

ORNL/HSSI (W6953)/MLSR-2002/10

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

**Monthly  
Letter Status  
Report**

**July 2002**

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HEAVY-SECTION STEEL IRRADIATION  
PROGRAM  
JCN W6953

MONTHLY LETTER STATUS REPORT  
FOR

JULY 2002

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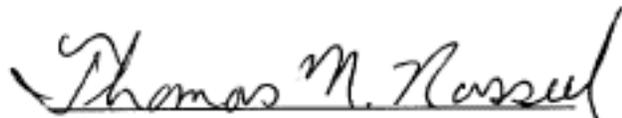
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## PREFACE

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**  
**July 2002**

<b>Job Code Number:</b>	<b>W6953</b>
<b>Project Title:</b>	<b>Heavy-Section Steel Irradiation Program</b>
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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) Discussions with the NRC concerning midyear funding continued. Critical issues such as the CRDM tensile testing, cost growth associated with the use of the University of Michigan, Ford Nuclear Reactor (FNR), and replacement parts for the IAR facilities and fracture test equipment were emphasized.

(Milestone 1.2.B) Irradiation of the ORNL and University of California Santa Barbara's specimens in the HSSI facilities at the University of Michigan FNR continued during this reporting period without incident. However, the future status of the FNR remains uncertain without additional support from the DOE Nuclear Science and Technology Office and from the University Administration.

## **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. No significant progress during this reporting period. However, as they become available, additional data sets will be analyzed and a revised database assembled.

## 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  $8.4 \times 10^{18}$  n/cm<sup>2</sup> 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  $2.5 \times 10^{19}$  n/cm<sup>2</sup> (>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 on schedule in 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 during the August-September time frame.

(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/cm<sup>2</sup> (>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 was primarily suspected to be due, at least in part, to the occurrence of intergranular

fracture in the test specimens because the same behavior was 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. Moreover, the irradiation-induced Charpy 41-J shift and  $T_0$  shift are about the same for the KS-01 steel, whereas the relationship for the intergranular fracture study in Subtask 2.6 revealed that material did not conform to the expected relationship between the two measures of toughness. Thus, the contribution of IGF is not clear and the nonconformance of the KS-01 irradiated fracture toughness data may be predominantly due to the high degree of irradiation embrittlement. Further statistical analysis will be performed with these data.

As noted previously, three additional tensile tests have been completed at 250, 200, and  $-100^\circ\text{C}$ . These results were expected to shed light on the effects of the intergranular fracture observations relative to expected irradiation-induced hardening. The yield and ultimate strengths for these tests exhibited the expected irradiation-induced strengthening, indicating that intergranular fracture was not the dominant fracture mechanism.

A draft NUREG report was submitted to the NRC Program Manager at the end of June, a presentation was made at the IGRDM meeting in Japan in May, and a presentation will be made at the ASTM International Symposium on Radiation Effects in Materials in Tucson, Arizona, June 2002. The draft NUREG report is currently undergoing internal review. Additionally, 12 irradiated precracked Charpy specimens of KS-01 are scheduled for testing in the ORNL hot cells during August or September.

(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) In preparation for the testing phase of this project, 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, “Statistical Representation of Valid  $K_{Ic}$  Data for Irradiated RPV Steels,” by J. G. Merkle, M. A. Sokolov, R. K. Nanstad, and D. E. McCabe, previously submitted to the NRC Program Manager, has now been completed following review and revisions. The abstract from the report is given below.

The HSSI Program at ORNL includes various tasks associated with evaluation of the fracture toughness Master Curve, including its application to operating commercial RPVs. 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. The equations derived are the direct result of the simultaneous solution of the equations for the Weibull size effect and the E 399 validity criterion. Both logic and experimental data support the approach presented. Specifically, extrapolation of the Weibull size effect to infinite specimen size produces an illogical result, and large-scale thermal shock data support the concept of  $K_{Ic}$ . The resulting equations for calculating tolerance bounds, cumulative probabilities, and probability density functions all exist in closed form. Furthermore, they preserve the present practice, justified by experiment, of treating the high-constraint fracture toughness of a steel as a material property independent of increases in component thickness and crack dimensions beyond those required for validity. By all evidence, the results obtained agree well with the ASME  $K_{Ic}$  database, as well as the data from both large and small specimens for HSST Plate 02 and the ORNL thermal shock experiments. These results, therefore, offer a promising approach for estimating values of  $K_{Ic}$  and their statistics based on small-specimen, fracture-toughness data. This result presents a distinct advantage for irradiated nuclear RPVs, for which only small surveillance specimens are available for testing.

The letter report will be published by the end of August.

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) No significant progress during this reporting period. However, 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 as noted previously. This report has been incorporated as an appendix of the KS01 NUREG report described in Task 2.2.

It is planned that radiometric dosimeter sets will be prepared for each IAR capsule shelf or cell so as to provide a more accurate characterization of the fluences as specimens are shuffled within the irradiation facility to maximize irradiation efficiency. These will be prepared prior to any additional specimens being added to the IAR.

(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  $K_{Jc}$  values obtained. This information can be obtained on the lower shelf and, in part, into the transition range.

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

The modified A302 grade B steel selected to evaluate intergranular-fracture effects on the universal MC shape assumption was specially heat treated to temper embrittle the material, and fracture-toughness testing was performed. In the analysis of the data, however, it became clear that additional testing was deemed necessary to allow for a more definitive conclusion regarding the relationship between the intergranular fracture results and the Master Curve. 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 activity. 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 has now been published in the IAEA meeting proceedings: R. K. Nanstad, D. E. McCabe, and J. G. Merkle, "Relationship

of Fracture Toughness From Intergranular Fracture to the Master Curve,” *Master Curve Testing and Results Application, TWG-LMNPP-01/3*, pp. 123-137, IAEA, Vienna, Austria, 2002.

(Milestone 2.6.B) 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 Mpa√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 under final review. It will be submitted to the NRC Program Manager in August. The results of this project were also incorporated in a presentation at the NRC Workshop on Fracture Mechanics in Rockville on February 20-21 and in a paper presented by R. K. Nanstad at the NATO Advanced Research Workshop in Kiev, Ukraine, 21-25 April 2002. That paper will be published in a NATO Technical Series book following technical review.

#### 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) As reported previously, the testing and analysis of specimens has been completed. These specimens were machined from three blocks of materials into 1TC(T) and precracked Charpy specimens for the size effect study. Two of the blocks are broken halves of 4TC(T) specimens of two A302B plates previously tested by the HSSI Program. The third block of material is the well-characterized Plate 13A. This study is specifically designed as an evaluation of the precracked Charpy specimen. 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 by 5 mm and 5 by 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 with completion anticipated in September.

### 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.

As noted in the last report, 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 has been completed by Jy-An Wang and a summary is presented below.

#### New Charpy Impact Test Curve Fitting Development

A new methodology that incorporates the chemical compositions into the Charpy trend curve was developed. The purpose of this new fitting procedure is to generate a new multispace topography that can properly reflect the inhomogeneity of the surveillance materials and utilize this multi-space trend surface to link and project the surveillance test results to that of reactor pressure vessel steels. Furthermore, based on this new approach, the advanced fitting procedure achieves a reduction in uncertainty by 27%, compared to that of conventional hyperbolic tangent fit procedures. However, caution should be exercised when using these fitting functions due to high-order nonlinearity. Additionally, the chemistry of the target materials should be within one-standard deviation of the mean chemistry from which the new fitting equation was developed.

(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.

### Subtask 2.9: Application of the Master Curve to Highly Embrittled Materials (M. A. Sokolov)

The purpose of this task is to determine the effect of the interaction of low-energy ductile crack initiation and intergranular fracture with cleavage in the transition region for highly embrittled materials. The approach used is to prepare up to twelve 0.4T C(T) specimens from previously irradiated and tested KS01 specimens and determine fracture toughness. These data will be compared with results from small and large compact specimens as well as pre-cracked Charpy specimens from the same material in the unirradiated and irradiated conditions.

(Milestone 2.9.A) The computer numerically controlled (CNC) milling machine in the hot cell has been exercised in preparation for machining of 0.4T compact specimens from the broken irradiated 1T compact specimens of KS-01 previously tested. Programming of the CNC system and design of fixtures has continued with final testing on the prototype machine expected during the next reporting period. These 0.4T specimens will be tested in the same general temperature range as the 1Ts described in Task 2.2 to expand the database further for this material, and will provide for a comparison of compact specimen results with those from the similar size pre-cracked Charpy specimens. This comparison is directed at the bias indicated in some precracked Charpy data that results in somewhat lower determinations of  $T_0$  relative to compact specimens.

Subtask 2.10: Investigate the Bias Term Added to  $T_0$  Values Determined from Pre-Cracked Charpy Specimens (R. K. Nanstad)

The purpose of this task is to perform a systematic study of the bias term added to  $T_0$  values determined from pre-cracked Charpy specimens, such as that used in the Kewaunee evaluation. The approach would utilize both analytical and experimental methods. HSSI Plate 02 material will be used since extensive C(T) data on this material are available.

(Milestone 2.10.A) Planning for this task has been initiated. The experimental phase will likely include 1T three-point bend specimens, precracked Charpy specimens with and without side-grooves, and Charpy thickness [10 mm (0.394 in.)] compact specimens. The issue of two different materials is also under consideration. Once a draft plan is internally developed, the plan will be discussed with appropriate and interested reviewers outside of ORNL.

**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 published and distributed.

(Milestone 3.1.B) As noted previously, progress 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 has been discussed with the NRC technical monitor and approved. Plans are now underway for specimen machining in preparation for Gleeble treatment. Consideration is also being given to reirradiation of the remaining specimens from the initial series. This work may be accelerated with the receipt of mid-year funding.

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 were previously tested and the results were presented in a previous progress report. A presentation on this work, to include 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 co-authored by Ph. Tipping (Swiss HSK), G. Waeber (PSI), and Kalkhof (PSI). A previous progress report graphically showed the results.

As reported previously, the four remaining Charpy impact specimens in the irradiated condition were tested and the data reanalyzed. A number of other specimens in the two irradiation/annealed/reirradiated (IAR) conditions were thermally annealed at 460°C for either 18 h or 168 h and tested to provide data for the material in the IARA condition. Additionally, some of the IAR specimens were thermally annealed and will be reinserted into the HSSI irradiation facility for further reirradiation to provide results in the IARAR condition. A presentation on this work was made by R. K. Nanstad at the 10<sup>th</sup> meeting of the International Group on Radiation Damage Mechanisms (IGRDM) in Pressure Vessel Steels, 19-24 May, 2002 in Awaji Island, Japan.

During the previous period, the precracked Charpy specimens were tested in the irradiated condition, in the irradiated/annealed condition, and in two different IAR conditions. A presentation on the preliminary results from this work was made by R. K. Nanstad at the ASTM Symposium on Radiation Effects in Materials in Tucson, Arizona, in June. Photographs of specimen fracture surfaces have been made, crack lengths have been measured, and final analyses are underway. During the hot cell testing, it was discovered that many of the specimens have relatively shallow flaws, with a/W ratios of about 0.3. Results from these specimens do not, of course, satisfy the requirements of E 1921 for valid fracture toughness data. Thus, the data will be evaluated giving consideration to the potential loss of constraint on the results. An initial comparison of the test results in the irradiated and the irradiated/annealed conditions, both of which included specimens with both short and long cracks, provided mixed results. In one case, the average  $K_{Jc}$  values were about the same, while in the other case they were substantially different. Moreover, neither comparison is based on a statistically strong database.

#### **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 attended the IAEA Specialists' Meeting on Master Curve Fracture Toughness, held in Prague, Czech Republic, in September 2001. Additionally, R. K. Nanstad attended a meeting of the IAEA CRP-5 in Prague. A trip report was completed by R. K. Nanstad in January 2002 and submitted (ORNL/FTR-142586). R.K. Nanstad attended a meeting of the IAEA CRP-5 in Paris, France in April 2002 and submitted a trip report (ORNL/FTR-156789). R. K. Nanstad also attended a NATO Advanced Research Workshop in Kiev, Ukraine in April 2002 as an invited speaker; a trip report is in preparation.

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 has revised the IGRDM charter for consideration by the Executive Committee. The 10th meeting of the IGRDM was held in Awaji Island, Japan, from 20-24 May, 2002. More than 90 presentations were made at the meeting. R. K. Nanstad attended the meeting as a representative of the HSSI Program and made a presentation on the results of the JRQ collaboration with PSI. M. K. Miller, M. A. Sokolov, and R. E. Stoller also made presentations and participated in the meeting under the sponsorship of DOE programs.

#### 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 subsized Charpy specimens has not been conducted, but is now anticipated for late August or early September. A letter report will be prepared following completion of all testing and evaluation. A paper, for which M. K. Miller was the lead author, including the unirradiated Charpy results and the atom probe tomography results was presented at the Tenth International Conference on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, August 5-9, 2001, in Lake Tahoe, Nevada. R. K. Nanstad attended the meeting and presented the paper. Additionally, M. K. Miller, S. S. Babu, M. A. Sokolov, R. K. Nanstad, and S. K. Iskander, "Effect of Stress Relief Temperature and Cooling Rate on Pressure Vessel Steel Welds," *Mater. Sci. Eng. A* 327, 76-79 (2002) was published.

(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 September 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  $4 \times 10^{19}$  n/cm<sup>2</sup> and the irradiation has been completed. The specimens have been received at the ORNL hot cells and will be scheduled for testing in the 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) As part of the NRC evaluation of control rod drive mechanism housing materials, the HSSI Program was asked to perform special tensile testing of Inconel 182 weld metal and three other materials in collaboration with Battelle Columbus Laboratories (BCL) and Engineering Mechanics Corporation (ECM) of Columbus. The Inconel 182 weldment was supplied by BCL. The weld metal was solution annealed by ORNL at 1900°F for 30 minutes and air cooled, followed by machining into 0.25-in.-diam tensile specimens. Tensile tests have been conducted at five temperatures: room temperature, 600, 1000, 1400, and 1800°F.

For the Inconel 182 weld metal, the A508 class 3 steels, and the A516 grade 70 steel, all the tests have been completed and the digital stress-strain curves sent to BCL and EMC. The A508 and A516 steels were tested in the as-received condition and were conducted at the same five test temperatures indicated above. No A508 class 2 steel was available at the time, and a suggestion was made to BCL and ECM to consider normalizing the A508 class 3 results to high temperature tensile results for A508 class 2 in an EPRI Report, a copy of which was sent to BCL.

(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 resubmitted to the NRC in April due to mail security damage.

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 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 issued in final form in February. This activity is complete.

### **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-6643, (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) No significant progress during this reporting period.

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 surveillance report, Analysis of Capsule 284 from the Florida Power & Light Company St. Lucie Unit 1 Reactor Vessel Radiation Surveillance Program, WCAP-15446, January 2002," was converted and input as PR-EDB database format, including the following three major categories, namely, irradiation environment, RPV material history, and mechanical test results.

The following new surveillance reports were recently found in NRC ADAMS and will be integrated into PR-EDB pending on available funding.

BAW-2355, "Capsule X of Shearon Harris."  
BAW-2399, "Capsule W-104 of Arkansas Unit 2."  
WCAP-15369, "Capsule W of Braidwood Unit 2."  
WCAP-15400, "Capsule X of Callaway Unit 1."  
WCAP-15405, "Capsule X of Millstone Unit 3."  
WCAP-15423, "Capsule V of Diablo Canyon Unit 2."

WCAP-15551, "Capsule Y of Beaver Valley Unit 1."  
WCAP-15589, "Capsule 38° of Palo Verde Unit 1."  
WCAP-15805, "Capsule X of H. B. Robinson Unit 2."

The UPDATE-12 of PR-EDB will be prepared and transmitted to the US NRC technical program monitor after additional new surveillance reports have been received and analyzed.

(Milestone 5.3.B) As reported previously, a new methodology that incorporates the chemical compositions into the Charpy trend curve was developed. The purpose of this new fitting procedure is to generate a new multi-space topography that can properly reflect the inhomogeneity of the surveillance materials and utilize this multi-space trend surface to link and project the surveillance test results to that of reactor pressure vessel steels. Please see Task 2.8 for additional details.

### **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 irradiation facilities continued without incident during this reporting period. During this period, the facilities were irradiated for the last three days of reactor half-cycle 473A, 9.7 days during reactor half-cycle 473B, and for the first 7.4 days of reactor half-cycle 474A.

During the last three days of reactor half-cycle 473A the HSSI-IAR irradiation facilities received a total of 69 EFPH (effective full power hours). The facilities also received 234 EFPH during reactor half-cycle 473B, followed by an additional 177 EFPH during the first 7.4 days of reactor half-cycle 474A. During this reporting period, the HSSI-IAR irradiation facilities received a total of 480 EFPH.

At the beginning of this reporting period, the second group of specimens to be irradiated in the HSSI-IAR facilities had been irradiated for a total of 11,021 EFPH. At the end of this reporting period, the second group of specimens had been irradiated for a total of 11,501 EFPH. The

HSSI-IAR irradiation facilities have been in service for a total of 16,211 EFPH since they were installed at the FNR in December, 1998.

(Milestone 6.1.B) The NUREG report, D. W. Heatherly, K. R. Thoms, M. T. Hurst and G. E. Giles, UT-Battelle, LLC, Oak Ridge, Tenn., *Heavy-Section Steel Irradiation Program's Reusable Irradiation Facility*, USNRC NUREG/CR-6779, (ORNL/TM-2002/77) was submitted to the NRC in March. Requested corrections will be submitted at the beginning of the next 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 HSSI-UCSB irradiation facility continued to operate without incident during this reporting period. During this period, the facility was irradiated for the last three days of reactor half-cycle 473A, 9.7 days during reactor half-cycle 473B, and for the first 7.4 days of reactor half-cycle 474A.

During the last three days of reactor half-cycle 473A, the HSSI-UCSB irradiation facility received a total of 69 EFPH (effective full power hours). The facility received 234 EFPH during reactor half-cycle 473B, followed by an additional 177 EFPH during the first 7.4 days of reactor half-cycle 474A. During this reporting period, the irradiation facility received a total of 480 EFPH.

At the beginning of this reporting period the HSSI-UCSB facility and original specimen compliment had been irradiated for a total of 22,871 EFPH. At the end of this reporting period, the facility and original specimen compliment had been irradiated for a total of 23,351 EFPH. The original irradiation plan received from the UCSB experimenters indicated that the final specimens would be removed from the irradiation 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 173% of the original desired irradiation time. The HSSI UCSB irradiation facility has been in operation at the FNR since December, 1996.

#### **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:**

**4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:**

**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.

<b>Item</b>	<b>Cost (\$)</b>
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: 6/24/02-7/28/02

	Current Month	Fiscal Year to Date	Cumulative Project to date
I. Direct Staff Effort	3 MM	3.6 MY	42.0 MY
II. A. Direct Lab Staff Effort (\$)			
Direct Salaries	48,343	720,513	4,565,395
Materials and Services	1,321	47,880	435,325
ADP Support	32	275	2,479
Subcontracts	31,466	257,217	757,414
Travel	4,602	32,531	175,399
Other: NRC-PO Tax	6,403	40,606	215,106
General and Administrative	25,443	362,902	2,098,105
 Total UT-Battelle Costs	 117,610	 1,461,924	 8,249,223
B. DOE Federal Admin. Costs	3,528	43,858	85,771
 TOTAL PROJECT COSTS	 121,138	 1,505,782	 8,334,994
 Percentage of available cumulative funds costed		88	
Percentage of available current FY funds costed		57	
Funds Remaining		1,170,006	
Commitments:		238,948	
BA Remaining		931,058	
BA Remaining Less Projected FAC		896,980	

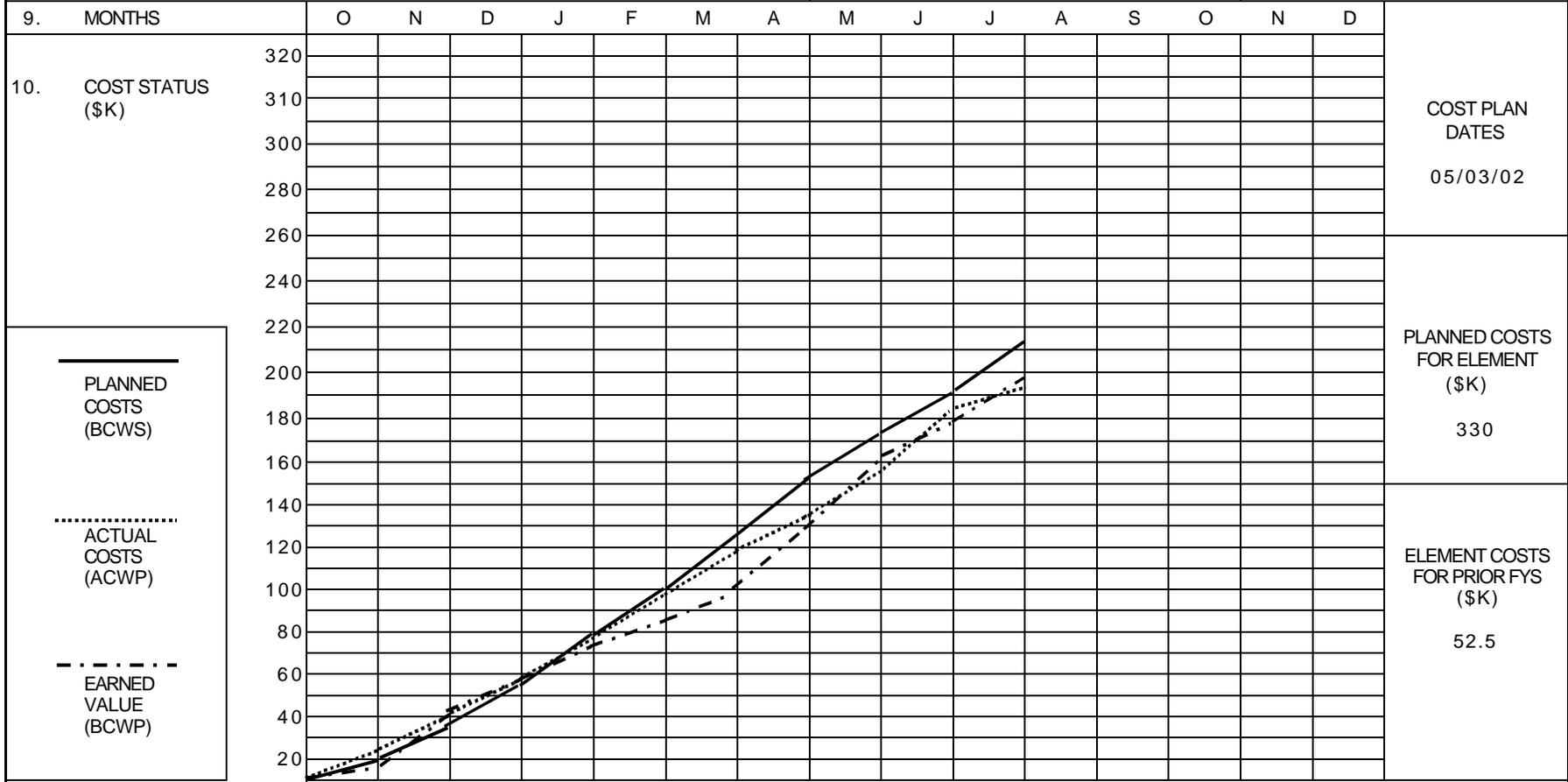
III. Funding Status

Prior FY Carryover	FY 02 Projected Funding Level	FY 02 Funds Received to Date	FY 02 Funding Balance Needed	Cumulative Amt. Obligated	Cumulative Amt. Costed
514,538	2,491,000	2,146,000	345,000	9,505,000	8,334,994

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

1. CONTRACT REPORTING ELEMENT <b>HSSI - Heavy-Section Steel Irradiation Program</b>										2. REPORTING PERIOD <b>6/24/2002 - 7/28/2002</b>					3. JCN NO. <b>W6953</b>						
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>										5. CONTRACT PERIOD <b>FY 1998 - 2003</b>					6. ACTIVITY NUMBER <b>W41 W5 85 3W 1</b>						
										7. NRC B&R NO. <b>860 15 21 20 05</b>					8. DOE B&R NO. <b>40 10 01 06</b>						
9. MONTHS		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D					
10. COST STATUS (\$K)																	COST PLAN DATES 07/25/02				
																	PLANNED COSTS FOR ELEMENT (\$K) 2486				
																	ELEMENT COSTS FOR PRIOR FYS (\$K) 514				
ACCRUED COSTS (\$K)	PLANNED	126	126	129	198	157	159	171	170	170	212	206	188	171	171	132					
	ACTUAL	77	97	181	139	126	77	271	195	181	118	0	0	0	0	0					
	EARNED	105	128	131	143	112	87	205	212	185	164	0	0	0	0	0					
	CUM. PLANNED	126	252	381	579	736	895	1066	1236	1406	1618	1824	2012	2183	2354	2486					
	CUM. ACTUAL	77	174	355	494	620	697	968	1163	1344	1462	0	0	0	0	0					
	CUM. EARNED	105	233	364	507	619	706	911	1123	1308	1508	0	0	0	0	0					
11. REMARKS Total/Planned Cost reflects reduction in funds received due to FAC.																					

1. CONTRACT REPORTING ELEMENT <b>HSSI - 1. Program Management</b>	2. REPORTING PERIOD <b>6/24/2002 - 7/28/2002</b>	3. JCN NO. <b>W6953</b>
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>	5. CONTRACT PERIOD <b>FY 1998 - 2003</b>	6. ACTIVITY NUMBER <b>W41 W5 85 3W 1</b>
	7. NRC B&R NO. <b>860 15 21 20 05</b>	8. DOE B&R NO. <b>40 10 01 06</b>

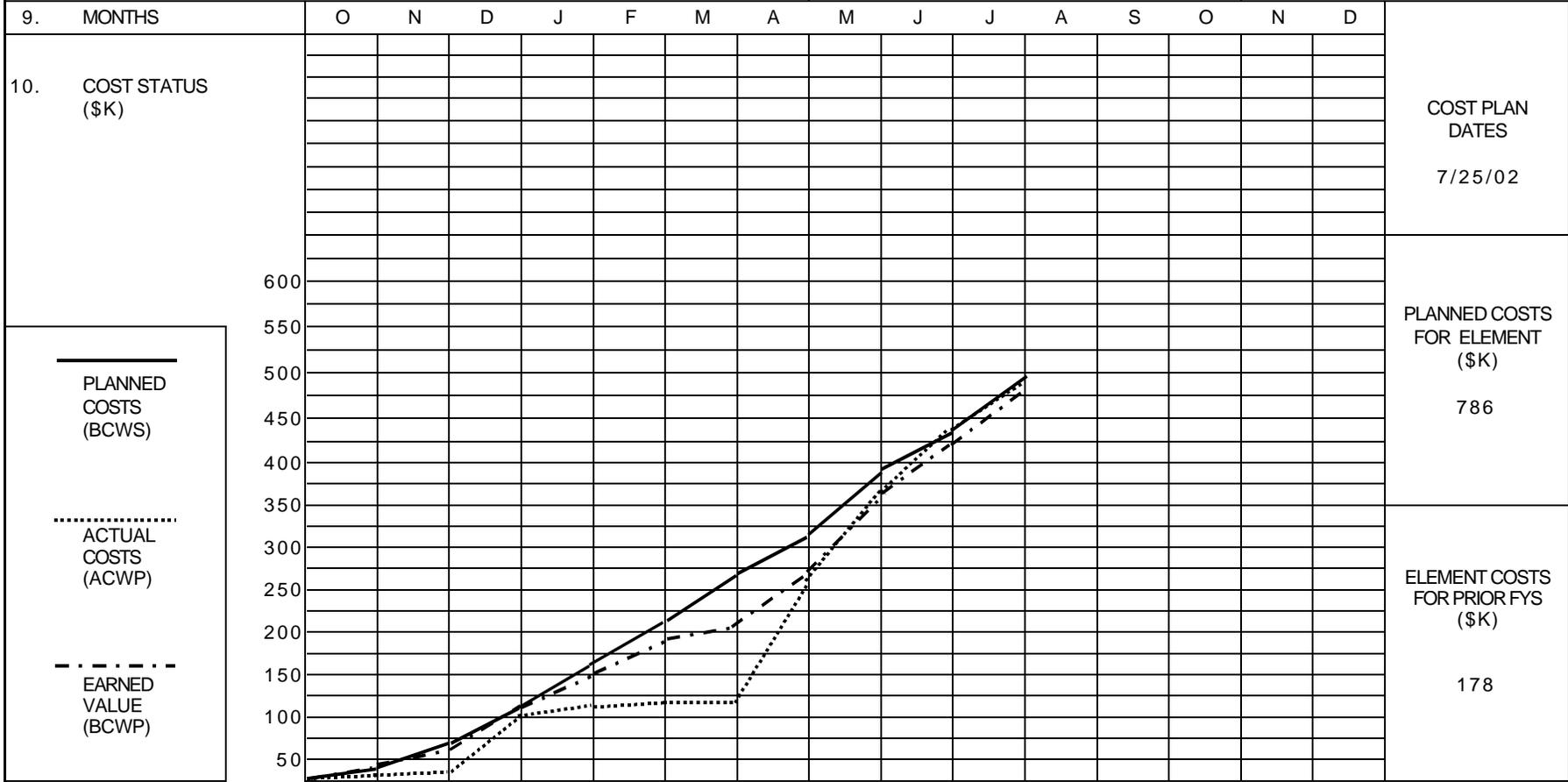


ACCRUED COSTS (\$K)	PLANNED	18	16	19	24	23	23	28	21	18	24	24	22	25	27	23
	ACTUAL	22	18	17	21	21	18	18	21	17	20	0	0	0	0	0
	EARNED	15	25	13	18	14	14	31	30	18	21	0	0	0	0	0
	CUM. PLANNED	18	34	53	77	100	123	151	172	190	214	238	260	285	312	335
	CUM. ACTUAL	22	40	57	78	99	117	135	156	173	193	0	0	0	0	0
	CUM. EARNED	15	40	53	71	85	99	130	160	178	199	0	0	0	0	0

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



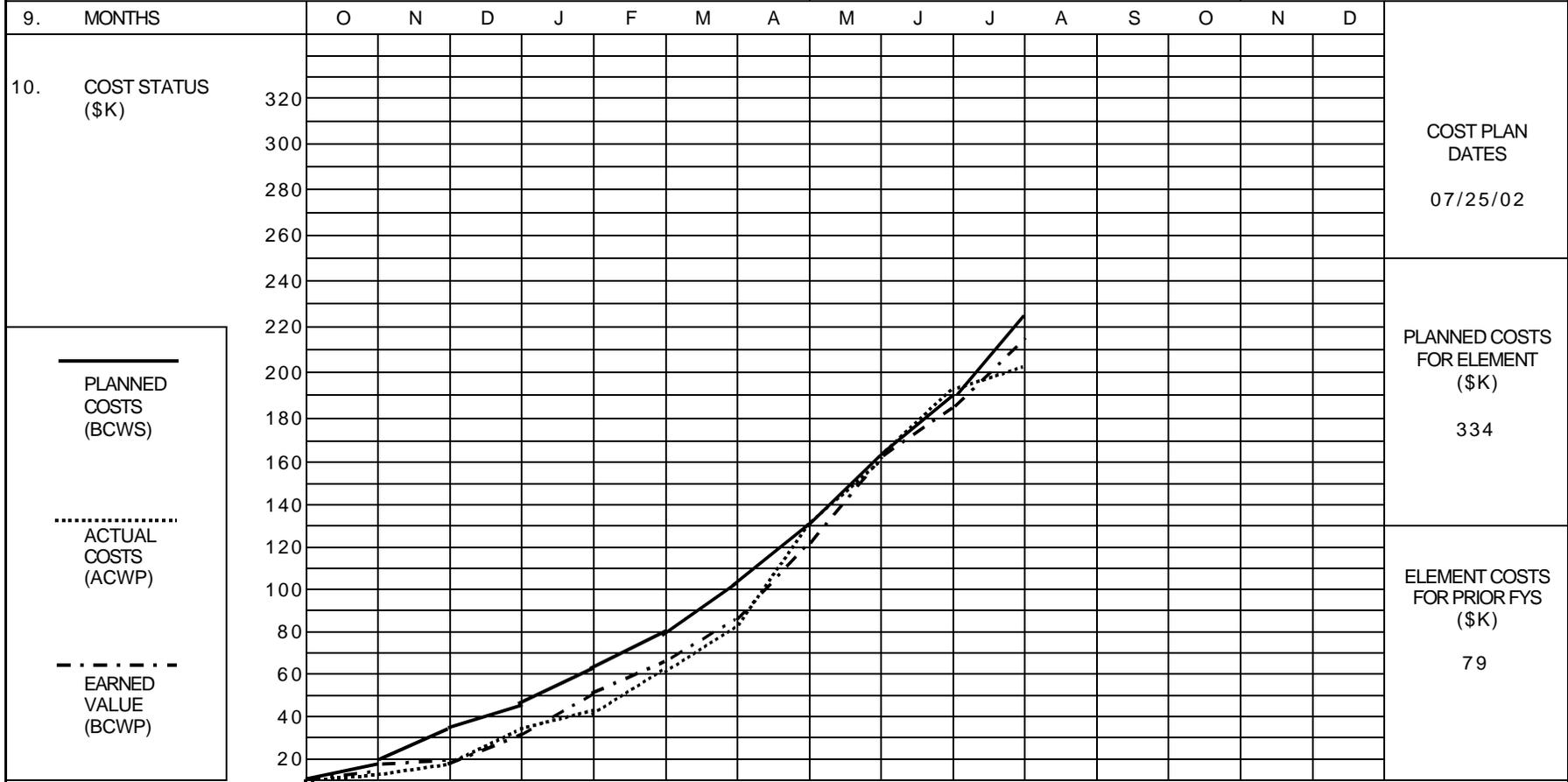
1. CONTRACT REPORTING ELEMENT <b>HSSI - 3. Irradiation Embrittlement of RPV Steel</b>	2. REPORTING PERIOD <b>6/24/2002 -7/28/2002</b>	3. JCN NO. <b>W6953</b>
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>	5. CONTRACT PERIOD <b>FY 1998 - 2003</b>	6. ACTIVITY NUMBER <b>W41 W5 85 3W 1</b>
	7. NRC B&R NO. <b>860 15 21 20 05</b>	8. DOE B&R NO. <b>40 10 01 06</b>



ACCRUED COSTS (\$K)	PLANNED	31	43	38	56	48	56	50	60	48	60	68	65	57	58	48
	ACTUAL	3	7	92	14	1	0	148	89	90	49	0	0	0	0	0
	EARNED	30	41	41	35	30	27	65	75	78	60	0	0	0	0	0
	CUM. PLANNED	31	74	112	168	216	272	322	382	430	490	558	622	680	738	786
	CUM. ACTUAL	3	10	102	116	117	117	265	354	444	493	0	0	0	0	0
	CUM. EARNED	31	72	112	147	177	204	269	344	422	482	0	0	0	0	0

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

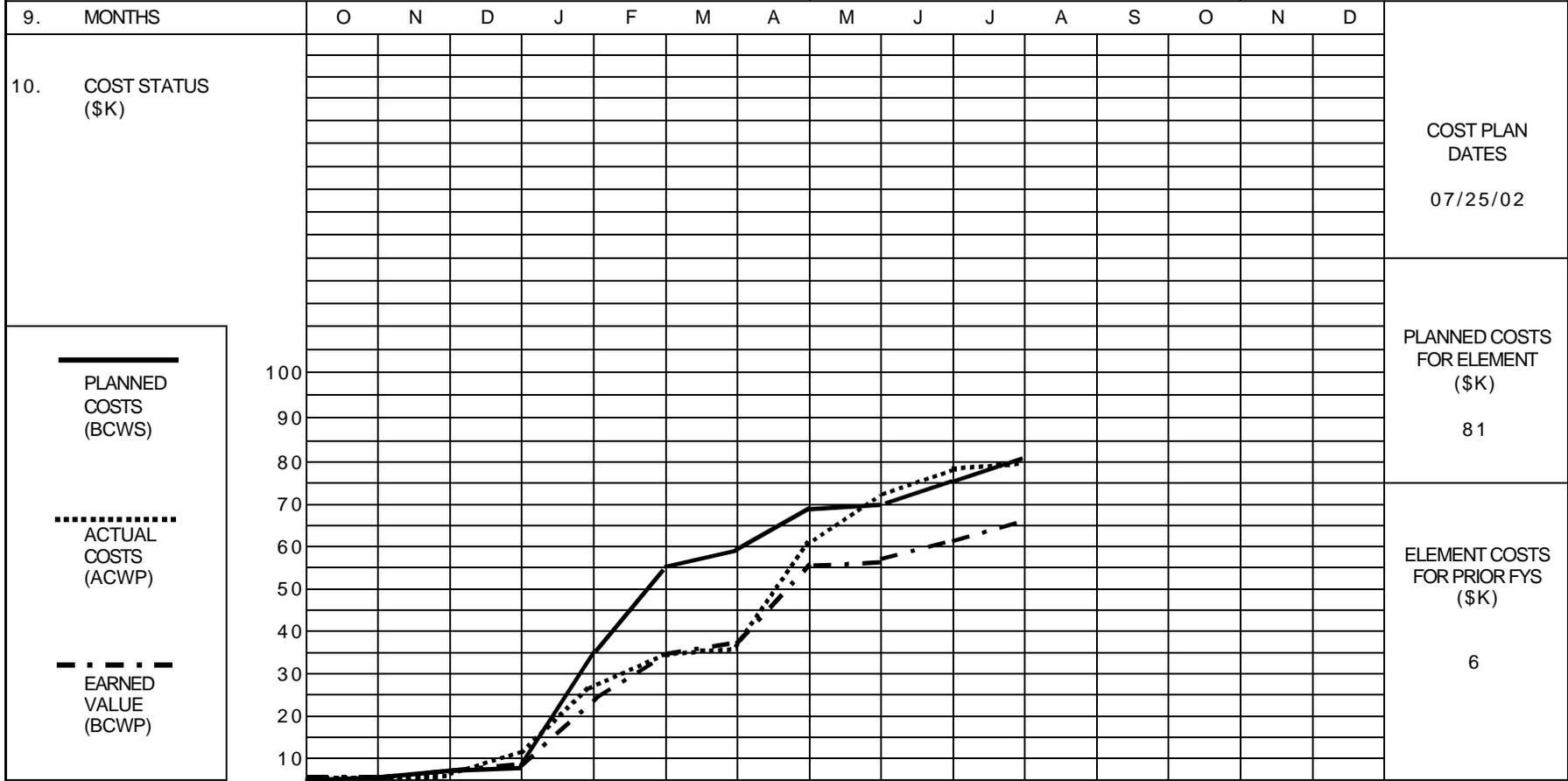
1. CONTRACT REPORTING ELEMENT <b>HSSI - 4. Validation of Irradiated and Aged Materials</b>	2. REPORTING PERIOD <b>6/24/2002 - 7/28/2002</b>	3. JCN NO. <b>W6953</b>
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>	5. CONTRACT PERIOD <b>FY 1998 - 2003</b>	6. ACTIVITY NUMBER <b>W41 W5 85 3W 1</b>
	7. NRC B&R NO. <b>860 15 21 20 05</b>	8. DOE B&R NO. <b>40 10 01 06</b>



ACCRUED COSTS (\$K)	PLANNED	16	16	15	19	14	22	30	30	28	33	30	28	20	22	11
	ACTUAL	4	14	14	10	19	17	45	36	32	10	0	0	0	0	0
	EARNED	9	11	1	19	14	18	38	43	21	34	0	0	0	0	0
	CUM. PLANNED	16	32	47	66	80	102	132	162	190	223	253	281	301	323	334
	CUM. ACTUAL	4	18	32	42	61	78	123	160	192	202	0	0	0	0	0
	CUM. EARNED	9	20	31	50	64	82	120	163	184	218	0	0	0	0	0

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

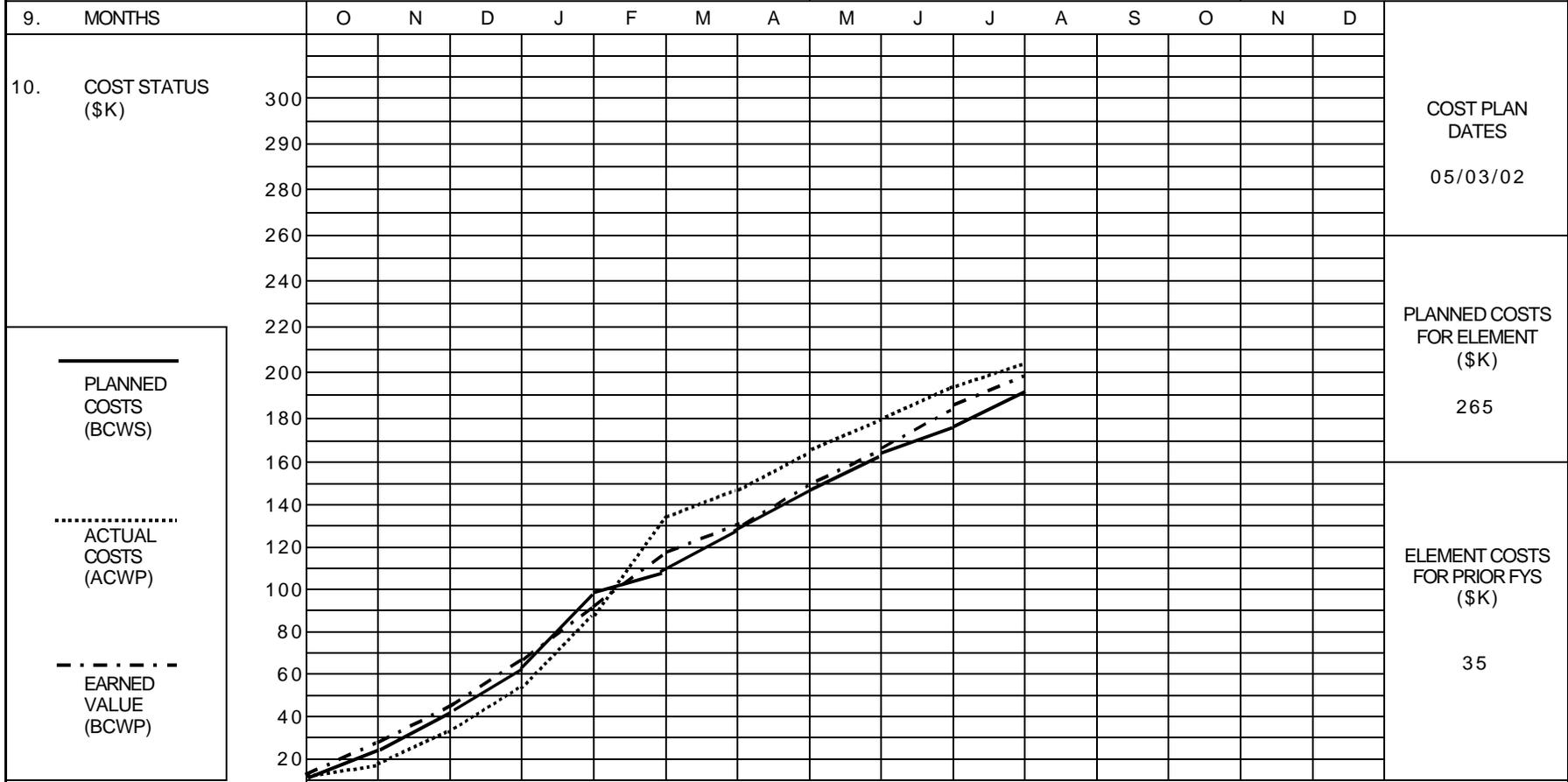
1. CONTRACT REPORTING ELEMENT <b>HSSI - 5. Modeling and Microstructural Analysis</b>	2. REPORTING PERIOD <b>6/24/2002 - 7/28/2002</b>	3. JCN NO. <b>W6953</b>
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>	5. CONTRACT PERIOD <b>FY 1998 - 2003</b>	6. ACTIVITY NUMBER <b>W41 W5 85 3W 1</b>
	7. NRC B&R NO. <b>860 15 21 20 05</b>	8. DOE B&R NO. <b>40 10 01 06</b>



ACCRUED COSTS (\$K)	PLANNED	2	3	3	27	20	4	10	1	6	5	0	0	0	0	0
	ACTUAL	0	5	10	16	8	1	25	10	6	1	0	0	0	0	0
	EARNED	1	2	3	19	8	4	18	11	5	4	0	0	0	0	0
	CUM. PLANNED	2	5	8	35	55	59	69	70	76	81	84	81	0	0	0
	CUM. ACTUAL	0	1	11	27	35	36	61	71	77	78	0	0	0	0	0
CUM. EARNED	1	3	6	25	33	37	55	56	61	65	0	0	0	0	0	

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

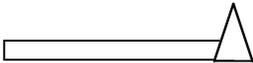
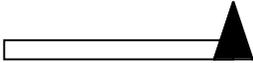
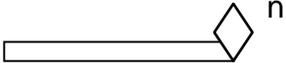
1. CONTRACT REPORTING ELEMENT <b>HSSI - 6. Irradiation Coordination</b>	2. REPORTING PERIOD <b>6/24/2002 - 7/28/2002</b>	3. JCN NO. <b>W6953</b>
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>	5. CONTRACT PERIOD <b>FY 1998 - 2003</b>	6. ACTIVITY NUMBER <b>W41 W5 85 3W 1</b>
	7. NRC B&R NO. <b>860 15 21 20 05</b>	8. DOE B&R NO. <b>40 10 01 06</b>



ACCRUED COSTS (\$K)	PLANNED	23	18	23	35	14	16	18	14	16	14	14	16	16	14	14
	ACTUAL	15	17	20	37	45	15	15	15	12	15	0	0	0	0	0
	EARNED	26	19	22	26	24	12	19	17	17	17	0	0	0	0	0
	CUM. PLANNED	23	41	64	99	113	129	147	161	177	191	205	221	237	251	265
	CUM. ACTUAL	15	32	52	89	134	149	164	179	191	206	0	0	0	0	0
	CUM. EARNED	26	45	67	93	117	129	148	165	182	199	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 <b>HSSI - 2. Fracture Toughness Transition &amp; MC Methodology</b>		2. REPORTING PERIOD <b>6/24/2002-7/28/2002</b>		3. JCN NO. <b>W6953</b>	
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>		5. CONTRACT PERIOD <b>FY 1998-2003</b>		6. ACTIVITY NUMBER <b>41 W6 95 3W 1</b>	
		7. NRC B&R NO. <b>860 15 21 20 05</b>		8. DOE B&R NO. <b>40 10 01 06</b>	
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION	FY 2001 O N D J F M A M J J A S		FY 2002 O N D J F M A M J J A S	
				FY 2003 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 from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.A.	Irradiate Midland and Hi-Ni Specimens	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.B.	Receive Specimens	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.C.	Test Unirradiated & Irradiated KSØ1 for Master Curve	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.D.	Test Unirradiated & Irradiated Hi-Ni Midland Weld Specimens	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.E.	Draft Letter and NUREG Report for KSØ1	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.F.	Draft Letter and NUREG Report for Midland Weld	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
2.2.G.	Draft Letter and NUREG Report for High Ni	[Bar from Dec 2001 to Aug 2002]		[Bar from Dec 2001 to Aug 2002]	
		O N D J F M A M J J A S		O N D J F M A M J J A S	
		FY 2001		FY 2002	
11. REMARKS					



1. CONTRACT REPORTING ELEMENT <b>HSSI - 2. Fracture Toughness Transition &amp; MC Methodology</b>		2. REPORTING PERIOD <b>6/24/2002-7/28/2002</b>		3. JCN NO. <b>W6953</b>																															
4. CONTRACTOR (NAME AND ADDRESS) <b>OAK RIDGE NATIONAL LABORATORY P. O. BOX 2008 OAK RIDGE, TN 37831</b>		5. CONTRACT PERIOD <b>FY 1998-2003</b>		6. ACTIVITY NUMBER <b>41 W6 95 3W 1</b>																															
		7. NRC B&R NO. <b>860 15 21 20 05</b>		8. DOE B&R NO. <b>40 10 01 06</b>																															
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																																		
2.9.A.	Develop Machining Procedures																																		
2.9.B.	Machine Specimens																																		
		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																																			









