ORNL/HSSI (W6953)/MLSR-2003/03

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

## Monthly Letter Status Report

**December 2002**

ORNL/HSSI (W6953)/MLSR-2003/03

# HEAVY-SECTION STEEL IRRADIATION PROGRAM

JCN W6953

# MONTHLY LETTER STATUS REPORT

FOR

December 2002

Submitted by

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Submitted to
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# PREFACE

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

This report gives information on several topics corresponding to events during the reporting month: (1) overall project objective, (2) technical activities, (3) meetings and trips, (4) publications and presentations, (5) property acquired, (6) problem areas, and (7) plans for the next reporting period. Next the report gives a breakdown of overall program costs as well as cost summaries and earned-value-based estimates for performance for the total program and for each of the 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**
**December 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** |
| **Performing Organization:** | **Oak Ridge National Laboratory** |
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## 1. PROJECT OBJECTIVE:

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

## 2. TECHNICAL ACTIVITIES:

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

This task is responsible for managing the program to ensure that the overall objectives are achieved. The management responsibilities include three major activities: (1) program planning and resource allocation; (2) program monitoring and control; and (3) documentation and technology transfer. Program planning and resource allocation includes: (a) developing and preparing annual budgetary proposals and (b) issuing and administrating subcontracts to other contractors and consultants for specialized talents not available at Oak Ridge National Laboratory (ORNL) or that supplement those at ORNL. Program monitoring and control includes: (a) monitoring and controlling the project through an earned-value, project-management system; (b) ensuring that quality assurance (QA) requirements are satisfied; and (c) issuing monthly management reports. Documentation and technology transfer includes: (a) participating in appropriate codes and standards committees; (b) preparing briefings for the NRC; (c) coordinating NRC and internal ORNL review activities; (d) coordinating domestic and foreign information exchanges approved by NRC; and (e) documenting the activities of the program through letter and NUREG reports.

(Milestone 1.1.B) The University of Michigan's Office of the Vice President for Research issued a letter on December 9, 2002, informing the HSSI Program Manager that the University expects to operate the FNR at least through July and will provide a 90-day notification before permanently ceasing operation of the reactor.

On December 11 –13, T. M. Rosseel and K. R. Thoms traveled to McMaster University in Hamilton, Ontario, Canada to evaluate the McMaster University Nuclear Reactor (MNR) as a suitable site to perform irradiations of pressure vessel materials after the University of Michigan Ford Nuclear Reactor (FNR) shuts down for decommissioning in 2003.

(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. Reactor instrument problems and a problem with a faulty gas flow controller on the exit side of the HSSI-UCSB irradiation facility resulted in a loss of 7 irradiation days for each problem during this reporting period. Please see Task 6 for additional details.

(Milestone 1.3.C) Discussions with an individual concerning a possible guest assignment of up to one year with the HSSI Program continued. If an acceptable arrangement can be implemented with the guest's home institution, it is expected that the assignment will begin in April and focus on dynamic fracture toughness and sub-size specimen effects. A letter of invitation will be prepared noting that all approvals and financial arrangements must be satisfactorily resolved for all parties.

The HSSI Program provided SCKCEN, Belgium with one piece each of 72W and 73W for an irradiation program that will begin in 2003. The program will be examining irradiation and re-irradiation effects with the results being made available for comparison with HSSI Program results. The pieces supplied were cubes of approximately three inch edges.

(Milestone 1.3.D) Three reports are nearing completion. The long-delayed crack arrest NUREG report, a draft letter report on an Atom Probe study of the effects of Mn and Cu on precipitates formed during irradiation embrittlement (in collaboration with G. R. O'dette), and a NUREG report on the mechanical properties of the KS01 weld. It is anticipated that these reports will be submitted during the next reporting period.

## 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.

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

The purpose of this subtask is to collect and statistically analyze pertinent fracture-toughness data to assess the shift and potential change in shape of the fracture-toughness curves due to neutron irradiation. The MC methodology will be applied to provide a statistical analysis of the fracture-toughness data and Charpy data will be fitted by hyperbolic tangent 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.

<u>Subtask 2.2: Irradiation Effects on Fracture-Toughness Curve Shape</u> (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 x $10^{18}$ n/cm$^2$ 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 x $10^{19}$ n/cm$^2$ (>1 MeV). This irradiation is being conducted to evaluate the assumption of constant shape for the master curve with highly embrittled low upper-shelf RPV steels that exhibit onset of stable ductile tearing at relatively low fracture toughness.

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. These specimens were sorted and identified in preparation for testing.

Charpy impact tests of the unirradiated specimens and specimens irradiated to $\approx 1.6 \times 10^{19}$ n/cm$^2$ (>1 MeV) were performed. The material exhibited a Charpy 41-J shift of 101ºC. Using the assumed fluence, this is considerably less than the predicted shift of 154ºC by *Regulatory Guide 1.99* (Rev. 2) and the predicted shift of 139ºC by the Eason, Wright, Odette (EWO) equation. Both predictions are, of course, dependent on the chemical composition variables used. The chemical composition used was an average of values available for the weld. Additional analyses will be conducted with the tested specimens to verify those values.

(Milestone 2.2.C) As noted previously, 21 1T and six additional 0.5T compact specimens of the submerged-arc weld KS-01, irradiated to $\sim 0.8 \times 10^{19}$ n/cm$^2$ (>1 MeV), were successfully tested. The results have been evaluated relative to the shape of the master curve. 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.

Three additional tensile tests, as noted previously, have been completed at 250, 200, and –100°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 was made at the ASTM International Symposium on Radiation Effects in Materials in Tucson, Arizona, June 2002. Internal review of the draft NUREG report has been completed and the report is being prepared for publication. Additionally, testing of 12 irradiated precracked Charpy KS-01 specimens have been completed and the results are undergoing analysis.

(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 $T_o$ 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 been published and distributed in November.

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) Two fissionable radiometric dosimeter sets (FRDs) were prepared and placed inside a dummy Chapry specimen for the two cells to be shipped to the FNR during the next reporting period. This was done so as to provide a more accurate characterization of the fluences as specimens are shuffled within the irradiation facility in an attempt to maximize irradiation efficiency. The cells contain HAZ specimens prepared under conditions noted in Task 3.1.

No other 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 draft KS01 NUREG report described in Task 1 and 2.2.

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

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

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 paper based on a presentation by R. K. Nanstad at the IAEA Specialists' Meeting on Master Curve in Prague, Czech Republic, has 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 100ºC, with brittle intergranular fracture up to 50ºC. The fracture toughness vs temperature relationship appears to follow the master curve shape up to about 150 Mpa√m with an apparent $T_o$ of -100ºC. 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 150ºC above the master curve $T_o$. Additionally, the relationship between fracture toughness and Charpy toughness was significantly different from cleavage fracture results.

As discussed in Task 2.2 above, the KS-01 weld metal exhibited 10 to 20% IGF in the unirradiated condition and did not exhibit the same characteristics as the temper embrittled steel evaluated in this task that exhibited 100% IGF. Thus, the percentage of IGF necessary to cause a departure in fracture behavior from that described by the Master Curve is uncertain.

(Milestone 2.6.C) The letter report has been completed and was published in December as ORNL/NRC/LTR-00/03. 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. The paper is entitled "Applicability Of The Fracture Toughness Master Curve To Irradiated Highly Embrittled Steel And Intergranular Fracture" by R. K. Nanstad, M. A. Sokolov, and D. E. McCabe. The abstract from ORNL/NRC/LTR-00/03 is provided below:

> The Heavy-Section Steel Irradiation (HSSI) Program at Oak Ridge National Laboratory includes a task to investigate the shape of the fracture toughness Master Curve for a reactor pressure vessel (RPV) steel which experiences significant intergranular fracture. A companion study previously observed significant intergranular fracture in an irradiated and thermally annealed pressure vessel steel given a fast cool following postweld heat treatment. A modified A302 grade B steel was selected for the evaluation and heat treated to create very large austenite grains to sensitize it to temper embrittlement. The sensitized steel was then aged to produce a temper embrittled microstructure. A comparison was made between transition-range behavior by an intergranular mechanism versus the more usual cleavage-to-ductile upper-shelf behavior, the fracture mode applicable to the

fracture toughness Master Curve. Compact specimens of 0.5T, 1T, and 2T size were tested from -125 to 100ºC. Scanning electron fractography of the temper embrittled A302B (Modified) steel revealed almost full intergranular fracture. It was found that the intergranular mechanism significantly extends the transition temperature range. Furthermore, the correlations that have been developed between Charpy impact energy and fracture toughness, $K_{Jc}$, are severely disrupted by the intergranular fracture mechanism. This evidence was developed using an extreme metallurgical heat treatment to produce very large grain sizes.

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). Subsized specimens will be fabricated from previously characterized materials within the HSSI Program, such as HSST Plate 02, HSSI Welds 68W through 73W, the Midland beltline weld and plate JRQ.

(Milestone 2.7.A) As reported previously, 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 January.

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.

As noted previously, a different methodology has been evaluated for potential application to this issue. The methodology involves a combination of nonlinear estimators including domain models, neural networks, vector space methods, and nearest neighbor regressions. The evaluation examined, 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 was presented in a previous progress report.

(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) Programming of the computer numerically controlled (CNC) milling machine CNC system and the design of fixtures has been completed. However, due to loss of a hot cell operator to long-term disability, the machining of the 0.4T compact specimens from the broken irradiated 1T compact specimens of KS-01 previously tested will be delayed until January. Following machining, these 0.4T specimens will be tested in the same general temperature range as the 1Ts described in Task 2.2 to expand the database further for this material, and will provide for a comparison of compact specimen results with those from the similar size pre-cracked Charpy specimens. This comparison is directed at the bias indicated in some precracked Charpy data that results in somewhat lower determinations of $T_o$ relative to compact specimens.

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

The purpose of this task is to perform a systematic study of the bias term added to $T_0$ 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.

An additional activity of this subtask is verify the $T_0$ value for HSSI weld 72W. The ASME Materials Properties Council conducted a round-robin testing program a few years ago with pre-cracked Charpy specimens of two RPV steels, one of which was HSSI Weld 72W. The specimens were machined from the "second batch" of weld 72W. The results showed a disparity in the $T_0$ values of about 20° C between that determined from the pre-cracked Charpy specimens and that from the fracture-toughness data using the "first batch" of 72W. To accomplish this verification, twelve 1T compact tension specimens from the "second batch" of Weld 72W will be machined and tested so as to provide a comparable $T_0$ value as obtained for the "first batch." The evaluation should also provide additional information regarding the overall comparison of master curve data from precracked Charpy specimens with larger specimens.

(Milestone 2.10.A) Planning for this task has continued. The experimental phase will likely include 1T three-point bend specimens, precracked Charpy specimens with and without side-grooves, Charpy thickness [10 mm (0.394 in.)] compact specimens, some with the standard ligament and some with half the standard ligament to provide a direct comparison with the precracked Charpy specimen. 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. R. K. Nanstad visited SCK-CEN, Mol, Belgium, in September and discussed this issue with Eric Van Walle and his staff. Additionally, presentations and discussions from the ASTM E-08 Workshop on Constraint are being evaluated relative to planning of the experimental and analytical needs.

A block of HSSI Weld 72W has been located, drawings have been prepared, and the block will be sent for machining of at least 12 1T compact specimens. The testing will be conducted in January.

**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, to investigate the effect of cooling rate following postweld heat treatment, additional material would be treated in the Gleeble system to simulate the coarse-grain HAZ as accomplished previously. This would then be followed by thermal aging, as well as by irradiation and post-irradiation thermal annealing. The A302 grade B (modified) steel in the previous study (designation Z-7) has a phosphorus content of 0.07 wt %. A second steel, A302 grade B (modified) with phosphorus content of 0.14 wt % (designation Z-5) is also included in this study for comparison. Excess material of each heat from the original investigation was identified and Gleeble specimens [(rods of about 75 mm (3 in.) length and 14.3 mm (0.562 in.) diameter] were machined. Gleeble treatment, using the same procedure employed in the previous study has been completed for the 84 specimens designated for insertion into the IAR facility for irradiation and subsequent thermal annealing. Following Gleeble treatment, the specimens were postweld heat treated at 615ºC (1140ºF) for 24 h, then furnace cooled at ~15ºC/h. Charpy and tensile specimens were machined from the Gleeble specimens, notched and some were fatigue precracked for testing as precracked Charpy (PCVN) specimens. A total of 50 CVN (20 of Z-5 and 30 of Z-7), 20 PCVN (all of Z-7), and 16 tensile (4 of Z-5 and 12 of Z-7) specimens were packaged in two specially steel boxes and will be inserted into the IAR facility at the Ford Reactor in January. Consideration is also being given to reirradiation of the remaining specimens from the initial series.

<u>Subtask 3.2 (formerly 3.3): Evaluation of Reirradiated JRQ Specimens</u> (R. K. Nanstad, E. T. Manneschmidt, and T. M. Rosseel)

The purpose of this subtask is to examine the fracture-toughness behavior of 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 P. 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 10th meeting of the International Group on Radiation Damage Mechanisms (IGRDM) in Pressure Vessel Steels, 19-24 May, 2002 in Awaji Island, Japan.

During June, the precracked Charpy specimens were tested in the irradiated condition, in the irradiated/annealed condition, and in two different IAR conditions. A presentation on the preliminary results from this work was made by R. K. Nanstad at the ASTM Symposium on Radiation Effects in Materials in Tucson, Arizona, in June. Photographs of specimen fracture surfaces have been made, crack lengths have been measured, and final analyses have been completed. During the hot cell testing, it was discovered that many of the specimens have relatively shallow flaws, with a/W ratios of about 0.3. Results from these specimens do not, of course, satisfy the requirements of E 1921 for valid fracture toughness data. Thus, the data will be evaluated giving consideration to the potential loss of constraint on the results. An initial comparison of the test results in the irradiated and the irradiated/annealed conditions, both of which included specimens with both short and long cracks, provided mixed results. In one case, the average $K_{Jc}$ values were about the same, while in the other case they were substantially different. Moreover, neither comparison is based on a statistically strong database in that the subsets comprise only 4 or 5 test results. A paper has been submitted to ASTM for review and publication in the STP for the Tucson meeting; the paper was reviewed by the two co-authors from Switzerland as well: "Irradiation and Post-Annealing Reirradiation Effects on Fracture Toughness of RPV Steel Heat JRQ," by R. K Nanstad, P. Tipping, and R. D. Kalkhof.

**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 has been completed.

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. A joint trip report, including co-authorship by G. R. Odette (University of California-Santa Barbara), has been submitted (ORNL/FTR-158401).

R. K. Nanstad attended the ATHENA Workshop in Madrid, Spain, on 18-20 September, 2002 and made a presentation on effects of irradiation and thermal aging on stainless steel cladding. Following that meeting, he visited SCK-CEN in Mol, Belgium for discussions regarding many issues, including the HSSI project to evaluate the bias effect associated with precracked Charpy specimens. A trip report is in preparation.

R. K. Nanstad attended the meeting of the IAEA Cooperative Research Program "Mechanisms of Nickel Content on Irradiation Embrittlement of RPV Steels," in Pamporovo, Bulgaria, 2-4 December, 2002. He made a presentation entitled "Comparison of Nickel Effects on Embrittlement Mechanisms in Prototypic WWER-1000 and A533B Steels," by Randy K. Nanstad, Mikhail A. Sokolov, Michael K. Miller, and G. Robert Odette. The presentation included a summary of HSSI Program activities in the area of nickel effects, the test results and atom-probe analysis results of the KS-01 weld, preliminary results of testing of the irradiated [to ~1.6 × 1019 n/cm$^2$ (>1 MeV)] high-nickel submerged-arc weld from the Palisades steam generator, and the Charpy impact test results for the CRP-supplied high-nickel forging and high-nickel weld (VVER-1000) in the unirradiated condition. The VVER-1000 specimens inserted in the IAR facility in April of 2001 will be removed in January at the behest of the CRP and transported to ORNL for testing as soon as practicable.

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) Testing of the irradiated subsize Charpy specimens in the ORNL hot cells has been completed. A letter report will be prepared following completion of all 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, a paper by M. K. Miller, S. S. Babu, M. A. Sokolov, R. K. Nanstad, and S. K. Iskander, "Effect of Stress Relief Temperature and Cooling Rate on Pressure Vessel Steel Welds," *Mater. Sci. Eng. A 327*, 76-79 (2002) was 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 was delayed due to personnel reductions. A draft report has now been completed by the subcontractor, Dr. Shafik Iskander, and has been submitted for preparation as a draft NUREG report by administrative support staff.

(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 final group of specimens was about $4 \times 10^{19}$ n/cm$^2$ and the irradiation has been completed. The specimens have been received at the ORNL hot cells and will be scheduled for testing early in 2003.

(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. Manneschmidt, R. K. Nanstad, T. M. Rosseel, and P. S. Bishop, was submitted to the NRC in January, 2001 as part of an Office of Research Operational Milestone.

(Milestone 4.3.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-6777 (ORNL/TM-2001/34), was published in August 2002.

<u>Subtask 4.4: Obtaining RPV material for SONGS-1</u> (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.

**<u>Task 5: Modeling & Microstructural Characterization and Embrittlement Data Base</u> (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.

<u>Subtask 5.1: Modeling of Damage Evolution</u> (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.

<u>Subtask 5.2: Microstructural Characterization</u> (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.

The Atom Probe will be used to study of Mn and high-nickel in the evolution of late blooming phases. Model alloys will be examined using Atom Probe Tomography (APT) and compare the results to those obtained by University of California-Santa Barbara (UCSB), using small angle neutron scattering (SANS) methods to determine the influence of manganese on the thermal stability of supersaturated iron-copper alloys. Palisades high-nickel steel specimens that have been irradiated to a fluence of 1.6 x $10^{19}$ will also be examined. Since Ni and Mn-rich phases in low Cu steels may contribute to hardening and embrittlement at high fluences, these evaluation are critical to developing an understanding of the so-called late blooming phases that may appear at long irradiation times.

(Milestone 5.2.A) A draft letter report, "*Precipitation in Thermally Aged and Neutron Irradiated Fe-Cu and Fe-Cu-Mn Model Alloys*" by M. K. Miller, (ORNL) K. F. Russell, (ORNL) G. R. Odette (UCSB) and D. Klingensmith (UCSB) has been prepared and is under review. The manuscript describes the microstructure of Fe- 0.80 at. % Cu and Fe-0.78 at. % Cu- 1.05% Mn model alloys that were thermally aged for 7,200 h at 290 and 350 °C or neutron irradiated to fluences of 0.04, 0.5 and ~1 x $10^{23}$ n $m^{-2}$ (E > 1 MeV) at 288 °C characterized by atom probe tomography. Ultrafine copper- and manganese-enriched precipitates were observed in both the 290 and 350 °C thermally aged conditions as well as the neutron irradiated conditions. After neutron irradiation to a fluence of ~1 x $10^{23}$ n $m^{-2}$ (E > 1 MeV), the number density of precipitates was approximately an order of magnitude higher in the Fe-Cu-Mn alloy than in the Fe-Cu alloy.

Additionally, an atom probe tomography characterization of a low copper steel from a thermal surveillance capsule in the EBR-II has been performed. The material is similar to an ASTM A543 steel which has higher nickel and chromium levels than an A533B steel. The nominal composition of this steel was Fe- 0.06 wt% Cu, 3.65 % Ni, 1.88% Cr, 0.51% Mo, 0.38% Mn, 0.29% Si, 0.023% S and 0.013% P. This steel was examined after thermally aging in the reactor for approximately 18 years at 370°C. Preliminary analysis of the data has revealed that there are no intragranular copper precipitates and no significant depletion of copper in the matrix. These results indicate that the copper level of the steel was below the copper solubility level in the matrix phase at the service temperature of 370°C. Some course carbides were observed and some of the chromium was found to partition to $M_{23}C_6$ carbides.

<u>Subtask 5.3: Modeling and Embrittlement Data Base (formerly 7.1)</u> (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 X from Pacific Gas & Electric Diablo Canyon Unit 2 Reactor Vessel Radiation Surveillance Program, WCAP-15423, September 2000," was converted to PR-EDB database format, including the following three major categories, namely, irradiation environment, RPV material history, and mechanical test results. It will need one more day of work to complete the EDB data input and data verification for this report.

The following five surveillance reports,

BAW-2355, " Capsule X of Shearon Harris,"
WCAP-15400, "Capsule X of Callaway Unit 1,"
WCAP-15405,"Capsule X of Millstone Unit 3."
WCAP-15589, "Capsule 38° of Palo Verde Unit 1," and
WCAP-15805, "Capsule X of H. B. Robinson Unit 2,"

will be integrated into PR-EDB over the next several months. All of these reports will be included in UPDATE-12 of PR-EDB, which will be prepared and transmitted to the US NRC technical program monitor by the end of March.

(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.

**<u>Task 6: Test Reactor Irradiation Coordination</u> (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.

<u>Subtask 6.1: Operate the HSSI Irradiation (IAR) Facility</u> (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 during this reporting period. During this period, the facilities were irradiated for the last 5.7 days of reactor half-cycle 478B. Reactor half-cycle 478B was a shortened cycle with a delayed start due to the Thanksgiving holiday. The facilities were then operated for the first 1.7 days of reactor half-cycle 479A, after which the reactor was shut down due to instrument problems in the reactor control room. The reactor instrument problems were corrected and the reactor operated for the remaining seven days of the half-cycle. The IAR facilities, however, were not operated during the last seven days of half-cycle 479A due to a faulty gas flow controller on the exit side of the HSSI-UCSB irradiation facility. The HSSI-UCSB irradiation facility occupies the space between the IAR-1 And IAR-2 irradiation facilities and all facilities must be started up and/or shut down at the same time. The faulty flow controller on the HSSI-UCSB irradiation facility was successfully replaced near the end of this reporting period and all facilities are ready for operation when the reactor resumes operation after the Christmas and New Year Holidays.

During the last 5.7 days of reactor half-cycle 478B, the IAR irradiation facilities received a total of 136 EFPH (effective full power hours). The facilities then received 41 EFPH during the first 1.7 days of reactor half-cycle 479A. During this reporting period, the HSSI-IAR irradiation facilities received a total of 177 EFPH.

At the beginning of this reporting period, the second group of specimens to be irradiated in the IAR facilities had been irradiated for a total of 13,075 EFPH. At the end of this reporting period, the second group of specimens had been irradiated for a total of 13,252 EFPH. The facilities have been in service for a total of 17,980 EFPH since they were installed and began operation 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.

(Milestone 6.1.C) To maintain maximum facility operational efficiency and to minimize down time, replacement and spare parts, such as a micro controller, heater controllers, panel meters, and moisture probes, will be needed before the FNR is shut down in the fall of 2003. A review of the priority of the equipment and parts was completed and discussed with the NRC Program Monitor. Several items have been procured with remaining items ordered during the next reporting period.

<u>Subtask 6.2: Operate the HSSI/UCSB Irradiation Facility</u> (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 during this reporting period without incidence. During this period, the facility was irradiated for the last 5.7 days of reactor half-cycle 478B. Reactor half-cycle 478B was a shortened cycle with a delayed start due to the Thanksgiving holiday. The facility was then operated for the first 1.7 days of reactor half-cycle 479A, after which the reactor was shut down due to instrument problems in the reactor control room. The reactor instrument problems were corrected and the reactor operated for the remaining seven days of the half-cycle. The HSSI-UCSB facility, however, was not operated during the last seven days of half-cycle 479A due to a faulty gas flow controller on the exit side of the facility. The faulty gas flow controller is used to control the internal gas pressure in the facility. The faulty flow controller on the irradiation facility was successfully replaced near the end of this reporting period and the facility is ready for operation when the reactor resumes operation after the Christmas and New Year Holidays.

During the last 5.7 days of reactor half-cycle 478B, the HSSI-UCSB irradiation facilities received a total of 136 EFPH (effective full power hours). The facility then received 41 EFPH during the first 1.7 days of reactor half-cycle 479A. During this reporting period, the irradiation facility received a total of 177 EFPH.

At the beginning of this reporting period, the HSSI-UCSB facility and specimens had been irradiated for a total of 24,943 EFPH. At the end of this reporting period, irradiation facility and specimens had been irradiated for a total of 25,120 EFPH. The original 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 186% 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:

During the period November 29 through December 6, 2002, R. K. Nanstad traveled to Pamporovo, Bulgaria, to participate in meetings of the International Atomic Energy Agency (IAEA) Cooperative Research Program (CRP) on Mechanisms of Nickel Effect in Radiation Embrittlement of Reactor Pressure Vessel Materials.

On December 11 – 13, T. M. Rosseel and K. R. Thoms traveled to McMaster University in Hamilton, Ontario, Canada to evaluate the MNR as a suitable site to perform irradiations of pressure vessel materials after the University of Michigan, FNR shuts down for decommissioning in 2003.

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

"Comparison of Nickel Effects on Embrittlement Mechanisms in Prototypic WWER-1000 and A533B Steels," by R. K. Nanstad, M. A. Sokolov, M. K. Miller, and G. R. Odette (presented by R. K. Nanstad), International Atomic Energy Agency Cooperative Research Program Meetings, Parmporovo, Bulgaria, December 2-4, 2002.

T. M. Rosseel, "Overview of the Heavy-Section Steel Irradiation Program," presented at McMaster University, Hamilton, Ontario, Canada, December 12, 2002.

K. R. Thoms and D. W. Heatherly, "Installation and Operation of the HSSI Irradiation Facilities at the FNR," presented by K. R. Thoms at McMaster University, Hamilton, Ontario, Canada, December 12, 2002.

## 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: 11/24/02-12/22/02

| | | Current Month | Fiscal Year to Date | Cumulative Project to date |
|---|---|---|---|---|
| I. | Direct Staff Effort | 6 MM | 1.3 MY | 43.9 MY |
| II. | A. Direct Lab Staff Effort ($) | | | |
| | Direct Salaries | 107,531 | 295,376 | 4,976,274 |
| | Materials and Services | 6,954 | 17,495 | 458,825 |
| | ADP Support | 58 | 160 | 2,702 |
| | Subcontracts | 12,360 | 7,950 | 812,731 |
| | Travel | 1,068 | 5,814 | 185,588 |
| | Other: NRC-PO Tax | 8,307 | 29,243 | 278,599 |
| | General and Administrative | 61,081 | 158,628 | 2,331,075 |
| | Total UT-Battelle Costs | 197,359 | 514,666 | 9,045,794 |
| | B. DOE Federal Admin. Costs | 5,921 | 15,440 | 109,668 |
| | TOTAL PROJECT COSTS | 203,280 | 530,106 | 9,155,462 |

| | |
|---|---|
| Percentage of available cumulative funds costed | 93 |
| Percentage of available current FY funds costed | 0 |
| Funds Remaining | 694,538 |
| Commitments: | 196,851 |
| BA Remaining | 497,687 |
| BA Remaining Less Projected FAC | 477,458 |

III. Funding Status

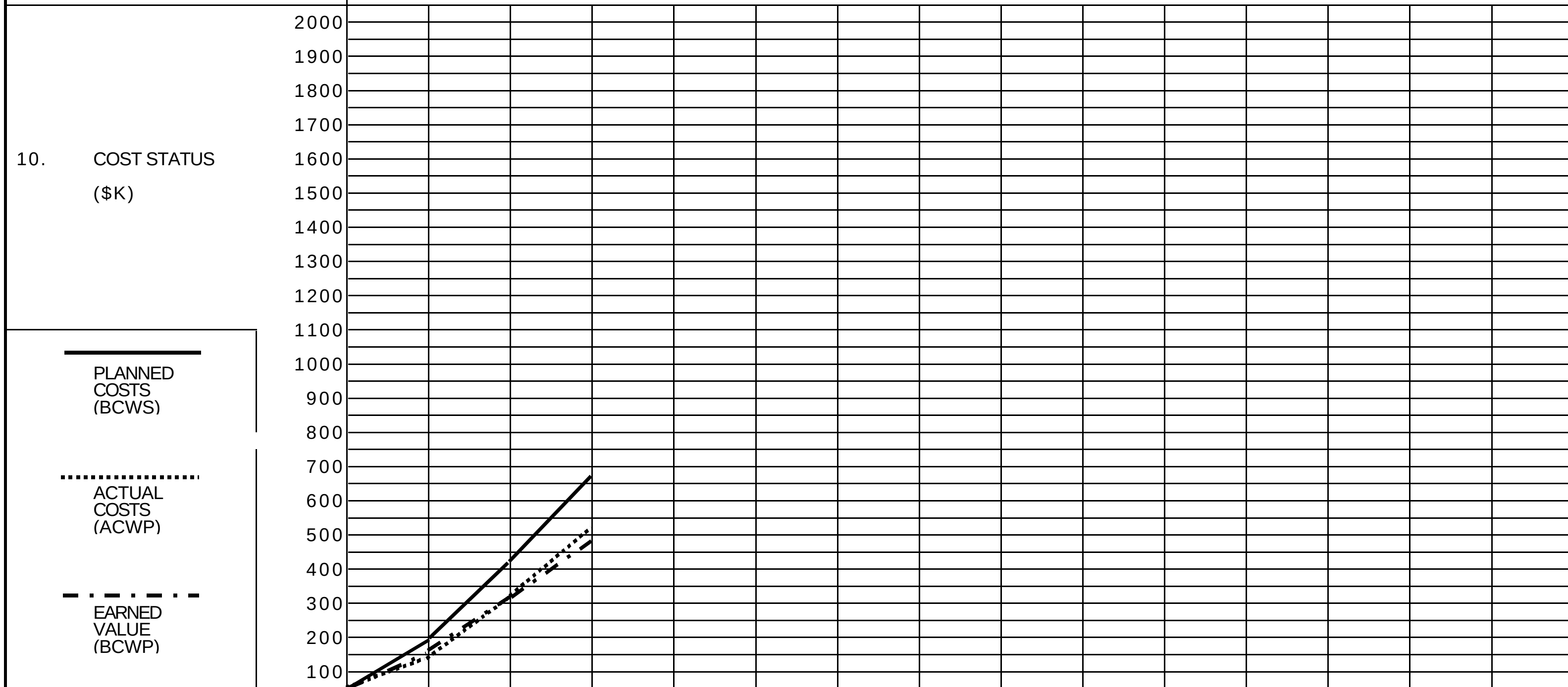
| Prior FY Carryover | FY 02 Projected Funding Level | FY 02 Funds Received to Date | FY 02 Funding Balance Needed | Cumulative Amt. Obligated | Cumulative Amt. Costed |
|---|---|---|---|---|---|
| 118,971,000 | 2,500,000 | 0 | 2,500,000 | 9,850,000 | 9,155,462 |

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

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - Heavy-Section Steel Irradiation Program** | 2. REPORTING PERIOD<br>**11/25/2002 - 12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998 - 2003** | 6. ACTIVITY NUMBER<br>**W41 W5 85 3W 1** |
| | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**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: 11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K): 1189

| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 195 | 248 | 242 | | | | | | | | | | | | |
| ACTUAL | 145 | 172 | 198 | | | | | | | | | | | | |
| EARNED | 153 | 157 | 172 | | | | | | | | | | | | |
| CUM. PLANNED | 195 | 443 | 685 | 685 | 685 | 685 | 685 | 685 | 685 | 685 | 685 | 685 | 685 | 685 | 685 |
| CUM. ACTUAL | 145 | 317 | 515 | 515 | 515 | 515 | 515 | 515 | 515 | 515 | 515 | 515 | 515 | 515 | 515 |
| CUM. EARNED | 153 | 310 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 | 482 |

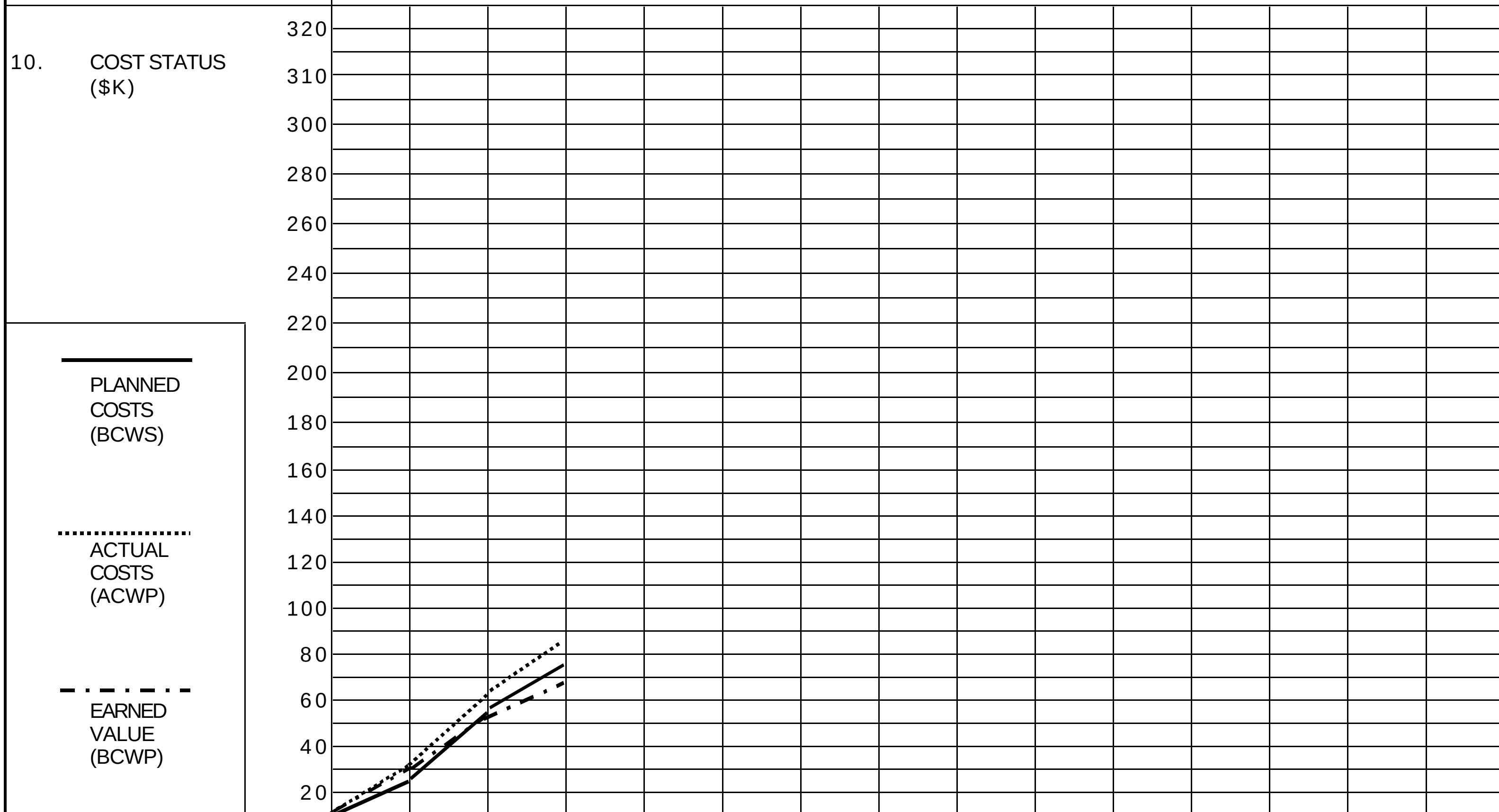
11. REMARKS

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

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 1. Program Management** | 2. REPORTING PERIOD<br>**11/25/2002 - 12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998 - 2003**<br>7. NRC B&R NO.<br>**860 15 21 20 05** | 6. ACTIVITY NUMBER<br>**W41 W5 85 3W 1**<br>8. DOE B&R NO.<br>**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

11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K)

124

| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 24 | 29 | 23 | | | | | | | | | | | | |
| ACTUAL | 30 | 32 | 24 | | | | | | | | | | | | |
| EARNED | 29 | 22 | 16 | | | | | | | | | | | | |
| CUM. PLANNED | 24 | 53 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 |
| CUM. ACTUAL | 30 | 62 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 |
| CUM. EARNED | 29 | 51 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 |

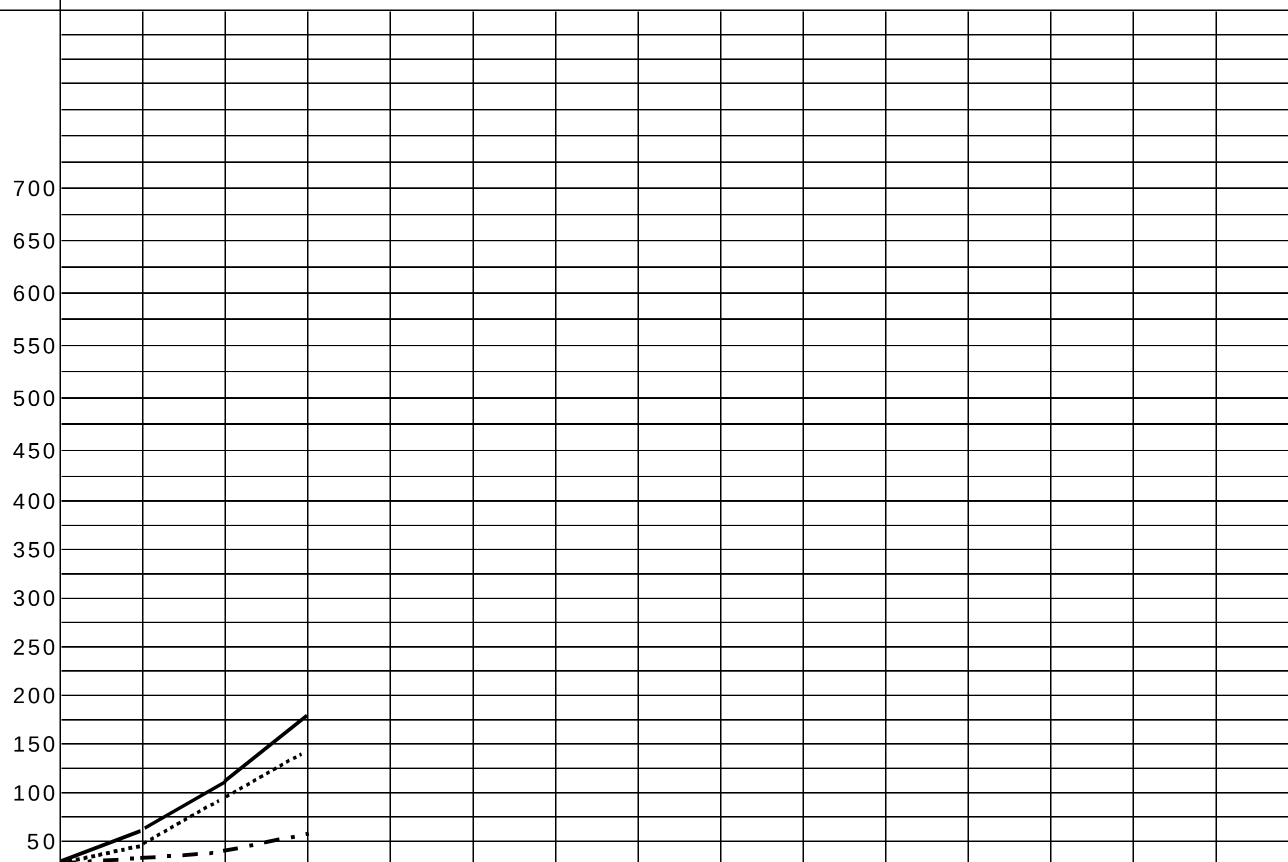
11. REMARKS

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

| 1. CONTRACT REPORTING ELEMENT | 2. REPORTING PERIOD | 3. JCN NO. |
|---|---|---|
| **HSSI - 2. Fracture Toughness Transition and MC Methodology** | **11/25/2002 - 12/22/2002** | **W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD **FY 1998 - 2003** | 6. ACTIVITY NUMBER **W41 W5 85 3W 1** |
| | 7. NRC B&R NO. **860 15 21 20 05** | 8. DOE B&R NO. **40 10 01 06** |

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

10. COST STATUS ($K)




PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

COST PLAN DATES

11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K)

402

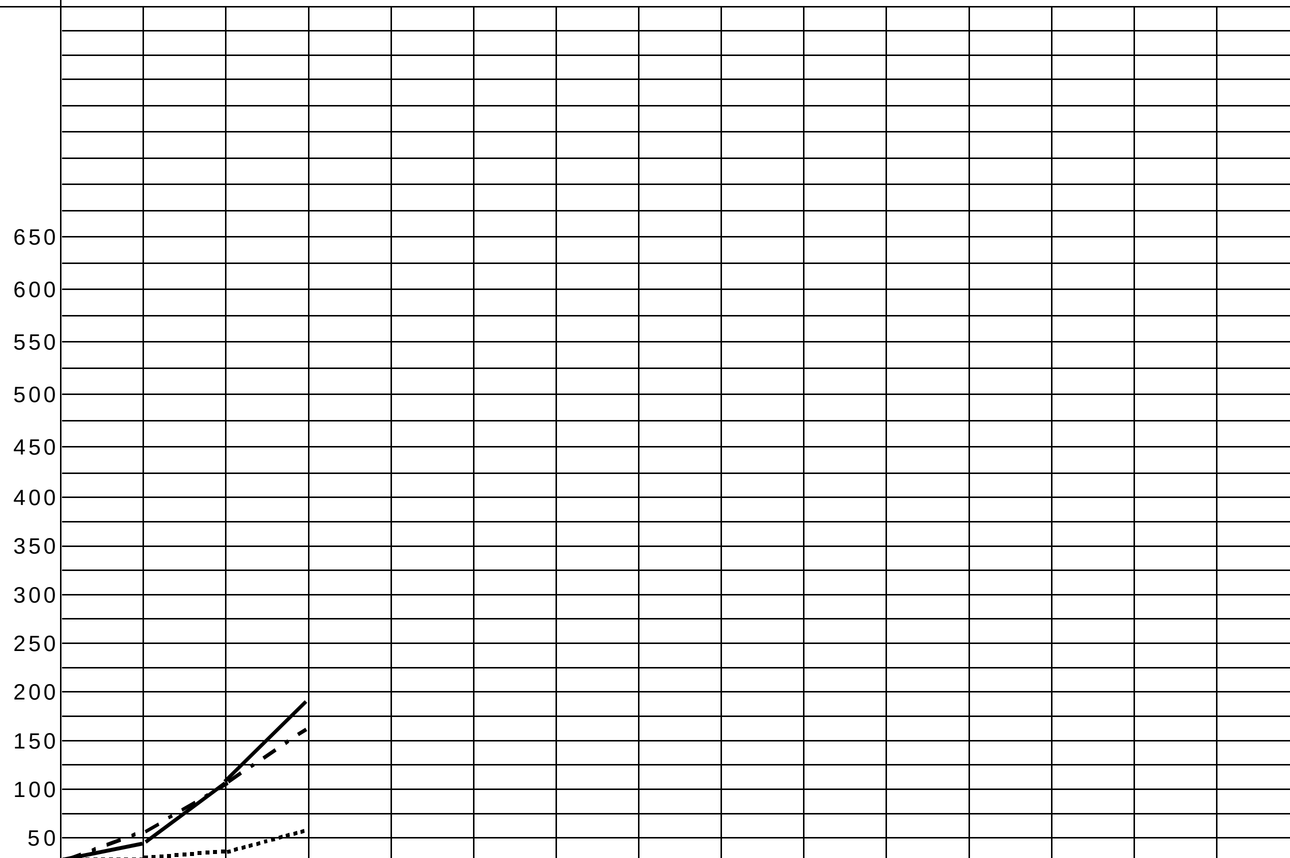
| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 54 | 62 | 61 | | | | | | | | | | | | |
| ACTUAL | 39 | 51 | 52 | | | | | | | | | | | | |
| EARNED | 12 | 12 | 42 | | | | | | | | | | | | |
| CUM. PLANNED | 54 | 116 | 177 | 177 | 177 | 177 | 177 | 177 | 177 | 177 | 177 | 177 | 177 | 177 | 177 |
| CUM. ACTUAL | 39 | 90 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 | 142 |
| CUM. EARNED | 12 | 24 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 | 66 |

11. REMARKS

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 3. Irradiation Embrittlement of RPV Steel** | 2. REPORTING PERIOD<br>**11/25/2002 - 12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998 - 2003**<br>7. NRC B&R NO.<br>**860 15 21 20 05** | 6. ACTIVITY NUMBER<br>**W41 W5 85 3W 1**<br>8. DOE B&R NO.<br>**40 10 01 06** |

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

10. COST STATUS ($K)




PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

COST PLAN DATES

11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K)

383

| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 39 | 65 | 88 | | | | | | | | | | | | |
| ACTUAL | 1 | 15 | 40 | | | | | | | | | | | | |
| EARNED | 51 | 53 | 55 | | | | | | | | | | | | |
| CUM. PLANNED | 39 | 104 | 192 | 192 | 192 | 192 | 192 | 192 | 192 | 192 | 192 | 192 | 192 | 192 | 192 |
| CUM. ACTUAL | 1 | 16 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| CUM. EARNED | 51 | 104 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 | 159 |

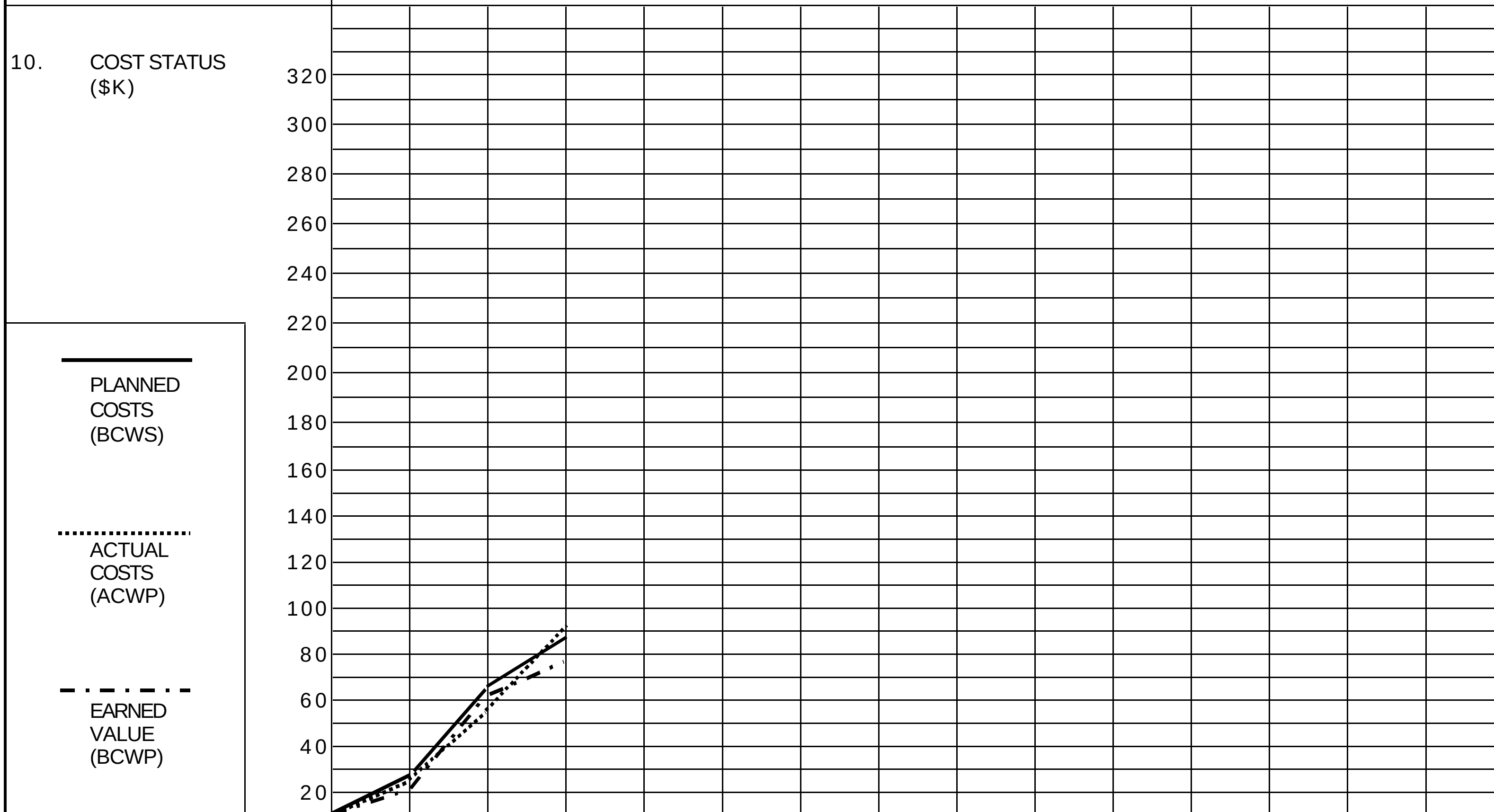
11. REMARKS

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

| | | | |
|---|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 4. Validation of Irradiated and Aged Materials** | | 2. REPORTING PERIOD<br>**11/25/2002 - 12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | | 5. CONTRACT PERIOD<br>**FY 1998 - 2003** | 6. ACTIVITY NUMBER<br>**W41 W5 85 3W 1** |
| | | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**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: 11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K): 152

| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 28 | 37 | 21 | | | | | | | | | | | | |
| ACTUAL | 27 | 27 | 38 | | | | | | | | | | | | |
| EARNED | 21 | 39 | 17 | | | | | | | | | | | | |
| CUM. PLANNED | 28 | 65 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 |
| CUM. ACTUAL | 27 | 54 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 |
| CUM. EARNED | 21 | 60 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 |

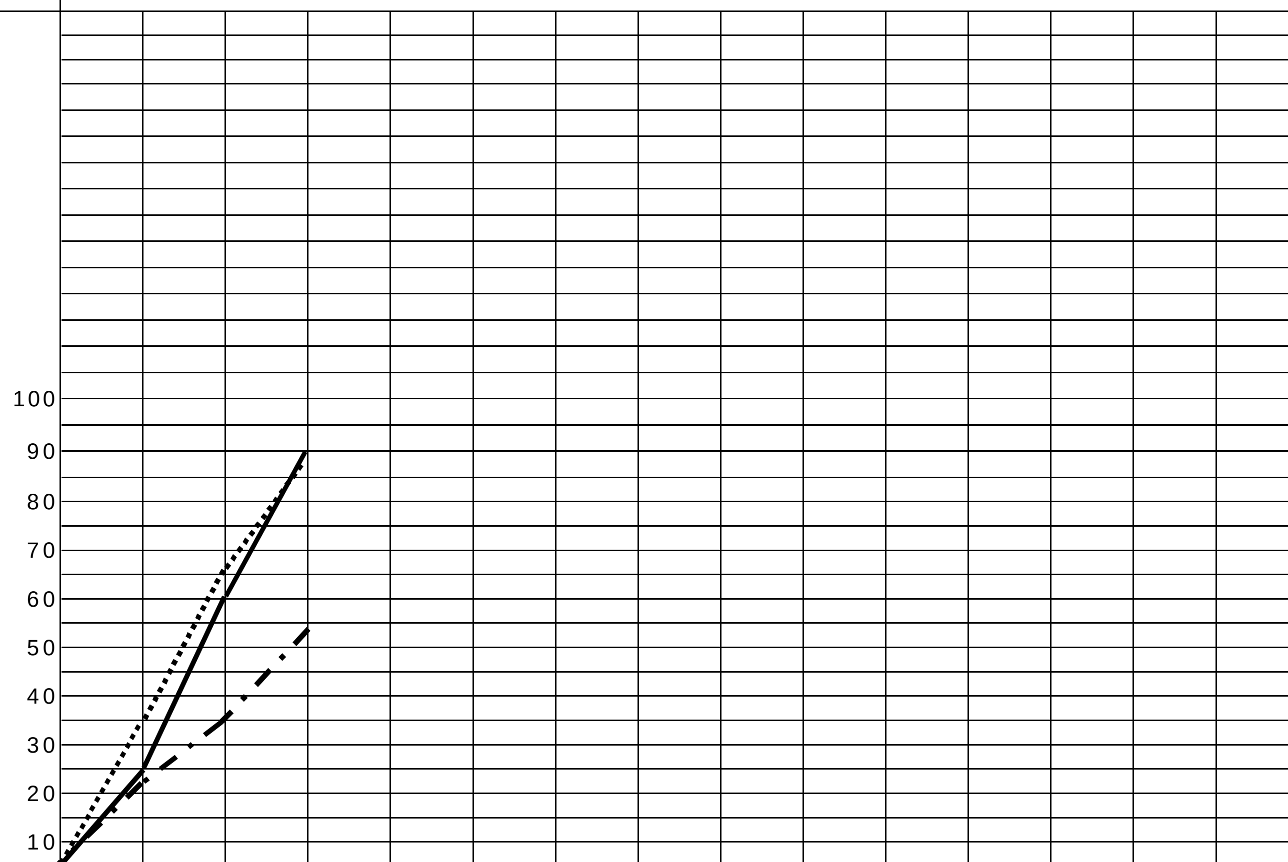
11. REMARKS

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

| | | | |
|---|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 5. Modeling and Microstuctural Analysis** | 2. REPORTING PERIOD<br>**11/25/2002 - 12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998 - 2003**<br>7. NRC B&R NO.<br>**860 15 21 20 05** | 6. ACTIVITY NUMBER<br>**W41 W5 85 3W 1**<br>8. DOE B&R NO.<br>**40 10 01 06** |

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

10. COST STATUS ($K)




PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

COST PLAN DATES

11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K)

75

| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 25 | 35 | 30 | | | | | | | | | | | | |
| ACTUAL | 35 | 31 | 22 | | | | | | | | | | | | |
| EARNED | 23 | 12 | 18 | | | | | | | | | | | | |
| CUM. PLANNED | 25 | 60 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| CUM. ACTUAL | 35 | 66 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 |
| CUM. EARNED | 23 | 35 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 | 53 |

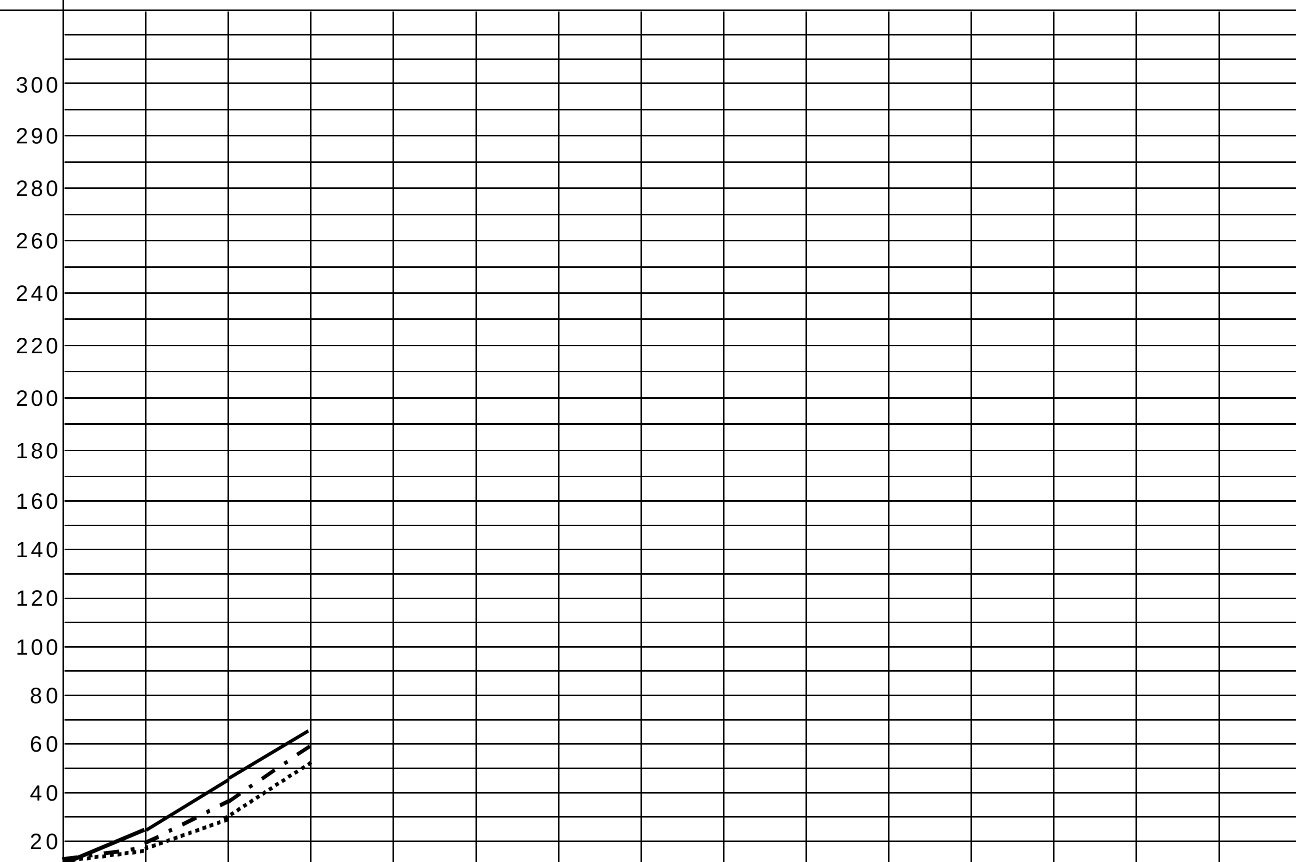
11. REMARKS

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

| | | | |
|---|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 6. Irradiation Coordination** | | 2. REPORTING PERIOD<br>**11/25/2002 - 12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | | 5. CONTRACT PERIOD<br>**FY 1998 - 2003** | 6. ACTIVITY NUMBER<br>**W41 W5 85 3W 1** |
| | | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**40 10 01 06** |

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

10. COST STATUS ($K)




PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

COST PLAN DATES

11/11/02

PLANNED COSTS FOR ELEMENT ($K)

ELEMENT COSTS FOR PRIOR FYS ($K)

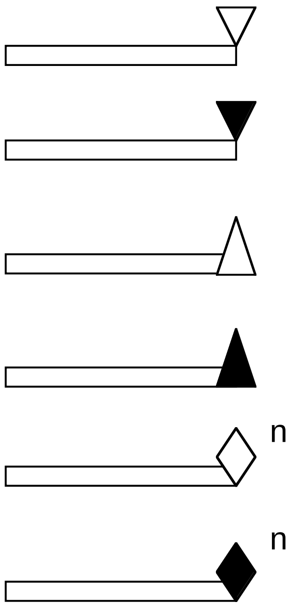
53

| ACCRUED COSTS ($K) | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PLANNED | 25 | 20 | 19 | | | | | | | | | | | | |
| ACTUAL | 13 | 16 | 22 | | | | | | | | | | | | |
| EARNED | 17 | 19 | 24 | | | | | | | | | | | | |
| CUM. PLANNED | 25 | 45 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| CUM. ACTUAL | 13 | 29 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| CUM. EARNED | 17 | 36 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |

11. REMARKS

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

Milestone Symbology




Intermediate milestone planned

Intermediate milestone completed

Major milestone planned

Major milestone completed

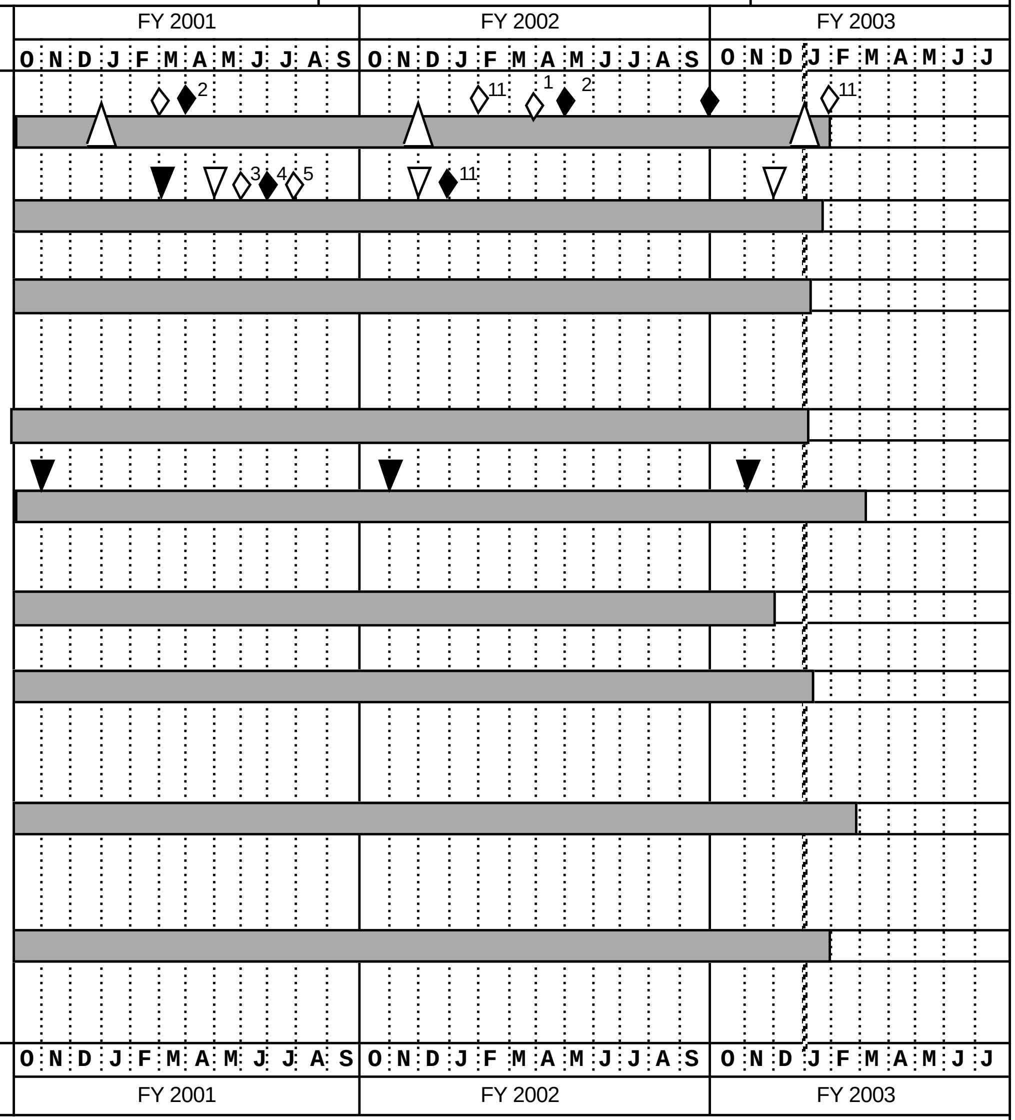
Rescheduled milestone planned

Rescheduled milestone completed

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

| 1. CONTRACT REPORTING ELEMENT | 2. REPORTING PERIOD | 3. JCN NO. |
|---|---|---|
| **HSSI - 1. Program Management** | **11/25/2002-12/22/2002** | **W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS) | 5. CONTRACT PERIOD | 6. ACTIVITY NUMBER |
| **OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | **FY 1998-2003** | **41 W6 95 3W 1** |
| | 7. NRC B&R NO. | 8. DOE B&R NO. |
| | **860 15 21 20 05** | **40 10 01 06** |

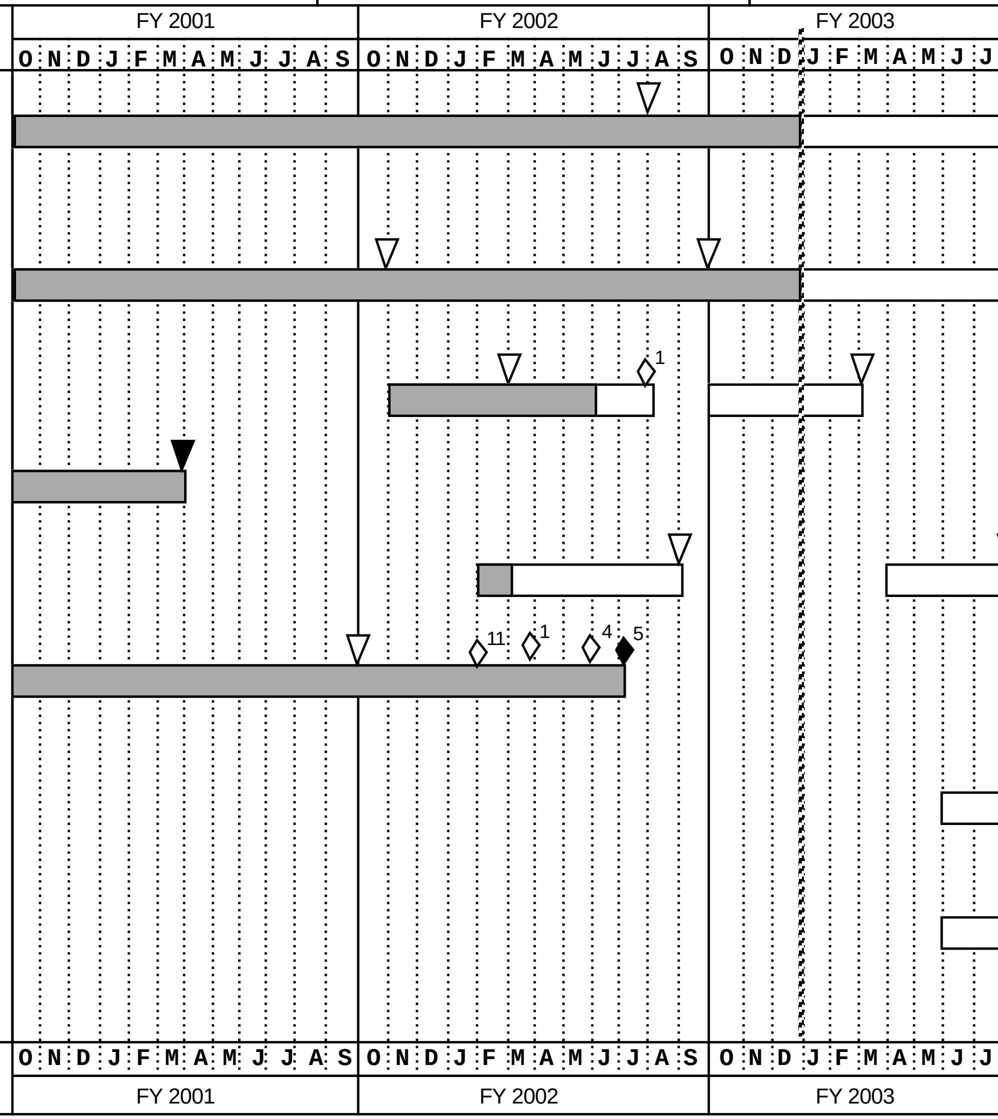
| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 1.1.A. | Issue Project & Budget Proposal |
| 1.1.B. | Select and Administer Subcontracts |
| 1.2.A. | Issue Earned Value Based Monthly Management Reports (by the end of subsequent month) |
| 1.2.B. | Ensure QA Requirements are met |
| 1.3.A. | Participate in NRC-Sponsored Meeting and Discussions |
| 1.3.B. | Coordinate NRC and Internal Reviews |
| 1.3.C. | Coordinate Domestic and Foreign Information Exchange as Approved by NRC-RES |
| 1.3.D. | Coordinate HSSI Letter and NUREG Reports |
| 1.3.E. | Document the Historical Information Generated by the Old HSSI Program |




11. REMARKS

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 2. Fracture Toughness Transition & MC Methodology** | 2. REPORTING PERIOD<br>**11/25/2002-12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998-2003**<br><br>7. NRC B&R NO.<br>**860 15 21 20 05** | 6. ACTIVITY NUMBER<br>**41 W6 95 3W 1**<br><br>8. DOE B&R NO.<br>**40 10 01 06** |

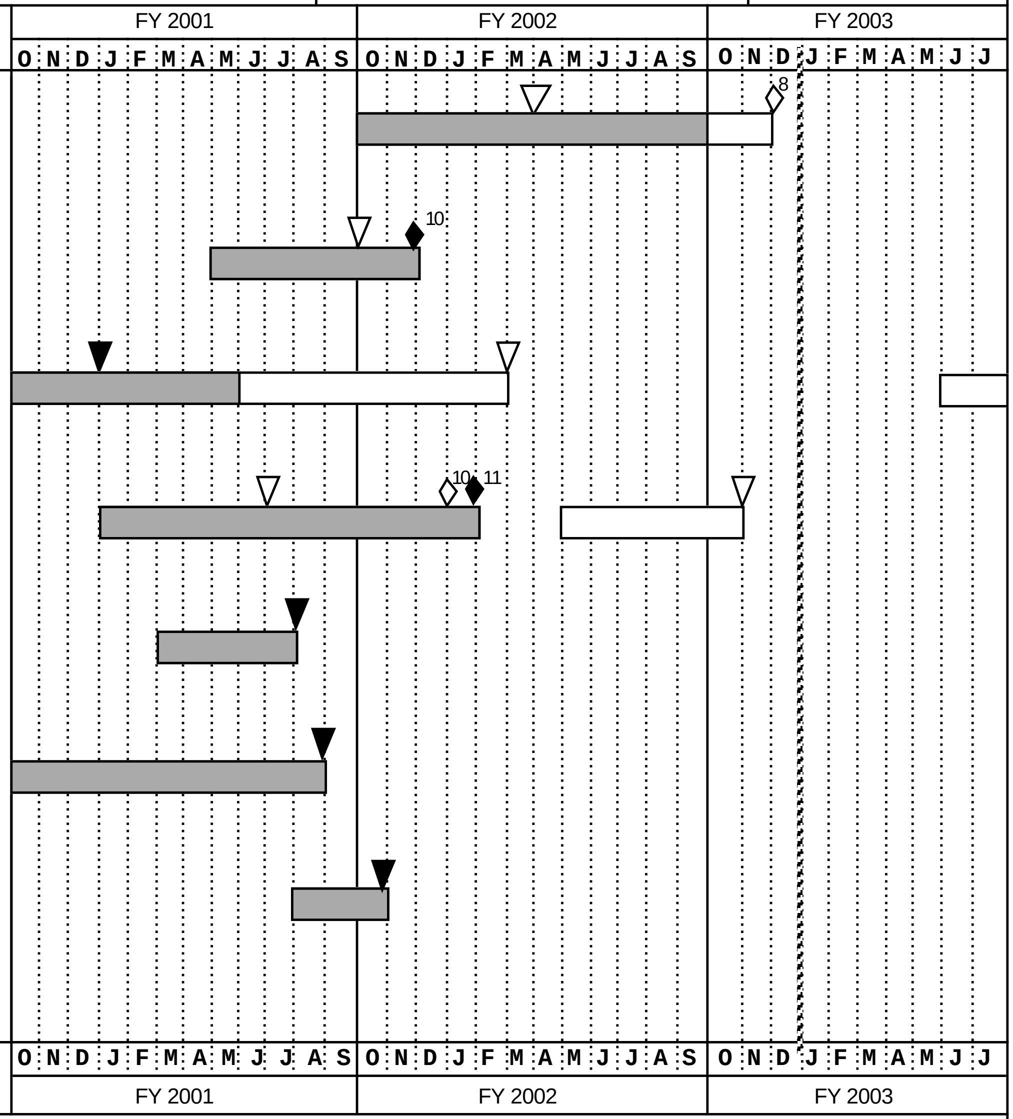
| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 2.1.A. | Continue to accumulate data on Comparison of CVN and Fracture Tougness Shifts |
| 2.2.A. | Irradiate Midland and Hi-Ni Specimens |
| 2.2.B. | Receive Specimens |
| 2.2.C. | Test Unirradiated & Irradiated KSØ1 for Master Curve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




11. REMARKS

| 1. CONTRACT REPORTING ELEMENT | 2. REPORTING PERIOD | 3. JCN NO. |
|---|---|---|
| **HSSI - 2. Fracture Toughness Transition & MC Methodology** | **11/25/2002-12/22/2002** | **W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS) | 5. CONTRACT PERIOD | 6. ACTIVITY NUMBER |
| **OAK RIDGE NATIONAL LABORATORY** | **FY 1998-2003** | **41 W6 95 3W 1** |
| **P. O. BOX 2008** | 7. NRC B&R NO. | 8. DOE B&R NO. |
| **OAK RIDGE, TN 37831** | **860 15 21 20 05** | **40 10 01 06** |

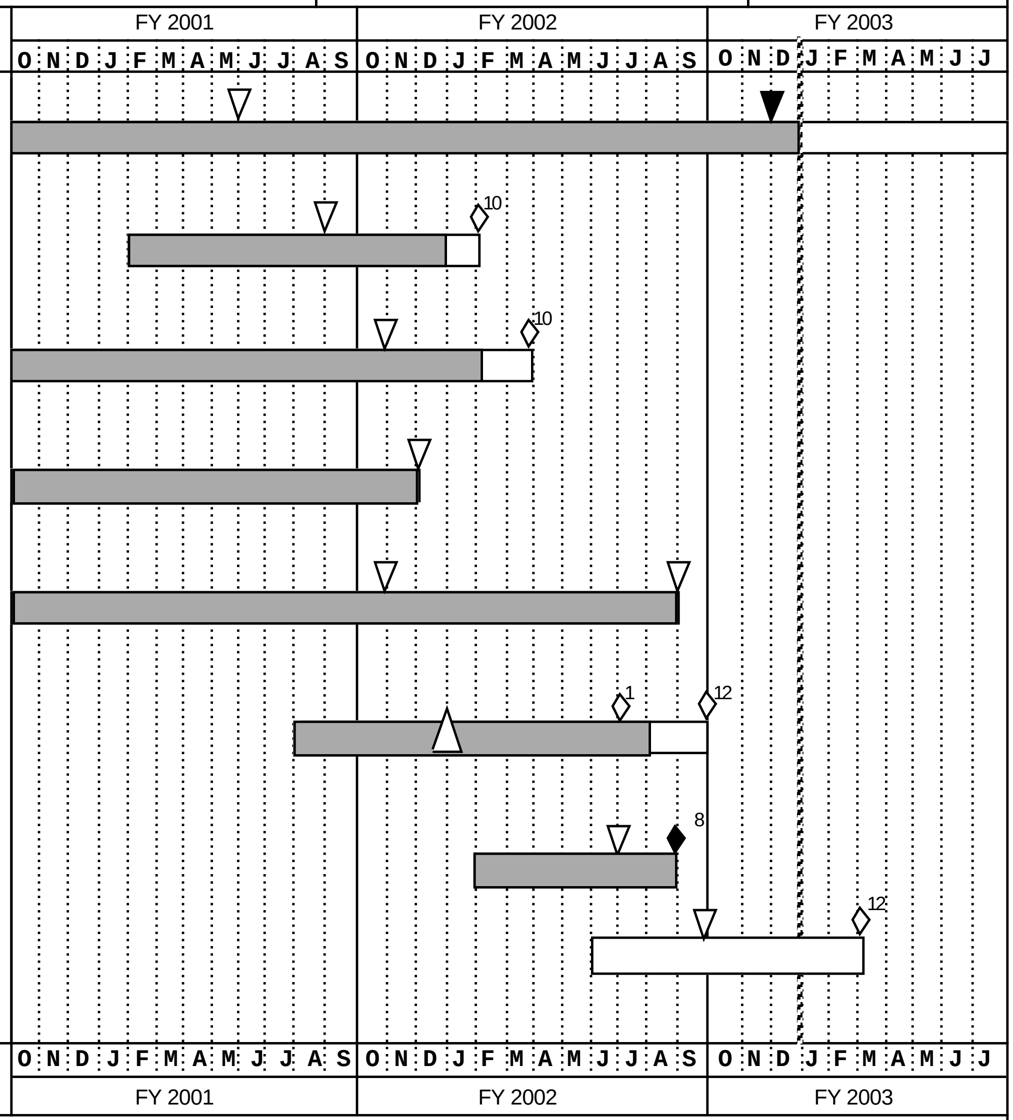
| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 2.3.A. | Develop Testing Plan for Dynamic Fracture Toughness Effects on MC |
| 2.4.A. | Letter Report on Statistical Representation of Valid $K_{JC}$ Data |
| 2.5.A. | Measure Activity and Prepare Report |
| 2.5.B. | Calculate Fluence and Prepare Report |
| 2.6.A. | Complete Testing of 0.5C(T) |
| 2.6.B. | Fractography Specimens |
| 2.6.C. | Final IGF Report |




11. REMARKS

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 2. Fracture Toughness Transition & MC Methodology** | 2. REPORTING PERIOD<br>**11/25/2002-12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998-2003** | 6. ACTIVITY NUMBER<br>**41 W6 95 3W 1** |
| | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**40 10 01 06** |

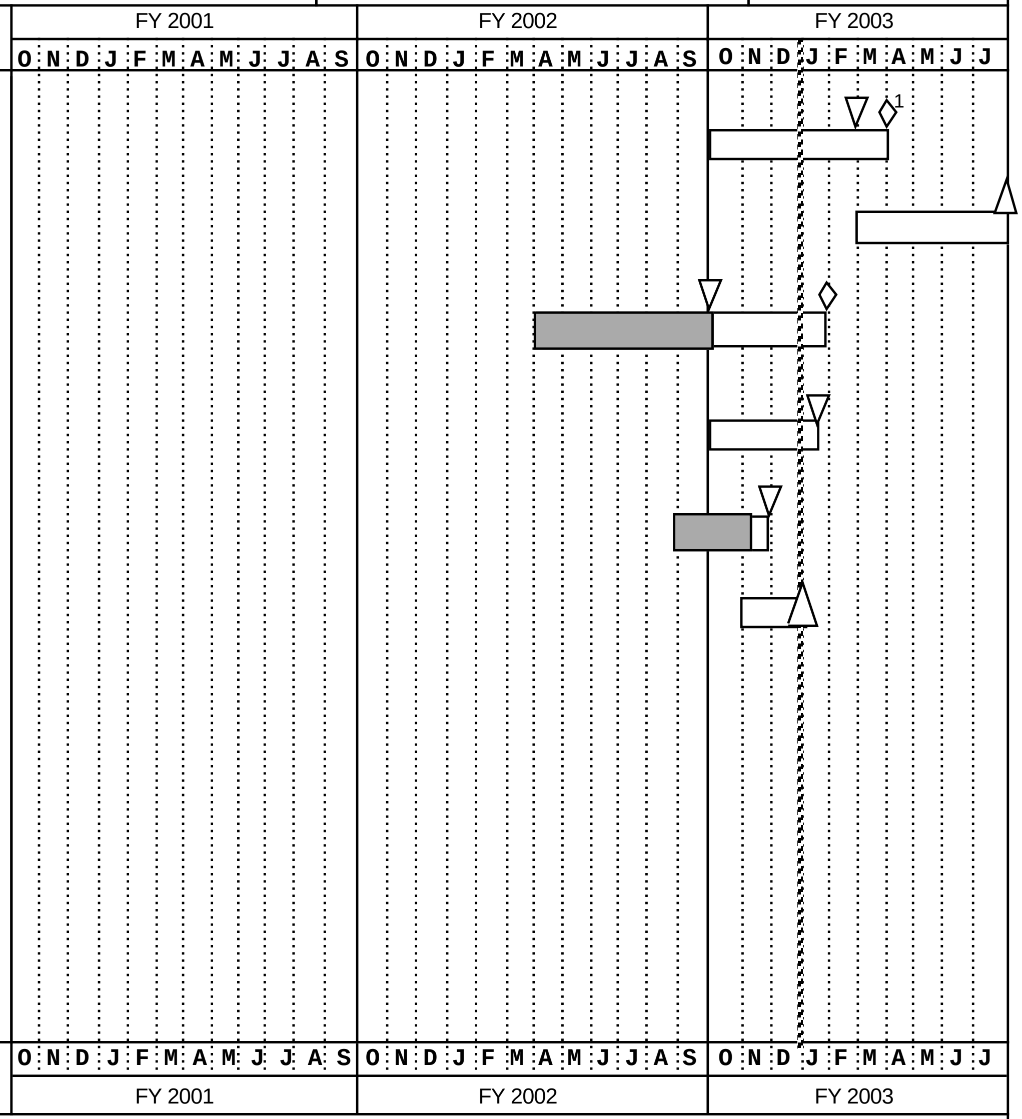
| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 2.7.A. | Complete Testing of Subsize Specimens |
| 2.7.B. | Testing of JRQ Plate |
| 2.7.C. | Complete Letter Report on Results of Subsize Specimen Fracture Toughness Tests |
| 2.8.A.1 | Complete Assembly and Compilation for Irradiated 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 |




11. REMARKS

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 2. Fracture Toughness Transition & MC Methodology** | 2. REPORTING PERIOD<br>**11/25/2002-12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998-2003** | 6. ACTIVITY NUMBER<br>**41 W6 95 3W 1** |
| | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**40 10 01 06** |

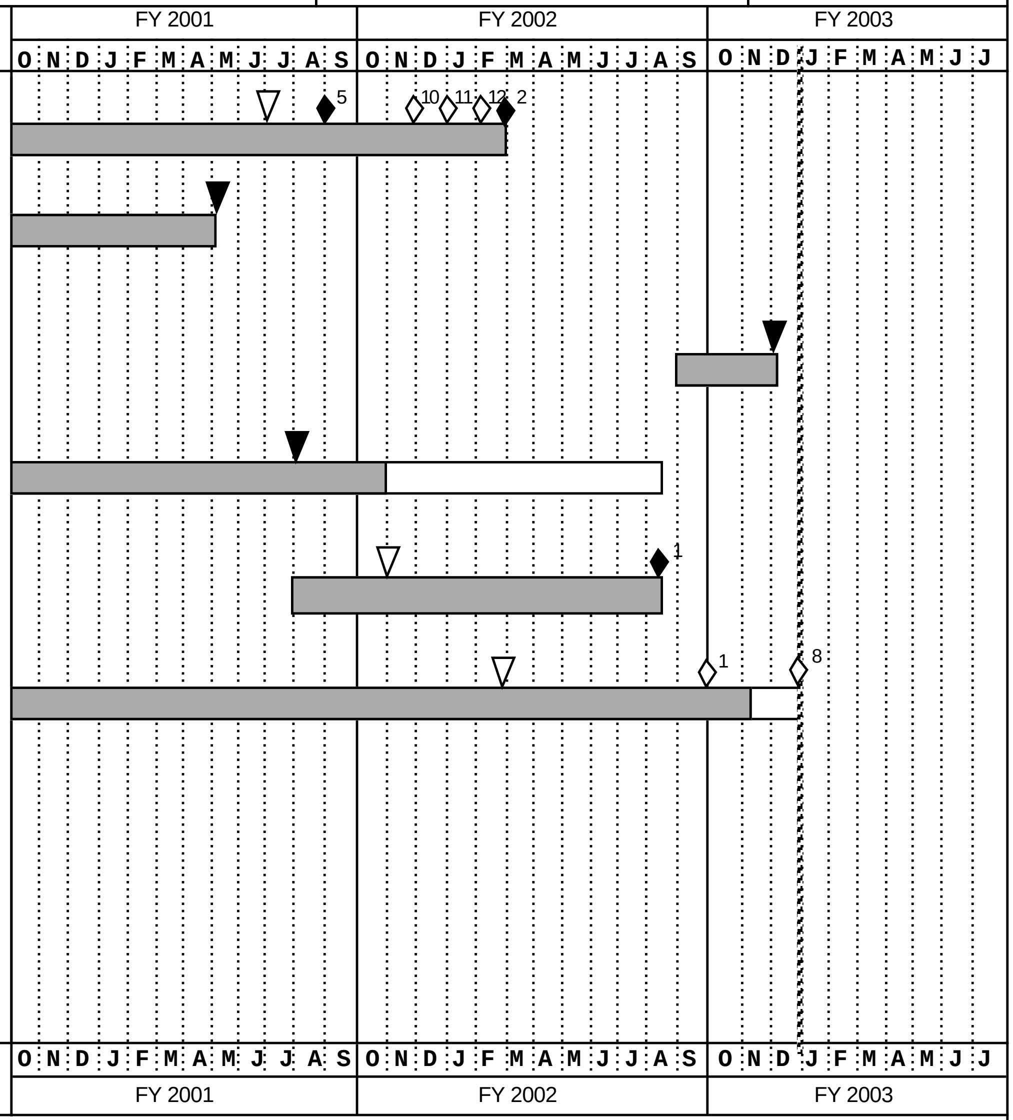
| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 2.9.C. | Test Specimens |
| 2.9.D. | Prepare Draft NUREG Report |
| 2.10.A. | Test 3-point Bend and PCVN Specimens |
| 2.10.B. | Prepare Draft NUREG Report |
| 2.10.C. | Machine and Test 72W ($T_o$) |
| 2.10.D. | Prepare Draft Report |




11. REMARKS

| 1. CONTRACT REPORTING ELEMENT | 2. REPORTING PERIOD | 3. JCN NO. |
|---|---|---|
| **HSSI - 3. Irradiation Embrittlement of RPV Steel** | **11/25/2002-12/22/2002** | **W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS) | 5. CONTRACT PERIOD | 6. ACTIVITY NUMBER |
| **OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | **FY 1998-2003** | **41 W6 95 3W 1** |
| | 7. NRC B&R NO. | 8. DOE B&R NO. |
| | **860 15 21 20 05** | **40 10 01 06** |

| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 3.1.G. | HAZ Letter Report |
| 3.1.H. | Evaluate Need for Additional Specimen Testing |
| 3.1.I. | Machine and Gleeble-treat HAZ Specimens |
| 3.2.A. | Complete JRQ Charpy Testing |
| 3.2.B. | Complete PCVN Testing |
| 3.2.C. | Complete Draft NUREG Report on IAR Results of JRQ |

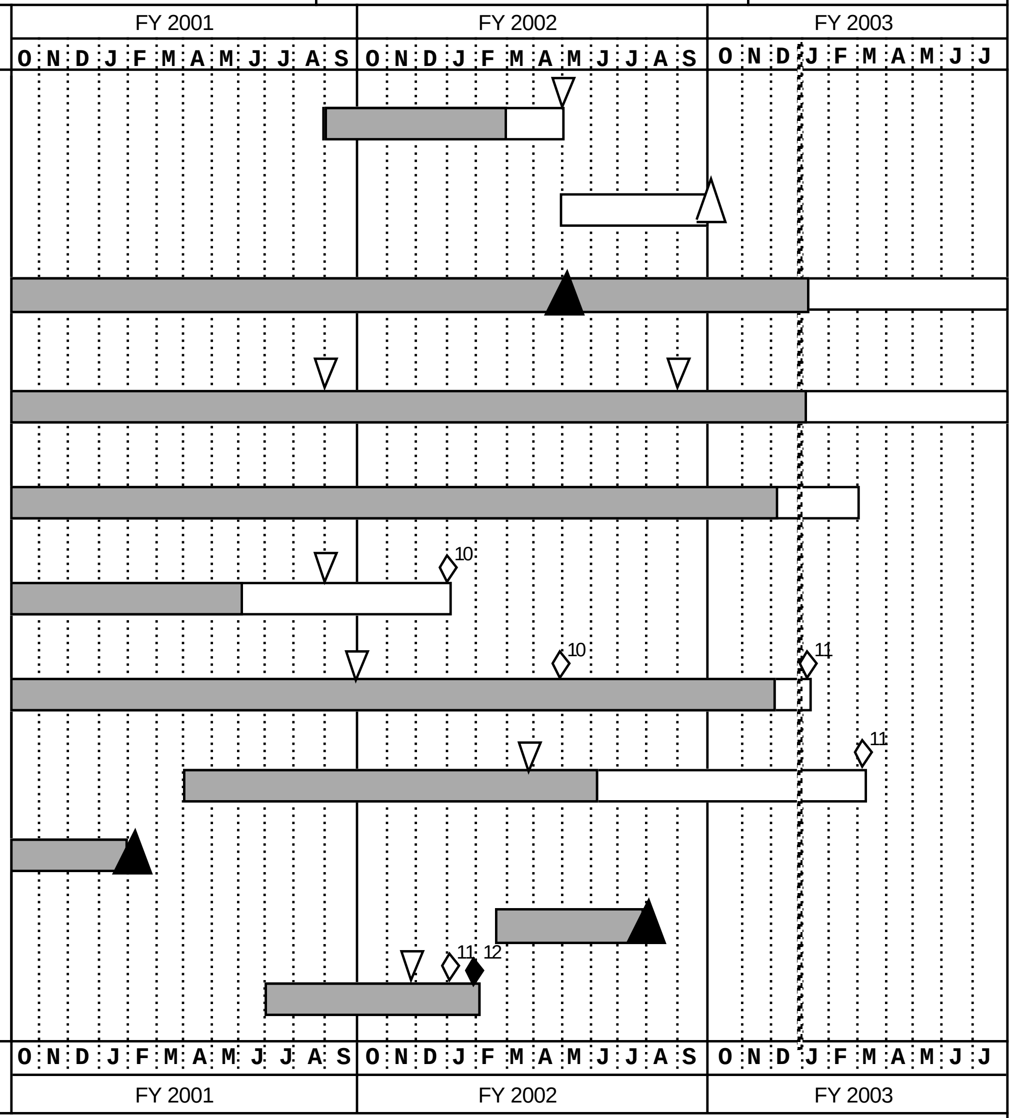



11. REMARKS

| 1. CONTRACT REPORTING ELEMENT | 2. REPORTING PERIOD | 3. JCN NO. |
|---|---|---|
| **HSSI - 4. Validation of Irradiated and Aged Materials** | **11/25/2002-12/22/2002** | **W6953** |

| 4. CONTRACTOR (NAME AND ADDRESS) | 5. CONTRACT PERIOD | 6. ACTIVITY NUMBER |
|---|---|---|
| **OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | **FY 1998-2003** | **41 W6 95 3W 1** |
| | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**40 10 01 06** |

| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 4.1.A. | Toughness Tests on SS Cladding |
| 4.1.B. | Letter Report |
| 4.2.A. | Participate in Periodic Meetings of IGRDM |
| 4.2.B. | Complete Progress Reports of Collaboration Activities |
| 4.3.A. | Letter Report on PWHT and Copper |
| 4.3.B. | Complete Letter Report on RPV Materials Available for Irradiation Study |
| 4.3.C. | Complete Crack Arrest NUREG Report |
| 4.3.D. | Complete Letter Report on IA of 73W |
| 4.3.E. | NUREG Report on JPDR Attenuation Effect |
| 4.3.F. | CRDM Tensile Tests |
| 4.4 | Letter Report on SONGS-1 Acquisition |

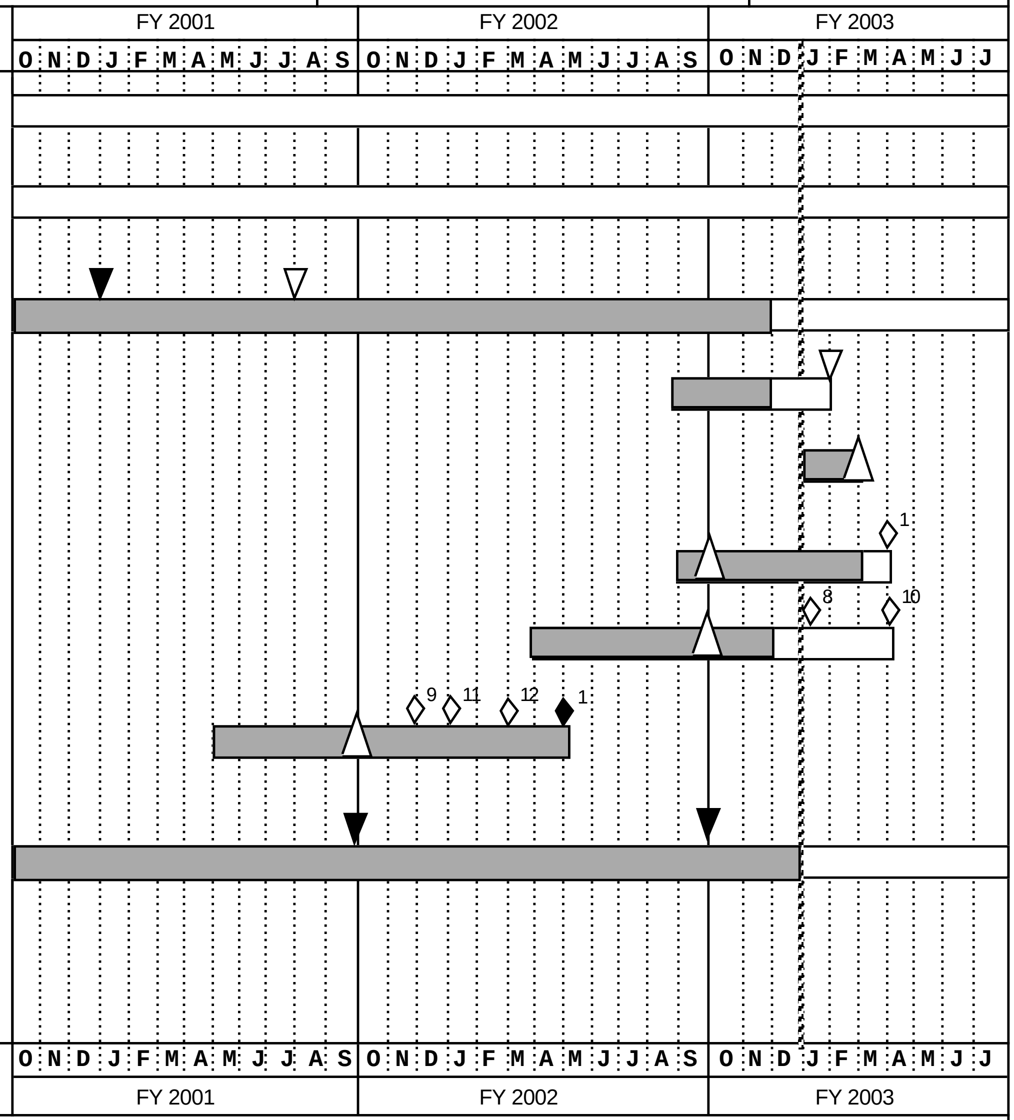



11. REMARKS

| 1. CONTRACT REPORTING ELEMENT | 2. REPORTING PERIOD | 3. JCN NO. |
|---|---|---|
| **HSSI - 5. Modeling & Microstructural Analysis** | **11/25/2002-12/22/2002** | **W6953** |

| 4. CONTRACTOR (NAME AND ADDRESS) | 5. CONTRACT PERIOD | 6. ACTIVITY NUMBER |
|---|---|---|
| **OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | **FY 1998-2003** | **41 W6 95 3W 1** |
| | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**40 10 01 06** |

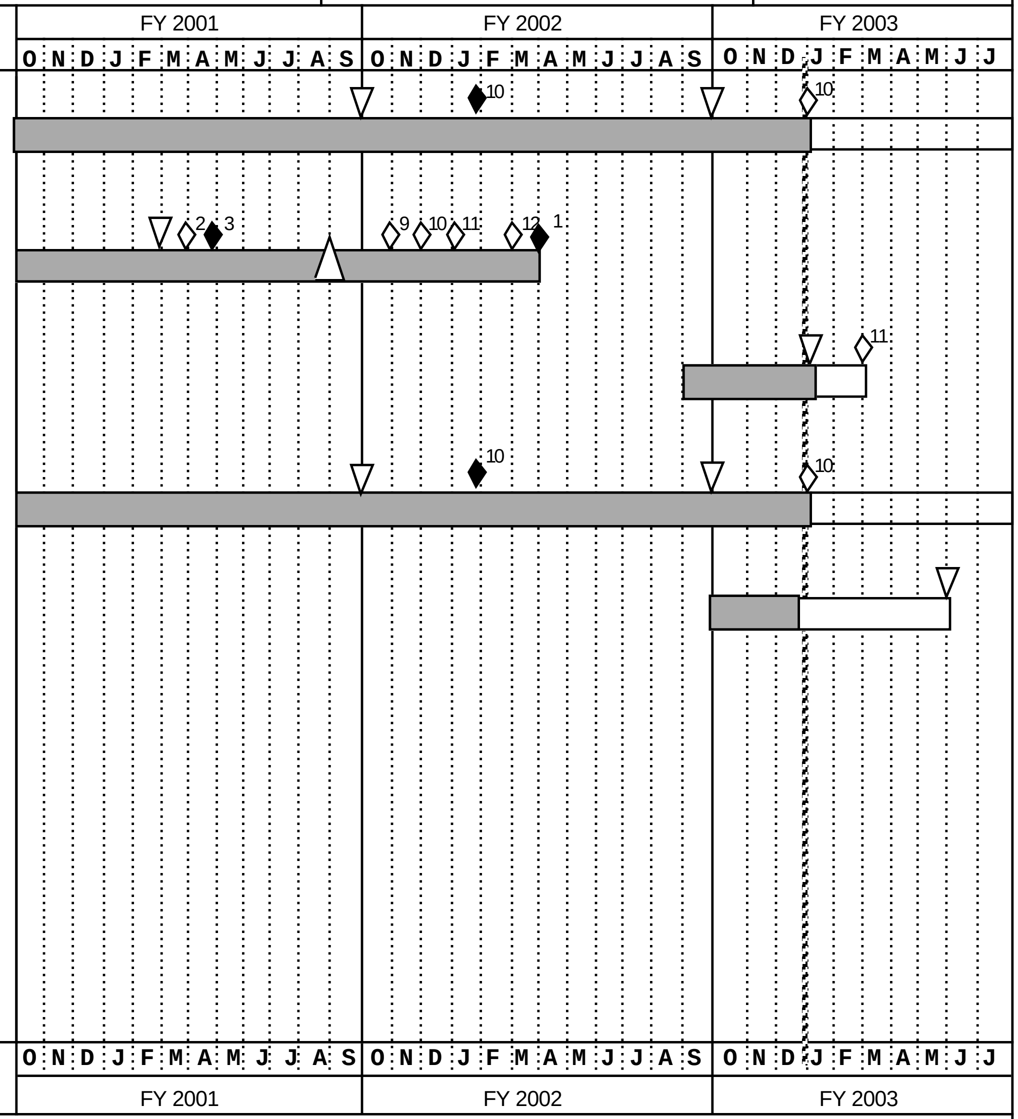
| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 5.1.A. | Development and Predictive use of Embrittlement Model |
| 5.2.A. | Coordinate and Analyze APFIM/SANS/FEGSTEM Round Robin Experiment |
| 5.2.B. | APFIM Characterization |
| 5.2.C. | APT of Late Blooming Phases |
| 5.2.D. | Prepare Draft Report |
| 5.3.A.1 | Evaluate and Input Surveillance Reports into Embrittlement Database |
| 5.3.A.2 | Complete Update 12 |
| 5.3.B. | Database Modeling Studies |
| 5.4. | Administration of Task Activities |




11. REMARKS

| | | |
|---|---|---|
| 1. CONTRACT REPORTING ELEMENT<br>**HSSI - 6. Irradiation Coordination** | 2. REPORTING PERIOD<br>**11/25/2002-12/22/2002** | 3. JCN NO.<br>**W6953** |
| 4. CONTRACTOR (NAME AND ADDRESS)<br>**OAK RIDGE NATIONAL LABORATORY**<br>**P. O. BOX 2008**<br>**OAK RIDGE, TN 37831** | 5. CONTRACT PERIOD<br>**FY 1998-2003** | 6. ACTIVITY NUMBER<br>**41 W6 95 3W 1** |
| | 7. NRC B&R NO.<br>**860 15 21 20 05** | 8. DOE B&R NO.<br>**40 10 01 06** |

| 9. MILESTONE IDEN. NO. | 10. MILESTONE DESCRIPTION |
|---|---|
| 6.1.A. | Coordinate the Operation, Data Collection, and Maintenance of the HSSI IAR Facility |
| 6.1.B. | Comprehensive Report on Reusable Irradiation Facilities and Report on Facility Options |
| 6.1.C. | Spare Parts for Irradiation Facilities |
| 6.2.A. | Coordinate the Operation, Data Collection, and Maintenance of the UCSB Irrad. Facility |
| 6.3.A. | Investigate alternativae irradiation Facilities for continuation of program after FNR shutdown |




11. REMARKS