ORNL/HSSI (W6953)/MLSR-2003/010

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

Monthly Letter Status Report

July 2003

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HEAVY-SECTION STEEL IRRADIATION

PROGRAM

JCN W6953

MONTHLY LETTER STATUS REPORT

FOR

July 2003

Submitted by

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managed by
UT-Battelle, LLC.
for the
U. S. DEPARTMENT OF ENERGY
Under DOE Contract No. DE-AC05-00OR22725

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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 July 2003, while the individual task budgets address the period from October 2002 to December 2003.

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

Thomas M. Rosseel, Manager
Heavy-Section Steel Irradiation

MONTHLY LETTER STATUS REPORT
July 2003

Job Code Number:	**W6953**
Project Title:	**Heavy-Section Steel Irradiation Program**
Period of Performance:	**4/1/98 to 4/1/03**
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1. PROJECT OBJECTIVE:

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

2. TECHNICAL ACTIVITIES:

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

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

(Milestone 1.1.A) All sections of the budget proposal document (189) for FY 2003 - FY 2005 were completed except for the budget information. Final action awaits a decision concerning additional support for hot cell work described in a cost growth letter submitted to the NRC Program Monitor in June.

(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 Ford Nuclear Reactor (FNR) ended during this reporting period. As planned by the University of Michigan Administration, the FNR was shut down permanently on July 3, 2003. This action ended a very successful series of RPV steel irradiation campaigns. The ORNL HSSI Program has been performing RPV steel irradiation experiments at the FNR for over 11 years on behalf of the NRC. The first two irradiation experiments involved one-time use irradiation vehicles similar to those previously used at the ORNL Bulk Shielding Reactor and the Oak Ridge Research Reactor. When recovery of irradiated specimens from the off-site reactor proved to be difficult and expensive, the HSSI Program developed reusable irradiation facilities in which test specimens could be inserted or removed as necessary in order to obtain the desired neutron fluences. Reusable irradiation facilities also produce far less irradiated material for disposal. (See Task 6 for details).

The HSSI Program Manager continues to serve on the ORNL Non-Reactor Nuclear Facilities Division (NNFD) Business and Cost Model Working Group. The purpose of the working group is to develop a cost model and allocation system that will help the new hot cell division better track and control the cost of conducting nuclear research in specialized facilities and improve operational efficiency. This model must be approved soon so as to ensure that budgeting and cost allocation methods are understood and can be implemented at start of the next fiscal year.

(Milestone 1.3.B) The planned visit to ORNL of Jack Strosnider, Deputy Director, Office of Nuclear Regulatory Research (RES); Mike Mayfield, Director of the Engineering Technology Division, RES; Gene Carpenter, RES; and Rich Bartlett, Director of the Engineering Division, Nuclear Reactor Regulation on Monday July 14, 2003, was cancelled.

(Milestone 1.3.D) On July 18, 2003, Dr. Milan Brumovsky visited ORNL to discuss the possible use of the LV-15 test reactor at NRI in Rez, Czech Republic for future HSSI irradiations. The LVR-15 is a 10 MW tank-type reactor that is operated typically at 8.8 MW for about 4500 hours per year. Based on Dr. Brumovsky's presentation, the NRI staff has the technical competence to carry out a wide variety of materials irradiation projects. Additionally, preliminary investigations by NRI staff suggest that two IAR-type facilities could be accommodated along one face of the core with fast neutron flux levels about a factor of three higher than was available at the FNR. Questions still remain concerning how the facilities would be moved relative to the core, and how the specimen transfers would be accomplished. The meeting provided a fruitful exchange of information, clearing up some questions of the HSSI staff and providing information to generate additional questions that can be more thoroughly addressed by a site visit. Please see Task 6.1.D for additional information.

On July 11, 2003, W. A. Server, ATI Consulting, visited ORNL to discuss Master Curve and embrittlement issues with the HSSI and other ORNL staff.

The effort to arrange for a guest assignment of up to one year focusing on dynamic fracture toughness and sub-size specimen effects is continuing. However, contractual issues have been raised that have prevented the implementation of an acceptable arrangement between ORNL and the guest's home institution. A final decision as to whether to proceed with the arrangement is expected in August.

(Milestone 1.3.E) The NUREG report on the mechanical properties of the KS01 weld has been completed and changes forwarded to technical publications for preparation for submittal to the US NRC. These changes will to be completed during the next reporting period. The first of three reviews of the Crack Arrest NUREG report was completed and corrections made. Additional comments are expected during the next reporting period. The 73W IAR NUREG report was being prepared for review.

The following manuscript was published: M. K. Miller, K. F. Russell, M. A. Sokolov, and R. K. Nanstad, "Atom Probe Tomography Characterization of Radiation-Sensitive KS-01 Weld," *J. Nucl. Mater*. **320** (2003)117.

Task 2: Fracture-Toughness Transition Issue and Master-Curve Methodology (M. A. Sokolov)

Fracture-toughness transition and Master Curve (MC) methodology will be broadly explored for pressure-vessel applications through a series of experiments, analyses, and evaluations in eight subtasks. Specifically, the effects of irradiation on fracture-toughness curve shape for highly embrittled RPV steels, dynamic effects, crack arrest, intergranular fracture, and subsized specimens will be explored; guidelines for the application of "surrogate" materials to the assessment of fracture toughness of RPV steels will be evaluated; and the fluence received in the HSSI irradiation experiments will be determined.

Subtask 2.1: Fracture-Toughness Transition-Temperature Shifts (M. A. Sokolov)

The purpose of this subtask is to collect and statistically analyze pertinent fracture-toughness data to assess the shift and potential change in shape of the fracture-toughness curves due to neutron irradiation. The MC methodology will be applied to provide a statistical analysis of the fracture-toughness data and Charpy data will be fitted by hyperbolic tangent functions. The resulting reference fracture-toughness temperature, T_0, shifts will be compared with Charpy shifts determined by various indexing methods.

(Milestone 2.1.A) The report by M. A. Sokolov and R. K. Nanstad, *Comparison of Irradiation-Induced Shifts of K_{Jc} and Charpy Impact Toughness for Reactor Pressure Vessel Steels*, NUREG/CR-6609 (ORNL/TM-13755), was published by the NRC in November 2000. There was no significant progress during this reporting period. However, as they become available, additional data sets will be analyzed and a revised database assembled.

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

The purpose of this subtask is to evaluate the assumption of constant shape for the MC even for highly embrittled RPV steels. The evaluation will be performed through the testing of a pressure-vessel steel weld that has been irradiated to a neutron fluence sufficient to produce a fracture-toughness transition-temperature shift (T_0) of about 150°C (270°F). A specially fabricated radiation-sensitive weld was selected to perform a pilot study on the ability of highly embrittled material to maintain the master curve shape. This weld had been fabricated and studied in Germany and supplied to ORNL by MPA, Stuttgart through a Memorandum of Agreement (MOA). The capsules, loaded with 21 1T compact specimens and a larger number of smaller specimens of Weld KS-01, were irradiated to a target fluence of 8.4×10^{18} n/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 2.5×10^{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 has been completed with shutdown of the University of Michigan FNR on July 3, 2003. Following an appropriate cooldown period, the specimens will be removed from the IAR facility and shipped to the ORNL hot cells for testing. Please also see Task 6.1. Some of the Palisades steam generator specimens irradiated to an intermediate fluence were removed previously and were received at the ORNL hot cells. These specimens were sorted and identified in preparation for testing, as discussed below.

Charpy impact tests of the Palisades unirradiated specimens and specimens irradiated to $\approx 1.38 \times 10^{19}$ 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 148ºC by *Regulatory Guide 1.99* (Rev. 2) and the predicted shift of 137ºC by the Eason, Wright, Odette (EWO) equation. Both predictions are, of course, dependent on the chemical composition variables used. The chemical composition used was an average of values available for the weld. Additional analyses will be conducted with the tested specimens to verify those values and will be compared with subsequent results from testing of the specimens irradiated to a higher fluence when they become available.

One broken half of a tested CVN specimen was submitted for atom-probe needle preparation. The fracture surface was cut from the specimen, then a 0.5 mm thick slice was cut from the remainder of the specimen. That slice was then cut into 0.5 mm thick blanks with approximate dimensions of 0.5x0.5x10 mm. The blanks have been stored in a lead pig awaiting transport to the atom probe preparation facility.

(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 ~0.8×10^{19} n/cm^2 (>1 MeV), were successfully tested. The results have been evaluated relative to the shape of the master curve. As reported previously, the occurrence of intergranular fracture in the test specimens was suspected to influence the deviation from MC shape observed. However, for a number of reasons also discussed previously, the contribution of IGF is not clear and the nonconformance of the KS-01 irradiated fracture toughness data may be predominantly due to the high degree of irradiation embrittlement. Further statistical analysis will be performed with these data. Three additional tensile tests, as noted previously, were expected to shed light on the effects of the intergranular fracture observations relative to expected irradiation-induced hardening. The yield and ultimate strengths for these tests exhibited the expected irradiation-induced strengthening, indicating that intergranular fracture was not the dominant fracture mechanism.

Testing of 12 irradiated precracked Charpy KS-01 specimens have been completed and the results are undergoing analysis. The draft NUREG report has completed technical review and incorporation of the reviewers comments, and will be submitted to the NRC for publication in August.

<u>Subtask 2.3: Dynamic Fracture Toughness [Combines previous subtasks 2.3 and 2.5]</u> (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, HSST Plate 13A, or HSSI Welds 72W/73W, and tested at a rate consistent with the dynamic elastic-plastic fracture toughness annex in ASTM E-1820-2001. This will allow for a direct comparison between T_o from quasi-static and dynamic tests. As mentioned above, a variation of loading rates within the E-1921 allowable range will also be considered.

Additionally, a review of instrumented impact testing of precracked Charpy specimens will be conducted to assess the potential inclusion of that technique in the project.

Subtask 2.4 - 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 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, was published and distributed in November. The concept described in this report is under consideration for inclusion in the "IAEA Guide on Master Curve Testing Results Application to Reactor Pressure Vessel Integrity Assessment", now under development in the IAEA Cooperative Research Project on Surveillance Results Application to Reactor Pressure Vessels.

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) The set of four Fissionable Radiometric Dosimeters (FRDs), removed from the IAR facilities in April 2001, and shipped to counting lab, will be used to verify the fluence estimates for the high-Nickel specimens and re-irradiation specimens removed from the FNR in 2001.

(Milestone 2.5.B formerly 3.2.B – I. Remec and E. D. Blakeman) Final conversion of the LSL-M2 code package from DOS to Linux is expected during the final quarter of the fiscal year.

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 under way.

(Milestone 2.6.A) As noted previously all testing has been completed on this activity. A presentation and paper on this subject were prepared and delivered by R. K. Nanstad at the IAEA Specialists' Meeting on Master Curve in Prague, Czech Republic, in September. The paper has now been published in the IAEA meeting proceedings: R. K. Nanstad, D. E. McCabe, and J. G. Merkle, "Relationship of Fracture Toughness From Intergranular Fracture to the Master Curve," *Master Curve Testing and Results Application, TWG-LMNPP-01/3*, pp. 123-137, IAEA, Vienna, Austria, 2002.

(Milestone 2.6.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 T_o Irradiated Highly Embrittled Steel And Intergranular Fracture" by R. K. Nanstad, M. A. Sokolov, and D. E. McCabe.

<u>Subtask 2.7: Sub-sized Specimens</u> (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. A letter report is in preparation with completion anticipated in August.

<u>Subtask 2.8: Quantification of Surrogate Materials for use in a Statistics-Based Fracture Toughness Assessment</u> (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 work, which has been completed by Jy-An Wang, was summarized in a previous progress report.

<u>Subtask 2.9: Application of the Master Curve to Highly Embrittled Materials</u> (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 system and the design of fixtures has been completed. Preparations for machining of the 0.4T compact specimens from the broken irradiated 1T compact specimens of KS-01 is under way with evaluation of the CNC machine operational status, design and fabrication of special fixtures for remote change-out of tools, remote lubrication of moving parts, etc. The machine has been exercised, various issues have been identified, and the issues are being resolved. A number of practice specimens have been machined and measured for comparison with established tolerances. This practice machining has identified a number of issues relevant to machining of compact specimens and the issues have been largely resolved, including the machining of new specimen holder fixtures from steel.

Following machining of the irradiated specimens, these 0.4T specimens will be tested in the same general temperature range as the 1Ts described in Task 2.2 to expand the database further for this material, and will provide for a comparison of compact specimen results with those from the similar size pre-cracked Charpy specimens. This comparison is directed at the bias indicated in some precracked Charpy data that results in somewhat lower determinations of T_o relative to compact specimens.

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 of the bias term project will tentatively 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. HSST Plate 13A is one material of choice because of the extensive compact specimen-derived fracture toughness database available for that material. One important aspect of such testing is the number of specimens needed to provide a statistically reliable estimate of the difference in T_o for each specimen geometry. There are various methods for such a calculation that will not be discussed here. However, if one desires to know T_o within ±10°C (±2 standard deviations) using the equation provided in E1921, the number of specimens needed is 13. If a two standard deviations variation of 5°C is desired, the number of specimens needed is 52. Thus, statistical considerations will play a strong role in the test matrix. The draft 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 literature review is in progress, including a review of linear elastic fracture mechanics (LEFM) results that may provide information regarding specimen configuration differences observed as the result of specimen fractures under predominantly elastic loading. The use of T-stress based constraint adjustments have received considerable discussions within the technical community and a comparison of such LEFM data may shed light on that specific subject.

A block of HSSI Weld 72W (second batch) was located, drawings were prepared, and 13 1T compact specimens were machined, fatigue precracked and tested without side-grooves, the same condition as in the HSSI Fifth Irradiation Program. Specimens were tested at –80, -50, and –30°C. Using the multi-temperature equation in E-1921, the T_o for this group of specimens from the "second batch" is –53.4°C. This compares with a T_o from the "first batch" of –56.6°C. The overall T_o for the combined database is –54°C. Thus, the results indicate no significant difference between the first and second batches. Therefore, the T_o result of –75°C from the MPC round robin program with PCVN specimens points to a difference of 21°C between the 1TC(T) and PCVN specimen for HSSI Weld 72W. A letter report, "Comparison of Fracture Toughness Reference Temperatures for the First and Second Batches of HSSI Weld 72W," by R. K. Nanstad, is in preparation with the draft report to be completed in August.

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, was published and distributed.

(Milestone 3.1.B) As noted previously, to investigate the effect of cooling rate following postweld heat treatment, additional material would be treated in the Gleeble system to simulate the coarse-grain HAZ as accomplished previously. This would then be followed by thermal aging, as well as by irradiation and post-irradiation thermal annealing. The A302 grade B (modified) steel in the previous study (designation Z-7) has a phosphorus content of 0.07 wt %. A second steel, A302 grade B (modified) with phosphorus content of 0.14 wt % (designation Z-5) is also included in this study for comparison. Excess material of each heat from the original investigation was identified and Gleeble specimens [(rods of about 75 mm (3 in.) long and 14.3 mm (0.562 in.) in diameter] were machined.

Gleeble treatment was performed with the same procedure used for the previous study and has now been completed for all the specimens. Following Gleeble treatment, the Gleeble specimens were postweld heat treated at 615ºC (1140ºF) for 24 h, then furnace cooled at ~15ºC/h. Charpy and tensile specimens were machined from the Gleeble specimens, notched and some were fatigue precracked for testing as precracked Charpy (PCVN) specimens. A total of 50 CVN (20 of Z-5 and 30 of Z-7), 20 PCVN (all of Z-7), and 16 tensile (4 of Z-5 and 12 of Z-7) specimens were packaged in two specially-fabricated steel boxes and were inserted into the IAR facility at the Ford Reactor in January.

The irradiation of these specimens was completed on July 3, 2003, with shutdown of the FNR. Following an appropriate cool-down period, the specimens will be removed from the IAR facility and shipped to the ORNL hot cells. At that time, a decision will be made regarding testing and thermal annealing of these specimens dependent on the neutron fluence achieved in the IAR. Consideration is also being given to reirradiation of the remaining specimens from the initial series, dependent on availability of an irradiation facility. Gleeble treatments and postweld heat treatments have been completed for the remaining specimens that will be tested in the unirradiated and thermally aged conditions. Machining of those specimens has now been completed. Thermal aging and testing will begin in August.

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

The purpose of this subtask is to examine the fracture-toughness behavior of a model steel that has been irradiated, tempered, and re-irradiated. The specimens, 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 (to duplicate previous PSI experiments) 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 of this work was made by R. K. Nanstad at the 10^{th} Meeting of the International Group on Radiation Damage Mechanisms (IGRDM) in Pressure Vessel Steels, 19-24 May 2002 in Awaji Island, Japan.

During June of 2002, the precracked Charpy specimens were tested in the irradiated condition, in the irradiated/annealed condition, and in two different IAR conditions. A presentation on the preliminary results from this work was made by R. K. Nanstad at the ASTM Symposium on Radiation Effects in Materials in Tucson, Arizona, in June. Photographs of specimen fracture surfaces have been made, crack lengths have been measured, and final analyses have been completed. During the hot cell testing, it was discovered that many of the specimens have relatively shallow flaws, with a/W ratios of about 0.3. Results from these specimens do not, of course, satisfy the requirements of E 1921 for valid fracture toughness data. There are some results in the literature indicating no significant effect of a/W ratios as low as 0.3 and this will be further pursued. Thus, the data will be evaluated giving consideration to the potential loss of constraint on the results. An initial comparison of the test results in the irradiated and the irradiated/annealed conditions, both of which included specimens with both short and long cracks, provided mixed results. In one case, the average K_{Jc} values were about the same, while in the other case they were substantially different. Moreover, neither comparison is based on a statistically strong database in that the subsets comprise only 4 or 5 test results. A paper 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.

A work package has been prepared for cutting of pieces of selected JRQ specimens to be submitted for atom-probe examination. The same work package includes packaging and transport of selected irradiated specimens to PSI for their thermoelectric power (TEP) testing. The selected specimens have been retrieved from the storage cans and identified. They will be packaged for shipment to PSI in August.

R. K. Nanstad visited PSI during the last week of July to discuss the various aspects and progress of the collaborative project that is conducted under a Memorandum of Agreement between ORNL and PSI. He met with Dr. Dietmar Kalkhof, the cognizant scientist for the PSI portion of the project, and Dr. Niffenegger of PSI, the researcher responsible for conduct and analysis of the TEP experiments. They have completed TEP measurements with both unirradiated and irradiated CVN specimens that had been previously tested at PSI. Comparison of the results with the Charpy impact results indicates the probability of a reasonable correlation between results from the two tests. Nanstad and Kalkhof discussed and agreed on the selection of broken CVN and PCVN specimens for shipment to PSI for additional TEP testing. One specimen from each group representing a specific irradiated condition) will also be sectioned for atom probe tomography at ORNL. A joint NUREG report and technical papers will be prepared following completion of all the experiments and analyses. A foreign trip report is in preparation.

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) The 11th meeting of the International Group on Radiation Damage Mechanisms (IGRDM) is now being planned for 10-16 September, 2003 in San Diego, California. R. K. Nanstad, as secretary of the IGRDM, has updated the membership list, prepared a revision of the charter, and is working with the local host for the meeting (R.G. Carter of the Electric Power Research Institute) and the IGRDM Chairman (T.J. Williams of Rolls-Royce, U.K.) to organize the meeting. Presentation titles from the HSSI Program have been submitted by M. K. Miller, R. K. Nanstad, M. A. Sokolov, and R. E. Stoller.

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, ORNL/FTR-162664, has been submitted.

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 2001 were removed in January at the behest of the CRP and transported to ORNL for testing as soon as practicable. A trip report, ORNL/FTR-164584, has been submitted.

The irradiated VVER-1000 Charpy impact specimens were tested in the ORNL hot cells in May. Twelve specimens each of a base metal (forging) and a weld were tested at various temperatures, with lateral expansion measurements and photographs of fracture surfaces made subsequent to testing. The forging contains about 1.2 wt% nickel, while the weld metal contains about 1.7 wt% nickel. The results have been analyzed and are in preparation for transmittal to the IAEA CRP committee members for inclusion in the committee database for those two materials. Following submittal of these data, the committee will complete the final analysis of all the data on the two materials and a final report for the CRP will be prepared.

R. K. Nanstad attended the meeting of the IAEA CRP "Surveillance Programmes Results Application to Reactor Pressure Vessel (RPV) Integrity Assessment," and an IAEA consultancy meeting on development of a new CRP on "Bias Terms for Master Curve application," in Vienna, Austria, 24-28 February 2003. R. K Nanstad is an author of a chapter on "Fluence Projection and Attenuation" for the IAEA guidelines document on application of the fracture toughness master curve, now in preparation. A trip report, ORNL/FTR-167446, has been prepared and submitted.

R. K. Nanstad visited PSI for discussions regarding the ORNL/PSI collaboration on irradiation/annealing/reirradiation of RPV steel. See 3.2 for details.

R. K. Nanstad attended a consultancy meeting at the IAEA in Vienna, Austria from 31 July-4 August. The meeting was held to edit and complete the IAEA Technical Report Series (TRS), “Neutron Irradiation Embrittlement of RPV Steels.” The book has languished with the death of the previous chief editor (Myrddin Davies) earlier in the year. Also, the former IAEA Technical Secretary responsible for the book, V. Lyssakov, completed his term in April and was replaced as Technical Secretary by Dr. Ki-Sig Kang. Dr. Kang setup and coordinated the consultancy meeting in Vienna. R. K. Nanstad is the author of Chapter 3, “Irradiation Effects on Mechanical Properties,” of the TRS and is also one of the three editors, including Mr. William Server of ATI Consulting in the U.S. and Dr. Milan Brumovsky of the Nuclear Research Institute in Rez, Czech Republic. All the chapters have now been written and edited with the exception of Chapter 4, “Radiation Damage Mechanisms,” primarily authored by Dr. Jean-Claude Van Duysen of EdF in France. Dr. Van Duysen will submit his chapter during the first half of August. The meeting in Vienna was very productive in that significant progress was made towards publication of the TRS. Such progress would not have happened without such a meeting.

On July 11, 2003, W. A. Server, ATI Consulting, visited ORNL to discuss Master Curve and embrittlement issues with the HSSI and other ORNL staff.

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. The report, which has been prepared by the subcontractor, Dr. Shafik Iskander is undergoing technical review.

(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 which was about 4×10^{19} n/cm^2 was obtained. Dosimeters associated with the experiment are waiting to be counted and analyzed (see Task 2.5). The specimens will be scheduled for testing at the ORNL hot cells in the latter part of 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.

<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 2002. This activity is complete.

Task 5: Modeling & Microstructural Characterization and Embrittlement Data Base (T. M. Rosseel)

This task shall determine the microstructural basis for radiation-induced property changes in RPV materials to aid in understanding and applying the experimental results obtained in Tasks 2 through 4. The three subtasks will comprise: (1) theoretical modeling and data analysis; (2) experimental investigations; and, (3) maintaining and updating the Embrittlement Data Base (EDB). The modeling work will include the development of an improved description of primary-damage formation in irradiated materials, and the further development and use of predictive models of radiation-induced microstructural evolution and its impact on the mechanical behavior of RPV materials. The experimental component will focus on detailed microstructural characterization of RPV materials in relevant conditions, including long-term, thermally-aged and high-fluence irradiated materials. The information obtained from the experiments and microstructural characterization will be used to support validation of the theoretical models. Further model verification will be carried out through use of the mechanical property data contained in the EDB, and data generated in other experiments coordinated by this task. Updated versions of the EDB will be issued as appropriate.

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

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

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

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

(Milestone 5.1.B) The NUREG report entitled *Evaluation of Neutron Energy Spectrum Effects Based on Primary Damage Simulations in Iron*, NUREG/CR-6643, (ORNL/TM-1999/334) was submitted to the NRC in July 2000.

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

APFIM characterization will be used to determine whether additional radiation-induced phases are forming. In addition, the methods of APFIM, SANS, and field-emission scanning transmission electron microscopy (FEGSTEM) have been used to determine the matrix copper content and the chemical composition of radiation-induced precipitates in RPV materials. Although there is qualitative agreement between the three methods, some significant inconsistencies exist. Comparisons among the techniques will be performed so as to resolve the apparent inconsistencies.

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 1.6×10^{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) The paper by M. K. Miller, K. F. Russell, M. A. Sokolov, and R. K. Nanstad, entitled, "Atom Probe Tomography Characterization of Radiation-Sensitive KS-01 Weld," J. Nucl. Mater. **320** (2003) 117, was published.

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

This subtask was, until March 1, 1999, part of the Embrittlement DataBase (EDB) and Dosimetry Evaluation Program, JCN: 6164. The objectives of the subtask have been reduced but the focus remains the same. Nuclear radiation embrittlement information from radiation embrittlement research on nuclear RPV steels and from power-reactor surveillance reports will be maintained in a database to be published on a periodic basis. The information will assist the Office of Nuclear Reactor Regulation and the Office of Nuclear Regulatory Research to effectively monitor current procedures and data bases used by vendors, utilities, and service laboratories in the pressure vessel irradiation surveillance program. The specific activity of the subtask is to maintain and update the EDB. Additional work on statistical analysis of toughness databases will also be performed. The purpose of this effort is to design a new data fitting procedure to generate a new multi-space trend surface that can properly reflect the inhomogeneity of the surveillance materials, and utilize this multi-space trend surface to link and to project the surveillance test results to that of reactor pressure vessel steels.

(Milestone 5.3.A) An evaluation of whether any of the embrittlement data presented by industry at the ASTM E-10.02 subcommittee meeting in Denver on June 18, 2003, were included in the most recent version, UPDATE_12 of the PR-EDB was been completed. Specifically, a comparison has been made of the 180 new surveillance data received from EPRI with that of the PR-EDB Update_12. Of the 180 new data, 60 are BWR data and 120 are PWR data. An updated transition temperature shift data file based on Update_12 of the PR-EDB, which contains a total of 953 transition temperature shift data points, was generated for the comparison.

It was found that 77 of the 180 new data were identified from the PR-EDB. The remaining 103 data of the 180 EPRI-supplied shift data are not contained in the current Update_12 of PR-EDB. A new file, EPRI_new_data.xls file, of this data includes all 60 BWR data and 43 PWR data. This information will be forwarded to NRC contractors as directed by the NRC Program Monitor.

It was determined that all of the 60 new BWR data are from the following two reports.

1. BWRVIP-87: BWR Vessel and Internals Project Testing and Evaluation of BWR Supplemental Surveillance Program Capsules D, G, and H, EPRI, Palo Alto and BWRVIP: 2000, 1000890.
2. BWRVIP-111: BWR Vessel and Internals Project Testing and Evaluation of BWR Supplemental Surveillance Program Capsules E, F, and I, EPRI, Palo Alto and BWRVIP: 2002, 1003553.

In order to complete the PR-EDB data collection process, the following surveillance reports are needed from the NRC.

1. BWRVIP-87: BWR Vessel and Internals Project Testing and Evaluation of BWR Supplemental Surveillance Program Capsules D, G, and H, EPRI, Palo Alto and BWRVIP: 2000. 1000890

2. BWRVIP-111: BWR Vessel and Internals Project, Testing and Evaluation of BWR Supplemental Surveillance Program Capsules E, F and I, EPRI, Palo Alto, CA: 2002. 1003553

3. Evaluation of Capsule PWR-5: EPRI-CRIEPI Integrated Reactor Vessel Surveillance Program (IRVSP) Capsule Irradiated in Davis Besse (PWRMRP-08), EPRI, Palo Alto, CA: 1999. TR-113891.

4. WCAP-15692, "Analysis of Capsule Y from PSEG Nuclear Salem Unit 2 Reactor Vessel Radiation Surveillance Program," August 2001.

5. WCAP-16001, "Analysis of Capsule Y from Dominion Surry Unit 2 Reactor Vessel Radiation Surveillance Program," February 2003.

6. WCAP-16012, "Analysis of Capsule W-83 from the Dominion Nuclear Connecticut Millstone Unit 2 Reactor Vessel Radiation Surveillance Program," February 2003.

7. WCAP-15958, "Analysis of Capsule V from the Pacific Gas and Electric Diablo Canyon Unit 1 Reactor Vessel Radiation Surveillance Program," January 2003.

8. WCAP-15916, "Analysis of Capsule X from the Florida Power and Light Company Turkey Point Unit 3 Reactor Vessel Radiation Surveillance Program," September 2002.

9. WCAP-16028, "Analysis of Capsule X from the Wolf Creek Nuclear Operating Corporation, Wolf Creek Reactor Vessel Radiation Surveillance Program," February 2003.

10. WCAP-15046, "Analysis of Capsule U from the Tennessee Valley Authority Watts Bar Unit 1 Reactor Vessel Radiation Surveillance Program," June 1998.

11. "River Bend 183 Degree Surveillance Capsule Report," MPM Report Number MPM-1202971, January 2003.

12. "Fracture Toughness of Reactor Pressure Vessel Steel Welds," EPRI Research Project RP2180-6, (Unpublished) Final Report, M.T. Wang, August 1983.

The update of the PR-EDB from a DOS environment to Windows platform is expected to begin before the end of the fiscal year.

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

This task provides the support required to supply and co-ordinate irradiation services needed by NRC contractors (such as the UCSB and the ORNL HSSI Program) at the University of Michigan FNR. These services include the design and assembly of irradiation facilities (and/or capsules), as well as arranging for their exposure, periodic monitoring by remote computer access and interaction with the FNR staff, and return of specimens to the originating research organization.

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

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

(Milestone 6.1.A) Irradiation of the ORNL specimens in the HSSI-IAR irradiation facilities continued for a short time during this reporting period. As planned by the University of Michigan Administration, the FNR was shut down permanently on July 3, 2003. This action terminated all NRC-sponsored materials irradiation experiments.

During this period, the HSSI-IAR facilities were irradiated for the last 2.6 days of the FNR’s final half-cycle 486A. During the 2.6 days of reactor half-cycle 486A the IAR irradiation facilities received a total of 63 EFPH (effective full power hours).

At the beginning of this reporting period, the second group of specimens to be irradiated in the new IAR facilities had been irradiated for a total of 15,672 EFPH. At the end of this reporting period, the second group of specimens had been irradiated for a total of 15,735 EFPH. The facilities had been in service for a total of 20,463 EFPH since they were installed and began operation at the FNR in December 1998.

Shutdown of the FNR ended a very successful RPV steel irradiation campaign. ORNL HSSI Program and UCSB researchers had been performing RPV steel irradiation experiments for the NRC at the FNR for over 11 years. The first two irradiation experiments involved one-time use irradiation vehicles similar to those previously used at the ORNL Bulk Shielding Reactor and the Oak Ridge Research Reactor. When recovery of irradiated specimens from the off-site reactor proved to be difficult and expensive, the HSSI Program developed reusable irradiation facilities in which test specimens could be inserted or removed as necessary in order to obtain the desired neutron fluences. Reusable irradiation facilities also produce far less irradiated material for disposal.

In 1998, the HSSI Program designed, fabricated, and installed at the FNR two reusable irradiation facilities for irradiating compact tension, tensile, and Charpy specimens. The test specimens were prepared so as to develop 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 and reactor plant life extension. It included studies of the effects of irradiation on the degradation of mechanical and fracture properties of vessel materials. Effects of specimen size; material chemistry; product form and microstructure; irradiation fluence, flux, temperature, and spectrum; and post-irradiation mitigation have been and will continue to examined on a wide range of fracture properties. At the time the FNR was shut down for decommissioning these two facilities, including preliminary testing, had been in operation for 20,497 EFPH and they remain 100% operational.

(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 2002.

(Milestone 6.1.D) Assessments of alternative test reactors have continued. For example, on July 18, 2003, the HSSI staff met with Dr. Milan Brumovsky of the Nuclear Research Institute (NRI), Rez, Czech Republic, for discussions on the potential use of the LVR-15 research reactor for future HSSI irradiations. After ORNL staff described the HSSI program and irradiation facilities at the FNR, Dr. Brumovsky described the research activities at NRI and provided a physical description of the LVR-15. The LVR-15 is a 10 MW tank-type reactor that is operated typically at 8.8 MW for about 4500 hours per year. It was apparent from Dr. Brumovsky's presentation that the NRI staff has the technical competence to carry out a wide variety of materials irradiation projects. Based on preliminary investigations by NRI staff it appears that two IAR-type facilities could be accommodated along one face of the core with fast neutron flux levels about a factor of three higher than was available at the FNR. The available space would likely permit making each of the facilities 33% larger than those at FNR, i.e., each facility would accommodate the equivalent of 20 1T-CT specimens instead of 15 specimens. Questions still remain concerning how the facilities would be moved relative to the core, and how the specimen transfers would be accomplished. The meeting provided a fruitful exchange of information, clearing up some questions of the HSSI staff and providing information to generate additional questions that can be more thoroughly addressed by a site visit.

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

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

(Milestone 6.2.A) Irradiation of the UCSB specimens in the HSSI-UCSB irradiation facility continued for a short time during this reporting period. As planned by the University of Michigan Administration, the FNR was shut down permanently on July 3, 2003. This action terminated all materials irradiation experiments at FNR after more than six years of operation using these facilities and over 11 years of operation for the HSSI Program.

During this reporting period, the HSSI-UCSB facility was irradiated for the last 2.6 days of the FNR's final half-cycle 486A. During the 2.6 days of reactor half-cycle 486A, the irradiation facility received a total of 63 EFPH.

At the beginning of this reporting period, the HSSI-UCSB facility and original specimen compliment had been irradiated for a total of 27,540 EFPH. At the end of this reporting period, the facility and original specimen compliment had been irradiated for a total of 27,603 EFPH. The original irradiation plan prepared by the UCSB experimenters indicated that the final specimens would be removed from the UCSB facility after 13,500 EFPH. Additional specimen irradiations were been added to the original plan and, at the end of operations for the FNR. The UCSB irradiation program has obtained 204% of the original desired irradiation time**.** The HSSI-UCSB irradiation facility had been in operation at the FNR since December 1996.

Shutdown of the FNR ended a very successful RPV steel irradiation campaign. The UCSB researchers had been performing RPV steel irradiation experiments for the NRC at the FNR for over six years. When recovery of irradiated specimens from the off-site reactor proved to be difficult and expensive, the HSSI Program developed a reusable irradiation facility in which test specimens could be inserted or removed as necessary in order to obtain the desired neutron fluences. Reusable irradiation facilities also produce far less irradiated material for disposal.

In 1996, the Irradiation Engineering Group of the ORNL Engineering Technology Division (currently the Thermal Hydraulics and Irradiation Engineering Group of The Nuclear Science and Technology Division) designed, fabricated, and installed at the FNR a totally reusable facility to irradiate a large numbers of small specimens. The test specimens were supplied by UCSB researchers working with the NRC to develop a database for use in making decisions on reactor plant life extension. The original experimental plan required a single reusable irradiation facility capable of operating successfully for a total of 13,500 EFPH. At the time the FNR was shut down for decommissioning, the facility had been in operation for 27,649 EFPH and remains 100% operational.

Test specimens irradiations were performed for 64 separate conditions such as temperature, neutron flux, and total fluence. A total of 90 different alloys have been irradiated including commercial/archival weld and plate material, split-melt commercial model steels and simple model alloys. These test specimens were irradiated in neutron flux ranging from 7 x 10^{10} to 1 x

10^{12} n/cm^2/sec, to fluences of 6 x 10^{16} to 3.6 x 10^{19} n/cm^2, and at temperatures of 270, 290 and 310°C. The capsules irradiated at these conditions contained 6600 tensile specimens (currently over 3100 tested), 1300 SANS (small angle neutron scattering) specimens (with over 270 tested to date), plus full size and 1/3 CVNs, miniature bend bars, compact tension specimens, micro-hardness wafers and APFIM wire specimens.

3. MEETINGS AND TRIPS:

On July 11, 2003, W. A. Server, ATI Consulting, visited ORNL to discuss Master Curve and embrittlement issues with the HSSI and other ORNL staff.

On July 18, 2003, Dr. Milan Brumovsky visited ORNL to discuss issues the possible use of the LV-15 test reactor at NRI in Rez, Czech Republic for future HSSI irradiations.

On July 27-August 5, R. K. Nanstad traveled to the Paul Scherrer Institute (PSI) in Villigen, Switzerland, to meet with PSI researchers regarding testing and evaluation of irradiation/annealing/reirradiation effects on reactor pressure vessel steels. He also traveled to the International Atomic Energy Agency (IAEA) in Vienna, Austria, and attended an IAEA Editorial Board meeting regarding preparation of a report on "Irradiation Embrittlement of Reactor Pressure Vessels."

4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:

M. K. Miller, K. F. Russell, M. A. Sokolov, and R. K. Nanstad, “Atom Probe Tomography Characterization of Radiation-Sensitive KS-01 Weld,” *J. Nucl. Mater*. **320** (2003) 117.

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: 6/23/03-7/27/03

		Current Month	Fiscal Year to Date	Cumulative Project to date
I.	Direct Staff Effort	5 MM	4.6 MY	47.2 MY
II.	A. Direct Lab Staff Effort ($)			
	Direct Salaries	101,059	1,083,175	5,764,073
	Materials and Services	4,312	75,456	516,786
	ADP Support	0	479	3,021
	Subcontracts	3,063	241,503	1,046,284
	Travel	1,169	24,773	204,547
	Other: NRC-PO Tax	8,290	55,517	304,873
	General and Administrative	52,591	570,808	2,743,255
	Total UT-Battelle Costs	170,484	2,051,711	10,582,839
	B. DOE Federal Admin. Costs	5,115	61,551	155,779
	TOTAL PROJECT COSTS	175,599	2,113,262	10,738,618

Percentage of available cumulative funds costed	92
Percentage of available current FY funds costed	71
Funds Remaining	911,382
Commitments:	123,137
BA Remaining	788,245
BA Remaining Less Projected FAC	761,700

III. Funding Status

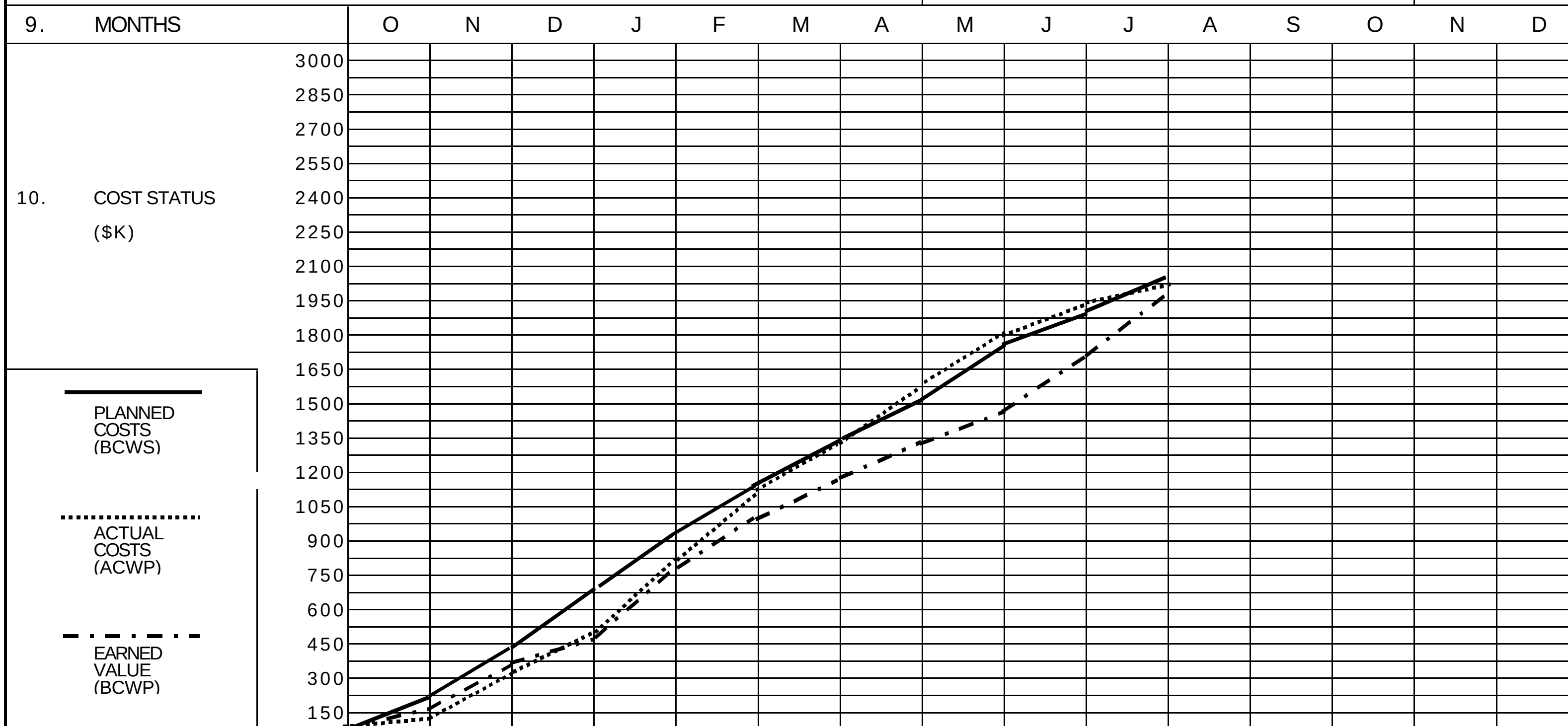
Prior FY Carryover	FY 02 Projected Funding Level	FY 02 Funds Received to Date	FY 02 Funding Balance Needed	Cumulative Amt. Obligated	Cumulative Amt. Costed
1,188,971	2,250,000	1,800,000	450,000	11,650,000	10,738,618

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

1. CONTRACT REPORTING ELEMENT **HSSI - Heavy-Section Steel Irradiation Program**		2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**		5. CONTRACT PERIOD **FY 2003 - 2006**	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
		7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MONTHS

10. COST STATUS ($K)



COST PLAN DATES: 07/20/03

PLANNED COSTS FOR ELEMENT ($K): 2936

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	247	242	233	218	184	200	168	188	208					
ACTUAL	145	172	198	312	241	248	254	179	132	170					
EARNED	160	169	179	244	179	178	202	176	191	234					
CUM. PLANNED	195	442	684	917	1135	1319	1519	1687	1875	2083	2083	2083	2083	2083	2083
CUM. ACTUAL	145	317	515	827	1068	1316	1570	1749	1881	2051	2051	2051	2051	2051	2051
CUM. EARNED	160	329	508	752	931	1109	1311	1487	1678	1912	1912	1912	1912	1912	1912

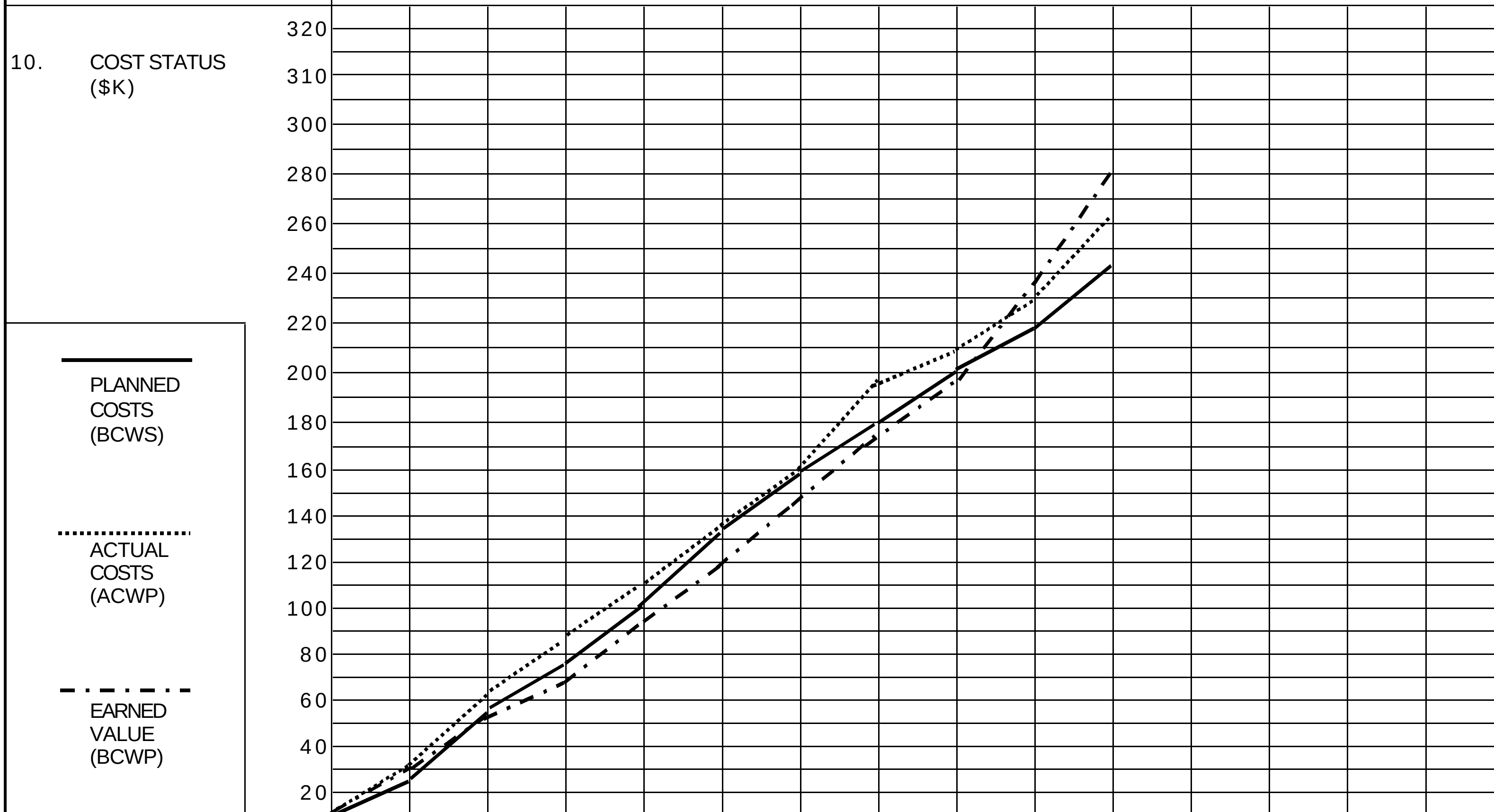
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 1. Program Management**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003 - 2006**	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES: 07/20/03

PLANNED COSTS FOR ELEMENT ($K): 393

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	28	23	26	30	25	22	22	18	24					
ACTUAL	30	32	24	24	25	25	28	22	20	32					
EARNED	29	22	16	26	25	29	26	25	40	44					
CUM. PLANNED	24	52	75	101	131	156	178	200	218	242	242	242	242	242	242
CUM. ACTUAL	30	62	86	110	135	160	188	210	230	262	262	262	262	262	262
CUM. EARNED	29	51	67	93	118	147	173	198	238	282	282	282	282	282	282

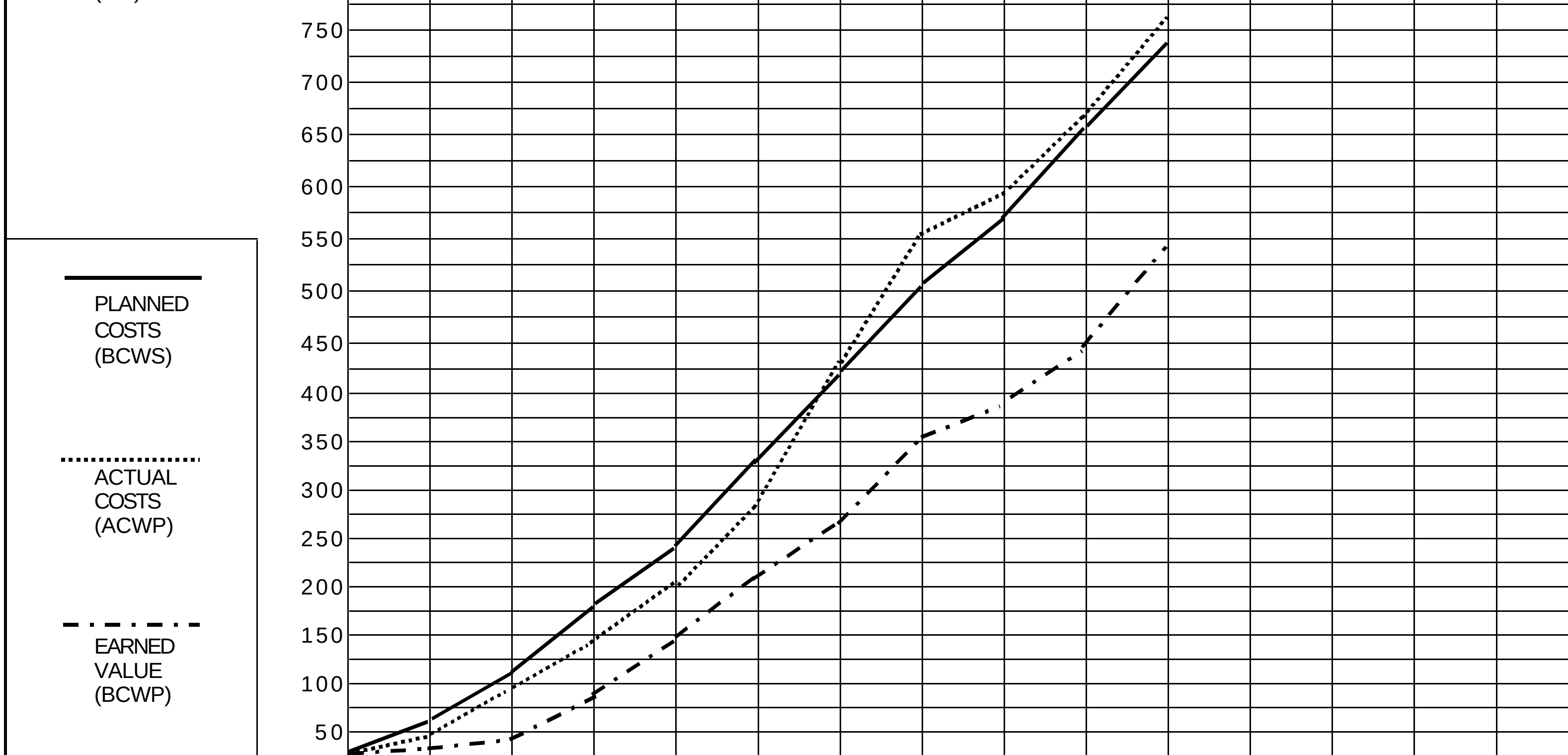
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 2. Fracture Toughness Transition and MC Methodology**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003 - 2006** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **W41 W5 85 3W 1** 8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES: 07/20/03

PLANNED COSTS FOR ELEMENT ($K): 916

ELEMENT COSTS FOR PRIOR FYS ($K): 402

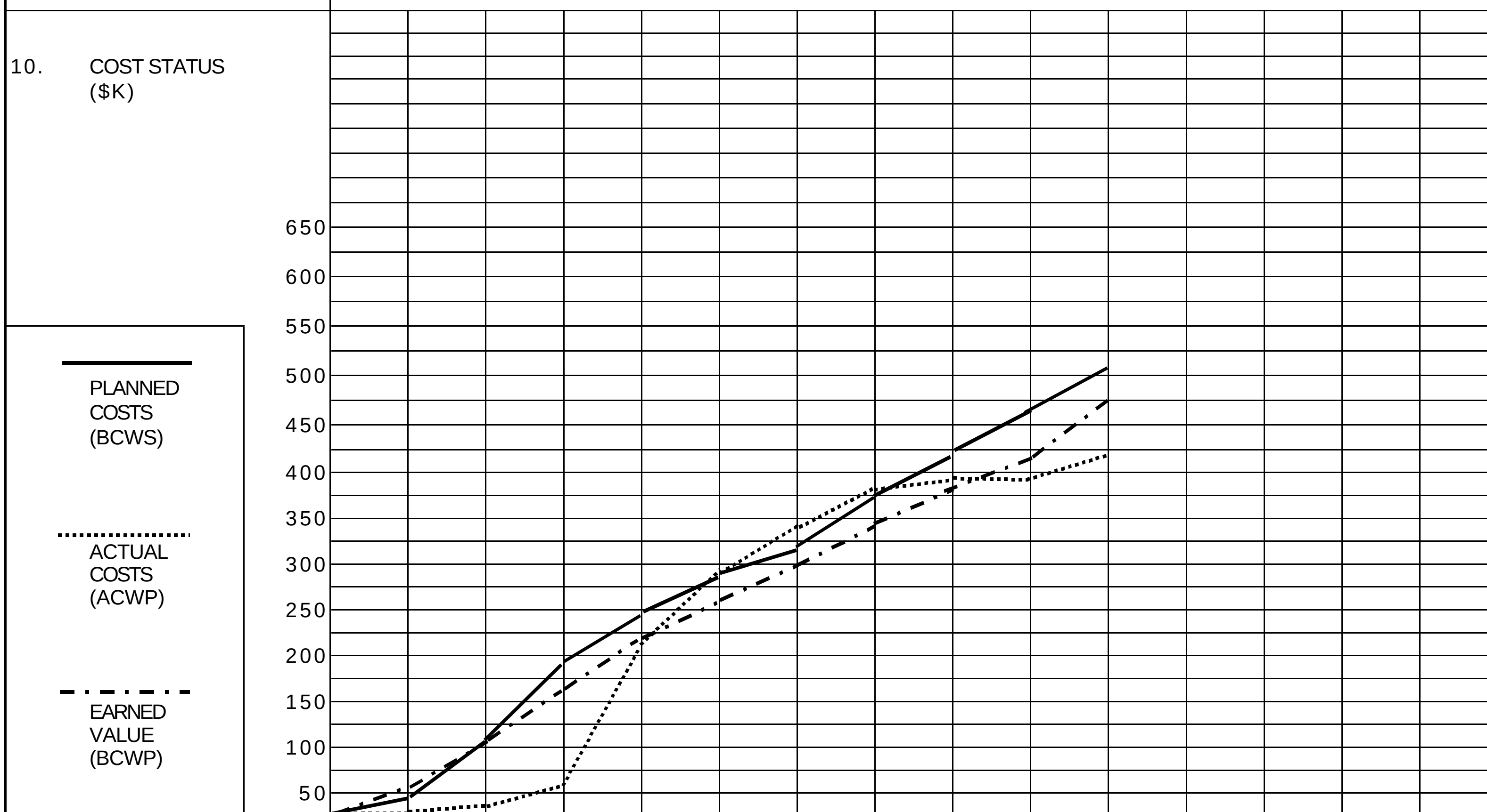
ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	54	62	61	64	89	86	85	70	84	87					
ACTUAL	39	51	52	65	77	142	131	41	72	85					
EARNED	19	16	46	67	59	54	89	36	62	93					
CUM. PLANNED	54	116	177	241	330	416	501	571	655	742	742	742	742	742	742
CUM. ACTUAL	39	90	142	207	284	426	557	598	670	755	755	755	755	755	755
CUM. EARNED	19	35	81	148	207	261	350	386	448	541	541	541	541	541	541

11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 3. Irradiation Embrittlement of RPV Steel**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003 - 2006** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **W41 W5 85 3W 1** 8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES

7/20/03

PLANNED COSTS FOR ELEMENT ($K)

636

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	57	34	30	60	45	45	40					
ACTUAL	1	15	40	157	77	51	40	8	-7	9					
EARNED	51	53	55	61	35	44	40	37	44	55					
CUM. PLANNED	39	104	192	249	283	313	373	418	463	503	503	503	503	503	503
CUM. ACTUAL	1	16	56	213	290	341	381	389	382	391	391	391	391	391	391
CUM. EARNED	51	104	159	220	255	299	339	376	420	475	475	475	475	475	475

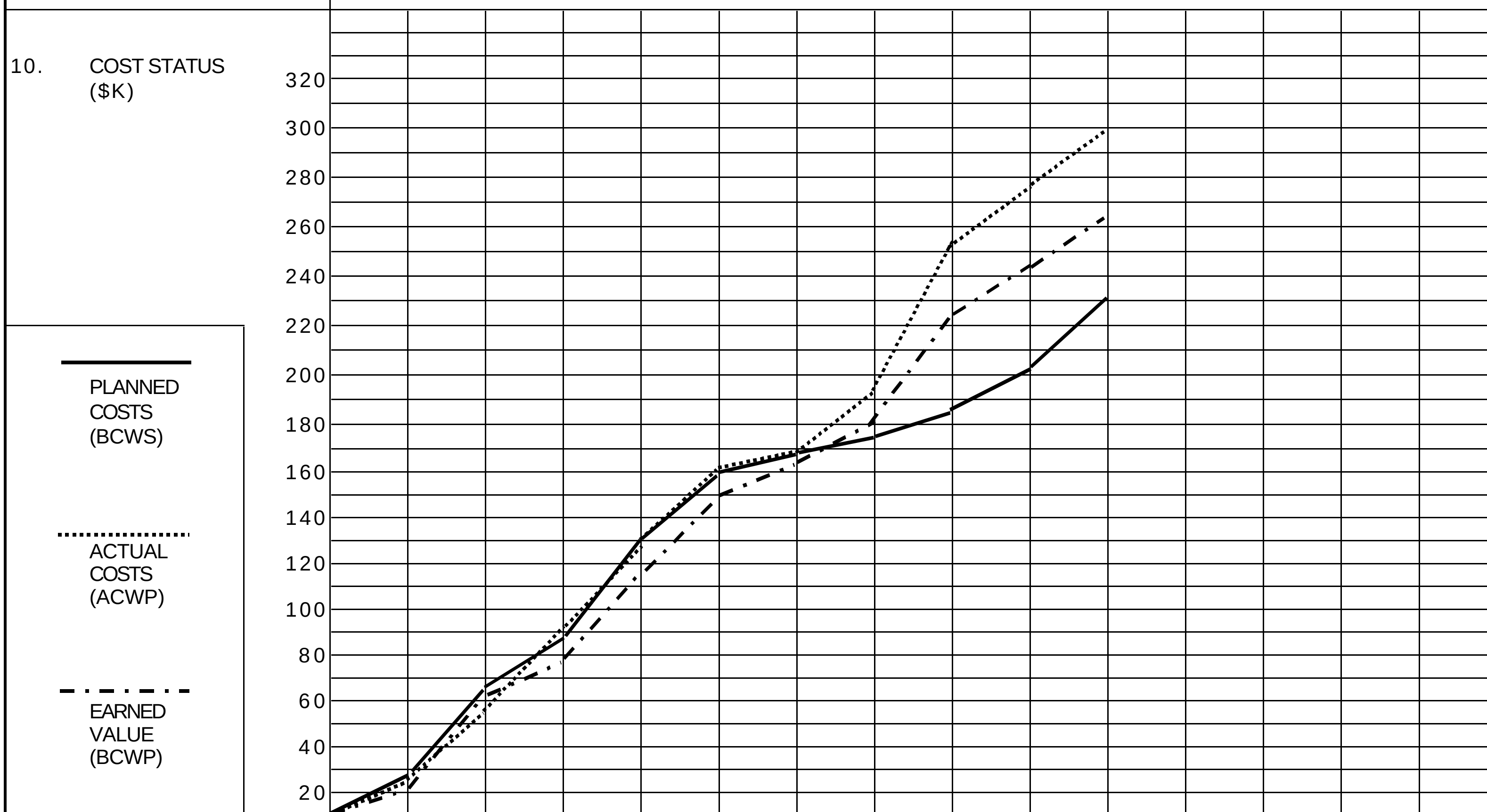
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 4. Validation of Irradiated and Aged Materials**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003 - 2006** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **W41 W5 85 3W 1** 8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES: 07/20/03

PLANNED COSTS FOR ELEMENT ($K): 405

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	44	27	11	7	7	20	28					
ACTUAL	27	27	38	36	33	8	24	61	23	22					
EARNED	21	39	17	39	34	12	18	45	18	21					
CUM. PLANNED	28	65	86	130	157	168	175	182	202	230	230	230	230	230	230
CUM. ACTUAL	27	54	92	128	161	169	193	254	277	299	299	299	299	299	299
CUM. EARNED	21	60	77	116	150	162	180	225	243	264	264	264	264	264	264

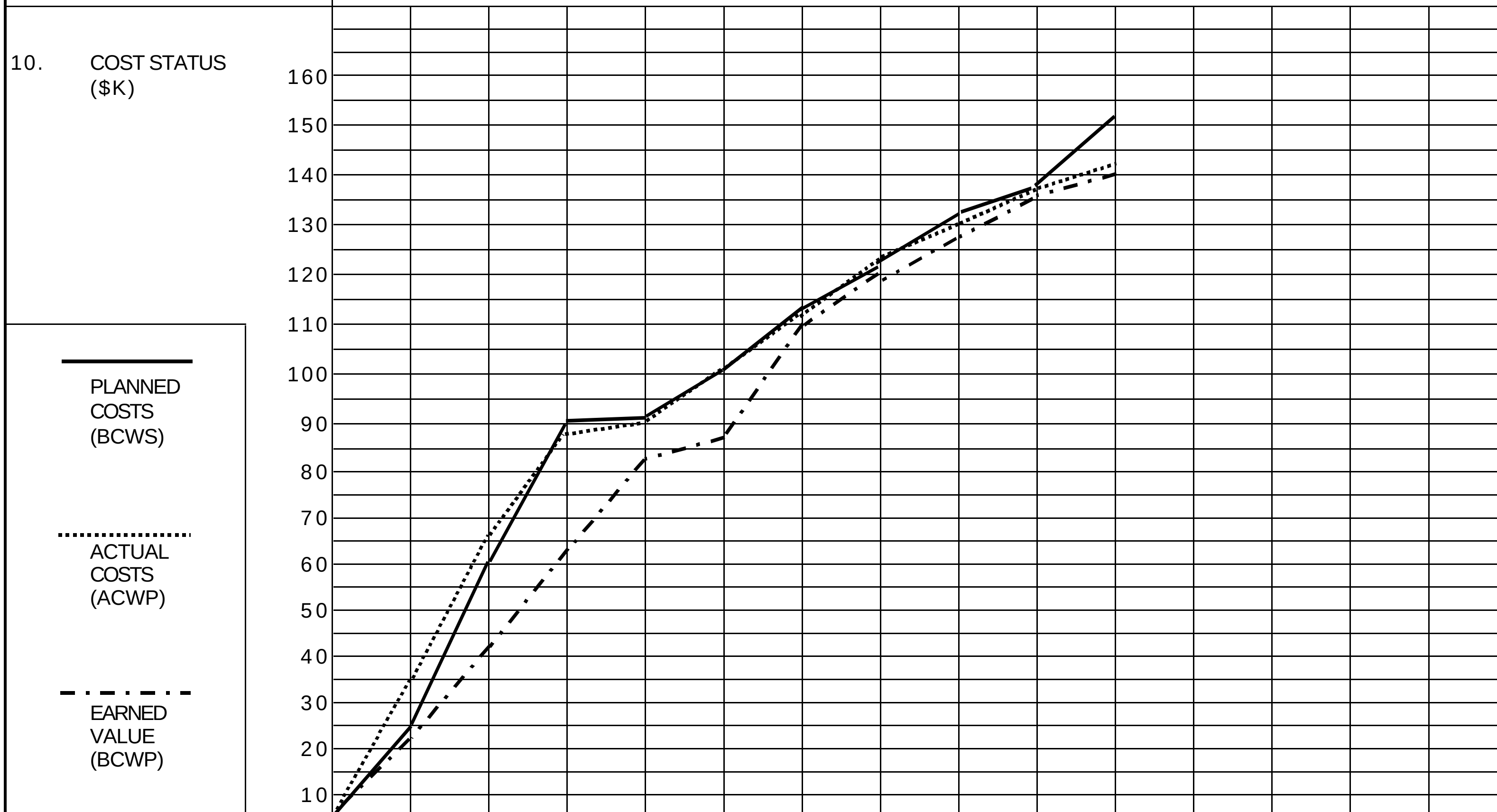
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 5. Modeling and Microstuctural Analysis**		2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**		5. CONTRACT PERIOD **FY 2003 - 2006**	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
		7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES

07/20/03

PLANNED COSTS FOR ELEMENT ($K)

220

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	2	10	10	10	10	5	15					
ACTUAL	35	31	22	2	12	10	12	6	7	4					
EARNED	23	20	21	19	4	23	10	7	8	5					
CUM. PLANNED	25	60	90	92	102	112	122	132	137	152	152	152	152	152	152
CUM. ACTUAL	35	66	88	90	102	112	124	130	137	141	141	141	141	141	141
CUM. EARNED	23	43	64	83	87	110	120	127	135	140	140	140	140	140	140

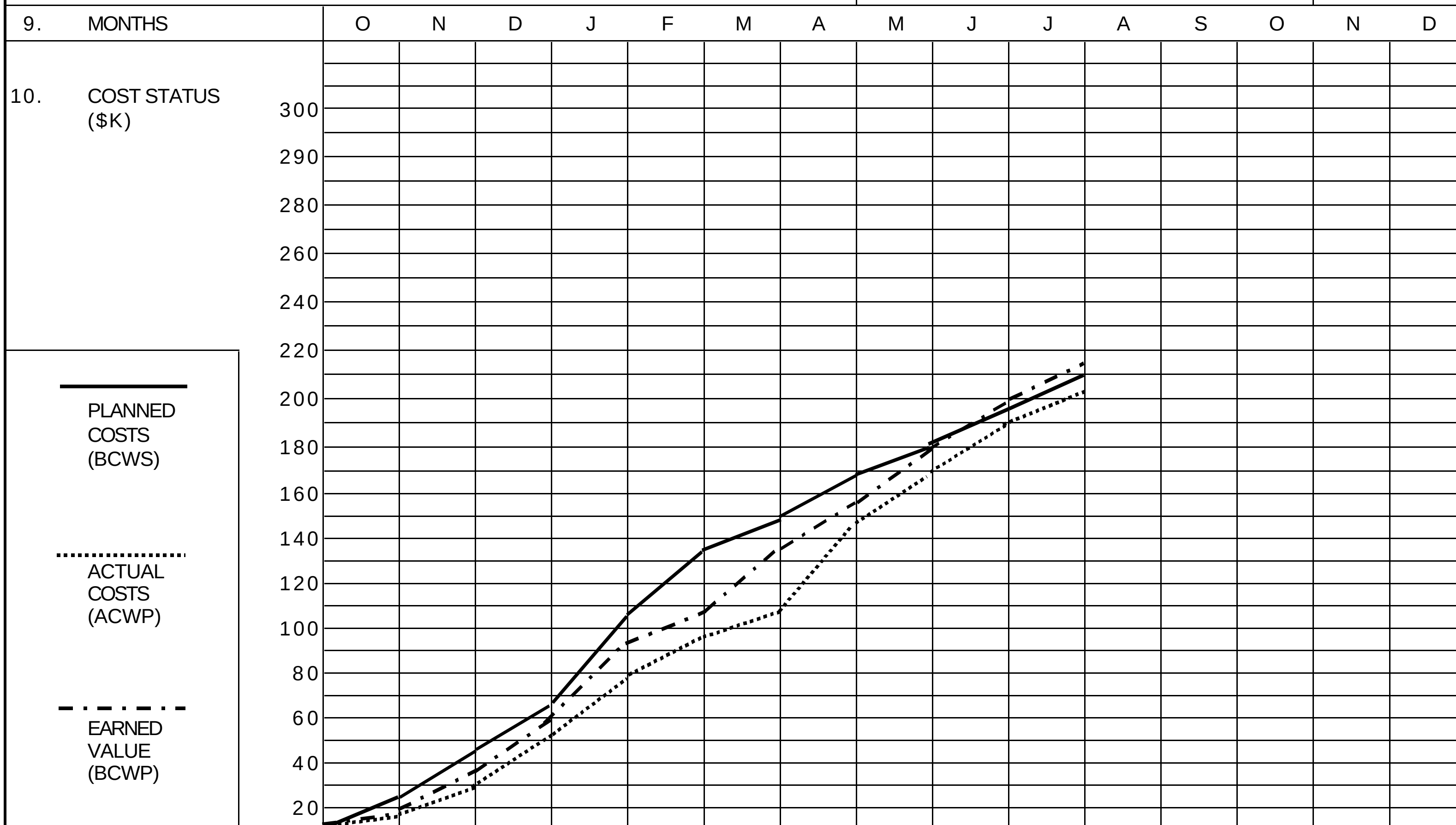
11. REMARKS

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

1. CONTRACT REPORTING ELEMENT **HSSI - 6. Irradiation Coordination**	2. REPORTING PERIOD **6/23/2003 -7/27/2003**
	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 2003 - 2006**
	6. ACTIVITY NUMBER **W41 W5 85 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**
	8. DOE B&R NO. **40 10 01 06**

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

10. COST STATUS ($K)



COST PLAN DATES

07/20/03

PLANNED COSTS FOR ELEMENT ($K)

307

ELEMENT COSTS FOR PRIOR FYS ($K)

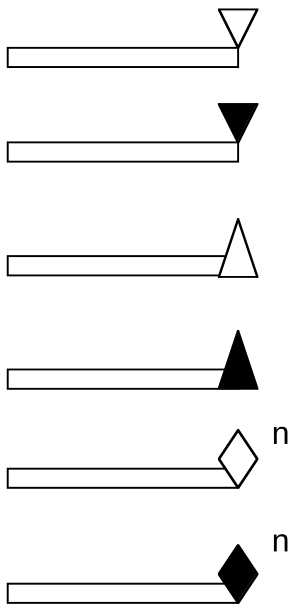
53

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	25	20	19	42	28	16	16	14	16	14					
ACTUAL	13	16	22	28	17	13	19	40	16	18					
EARNED	17	19	24	32	22	21	19	26	19	16					
CUM. PLANNED	25	45	64	106	134	150	166	180	196	210	210	210	210	210	210
CUM. ACTUAL	13	29	51	79	96	109	128	168	184	202	202	202	202	202	202
CUM. EARNED	17	36	60	92	114	135	154	180	199	215	215	215	215	215	215

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

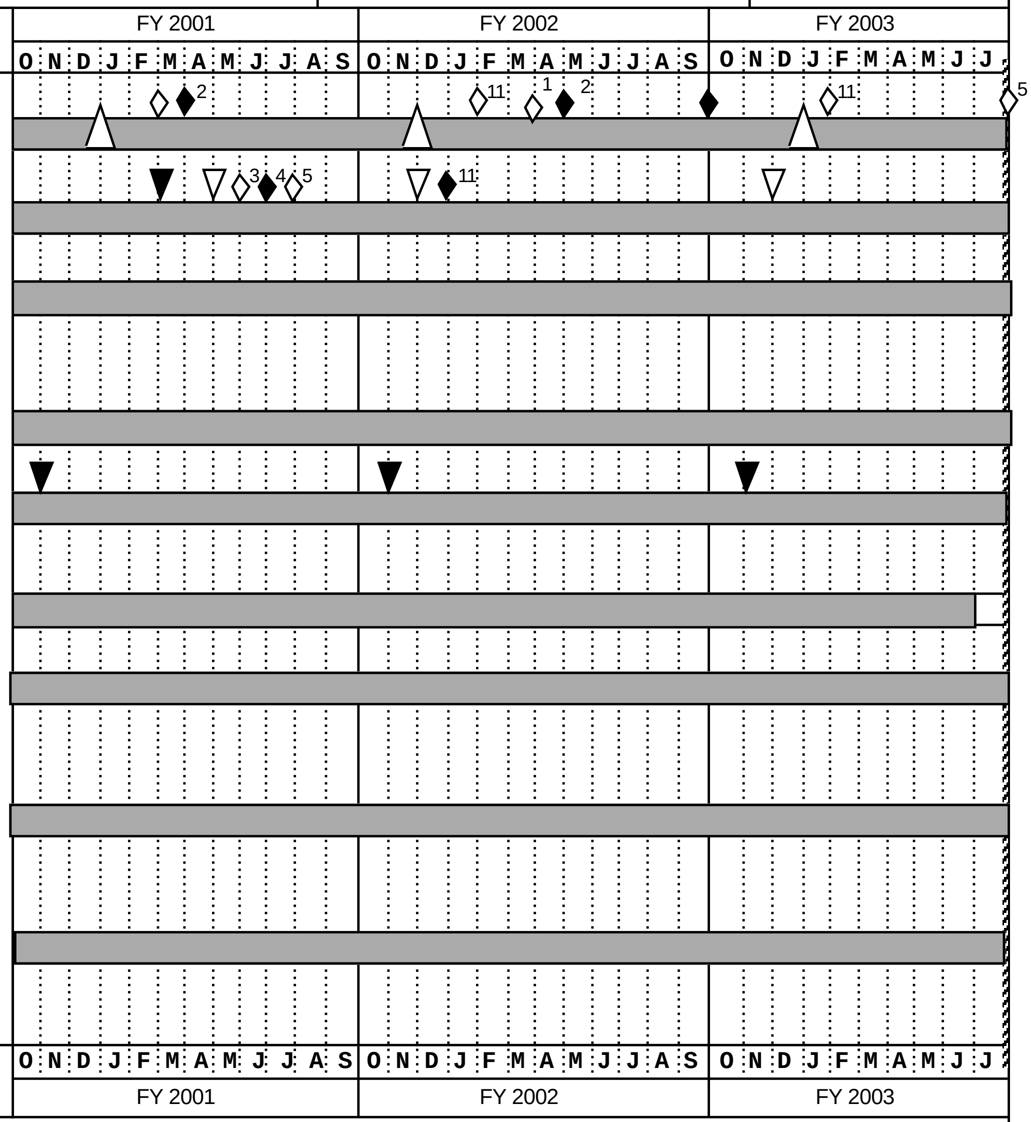
Rescheduled milestone planned

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	**6/23/2003 - 7/27/2003**	**W6953**
4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NUMBER
OAK RIDGE NATIONAL LABORATORY **P. O. BOX 2008** **OAK RIDGE, TN 37831**	**FY 1998-2003**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

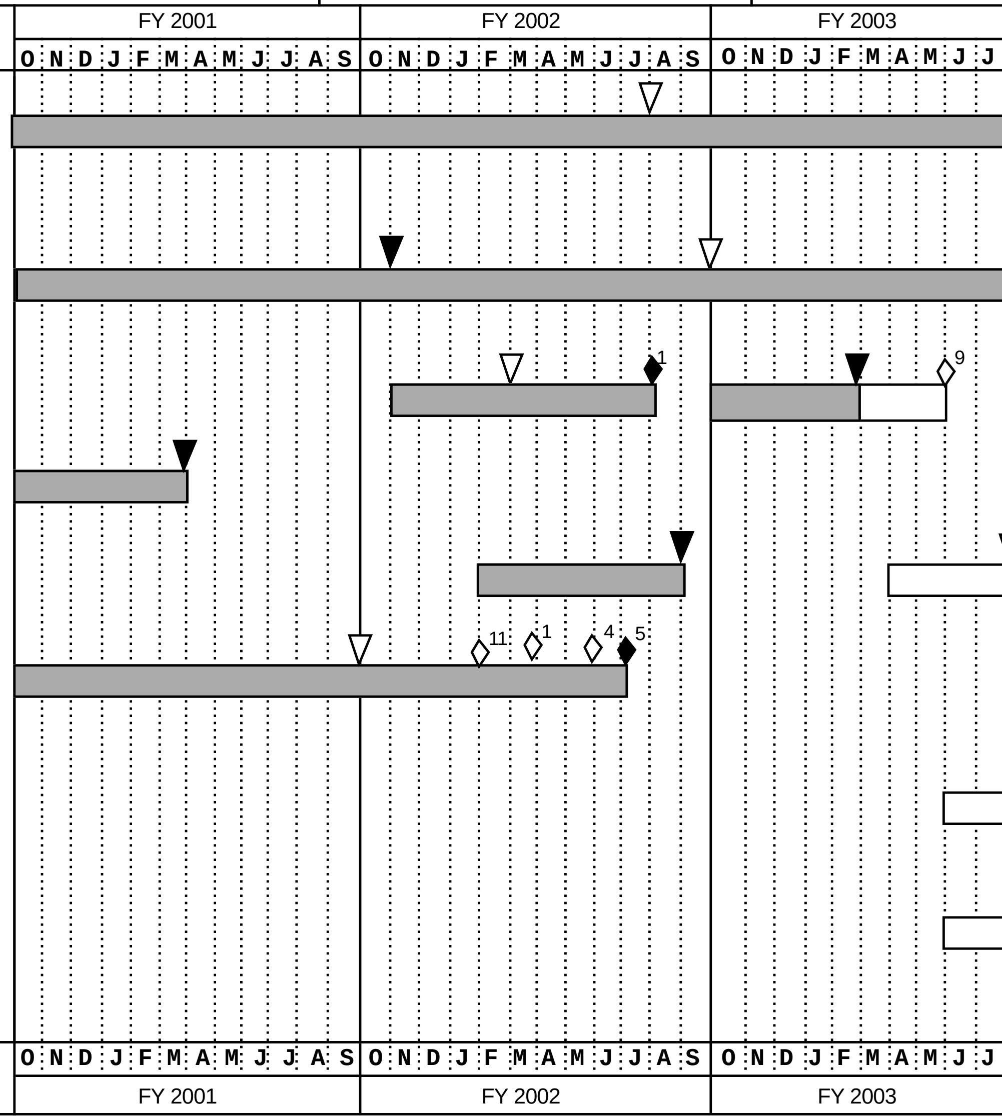
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
1.1.A.	Issue Project & Budget Proposal
1.1.B.	Select and Administer Subcontracts
1.2.A.	Issue Earned Value Based Monthly Management Reports (by the end of subsequent month)
1.2.B.	Ensure QA Requirements are met
1.3.A.	Participate in NRC-Sponsored Meeting 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 **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NUMBER **41 W6 95 3W 1** 8. DOE B&R NO. **40 10 01 06**

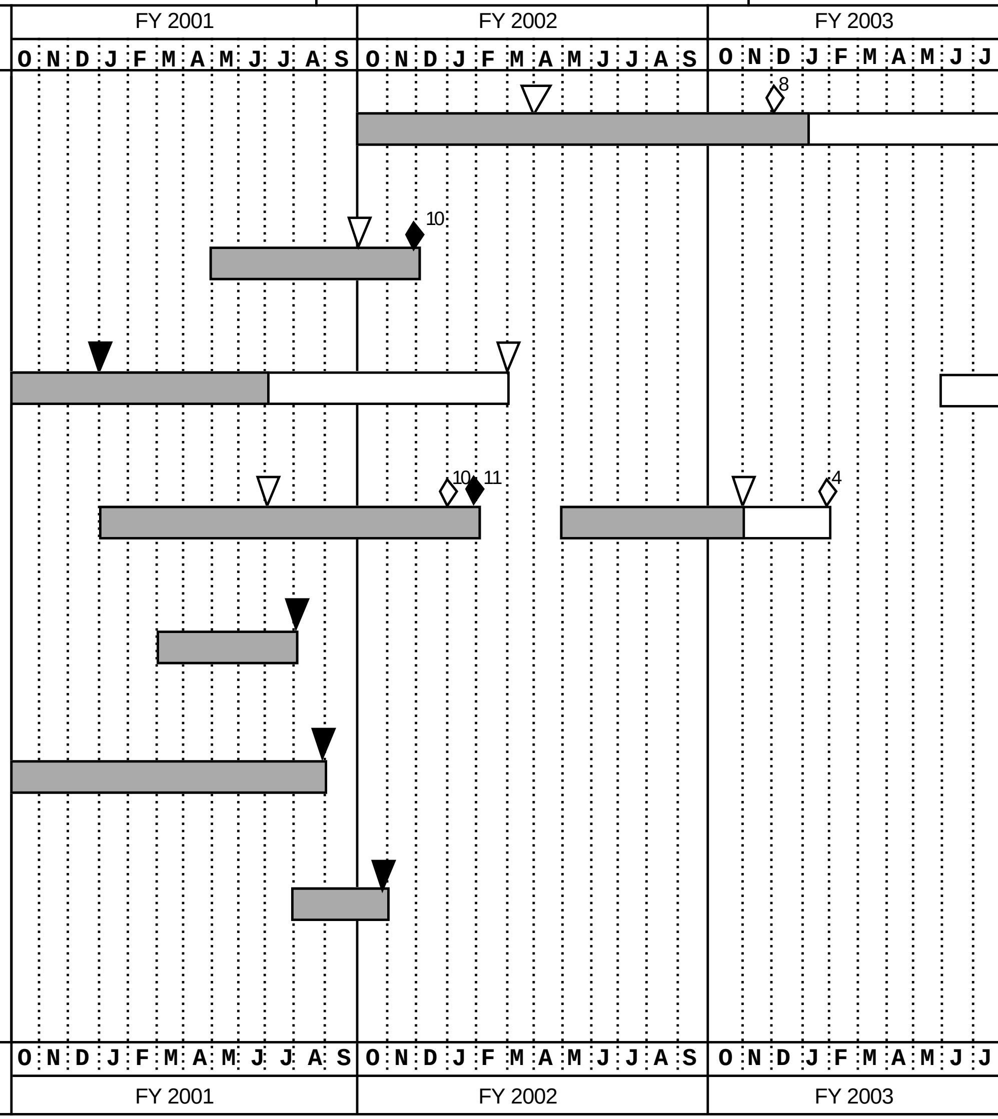
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.1.A.	Continue to accumulate data on Comparison of CVN and Fracture Tougness Shifts
2.2.A.	Irradiate Midland and Hi-Ni Specimens
2.2.B.	Receive Specimens
2.2.C.	Test Unirradiated & Irradiated KSØ1 for Master Curve
2.2.D.	Test Unirradiated & Irradiated 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 **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003**	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

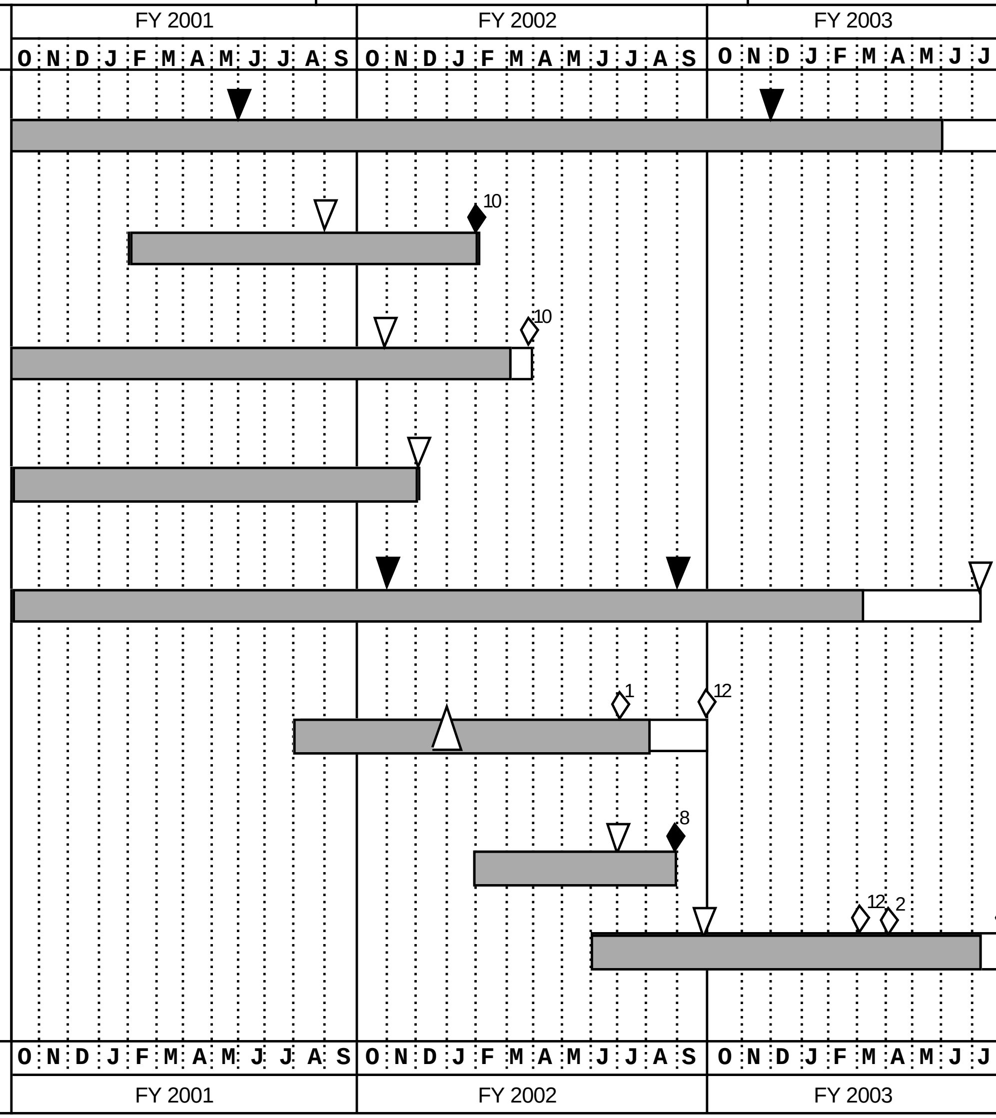
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.3.A.	Develop Testing Plan for Dynamic Fracture Toughness Effects on MC
2.4.A.	Letter Report on Statistical Representation of Valid K_{JC} Data
2.5.A.	Measure Activity and Prepare Report
2.5.B.	Calculate Fluence and Prepare Report
2.6.A.	Complete Testing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



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**
	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003**
	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**
	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
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
HSSI - 2. Fracture Toughness Transition & MC Methodology

2. REPORTING PERIOD
6/23/2003 - 7/27/2003

3. JCN NO.
W6953

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

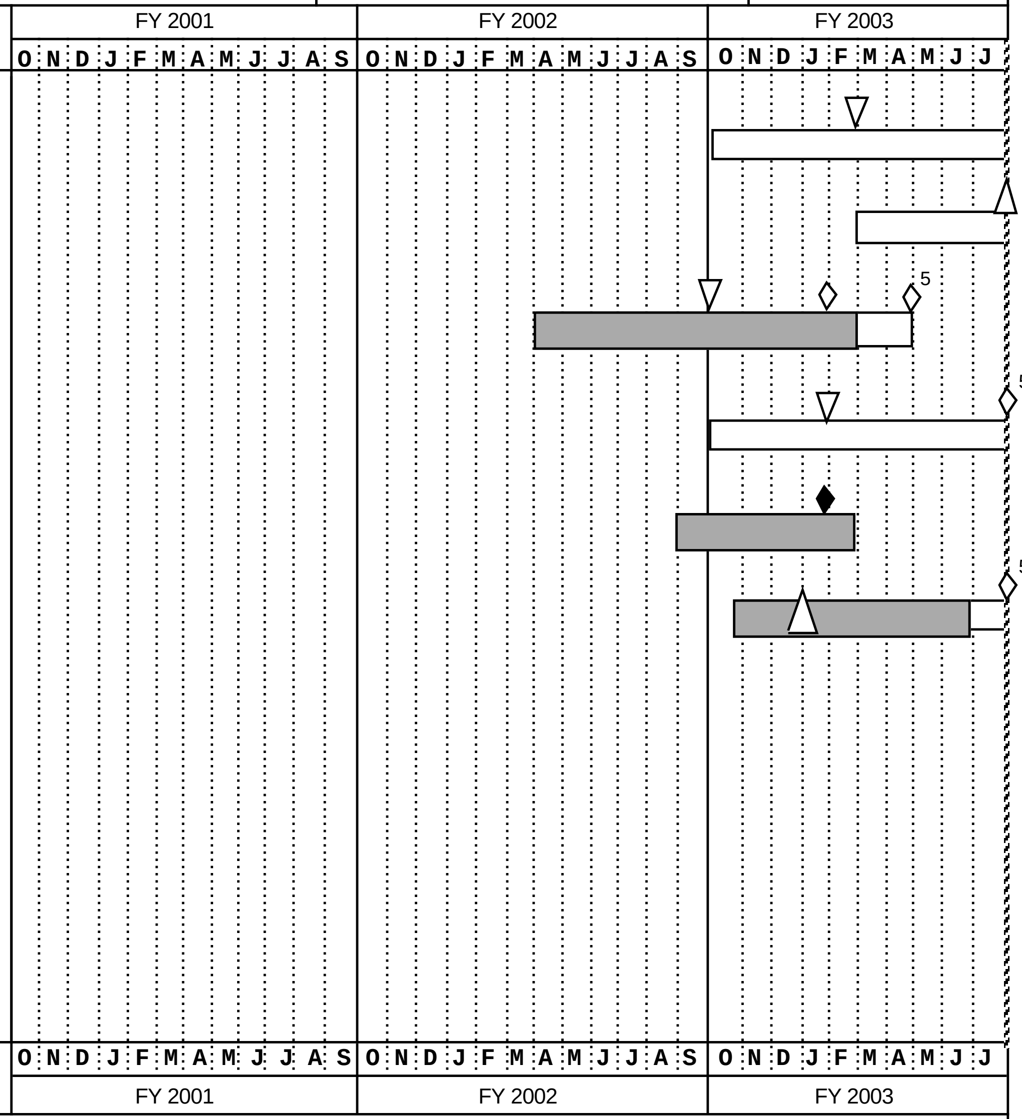
5. CONTRACT PERIOD
FY 1998-2003

6. ACTIVITY NUMBER
41 W6 95 3W 1

7. NRC B&R NO.
860 15 21 20 05

8. DOE B&R NO.
40 10 01 06

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
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

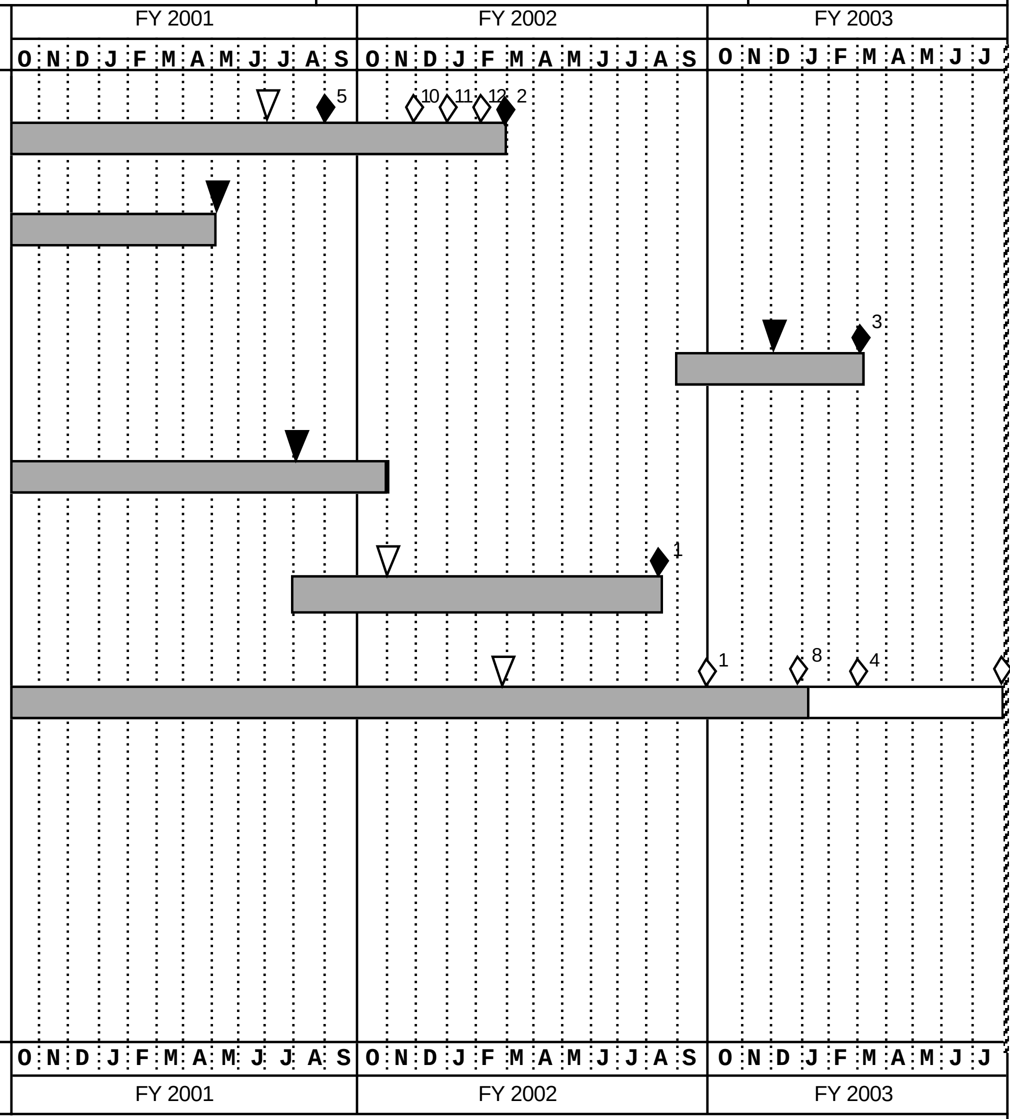


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 3. Irradiation Embrittlement of RPV Steel	**6/23/2003 - 7/27/2003**	**W6953**

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

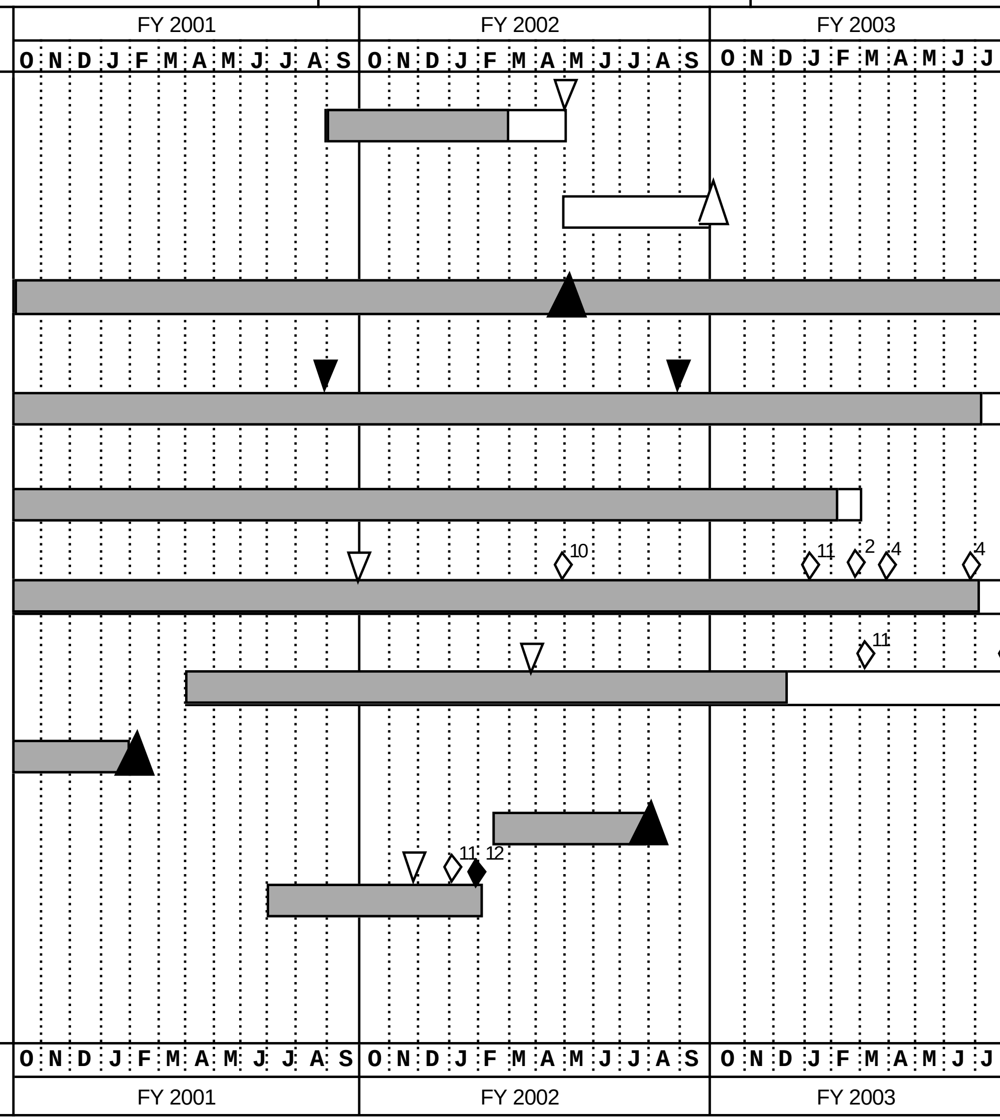
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
3.1.G.	HAZ Letter Report
3.1.H.	Evaluate Need for Additional Specimen Testing
3.1.I.	Machine and Gleeble-treat HAZ Specimens
3.2.A.	Complete JRQ Charpy Testing
3.2.B.	Complete PCVN Testing
3.2.C.	Complete Draft NUREG Report on IAR Results of JRQ



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 4. Validation of Irradiated and Aged Materials**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003**	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
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.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
HSSI - 5. Modeling & Microstructural Analysis

2. REPORTING PERIOD
6/23/2003 - 7/27/2003

3. JCN NO.
W6953

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

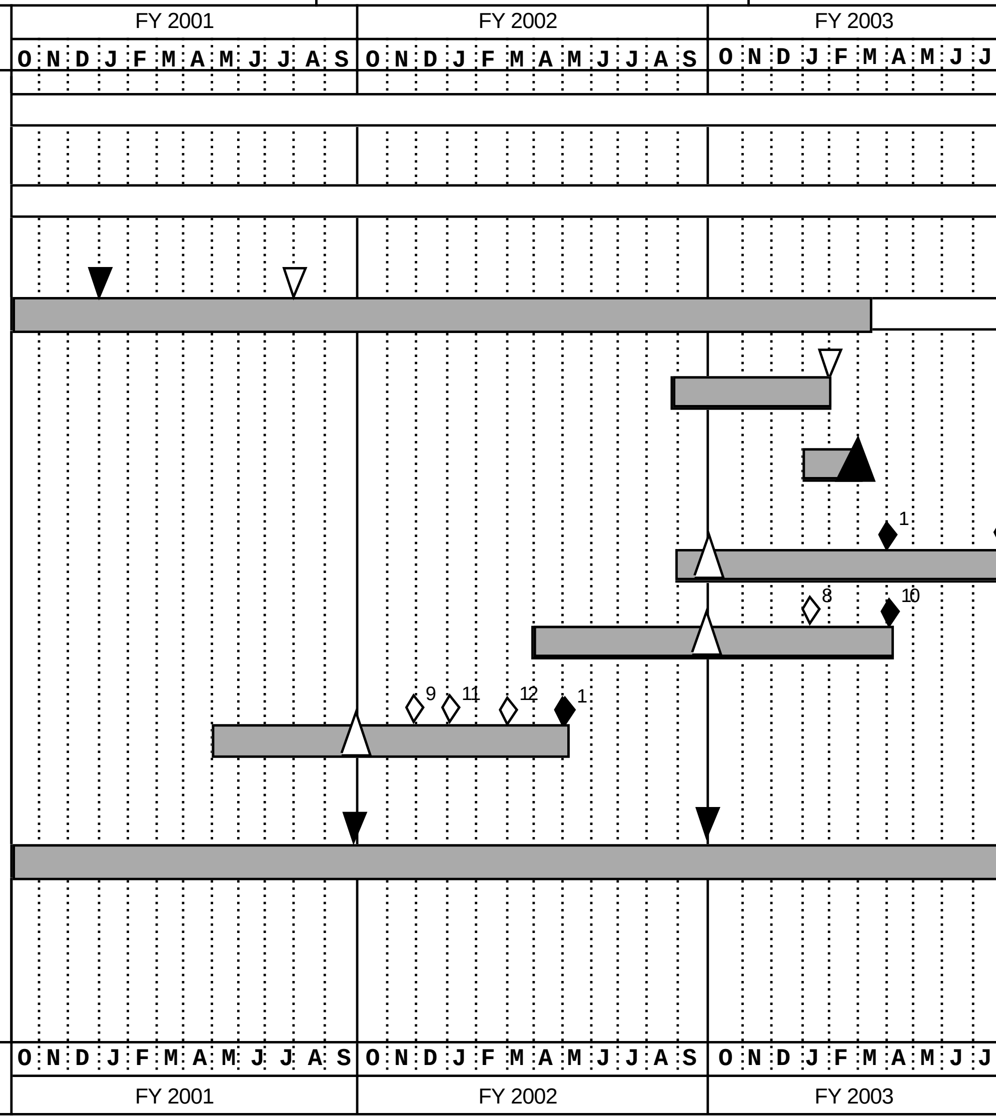
5. CONTRACT PERIOD
FY 1998-2003

6. ACTIVITY NUMBER
41 W6 95 3W 1

7. NRC B&R NO.
860 15 21 20 05

8. DOE B&R NO.
40 10 01 06

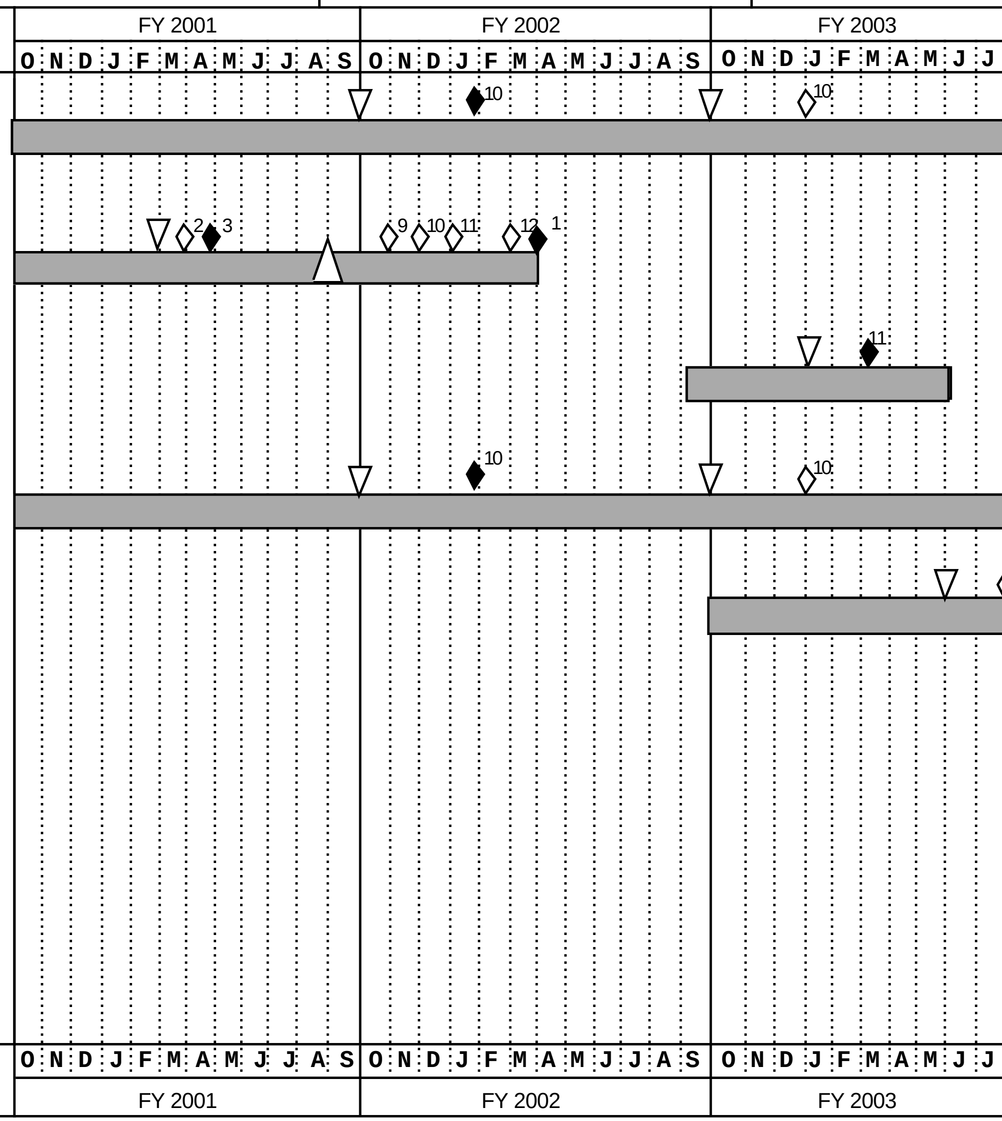
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
5.1.A.	Development and Predictive use of Embrittlement Model
5.2.A.	Coordinate and Analyze APFIM/SANS/FEGSTEM Round Robin Experiment
5.2.B.	APFIM Characterization
5.2.C.	APT of Late Blooming Phases
5.2.D.	Prepare Draft Report
5.3.A.1	Evaluate and Input 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 **HSSI - 6. Irradiation Coordination**	2. REPORTING PERIOD **6/23/2003 - 7/27/2003**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P. O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003**	6. ACTIVITY NUMBER **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
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