

ORNL/HSSI (W6953)/MLSR-2002/05

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

**Monthly
Letter Status
Report**

February 2002

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HEAVY-SECTION STEEL IRRADIATION
PROGRAM
JCN W6953

MONTHLY LETTER STATUS REPORT
FOR
FEBRUARY 2002

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for the
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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 March 7, 2001. 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 2001 to December 2002.

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



Thomas M. Rosseel, Manager
Heavy-Section Steel Irradiation

MONTHLY LETTER STATUS REPORT
February 2002

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| 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. 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 administering 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) An effort to evaluate the tensile properties of A516 grade 70 with a safe-end of forged stainless steel 316 pipe obtained from Battelle has been initiated. This work is being performed under the technical assistance task (See Task 4.3).

(Milestone 1.2.B.1) At the end of the previous reporting period, the irradiation facilities at FNR remained shut down due to problems with the micro-dcs (digital control system) plus unit, the controller used to operate the HSSI-IAR irradiation facilities. The ORNL instrument technicians, however, were able to determine that the operating program on the internal flashcard had been damaged by internet virus attacks. This is believed to have occurred during remote operating condition inquiries and data retrieval operations. The system was reprogrammed and a sister computer, called the HSSI computer, which is used for data storage, was placed between the controller and the internet so as to serve as a firewall. The HSSI computer virus protection is now updated on a weekly basis. Upon completion of the programming and virus-protection firewall installation, the facilities resumed operation with the startup for reactor half-cycle 468B on February 20, 2002. Additional details may be found in Task 6.1.

(Milestone 1.2.B.2) The HSSI Program manager was selected to serve on the FY 2002 ORNL hot cell review committee representing the ORNL NRC Programs. Gordon Michaels, Director of the Nuclear Technology Programs at ORNL is the chairman. The purpose of the committee is to address the financial and physical status of the 10 ORNL hot cell facilities that contain nearly fifty cells of varying sizes, restrictions, and capabilities. The preliminary analysis of the facilities indicates that the facility used by the HSSI Program, the Irradiated Materials Examination and Testing (IMET) facility, will not be negatively impacted by the action plan derived from this study. The NRC program monitor will be kept informed of any potential impact as additional information becomes available.

(Milestone 1.3.A) On February 19 – 21, J. G. Merkle, R. K. Nanstad, M. A. Sokolov, and T. M. Rosseel traveled to Rockville, MD to participate in the “MEB Workshop on Fracture Mechanics Technology.” Five presentations were given including an overview of the Program by the HSSI Program Manager.

(Milestone 1.3.C) Mikhail A. Sokolov has received an Award of Appreciation from the ASTM International Committee E-10 on Nuclear Technology and Applications at the recent Dallas meeting. The Award of Appreciation was given to Dr. Sokolov for his efforts on examining small specimen test techniques. Specifically, he was cited for: "For outstanding leadership and service to ASTM Committee E-10 as Chairman of the Fourth Symposium on Small Specimen Test Techniques, Reno Nevada, 2001 that resulted in the publication of STP 1418."

(Milestone 1.3.E) The following two NUREG report were submitted to the NRC:

K. Onizawa, E. van Walle, W. Pavinich, and R. K. Nanstad, UT-Battelle, LLC, Oak Ridge, Tenn., *Results and Analysis of The ASTM Round Robin On Reconstitution*, USNRC NUREG/CR-XXXX, (ORNL/TM-2001/34).

D. W. Heatherly, K. R. Thoms, and M. T. Hurst, UT-Battelle, LLC, Oak Ridge, Tenn., *Heavy-Section Steel Irradiation Program's Reusable Irradiation Facility*, USNRC NUREG/CR-XXXX, (ORNL/TM-2002/77).

Task 2: Fracture-Toughness Transition Issue 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. Specifically, the effects of irradiation on fracture-toughness curve shape for highly embrittled RPV steels, dynamic effects, crack arrest, intergranular fracture, and subsized specimens will be explored; guidelines for the application of "surrogate" materials to the assessment of fracture toughness of RPV steels will be evaluated; and 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 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 2000.

Several months ago, some additional data became available, 5 data sets for weld metal and 24 data sets for base metal. These data have not been analyzed in the same fashion as those in the NUREG, and are considered very preliminary. More detailed analysis of this new data will be performed upon receipt of the raw data and a new database will be assembled in preparation for a new overall analysis.

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 the testing of a pressure-vessel steel weld that has been irradiated to a neutron fluence sufficient to produce a fracture-toughness transition-temperature shift (T_0) of about 150°C (270°F). A specially

fabricated radiation-sensitive weld was selected to perform a pilot study on the ability of highly embrittled material to maintain the master curve shape. This weld had been fabricated and studied in Germany and supplied to ORNL by MPA, Stuttgart through a Memorandum of Agreement (MOA). The 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 8.4×10^{18} n/cm² at the FNR during the first HSSI-IAR irradiation campaign. 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 pre-cracked Charpy V-notch (PCVN) specimens, using both quasi-static and dynamic methods, will be tested to investigate the use of more practical surveillance-size specimens. Tensile specimens will also be tested to determine the irradiation-induced hardening. Testing of irradiated specimens is dependent upon the availability of suitable hot-cell facilities. Evaluation of the mechanical properties of the unirradiated weld has been completed.

Specimens of the Midland beltline weld were fabricated and placed into the IAR facility at the FNR for irradiation to a fluence of at least 2.5×10^{19} n/cm² (>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.

Irradiated high-nickel welds from the Palisades steam generator will also be examined. Not only will this material provide additional information on curve shape effects, but it will permit experimental validation of an assumption of linear relationship between Charpy 41J and fracture toughness shifts for highly-embrittled materials.

(Milestone 2.2.A) Irradiation of the Midland beltline weld and a high-nickel weld from the Palisades steam generator is under way and irradiation of the remaining specimens is proceeding at the University of Michigan FNR. Please also see Task 6.1. Some of the Palisades steam generator specimens irradiated to an intermediate fluence were removed previously and have been received at the ORNL hot cells. They are scheduled for testing in the next two months.

(Milestone 2.2.C) As noted previously, 21 1T compact specimens of the submerged-arc weld KS-01, irradiated to $\sim 0.8 \times 10^{19}$ n/cm² (>1 MeV), were successfully tested as follows: six at 125°C, six at 150°C, five at 175°C, and four at 200°C. Following evaluation of the results, six additional 0.5T compact specimens were also tested at 100°C. The results have been evaluated relative to the shape of the master curve. As a preliminary observation, the fracture toughness data up to a median K_{Jc} value of about 130 MPa√m reasonably follow the shape of the master curve. Above that value, however, the fracture toughness test results deviate substantially from the shape of the curve in a manner indicating a shallower curve shape. For this material, this latter effect is believed to be due, at least in part, to the occurrence of intergranular fracture in the test specimens and shows the same behavior as that observed in the intergranular fracture study performed within subtask 2.6. On the other hand, the unirradiated specimens also exhibited significant intergranular fracture, but the results did not deviate from the shape of the master curve. Further statistical analysis will be performed with these data. Furthermore, tensile tests yet to be performed may shed light on the effects of the intergranular fracture observations relative to expected irradiation-induced hardening. Additionally, an NRC Letter Report is in preparation and an abstract has been submitted for presentation at the ASTM International Symposium on

Radiation Effects in Materials in Tucson, Arizona, June 2002. Results of this project were also incorporated in a presentation at the NRC Workshop on Fracture Mechanics in Rockville on February 20-21.

The computer numerically controlled (CNC) milling machine in the hot cell has been exercised recently in preparation for machining of 0.4T compact specimens from the broken irradiated 1T compact specimens of KS-01 previously tested. Moreover, programming of the CNC system and design of fixtures has continued. These 0.4T specimens will be tested in the same general temperature range as the 1Ts to expand the database for this material.

(Milestone 2.2.G formerly 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, 2000.

Subtask 2.3: Dynamic Fracture Toughness [Combines previous subtasks 2.3 and 2.5]
(R. K. Nanstad)

The purpose of this subtask is to evaluate the applicability of the master curve to dynamic fracture toughness of RPV steels. There are limited data available that suggest reasonable applicability of the master curve to such data, however, sufficient data under high-rate loading conditions for a reliable statistical assessment are not available. 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 is high-rate loading of standard bend or compact specimens under non-impact conditions.

(Milestone 2.3.A) No significant progress during this reporting period. However, compact specimens (either 0.5T or 1.0T) will be machined from a material with a Master Curve pedigree, such as HSST Plate 02 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_0 from quasi-static and dynamic tests.

Subtask 2.4 - Statistical Representation of Valid K_{Ic} Data for Irradiated RPV Steels
(R. K. Nanstad and J. G. Merkle)

The purpose of this subtask is to develop a statistical representation of valid K_{Ic} data for irradiated RPV steels from available elastic-plastic fracture toughness data. In the estimation of failure probabilities for RPVs subjected to postulated pressurized thermal-shock loadings, it is necessary to employ realistic statistical representations of both flaw size and fracture toughness. The rationally based statistical model of weak-link behavior incorporated in ASTM Standard E1921 and available large-scale experimental fracture mechanics data, are the potential bases for developing an improved representation of the statistical behavior of valid K_{Ic} data, with the expectation that uncertainties will be less than those resulting from the present method.

(Milestone 2.4.A) The draft letter report has been completed. An initial review resulted in the identification of some minor changes as well as the need for preparation of an example calculation to be incorporated in the report. The following statements from the draft abstract of the letter report are provided:

“A statistical representation of valid K_{Ic} data for the ferritic steels typically used in structures, piping, and pressure vessels has been derived by combining the principles of the elastic-plastic Master Curve of American Society for Testing and Materials (ASTM) E 1921 and the criterion for validity under elastic conditions contained in ASTM E 399. By all evidence, the results obtained agree well with the American Society of Mechanical Engineers (ASME) K_{Ic} database, therefore offering a promising approach for estimating values of K_{Ic} and their statistics based on small specimen fracture toughness data.”

The draft letter report was submitted to the NRC Program Manager in December. It was also sent to three technical experts outside of ORNL for independent review.

Subtask 2.5 (formerly 2.10): 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 2.5.A formerly 2.10.A) With the completion of the exposure parameters calculations for the first metallurgical specimens (KS-01 specimens) irradiated in HSSI IAR facility, a draft report was completed and reviewed. This report will either be incorporated as appendices in appropriate NUREG reports reporting on specimens whose dosimetry was calculated from this report or prepared as a separate letter report. Additionally, radiometric dosimeter sets will be prepared for each IAR capsule shelf so as to provide a more accurate characterization of the fluences as specimens are shuffled within the irradiation facility to maximize irradiation efficiency.

(Milestone 2.5.B formerly 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.

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_0 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_{Ic} 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. Additional 0.5 T C(T) specimens have been fabricated and testing is underway.

(Milestone 2.6.A) All testing has been completed on this project. A presentation and paper on this subject were prepared and delivered by R. K. Nanstad at the IAEA Specialists' Meeting on Master Curve in Prague, Czech Republic, in September. The paper will be published in the IAEA meeting proceedings.

(Milestone 2.6.B) Additional scanning electron fractography has been performed to evaluate the fracture mode of the specimens previously tested at the highest temperatures (room temperature and above). The results have confirmed failure by intergranular fracture and have also confirmed 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.

A total of about 50 compact specimens of 0.5T, 1T, and 2T were tested from -125 to 100°C , with brittle intergranular fracture up to 50°C . The fracture toughness vs temperature relationship appears to follow the master curve shape up to about $150 \text{ Mpa}\sqrt{\text{m}}$ with an apparent T_0 of -100°C . However, the ductile to brittle transition-temperature behavior is significantly different than that observed for cleavage fracture in that brittle intergranular fracture is still observed for this material at test temperatures up to 150°C above the master curve T_0 . Additionally, the relationship between fracture toughness and Charpy toughness was significantly different from cleavage fracture results.

(Milestone 2.6.C) The draft letter report has been completed and is currently in the review process. It will be submitted to the NRC Program Manager in April. Results of this project were incorporated in a presentation at the NRC Workshop on Fracture Mechanics in Rockville on February 20-21.

Subtask 2.7: Sub-sized 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). Sub-sized 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) The testing and analysis of specimens has been completed. These specimens were machined from three blocks of materials 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. However, a series of subsize specimens of JRQ steel has also been completed. The specimens are 0.2TC(T) and 0.4TC(T), and 5×5 mm and 5×10 mm SE(B) specimens. Results of this project were incorporated in a presentation at the NRC Workshop on Fracture Mechanics in Rockville on February 20-21. A letter report is in preparation.

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 identify issues and make recommendations for the use of surrogate or non-identical materials in the assessment of fracture toughness of RPV steels. In many cases, surveillance programs for RPVs include specimens of a material that are not identical to the critical material in the RPV and test results from those surveillance specimens are used to represent the critical material in RPV analysis. This issue has been identified as an overarching issue in that a more complete understanding of most other issues is needed in order to reduce the uncertainties associated with material variability.

(Milestone 2.8.A) 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. A different methodology is being evaluated for potential application to this issue. The methodology involves a combination of non-linear estimators including domain models, neural networks, vector space methods, and nearest neighbor regressions. The evaluation will examine in a very preliminary manner, whether the methodology appears applicable to the issue and whether it can be implemented in a relatively straightforward manner. This effort, which began in July, has been completed except for the final report to the HSSI Program Manager, which is scheduled for the end of March.

(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.

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 thermal mitigation procedures to irradiated RPVs. The first will address the effects of temper

embrittlement on the coarse-grained HAZ in RPV steels. The second will examine the effects of reirradiation on K_{Jc} and K_{Ja} 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 in-part using specimens supplied by the Swiss HSK and PSI.

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

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 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 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, further studies are required to resolve the issue.

The first phase of this project 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.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, has been completed and will be sent to the NRC Program Manager during the next reporting period.

(Milestone 3.1.B) As noted in a 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 (formerly 3.3): Evaluation of Reirradiated JRQ Specimens (R. K. Nanstad, E. T. Manneschildt, 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, 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 various studies sponsored by the IAEA and is under consideration as a reference material for various other RPV studies, 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. Testing of irradiated specimens is dependent upon the availability of suitable hot-cell facilities.

(Milestone 3.2.A formerly 3.3.A) A total of 46 Charpy V-notch impact specimens of the JRQ plate, which were previously irradiated, annealed, and reirradiated by PSI, were tested in the ORNL hot cells during the first phase of the joint project in 2001. A presentation on this work, that included previous work by PSI, was 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 was coauthored by Ph. Tipping (Swiss HSK), G. Waeber (PSI), and D. Kalkhof (PSI). A previous progress report graphically showed the results. Completion of the Charpy impact testing is now anticipated for late March and initiation of the precracked Charpy fracture toughness testing is anticipated for April, dependent on hot cell availability.

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

The purpose of this subtask is to evaluate the effects of irradiation on fracture-toughness testing 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.B formerly 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.

Subtask 4.2: (formerly 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. 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.
2. Collaboration with AEA-Technology in the United Kingdom regarding fracture toughness testing and temper embrittlement of RPV HAZs.
3. Collaboration with institutes in the Czech Republic, Germany and Finland on fracture toughness with small specimens in support of MC evaluations.
4. Collaboration with PSI in Switzerland on evaluation of reirradiation effects.
5. 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.
6. Participation, including membership on the Executive Committee, in the International Group on Radiation Damage Mechanisms (IGRDM).
7. 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.
8. Collaboration with NRI, Rez (Czech Republic) in the area of microstructural evolution in RPV steels as a consequence of reirradiation.
9. Collaboration with MPA-Stuttgart in Germany regarding applicability of the master curve to highly embrittled RPV steels.
10. Collaboration with researchers at the University of Lille, France, in the area of primary radiation damage simulation.

(Milestone 4.2.A, formerly 4.4.B) R. K. Nanstad, as secretary of the International Group on Radiation Damage Mechanisms (IGRDM) in Pressure Vessel Steels, has updated the IGRDM membership list and is revising the IGRDM charter. The next meeting of the IGRDM will be held in Awaji Island, Japan, from 20-24 May, 2002; preliminary organization of the meeting is a cooperative effort between the secretary, the chairman (T. J. Williams, Rolls-Royce), the technical area coordinators, and the local host committee (chaired by Dr. Naoki Soneda,

CRIEPI). A total of 87 presentations have been offered by the members and the preliminary draft of the program has been prepared. R. K. Nanstad, M. A. Sokolov, R. E. Stoller, and M. K. Miller have all sent preregistration information to the local host committee for the purpose of securing adequate lodging, while all four members have also recently submitted proposed presentation titles as required.

Subtask 4.3: (formerly 4.5) Technical Assistance (R. K. Nanstad and M. A. Sokolov)

The purpose of this subtask is to provide special analytical, experimental, and administrative support to the NRC in resolving various regulatory issues related to irradiation effects. Specific activities will be identified, on an as-needed basis, by the NRC Project Manager. Examples of such activities include: 1) evaluation of the effects of post-weld heat treatment (PWHT) on the copper solubility and fracture toughness of unirradiated RPV steels and 2) machining of material removed from retired irradiated RPVs for evaluation of through-thickness attenuation of irradiation embrittlement.

(Milestone 4.3.B formerly 4.5.F) A presentation of progress on the PWHT study was made at the IGRDM meeting in September in Leuven, Belgium, and was also made at the IAEA Specialists' Meeting on Radiation Embrittlement and Mitigation in Gloucester, U.K., 14-17 May 2001. Because of hot cell scheduling issues, testing of the irradiated subsize Charpy specimens has not been conducted, but is now anticipated for March-April. A letter report will be prepared following completion of all testing and evaluation. A paper, for which M. K. Miller was the lead author, with 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. Additionally, a paper has been published in the Journal of Materials Science and Engineering:

Miller, M.K., Babu, S.S., Sokolov, M.A., Nanstad, R.K., and Iskander, S.K., "Effect of stress relief temperature and cooling rate on pressure vessel steel welds," *Mater. Sci. Eng. A* 327 (2002) 76-79.

(Milestone 4.3.C, formerly 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 June of 2002 due to personnel reductions.

(Milestone 4.3.D formerly 3.2.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 specimens is about 4×10^{19} n/cm² and the irradiation has been completed. The specimens have been received at the ORNL hot cells and will be scheduled for testing in the near future.

(Milestone 4.3.E formerly 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, J. T. Hutton, L. E. Creech, M. Suzuki, K. Onizawa, E. T. Manneschildt, 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.F) An effort to evaluate the tensile properties of A516 grade 70 with a safe-end of forged stainless steel 316 pipe obtained from Battelle has been initiated. The weld is about three to four in. wide while the safe-end is about 4 in. wide. The specimens will be oriented axially, meaning the length direction of the pipe, i.e., across the weld.

(Milestone 4.3.G, formerly 4.2.A) The NUREG report, K. Onizawa, E. van Walle, W. Pavinich, and R. K. Nanstad, UT-Battelle, LLC, Oak Ridge, Tenn., *Results and Analysis of The ASTM Round Robin On Reconstitution*, USNRC NUREG/CR-XXXX, (ORNL/TM-2001/34) was submitted to the NRC during this reporting period.

Subtask 4.4: Obtaining RPV material for SONGS-1 (R. K. Nanstad, R. E. Stoller, and T. M. Rosseel)

The purpose of this subtask is to obtain Southern California Edison's, the owner of San Onofre Nuclear Generating Station (SONGS) Unit 1 Reactor, consent and assistance in obtaining trepans from the SONGS-1 RPV and to provide a preliminary estimate of the potential problems that could be encountered during this operation as well as a preliminary estimate of the cost to obtain the trepans. This effort, which would permit the evaluation of through-thickness attenuation of irradiation embrittlement of a service-irradiated RPV, will be coordinated with EPRI. A letter report will also be prepared that describes the progress and status of that effort.

(Milestone 4.4.A) The draft letter report by R. E. Stoller and R. K. Nanstad, "A Proposal for Sampling the SONGS-1 Reactor Pressure Vessel," (ORNL/NRC/LTR-02/12), which incorporates the conceptual study of the scope and cost estimate to remove up to six, five-inch-diameter through-wall trepan samples from the San Onofre (SONGS) Unit 1 pressure vessel, was completed and submitted to the NRC project manager for review. Unless changes are indicated, it is anticipated that the report will be issued in final form during the next reporting period.

Task 5: Modeling & Microstructural Characterization 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 three subtasks will comprise: (1) theoretical modeling and data analysis; (2) experimental investigations; and, (3) maintaining and updating the Embrittlement Data Base (EDB). The modeling work will include 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 will focus on detailed microstructural characterization of RPV materials in relevant conditions, including long-term, thermally-aged and high-fluence irradiated materials. The information obtained from the experiments and microstructural characterization will be used to support validation of the

theoretical models. Further model verification will be carried out through use of the mechanical property data contained in the EDB, and data generated in other experiments coordinated by this task. Updated versions of the EDB will be issued as appropriate.

The major areas of inquiry include: (a) the effects of chemical composition; (b) the role of displacement rate (neutron flux); (c) damage attenuation through the RPV wall; and, (d) potential new hardening mechanisms and embrittlement behavior at very high fluence. 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 and the international community.

The nature of the modeling and data analysis carried out under this task requires that it extend over the lifetime of the program. Model development and validation is coordinated with the experimental activities in an iterative fashion. Work and milestone schedules will be contingent on available funding.

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

The modeling of damage evolution will focus on the development of an integrated microstructural model that includes components developed at ORNL and by other NRC contractors and will provide the basis of an improved embrittlement model. The integrated model may include thermodynamic components to account for chemical effects that may be particularly important at high-fluence and in low-copper steels. A more detailed treatment of point defect and solute clustering will also be pursued.

(Milestone 5.1.B) 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, 2000.

Subtask 5.2: Microstructural Characterization (M. K. Miller and K. F. Russell)

APFIM characterization will be used to determine whether additional radiation-induced phases are forming. 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.

(Milestone 5.2.A) Two abstracts, noted below, have been prepared for submission to the Joint 47th International Field Emission Symposium / 15th International Vacuum Microelectronic Conference to be held in Lyon France July 7-11.

M. K. Miller, K.F. Russell, M. A. Sokolov and R. K. Nanstad, “Atom Probe Tomography of Radiation-Sensitive KS-01 Weld” and

M. K. Miller, K. F. Russell, B. D. Wirth and G. R. Odette, “APT/SANS Characterization of Nanometer Cu Precipitates in Irradiated Model Alloys.”

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.

Subtask 5.3: Modeling and Embrittlement Data Base (formerly 7.1) (J.-A. Wang)

This subtask was, until March 1, 1999, part of the Embrittlement DataBase (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 data bases used by vendors, utilities, and service laboratories in the pressure vessel irradiation surveillance program. The specific activity of the subtask is to maintain and update the EDB. Additional work on statistical analysis of toughness databases will also be performed. The purpose of this effort is to design a new data fitting procedure to generate a new multi-space trend surface that can properly reflect the inhomogeneity of the surveillance materials, and utilize this multi-space trend surface to link and to project the surveillance test results to that of reactor pressure vessel steels.

(Milestone 5.3.A) 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.

(Milestone 5.3.B) The feasibility study for developing a new fitting model for surveillance materials is continuing and will be completed by the end of March.

Task 6: Test Reactor Irradiation Coordination (K. R. Thoms)

This task provides the support required to supply and co-ordinate 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) Irradiation of the ORNL specimens in the HSSI-IAR 1 and 2 irradiation facilities continued during the latter portion of this reporting period.

At the end of the previous reporting period, the irradiation facilities at FNR remained shut down due to problems with a micro-dcs (digital control system) plus, the controller used to operate the HSSI-IAR irradiation facilities. The controller was shipped to ORNL for evaluation. The initial evaluation revealed problems with the unit's operating system software. To reduce the down time, a search was begun at ORNL for a temporary (loaner) replacement until the IAR unit could be repaired or replaced with one from the manufacturer. Two separate units were identified as possible replacements but both were found to have different operating systems installed by the manufacturer and therefore could not be used as a substitute.

The original micro-dcs manufacturer suggested that it be returned to them for repair, which could take approximately 10 to 12 weeks. However, the ORNL instrument technicians were able to determine that the unit's firmware, the part of the operating system installed by the manufacturer, seemed to be intact. They were further able to determine that the operating program on the internal flashcard, installed by ORNL programmers, had been damaged by multiple virus attacks via the internet. This is believed to have occurred during remote operating condition inquiries and data retrieval operations.

The ORNL operating program was re-installed on the internal flashcard of the original micro-dcs and tested over several days to ensure that the system was operating normally. The unit was then shipped back to FNR and installed in the IAR control systems cabinet by FNR staff. Since it was not possible to install virus protection on the unit, the ORNL instrument technicians modified the facilities operating systems located at the FNR such that the micro-dcs would be protected by virus protection installed on a sister computer, called the HSSI computer, which is used for data storage. The only avenue to the micro-dcs via the internet is now through the HSSI computer firewall. Its virus protection is now updated on a weekly basis.

Upon completion of the new programming and virus protection firewall installation, the facilities resumed operation with the startup for reactor half-cycle 468B on February 20, 2002. During the 7.3 days of reactor half-cycle 468B, the IAR irradiation facilities received a total of 188 EFPH (effective full power hours). 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 9,687 EFPH. At the end of this reporting period, the second group of specimens had been irradiated for a total of 9875 EFPH. These facilities have been in service for a total of 14,584 EFPH.

(Milestone 6.1.B) The NUREG report, D. W. Heatherly, K. R. Thoms, and M. T. Hurst, UT-Battelle, LLC, Oak Ridge, Tenn., *Heavy-Section Steel Irradiation Program's Reusable Irradiation Facility*, USNRC NUREG/CR-XXXX, (ORNL/TM-2002/77) was submitted to the NRC program monitor at the end of the reporting period.

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) Irradiation of the UCSB specimens in the UCSB irradiation facility continued during the latter portion of this reporting period.

At the end of the previous reporting period, the HSSI-UCSB irradiation facilities at FNR remained shut down due to problems with a micro-dcs plus, the controller used to operate the HSSI-IAR irradiation facilities. The controller had just been received at ORNL for evaluation. It was eventually determined that the unit's operating system had been damaged by virus attacks via the internet. The operating program was re-installed into the unit and the unit shipped back to FNR. The unit was re-installed into the IAR control cabinet at FNR, but only after the system was modified so that virus protection for the micro-dcs was provided via a sister computer firewall. For more details, please see Milestone 6.1.A.

Upon completion of the revised programming and virus protection for the IAR facilities, the HSSI-UCSB irradiation facility resumed operation with the startup for reactor half-cycle 468B, which began on February 20, 2002. During the 7.3 days of reactor half-cycle, 468B the irradiation facility received a total of 188 EFPH.

At the beginning of this reporting period, the HSSI-UCSB facility and original specimen compliment had been irradiated for a total of 21,548 EFPH. At the end of this reporting period, the facility and original specimen compliment had been irradiated for a total of 21,736 EFPH. The latest irradiation plan received from the UCSB experimenters indicated that the final specimens would be removed from the facility after 13,500 EFPH. Additional specimen irradiations have been added to the original plan and at the end of this reporting period the UCSB irradiation program had obtained 161% of the original desired irradiation time.

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

This task was until March 1, 1999, the Embrittlement DataBase (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 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 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 task has been incorporated into Task 5.3

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 February 19-21, J. G. Merkle, R. K. Nanstad, T. M. Rosseel, and M. A. Sokolov traveled to Rockville, Maryland, to participate in and make presentations at the NRC Materials Engineering Branch Workshop on Fracture Mechanics Technology.

On February 24-27, R. K. Nanstad traveled to Los Angeles, California, to participate in meetings of the ASME Boiler and Pressure Vessel Code.

4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:

T. M. Rosseel, "Heavy Section Steel Irradiation (HSSI) Program Overview," presented at the NRC Materials Engineering Branch Workshop on Fracture Mechanics Technology, Rockville, MD, February 21, 2002.

M. A. Sokolov, R. K. Nanstad, J. G. Merkle, "Irradiation Effects on Fracture Toughness Curve Shift and Shape, and Use of Relatively Small Specimens," presented by M. A. Sokolov at the NRC Materials Engineering Branch Workshop on Fracture Mechanics Technology in Rockville, Maryland, February 20-21, 2002.

R. K. Nanstad, "Relationship of Master Curve to Intergranular Fracture," presented at the NRC Materials Engineering Branch Workshop on Fracture Mechanics Technology in Rockville, Maryland, February 20-21, 2002.

R. K. Nanstad, M. A. Sokolov, and J. G. Merkle, "Effects of Materials Variability on Fracture Toughness," presented by R. K. Nanstad at the NRC Materials Engineering Branch Workshop on Fracture Mechanics Technology in Rockville, Maryland, February 20-21, 2002.

R. K. Nanstad and G. R. Odette, "Major Technical Issues Regarding Irradiation Effects on Reactor Pressure Vessel Steels," presented by R. K. Nanstad at the NRC Materials Engineering Branch Workshop on Fracture Mechanics Technology in Rockville, Maryland, February 20-21, 2002.

Miller, M.K., Babu, S.S., Sokolov, M.A., Nanstad, R.K., and Iskander, S.K., "Effect of stress relief temperature and cooling rate on pressure vessel steel welds," *Mater. Sci. Eng. A* 327 (2002) 76-79.

5. PROPERTY ACQUIRED:

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

| Item | Cost (\$) |
|-------------|------------------|
| None | |

6. PROBLEM AREAS:

None

7. PLANS FOR THE NEXT REPORTING PERIOD:

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

FINANCIAL STATUS
for W6953

Reporting Period: 1/28/02-2/24/02

| | Current Month | Fiscal Year to Date | Cumulative Project to date |
|---|------------------|------------------------|-------------------------------|
| I. Direct Staff Effort | 9 MM | 3.4 MY | 41.8 MY |
| II. A. Direct Lab Staff Effort (\$) | | | |
| Direct Salaries | 67,366 | 336,927 | 4,181,809 |
| Materials and Services | 8,823 | 15,017 | 402,462 |
| ADP Support | 21 | 137 | 2,341 |
| Subcontracts | 8,184 | 80,268 | 580,465 |
| Travel | 6,133 | 15,570 | 158,438 |
| Other: NRC-PO Tax | 2,755 | 12,009 | 186,509 |
| General and Administrative | 33,883 | 160,875 | 1,896,078 |
| Total UT-Battelle Costs | 127,165 | 620,803 | 7,408,102 |
| B. DOE Federal Admin. Costs | 3,815 | 18,624 | 60,537 |
| TOTAL PROJECT COSTS | 130,980 | 639,427 | 7,468,639 |
| Percentage of available cumulative funds costed | | 90 | |
| Percentage of available current FY funds costed | | 44 | |
| Funds Remaining | | 836,361 | |
| Commitments: | | 170,571 | |
| BA Remaining | | 665,790 | |
| BA Remaining Less Projected FAC | | 641,430 | |

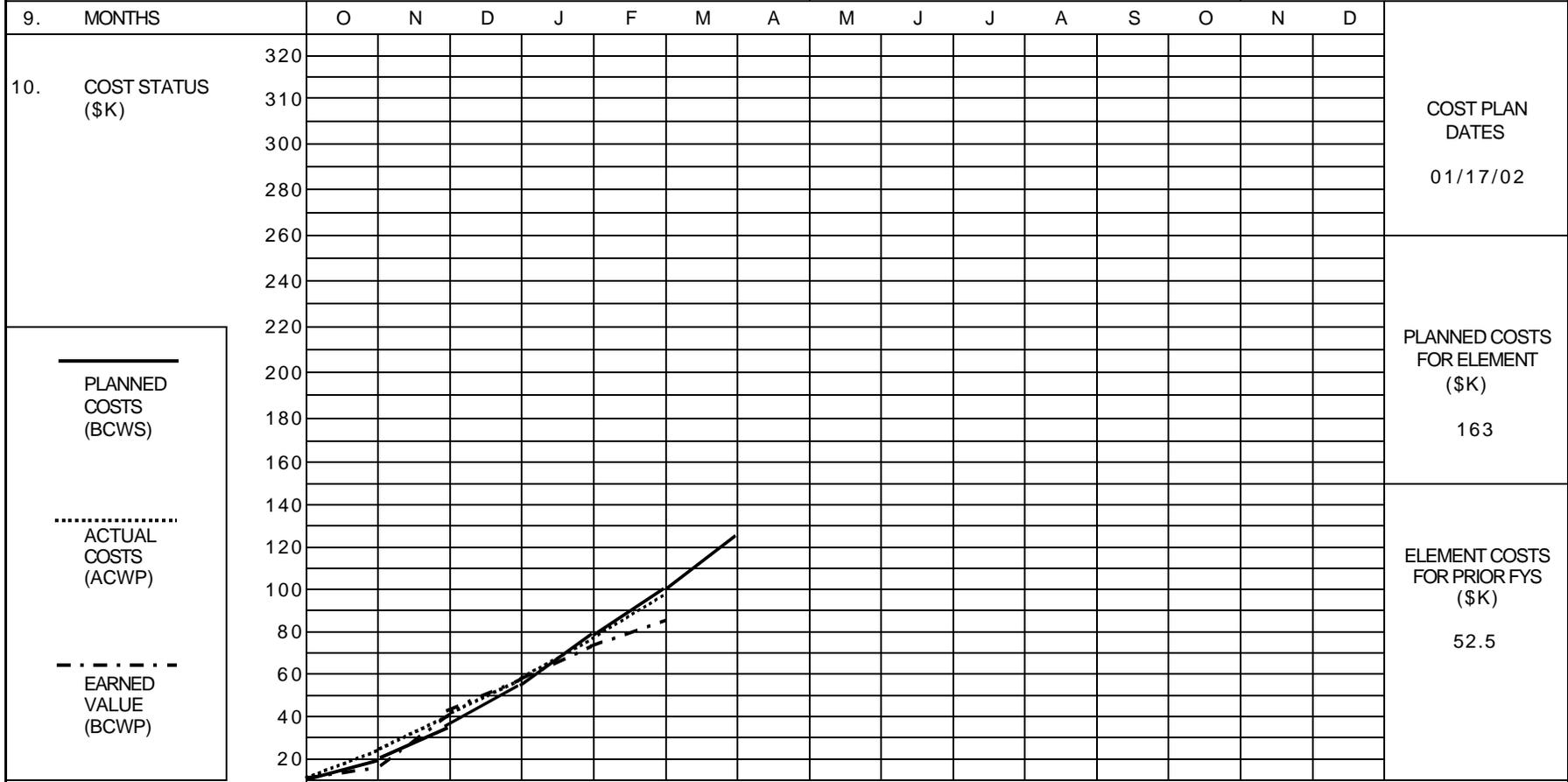
III. Funding Status

| Prior FY Carryover | FY 02 Projected Funding Level | FY 02 Funds Received to Date | FY 01 Funding Balance Needed | Cumulative Amt. Obligated | Cumulative Amt. Costed |
|-----------------------|----------------------------------|---------------------------------|---------------------------------|------------------------------|---------------------------|
| 514,538 | 2,225,000 | 946,000 | 1,279,000 | 8,305,000 | 7,468,639 |

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 1/28/2002 - 2/24/2002 | | | | | 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) | | 2000 | | | | | | | | | | | | | | | COST PLAN DATES 01/17/02 | | | | |
| | | 1900 | | | | | | | | | | | | | | | | | | | |
| | | 1800 | | | | | | | | | | | | | | | | | | | |
| | | 1700 | | | | | | | | | | | | | | | | | | | |
| | | 1600 | | | | | | | | | | | | | | | | | | | |
| | | 1500 | | | | | | | | | | | | | | | | | | | |
| | | 1400 | | | | | | | | | | | | | | | | | | | |
| | | 1300 | | | | | | | | | | | | | | | | | | | |
| | | 1200 | | | | | | | | | | | | | | | | | | | |
| | | 1100 | | | | | | | | | | | | | | | | | | | |
| | | 1000 | | | | | | | | | | | | | | | PLANNED COSTS FOR ELEMENT (\$K) 1460 | | | | |
| | | 900 | | | | | | | | | | | | | | | | | | | |
| | | 800 | | | | | | | | | | | | | | | | | | | |
| | | 700 | | | | | | | | | | | | | | | | | | | |
| | | 600 | | | | | | | | | | | | | | | | | | | |
| | | 500 | | | | | | | | | | | | | | | | | | | |
| | | 400 | | | | | | | | | | | | | | | | | | | |
| | | 300 | | | | | | | | | | | | | | | | | | | |
| | | 200 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | ELEMENT COSTS FOR PRIOR FYS (\$K) 514 | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| | | 100 | | | | | | | | | | | | | | | | | | | |
| ACCRUED COSTS (\$K) | PLANNED | 126 | 126 | 129 | 198 | 157 | 152 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | ACTUAL | 77 | 97 | 181 | 139 | 126 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | EARNED | 105 | 128 | 131 | 143 | 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | CUM. PLANNED | 126 | 252 | 381 | 579 | 736 | 888 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | CUM. ACTUAL | 77 | 174 | 355 | 494 | 620 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | CUM. EARNED | 105 | 233 | 364 | 507 | 619 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| 11. REMARKS Total/Planned Cost reflects reduction in funds received due to FAC. | | | | | | | | | | | | | | | | | | | | | |

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT HSSI - 1. Program Management | 2. REPORTING PERIOD 1/28/2002 - 2/24/2002 | 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 |



| | | | | | | | | | | | | | | | | |
|---------------------|--------------|----|----|----|----|-----|-----|---|---|---|---|---|---|---|---|---|
| ACCRUED COSTS (\$K) | PLANNED | 18 | 16 | 19 | 24 | 23 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | ACTUAL | 22 | 18 | 17 | 21 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | EARNED | 15 | 25 | 13 | 18 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CUM. PLANNED | 18 | 34 | 53 | 77 | 100 | 123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CUM. ACTUAL | 22 | 40 | 57 | 78 | 99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CUM. EARNED | 15 | 40 | 53 | 71 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

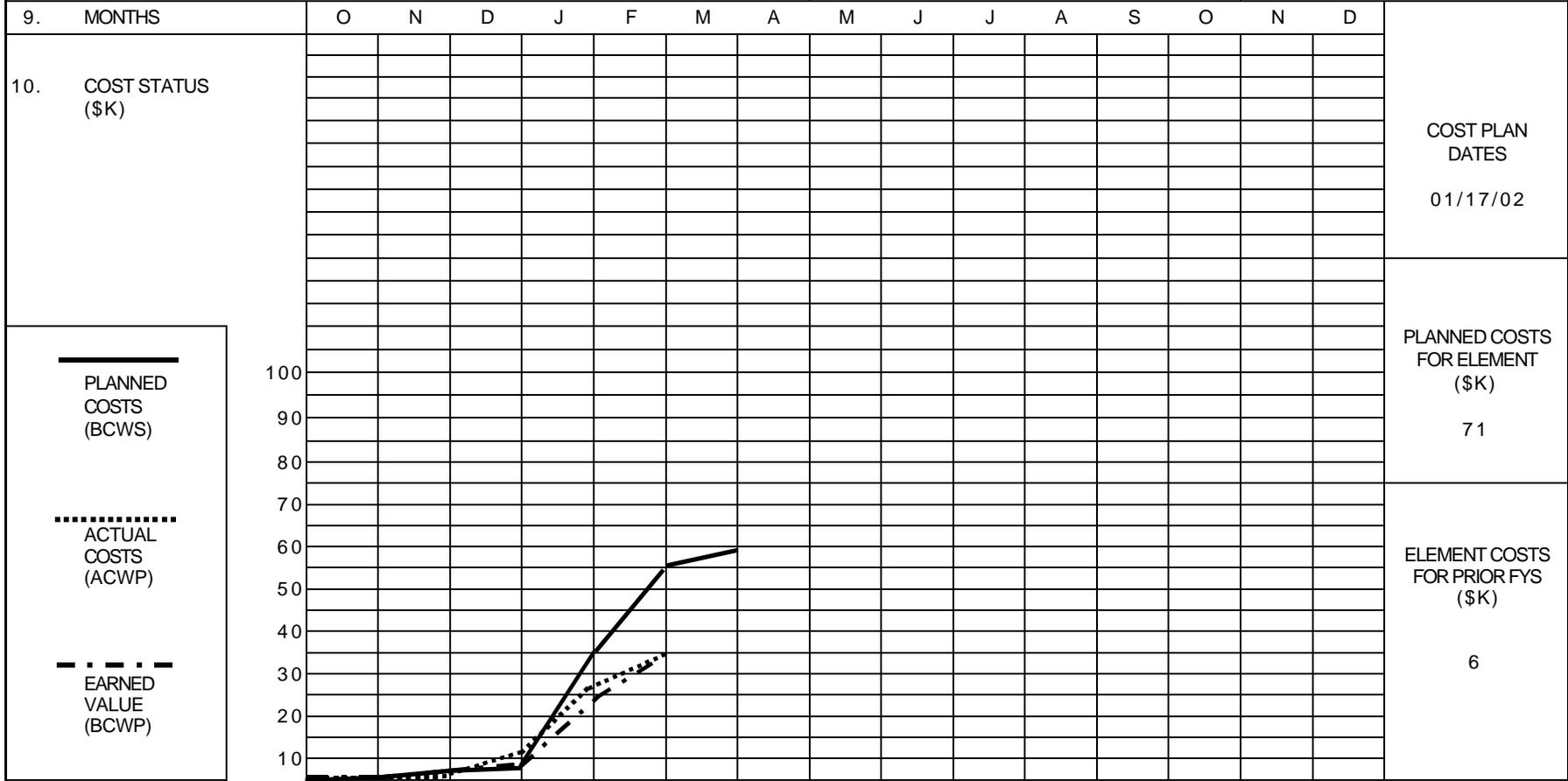
11. REMARKS
Total/Planned Cost reflects reduction in funds received due to FAC.

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT HSSI - 3. Irradiation Embrittlement of RPV Steel | 2. REPORTING PERIOD 1/28/2002 - 2/24/2002 | 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 1/17/02 |
| <div style="border: 1px solid black; padding: 5px; width: fit-content;"> <p>— PLANNED COSTS (BCWS)</p> <p>..... ACTUAL COSTS (ACWP)</p> <p>- - - - EARNED VALUE (BCWP)</p> </div> | 600 | | | | | | | | | | | | | | | PLANNED COSTS FOR ELEMENT (\$K) 360 ELEMENT COSTS FOR PRIOR FYS (\$K) 178 |
| | 550 | | | | | | | | | | | | | | | |
| | 500 | | | | | | | | | | | | | | | |
| | 450 | | | | | | | | | | | | | | | |
| | 400 | | | | | | | | | | | | | | | |
| | 350 | | | | | | | | | | | | | | | |
| | 300 | | | | | | | | | | | | | | | |
| | 250 | | | | | | | | | | | | | | | |
| | 200 | | | | | | | | | | | | | | | |
| | 150 | | | | | | | | | | | | | | | |
| | 100 | | | | | | | | | | | | | | | |
| | 50 | | | | | | | | | | | | | | | |
| ACCRUED COSTS (\$K) | 31 | 43 | 38 | 56 | 48 | 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| PLANNED ACTUAL | 3 | 7 | 92 | 14 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| EARNED | 30 | 41 | 41 | 35 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| CUM. PLANNED | 31 | 74 | 112 | 168 | 216 | 272 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| CUM. ACTUAL | 3 | 10 | 102 | 116 | 117 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| CUM. EARNED | 31 | 72 | 112 | 147 | 177 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

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

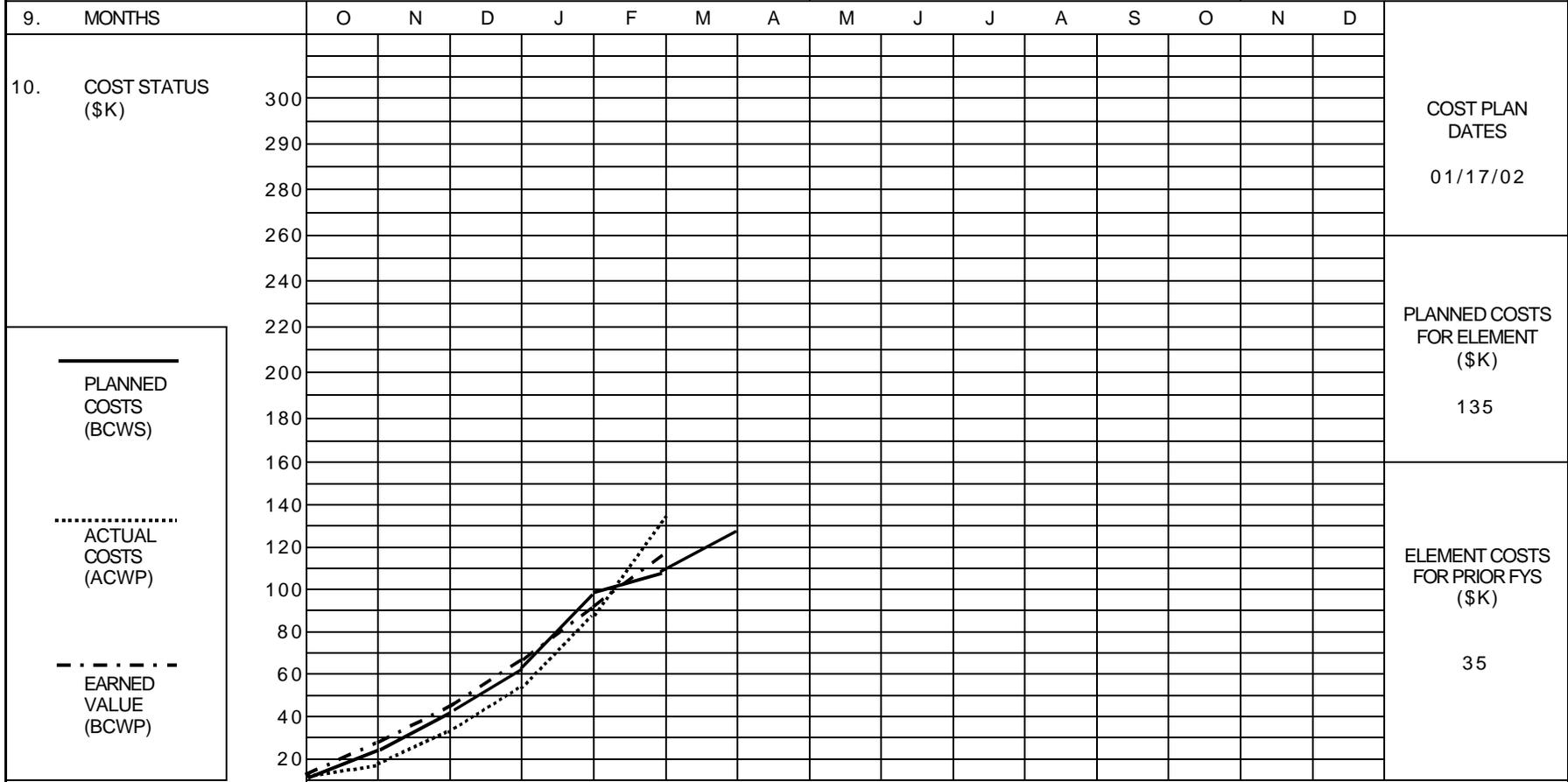
| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT HSSI - 5. Modeling and Microstructural Analysis | 2. REPORTING PERIOD 1/28/2002 - 2/24/2002 | 3. JCN NO. W6953 |
| 4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831 | 5. CONTRACT PERIOD FY 1998 - 2003 | 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 |



| | | | | | | | | | | | | | | | | |
|---------------------|--------------|---|---|----|----|----|----|---|---|---|---|---|---|---|---|---|
| ACCRUED COSTS (\$K) | PLANNED | 2 | 3 | 3 | 27 | 20 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | ACTUAL | 0 | 5 | 10 | 16 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | EARNED | 1 | 2 | 3 | 19 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CUM. PLANNED | 2 | 5 | 8 | 35 | 55 | 59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CUM. ACTUAL | 0 | 1 | 11 | 27 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CUM. EARNED | 1 | 3 | 6 | 25 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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

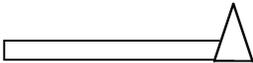
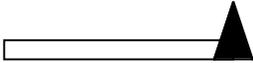
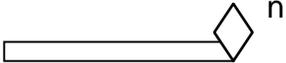
| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT HSSI - 6. Irradiation Coordination | 2. REPORTING PERIOD 1/28/2002 - 2/24/2002 | 3. JCN NO. W6953 |
| 4. CONTRACTOR (NAME AND ADDRESS) OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831 | 5. CONTRACT PERIOD FY 1998 - 2003 | 6. ACTIVITY 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 |



| ACCRUED COSTS (\$K) | PLANNED | ACTUAL | EARNED | CUM. PLANNED | CUM. ACTUAL | CUM. EARNED | | | | | | | | | | |
|---------------------|---------|--------|--------|--------------|-------------|-------------|---|---|---|---|---|---|---|---|---|---|
| | 23 | 18 | 23 | 35 | 14 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 15 | 17 | 20 | 37 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 26 | 19 | 22 | 26 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 23 | 41 | 64 | 99 | 113 | 129 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 15 | 32 | 52 | 89 | 134 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 26 | 45 | 67 | 93 | 117 | 0 | 0 | 0 | 0 | 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 - 2. Fracture Toughness Transition & MC Methodology | | 2. REPORTING PERIOD 1/28/2002 - 2/24/02 | | 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 | FY 2001 | | FY 2002 | | FY 2003 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J |
| 2.1.A. | Continue to accumulate data on Comparison of CVN and Fracture Toughness Shifts | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.A. | Irradiate Midland and Hi-Ni Specimens | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.B. | Receive Specimens | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.C. | Test Unirradiated & Irradiated KSØ1 for Master Curve | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.D. | Test Unirradiated & Irradiated Hi-Ni Midland Weld Specimens | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.E. | Draft Letter and NUREG Report for KSØ1 | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.F. | Draft Letter and NUREG Report for Midland Weld | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| 2.2.G. | Draft Letter and NUREG Report for High Ni | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | [Bar] | | | | | | | | | | | | | |
| | | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J |
| | | FY 2001 | | | | FY 2002 | | | | FY 2003 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11. REMARKS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| 1. CONTRACT REPORTING ELEMENT HSSI - 2. Fracture Toughness Transition & MC Methodology | | 2. REPORTING PERIOD 1/28/2002 - 2/24/02 | | 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 | FY 2001 | | | | | FY 2002 | | | | | FY 2003 | | | | | | | | | | | | | | | | | | | | | | | |
| | | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J |
| 2.7.A. | Complete Testing of Subsize Specimens | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.7.B. | Testing of JRQ Plate | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.7.C. | Complete Letter Report on Results of Subsize Specimen Fracture Toughness Tests | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.8.A.1 | Complete Assembly and Compilation for Irradiated Materials for Surrogate Materials DB | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.8.A.2 | Complete Statistical Analysis of Data Base for Irradiated Materials | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2.8.B. | Submit NUREG Report | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J |
| | | FY 2001 | | | | | FY 2002 | | | | | FY 2003 | | | | | | | | | | | | | | | | | | | | | | | |
| 11. REMARKS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

