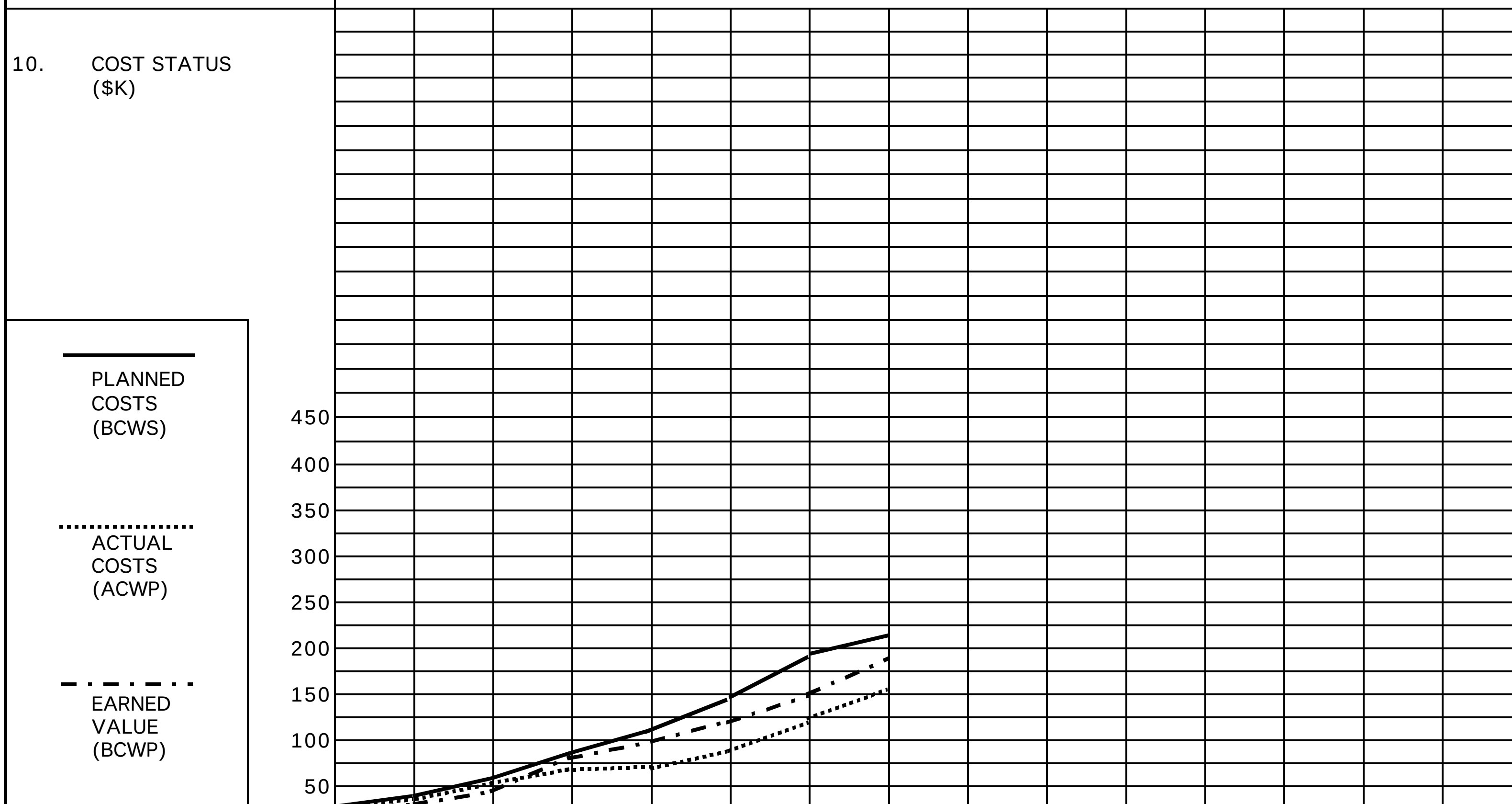
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 3. Irradiation Embrittlement of RPV Steel**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998 - 2003** 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

4/20/01

PLANNED COSTS FOR ELEMENT ($K)

443

ELEMENT COSTS FOR PRIOR FYS ($K)

98

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	33	26	24	26	37	39	25	35	34	32	29	40	42	31	
ACTUAL	32	26	9	2	22	23	37								
EARNED	24	24	30	20	22	29	30								
CUM. PLANNED	33	59	83	109	146	185	210	245	379	311	340	380	412	443	
CUM. ACTUAL	32	58	67	69	91	114	151								
CUM. EARNED	24	48	78	98	120	149	179								

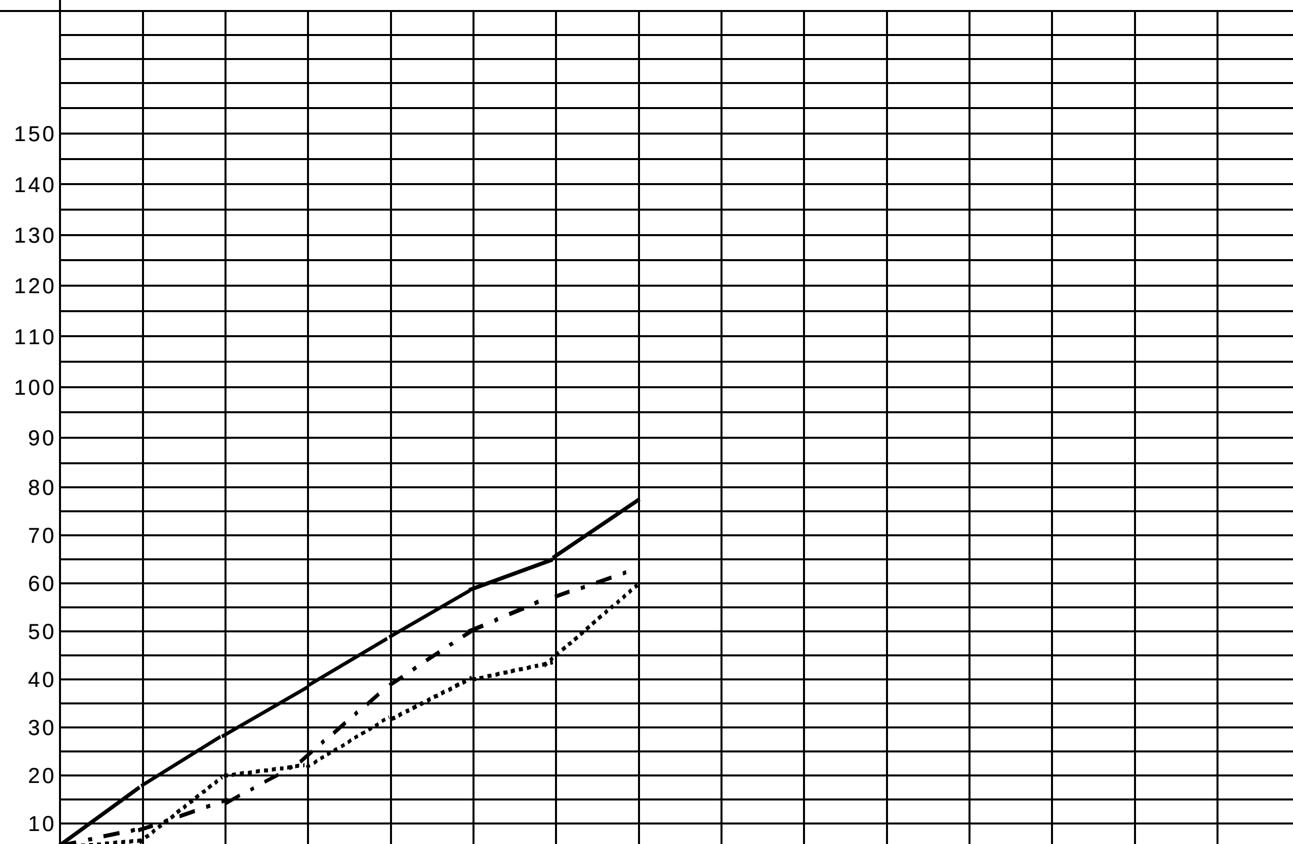
11. REMARKS

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 **03/26/01 - 04/22/01**	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 1998 - 2003**	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

04/20/01

PLANNED COSTS FOR ELEMENT ($K)

133

ELEMENT COSTS FOR PRIOR FYS ($K)

18

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	16	13	10	10	9	7	12	9	8	7	6	9	8	9	
ACTUAL	2	18	3	9	8	3	17								
EARNED	7	7	9	16	11	6	7								
CUM. PLANNED	16	29	39	49	58	65	77	86	94	101	107	116	124	133	
CUM. ACTUAL	2	20	23	32	40	43	60								
CUM. EARNED	7	14	23	39	50	56	63								

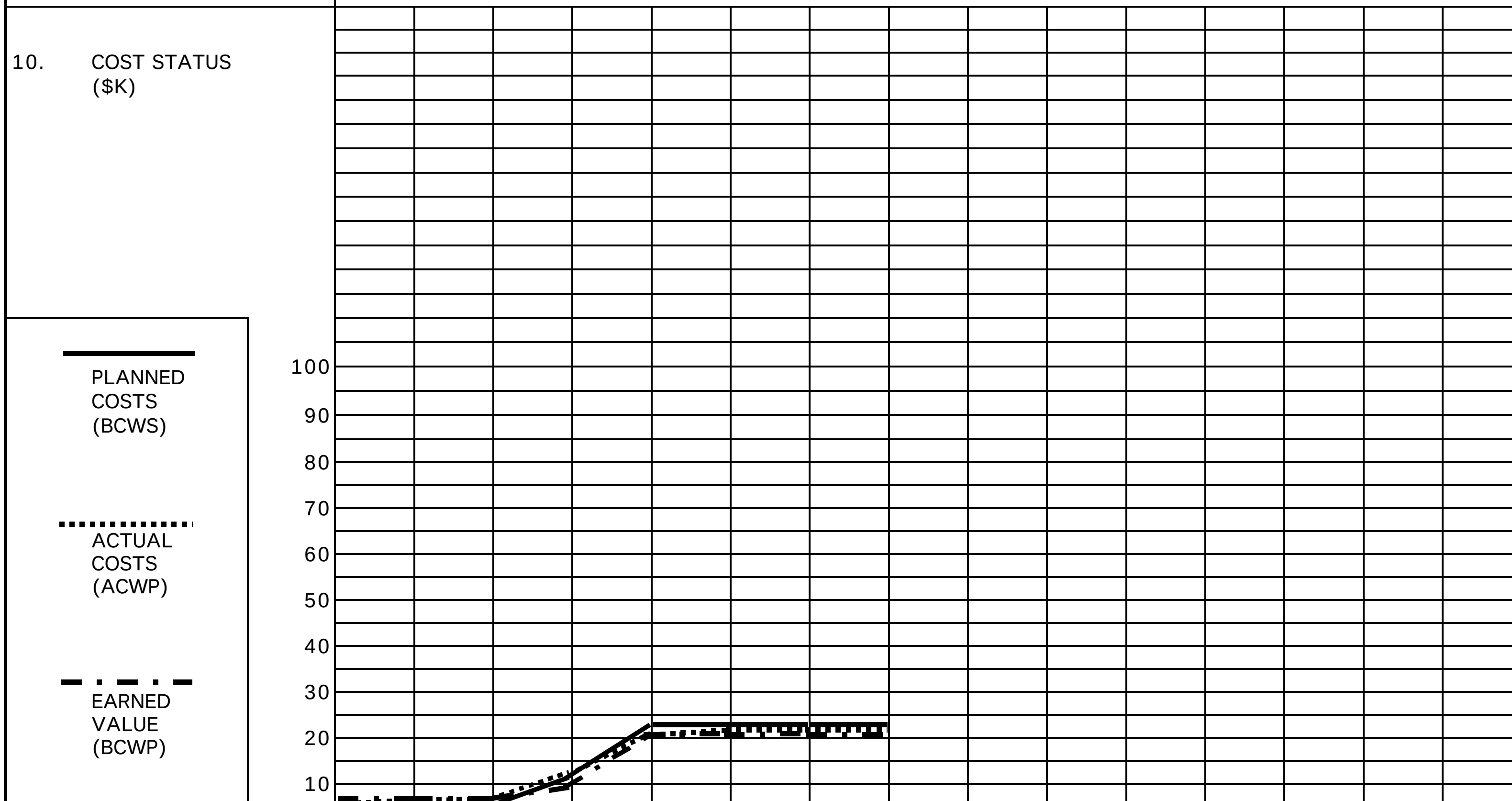
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 5. Modeling and Microstuctural Analysis**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998 - 2003**	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES
04/20/01

PLANNED COSTS FOR ELEMENT ($K)
58

ELEMENT COSTS FOR PRIOR FYS ($K)
2

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	0	0	12	11	0	0	0	6	10	5	4	6	4	0	
ACTUAL	0	0	12	9	1	0	0								
EARNED	0	0	8	13	0	0	0								
CUM. PLANNED	0	0	12	23	23	23	23	29	39	44	48	54	58	58	
CUM. ACTUAL	0	0	12	21	22	22	22								
CUM. EARNED	0	0	8	21	21	21	21								

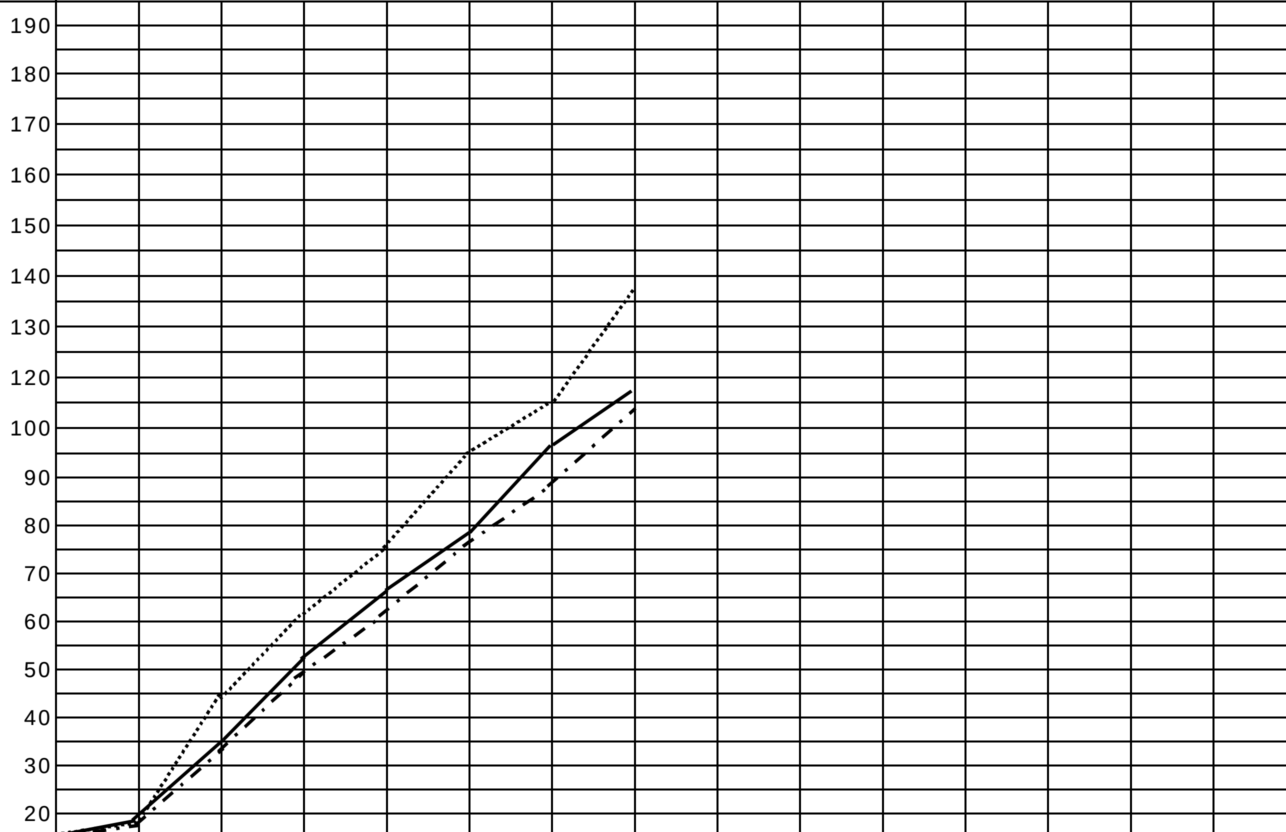
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 6. Irradiation Coordination**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998 - 2003**	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

04/20/01

PLANNED COSTS FOR ELEMENT ($K)

208

ELEMENT COSTS FOR PRIOR FYS ($K)

38

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	19	16	16	15	13	18	20	14	12	12	8	15	16	14	
ACTUAL	19	26	16	14	20	15	28								
EARNED	19	16	14	12	15	11	20								
CUM. PLANNED	19	35	51	66	79	97	117	131	143	155	163	178	194	208	
CUM. ACTUAL	19	45	61	75	95	110	138								
CUM. EARNED	19	35	49	61	76	87	107								

11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 7. Embrittlement DB & Dosimetry Evaluation**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998 - 2003** 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)

PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

100 90 80 70 60 50 40 30 20 10

COST PLAN DATES

04/20/01

PLANNED COSTS FOR ELEMENT ($K)

0

ELEMENT COSTS FOR PRIOR FYS ($K)

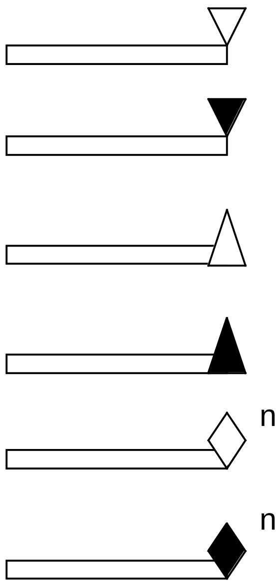
0

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	0	0	0	0	0	0	0								
ACTUAL	0	0	0	0	0	0	0								
EARNED	0	0	0	0	0	0	0								
CUM. PLANNED	0	0	0	0	0	0	0								
CUM. ACTUAL	0	0	0	0	0	0	0								
CUM. EARNED	0	0	0	0	0	0	0								

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

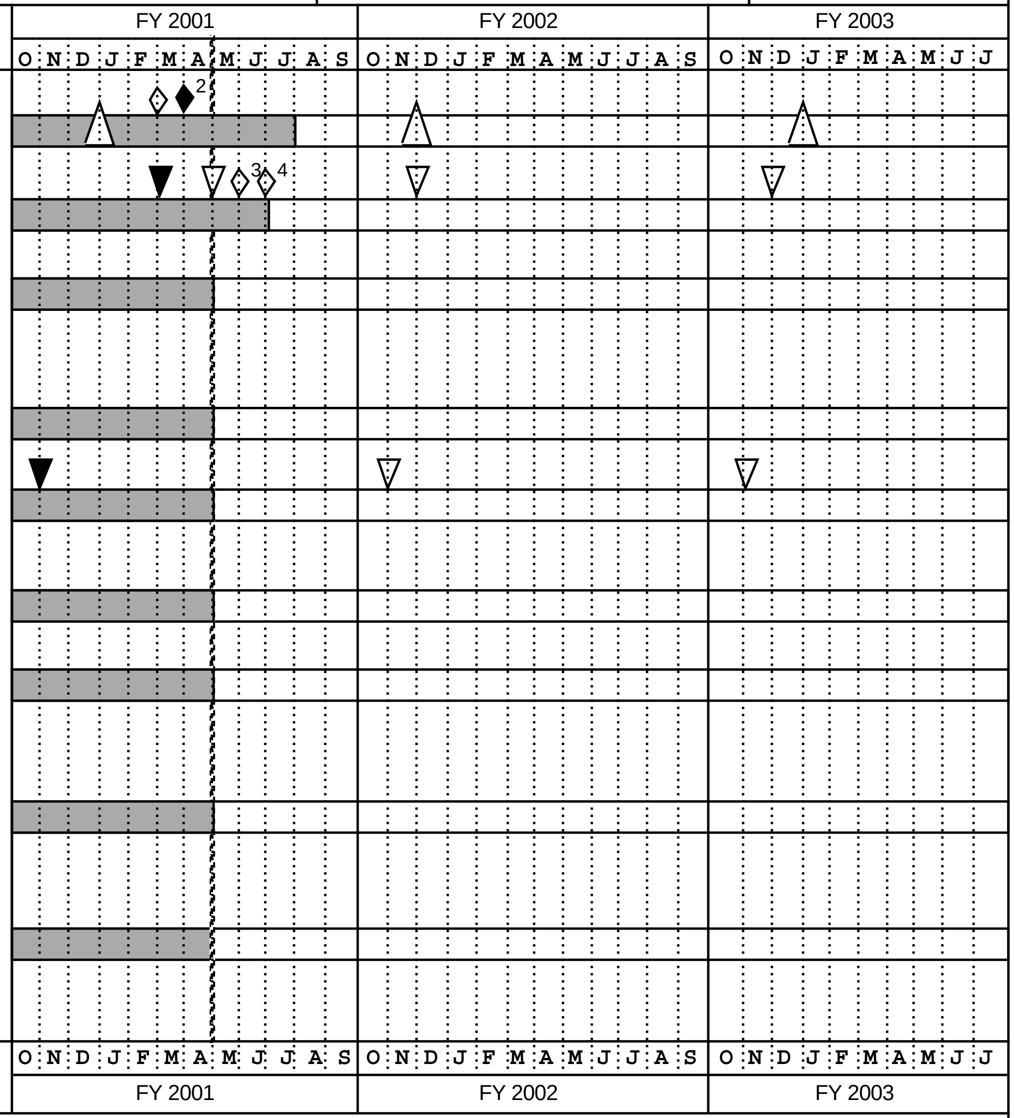
Rescheduled milestone planned

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 **03/26/01 - 04/22/01**	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 1998-2003**	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
1.1.A.	Issue Project & Budget Proposal
1.1.B.	Select and Administer Subcontracts
1.2.A.	Issue Earned Value Based Monthly Management Reports (by the end of subsequent month)
1.2.B.	Ensure QA Requirements are met
1.3.A.	Participate in NRC-Sponsored Meeting 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

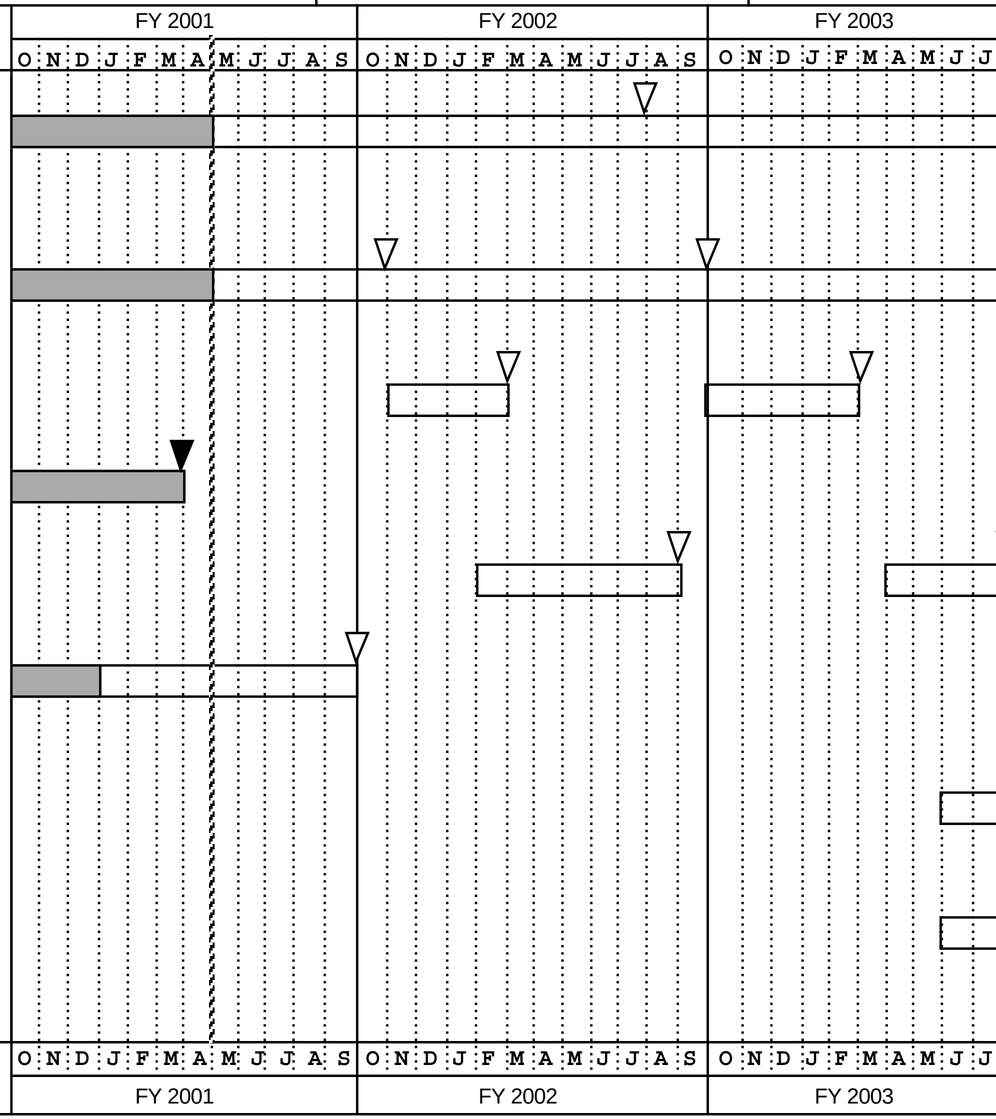


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 2. Fracture Toughness Transition & MC Methodology	**03/26/01 - 04/22/01**	**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 1998-2003**	**41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.1.A.	Continue to accumulate data on Comparison of CVN and Fracture Tougness Shifts
2.2.A.	IIrradiate Midland and Hi-Ni Speciments
2.2.B.	Receive Specimens
2.2.C.	Test Unirradiated & Irradiated KSØ1 for Master Curve
2.2.D.	Test Unirradiated & Irradiated Hi-Ni Midland Weld Specimens
2.2.E.	Draft Letter and NUREG Report for KSØ1
2.2.F.	Draft Letter and NUREG Report for Midland Weld
2.2.G.	Draft Letter and NUREG Report for High Ni

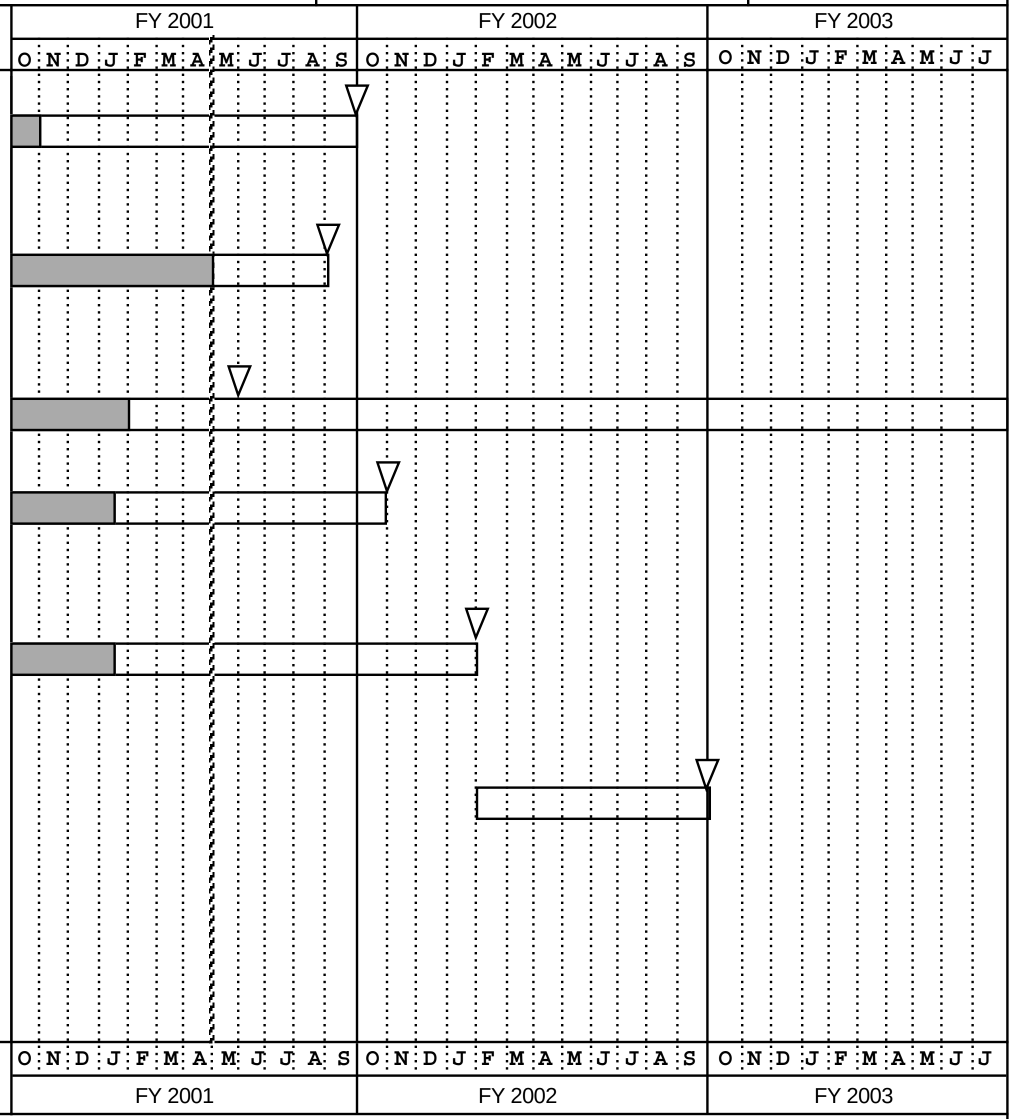


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 2. Fracture Toughness Transition & MC Methodology	**03/26/01 - 04/22/01**	**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 1998-2003**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

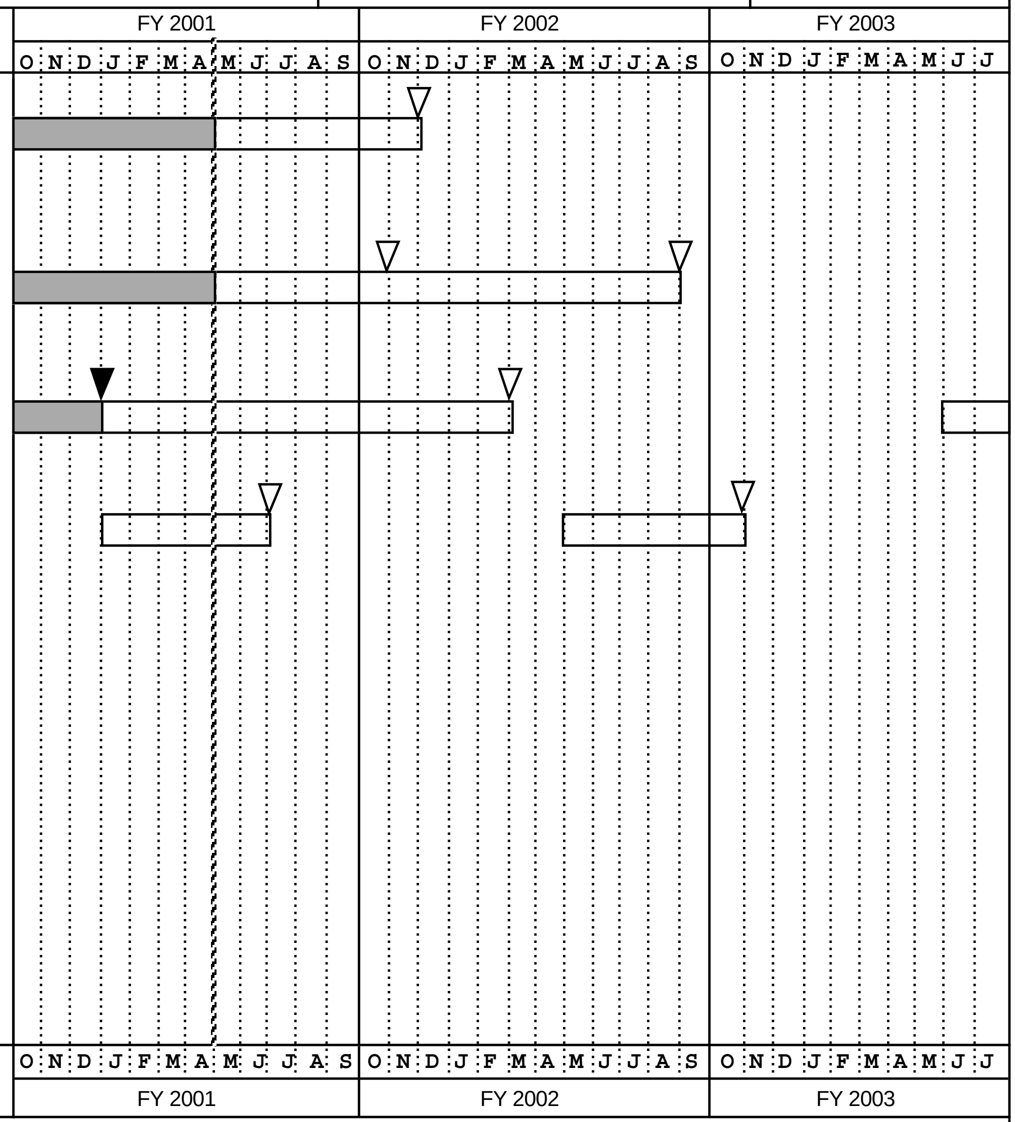
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.5.A.	Complete Crack Arrest NUREG Report
2.6.E.	Fractography and Final IGF Report
2.7.B.	Complete Testing of Subsize Specimens
2.7.C.	Complete NUREG Report on Results of Subsize Specimen Fracture Toughness Tests
2.7.E.	Test and Analyze A302B PCVN
2.7.F.	Prepare Letter Report on PCVN



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998-2003** 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**

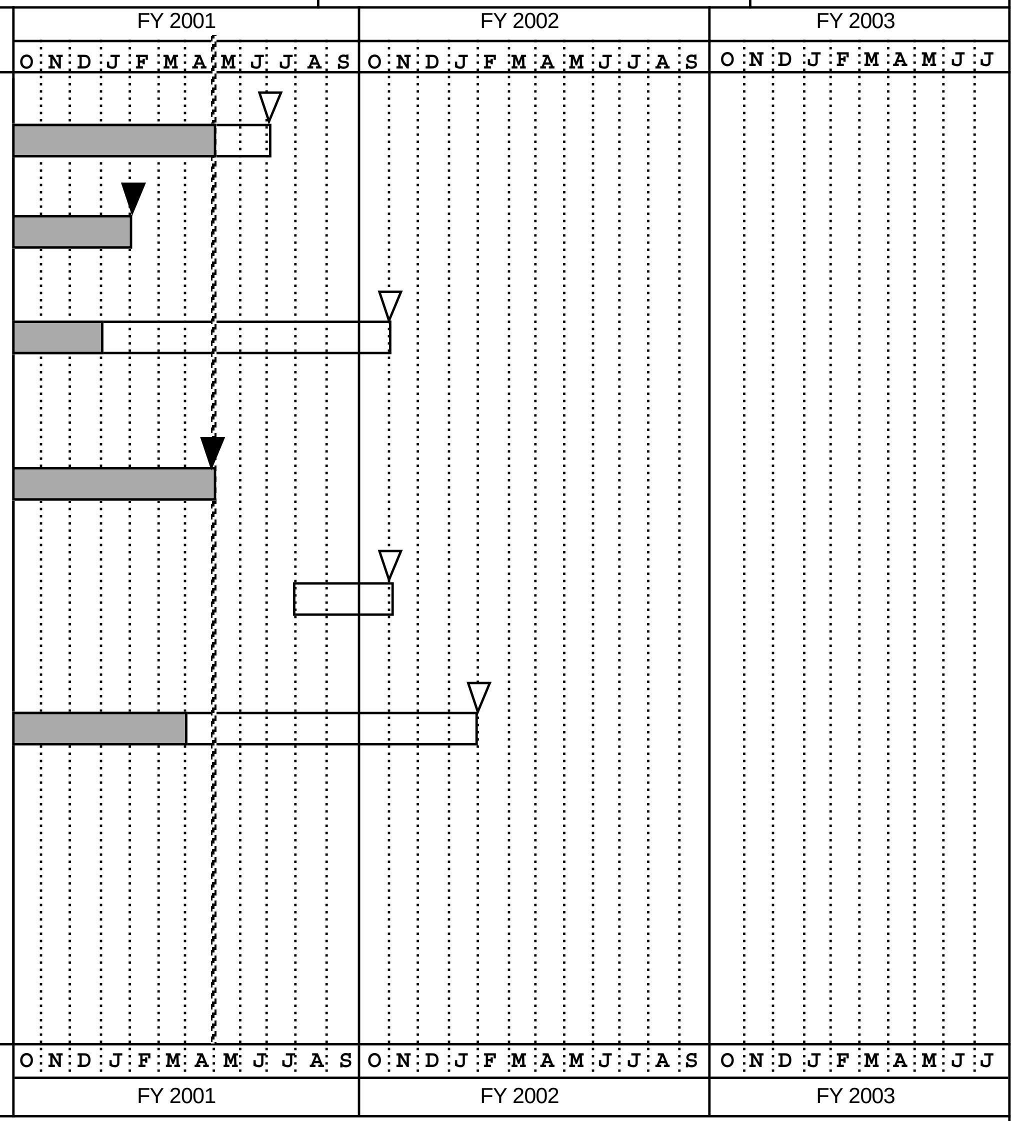
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.8.E.	Complete Assembly and Compilation for Irradiated Materials for Surrogate Materials DB
2.8.F.	Complete Statistical Analysis of Data Base for Irradiated Materials
2.10.A.	Measure Activity and Prepare Report
2.10.B.	Calculate Fluence and Prepare Report



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 3. Irradiation Embrittlement of RPV Steel**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998-2003** 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**

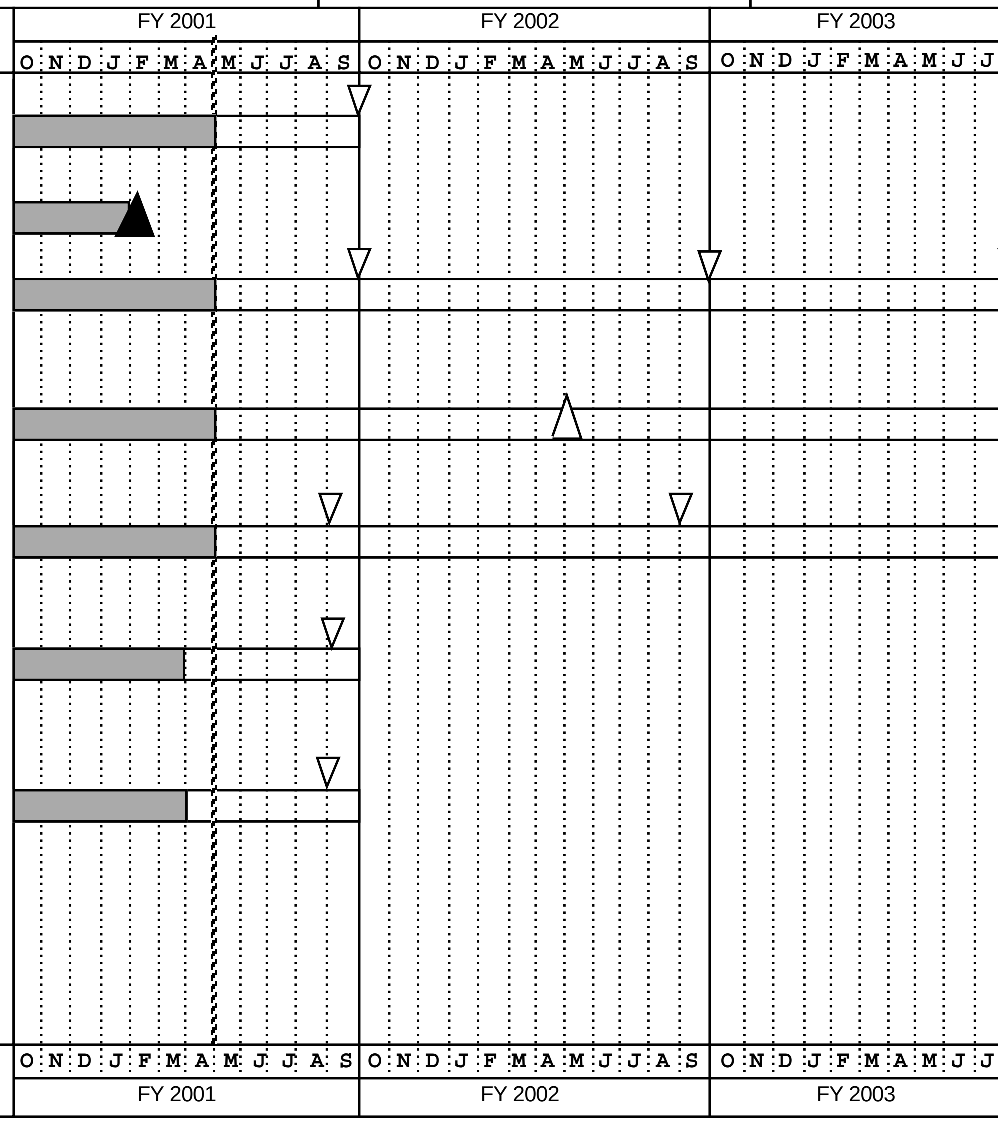
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
3.1.G.	HAZ NUREG Report
3.1.H.	Evaluate Need for Additional Specimen Testing
3.2.C.	NUREG on 30 CVNs (IAR)
3.3.C.	Complete JRQ Charpy Testing
3.3.D.	Complete PCVN Testing
3.3.E.	Complete Draft NUREG Report on IAR Results of JRQ



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 4. Validation of Irradiated and Aged Materials**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998-2003** 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
4.1.1.A.	Information Exchange with JAERI
4.1.1.C.	NUREG Report
4.4.A.	Complete Preparation of List of Anticipated Foreign Travel
4.4.B.	Participate in Periodic Meetings of IGRDM
4.4.C.	Complete Progress Reports of Collaboration Activities
4.5.B.	Complete Letter Report Regarding RPV Materials Available for Irradiation Study
4.5.D.	Complete Letter Report on Test results from MEA Capsule

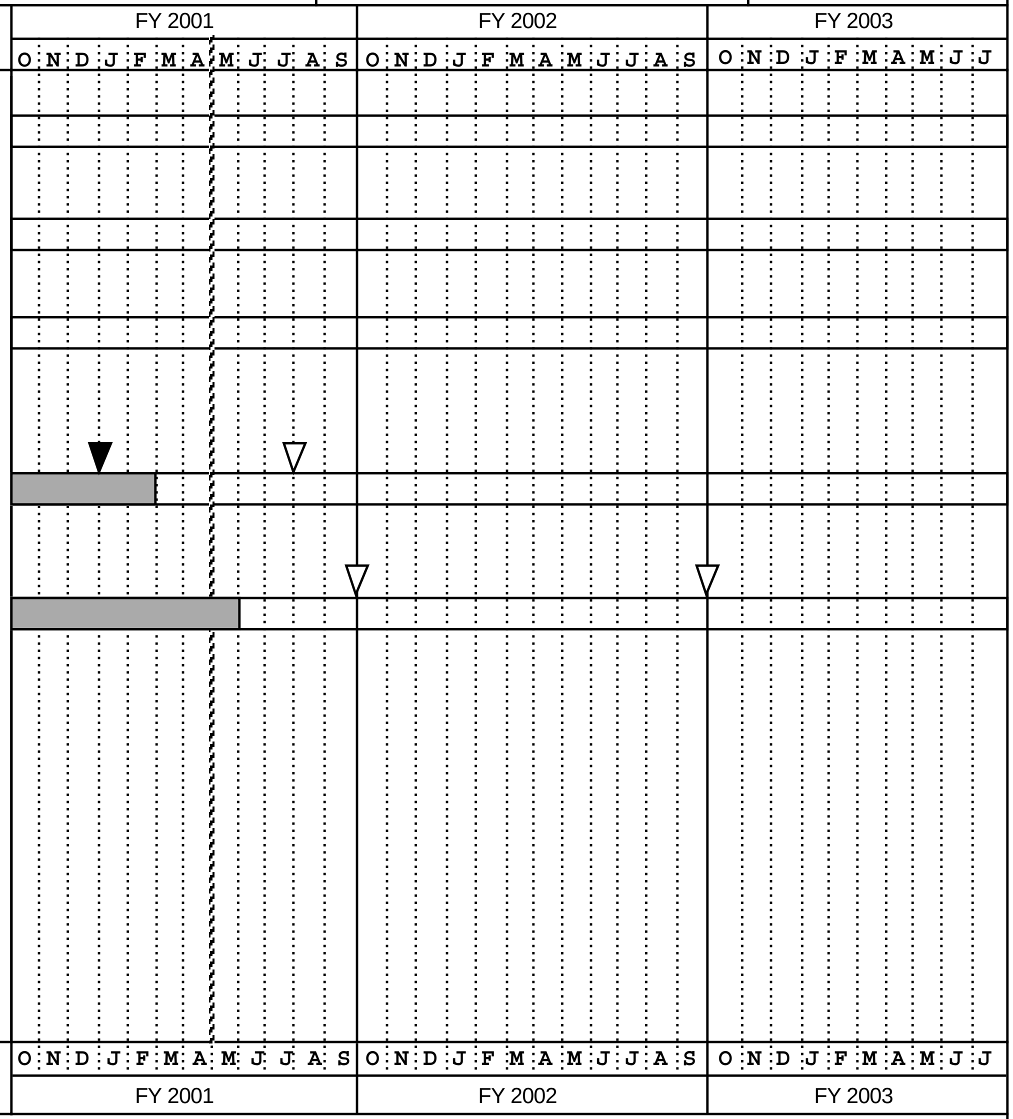


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 5. Modeling & Microstructural Analysis	**03/26/01 - 04/22/01**	**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 1998-2003**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

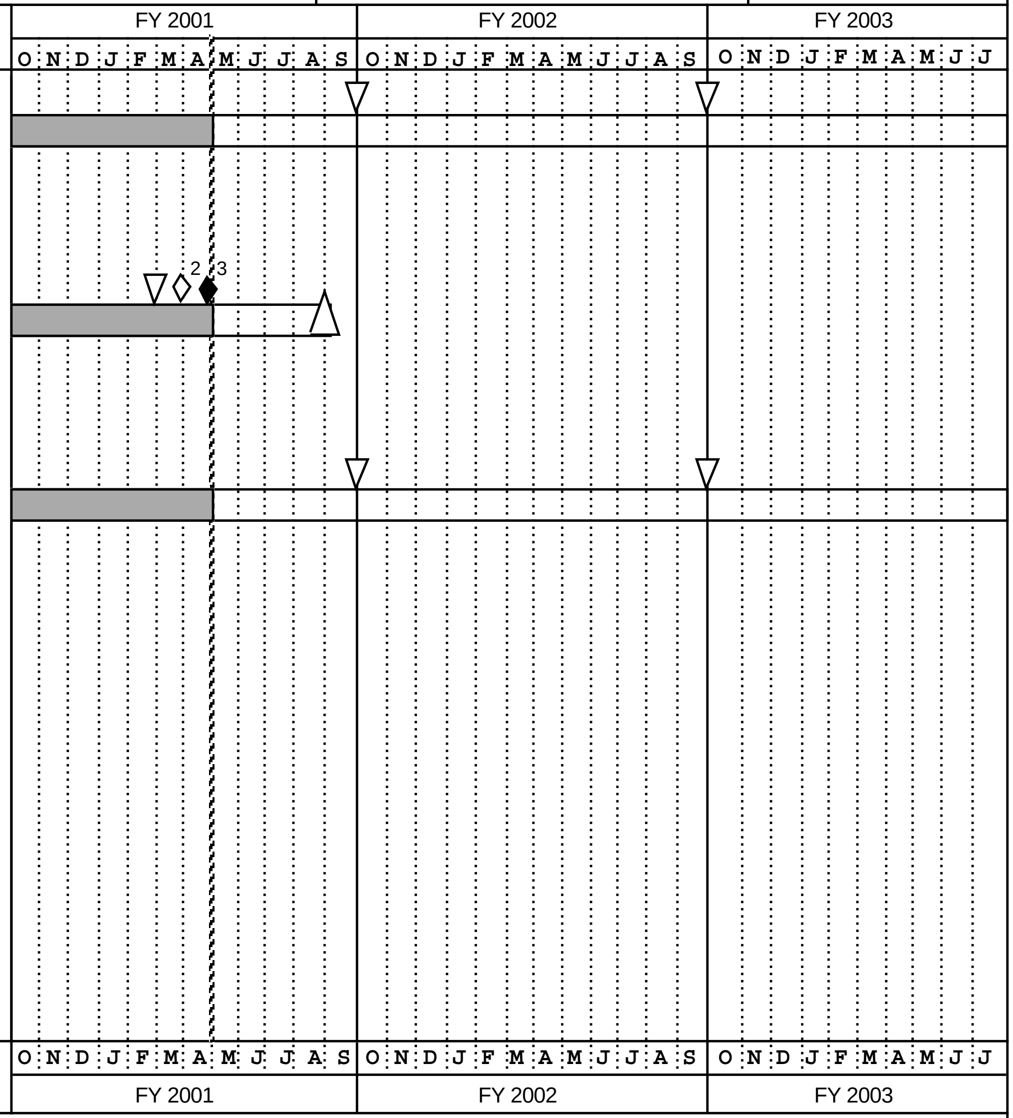
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
5.1.A.	Development and Predictive use of Embrittlement Model
5.1.B.	Model Validation and Data Analysis
5.2.A.	Coordinate and Analyze APFIM/SANS/FEGSTEM Round Robin Experiment
5.2.B.	APFIM Characterization
5.4.	Administration of Task Activities



11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 6. Irradiation Coordination	**03/26/01 - 04/22/01**	**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 1998-2003**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

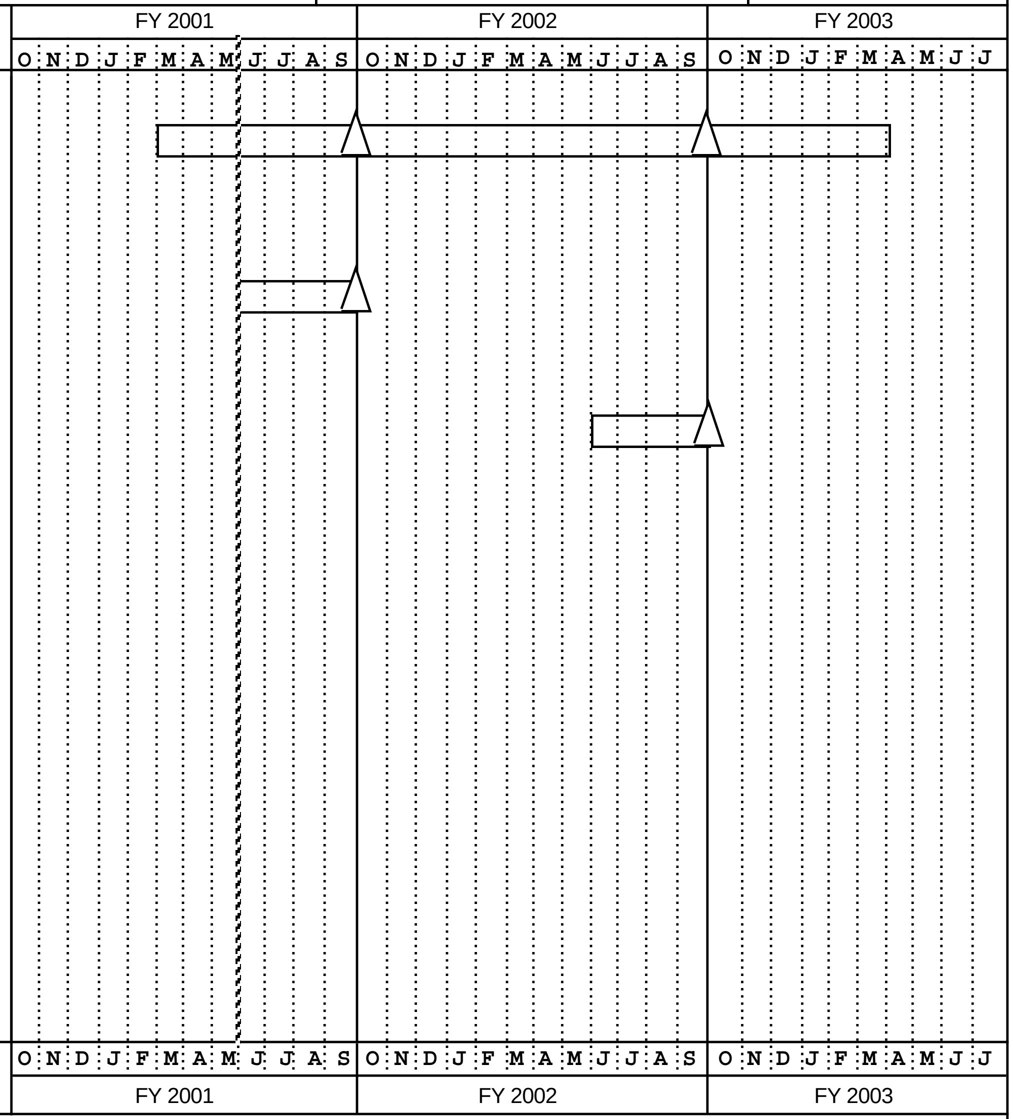
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
6.1.A.	Coordinate the Operation, Data Collection, and Maintenance of the HSSI IAR Facility
6.1.B.	Comprehensive Report on Reusable Irradiation Facilities and Report on Facility Options
6.2.A.	Coordinate the Operation, Data Collection, and Maintenance of the UCSB Irrad. Facility



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 7. Embrittlement DB & Dosimetry Evaluation**	2. REPORTING PERIOD **03/26/01 - 04/22/01**	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 1998-2003**	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
7.1.A.	Evaluate and Input Surveillance Reports into Embrittlement Database
7.1.B.	Complete Update 12
7.1.C.	Complete Update 13



11. REMARKS