ORNL/HSSI (6953)/MLSR-2001/4

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

Monthly Letter Status Report

January 2001

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HEAVY-SECTION STEEL IRRADIATION

PROGRAM

JCN W6953

MONTHLY LETTER STATUS REPORT

FOR

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Submitted by

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Submitted to
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PREFACE

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

This report gives information on several topics corresponding to events during the reporting month: (1) overall project objective, (2) technical activities, (3) meetings and trips, (4) publications and presentations, (5) property acquired, (6) problem areas, and (7) plans for the next reporting period. Next the report gives a breakdown of overall program costs as well as cost summaries and earned-value-based estimates for performance for the total program and for each of the eight program tasks. The seven tasks correspond to the 189, dated March 23, 1998, and modified by the inclusion of the former “Embrittlement Data Base and Dosimetry Evaluation” Program, JCN 6164 in March, 1999. The final part of the report provides financial status for all tasks and status reports for selected milestones within each task. The task milestones address the period from October 2000 to March 2003, while the individual task budgets address the period from October 2000 to February 2001.

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

Thomas M. Rosseel, Manager
Heavy-Section Steel Irradiation

MONTHLY LETTER STATUS REPORT
January 2001

Job Code Number:	**W6953**
Project Title:	**Heavy-Section Steel Irradiation Program**
Period of Performance:	**4/1/98 to 2/28/01**
Performing Organization:	**Oak Ridge National Laboratory**
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1. PROJECT OBJECTIVE:

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

2. TECHNICAL ACTIVITIES:

<u>TASK 1: Program Management</u> (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) In response to the long-term operational uncertainties at the University of Michigan, Ford Nuclear Reactor (FNR), the HSSI Program, at the direction of the NRC Office of Research is preparing two position papers on research reactor and facility options and the needs and benefits of an NRC-sponsored reactor-pressure-vessel (RPV) irradiation program. The first paper will address the options and costs associated performing irradiations at another reactor within the US or in a foreign country. Estimates of the cost of designing and fabricating new facilities and the disposal of existing facilities will be included in this white paper. The second paper will focus on the compelling issues that an RPV irradiation program can address for the NRC. This will include both anticipatory and confirmatory research.

A draft white paper entitled, Issues Regarding Irradiation Effects on Reactor Vessel Steels, by Randy K. Nanstad (Oak Ridge National Laboratory), G. Robert Odette (University of California, Santa Barbara), Glenn E. Lucas (University of California, Santa Barbara) was submitted at the end of this reporting period. It provides a brief summary of major technical issues regarding embrittlement of commercial nuclear RPVs. The motivation is to identify those issues that require further research to provide information not currently available or to enhance existing information with a view towards reducing the associated uncertainties. After summarizing progress in radiation damage mechanisms and fracture toughness, major technical issues are addressed, such as:

- Material Variability and Surrogate Materials,
- High Fluence, Long Irradiation Times, and Flux Effects,
- Master Curve,
- Attenuation,
- High-Nickel Welds,
- Modeling and Microstructural Analysis,
- Precracked Charpy and Smaller Specimens,
- Phosphorus Segregation and Intergranular Fracture,
- Annealing and Reirradiation,
- Database Development,
- Product Forms and Effective Copper Content,
- Advanced Materials, and
- NDE Characterization of Irradiated Steels

(Milestone 1.1 B) The HSSI Program Manager was notified that the cost of the neutrons provided by the FNR would increase by a factor of 2.5 beginning March 1, 20001, due the University of Michigan’s requirement of full-cost recovery for the extended operating time provided on behalf of the Program. Additionally, unless long-term support for the facility is identified, the FNR will be shut down by June 30, 2004 and prepared for decommissioning.

As requested by the HSSI Program, the University of Michigan provides 240 hours of uninterrupted, two Mega-Watt operations during an FNR "half cycle" of 10 continuous days in order to irradiate pressure-vessel specimens, at 288 °C in the HSSI-IAR and HSSI-UCSB reusable irradiation facilities. The FNR typically provides more than 20 half cycles during a one-year period. This extended operating schedule requires the services of licensed reactor operators to cover the swing and mid shifts, as well as the weekend day shifts, during the half cycle and currently costs the FNR approximately $ 325,000 per year. Since this extended service is not necessary to support the current research requirements of the university, it has determined that the costs must be born by those using the FNR facility, such as the HSSI Program. The University of Michigan has estimated that the NRC/HSSI share of this additional cost is approximately $180,000 per year and that it will be covered in part through an increase of 2.5 times the current cost for the exclusive use of the east face of the reactor beginning in March. A cost growth letter will be submitted to the NRC that reflects the anticipated increase in costs.

(Milestone 1.2.B) Although the repair of the 100-kip MTS servo-hydraulic machine in the IMET hot cell # 3 was completed, testing of the KS01 and the PSI-supplied JRQ re-irradiated specimens will be delayed until the next reporting cycle due to the installation of a new 5-ton crane and unanticipated repairs to the equipment in cell #2.

(Milestone 1.3.E) The following NUREG Reports were submitted during this reporting period or recently published.

The Effect of Aging at 343°C on the Microstructure and Mechanical Properties of Type 308 Stainless Steel Weldments, by D. J. Alexander, K. B. Alexander, M. K. Miller, and R. K. Nanstad, NUREG/CR-6628 (ORNL/TM-13767), was published in November 2000. However, ORNL has not received any copies of the report.

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 Program monitor as part of an NRC, Office of Research, Operational Milestone.

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

Fracture-toughness transition and master-curve (MC) methodology will be broadly explored for pressure-vessel applications through a series of experiments, analyses, and evaluations in eight Subtasks. For example, pertinent fracture-toughness data needed to assess the shift and potential change in shape of the fracture-toughness curves due to neutron irradiation will be collected and statistically analyzed. The effects of irradiation on fracture-toughness curve shape for highly embrittled RPV steels, dynamic effects, crack arrest, intergranular fracture, and subsized specimens will also be explored. Finally, guidelines for the application of "surrogate materials" to the assessment of fracture toughness of RPV steels will be evaluated.

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

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

(Milestone 2.1.A) As they become available, additional data are added to the database.

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 .

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

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

(Milestone 2.2.A) As previously reported, a hot cell entry had to be made to reroute one of the hydraulic hoses to increase the space needed for a shield around the base of the machine to keep items from falling into the pit. That activity was accomplished and machine is now back in service. The oven has also been reinstalled on the frame and a cell entry is scheduled for early February to make the electrical connections and install the shield so that the testing of 1T C(T) of KS-01 weld can be resumed.

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

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

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

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

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

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

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

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

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

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

(Milestone 2.5.A) The draft NUREG report, *Detailed Results of Testing Unirradiated and Irradiated Crack-Arrest Toughness Specimens from the Low Upper-Shelf Energy, High Copper Weld, WF-70,* by S. K. Iskander, C. A. Baldwin, D. W. Heatherly, D. E. McCabe, I. Remec, and R. L. Swain, NUREG/CR-6621 (ORNL/TM-13764), is nearly complete, but completion of the final report and submission to the NRC for publication will be delayed until about September due to personnel reductions.

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

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

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

(Milestone 2.6.B) As reported in the previous progress report, twelve 0.5T compact specimens were received, fatigue precracked, and seven specimens were tested at -125°C, the temperature estimated to result in a median K_{Jc} value of about 75 MPa√m using the Master Curve obtained from the previous results. The actual value obtained was very close to the predicted value based on the test results obtained at the higher temperatures. The remaining five specimens will be tested at a different temperature, and a multitemperature master curve analysis will be conducted and included in the final letter report. Those tests have been delayed due to personnel reductions and it is anticipated they will be conducted in February.

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

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

The purpose of this subtask is to evaluate the applicability of the weakest-link theory-based size-adjustment procedure in the MC methodology to specimen sizes that are the most likely to be present in surveillance capsules. The MC methodology will be applied using precracked Charpy-size or smaller specimens to test the lower-size limit applicability. Testing will be performed at two or more temperatures with at least six specimens at each temperature. The exact number of temperatures and specimens will be determined following analysis of initial results. The testing of these subsize specimens will also satisfy the HSSI Program suggested testing matrix within the New Coordinated Research Program (CRP) of the International Atomic Energy Agency (IAEA). Subsized specimens will be fabricated from previously characterized materials within the HSSI Program, such as HSST Plate 02, HSSI Welds 68W through 73W, the Midland beltline weld and plate JRQ.

The ASTM Fourth International Symposium on Small Specimen Techniques, with M. A. Sokolov serving as the Chairman, was held in Reno, Nevada, January 23-25, 2001.

(Milestone 2.7.A) Three blocks of materials were machined into 1T C(T) and precracked Charpy specimens for the size effect study. Two of the blocks are broken halves of 4T C(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 oriented towards an evaluation of the precracked Charpy specimen. The testing of these specimens is well under way and completion is expected in February.

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

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

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

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

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

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

(Milestone 2.10.A) Dosimeters included in the first two HSS-IAR metallurgical specimen capsules have been recovered, counted, and analyzed to determine the isotope activities used in calculating damage correlation parameters. Data files containing the activity information were prepared in the format used in all past HSS-IAR experiments. This includes the use of the previously defined coordinate system. From this data, the 3-D model, fuel changes and reshuffling, and the original dosimetry experiment results, the exposure parameters for these metallurgical specimens will be calculated.

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

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

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

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

(Milestone 3.1.B) As noted in the previous progress report, to investigate the effect of cooling rate following postweld heat treatment, additional material would be treated in the Gleeble system to simulate the coarse-grain HAZ as accomplished previously. This would then be followed by thermal aging, as well as by irradiation and thermal annealing. Excess material from the original investigation has been identified, and the proposed study will be discussed with the NRC technical monitor. Consideration is also being given to reirradiation of the remaining specimens from the initial series.

The paper by R. K. Nanstad, D. E. McCabe, M. A. Sokolov, C. A. English, and S. R. Ortner, *Investigation of Temper Embrittlement in Reactor Pressure Vessel Steels Following Thermal Aging, Irradiation, and Thermal Annealing*, which was presented at the ASTM 20th International Symposium on Radiation Effects on Materials, has been submitted in final form to ASTM for publication in Effects of Radiation on Materials: 20th International Symposium, *ASTM STP 1405*. The abstract of that paper is provided below:

The Heavy-Section Steel Irradiation Program at Oak Ridge National Laboratory includes a task to investigate the propensity for temper embrittlement in coarse grain regions of heat-affected zones in prototypic reactor pressure vessel (RPV) steel weldments as a consequence of irradiation and thermal annealing. For the present studies, five prototypic RPV steels with specifications of A302 grade B, A302 grade B (modified), A533 grade B class 1, and A508 class 2 were given two different austenitization treatments and various thermal aging treatments. Thermal aging treatments were conducted at 399, 425, 454 and 490°C for times of 168 and 2000 h. Charpy V-notch impact toughness vs temperature curves were developed for each condition with ductile-brittle transition temperatures used as the basis for comparing the effects of the various heat treatments. Very high austenitization heat treatment produced extremely large grains which exhibited a very high propensity for temper embrittlement following thermal aging. Intergranular fracture was the predominant mode of failure in many of the materials and Auger analysis confirmed significant segregation of phosphorus at the grain boundaries. Lower temperature austenitization treatment performed in a super Gleeble to simulate prototypic coarse grain microstructures in submerged-arc weldments produced the expected grain size with varying propensity for temper embrittlement dependent on the material as well as on the thermal aging temperature and time. Although the lower temperature treatment resulted in decreased propensity for temper embrittlement, the results did provide motivation for the investigation of the potential for phosphorus segregation as a consequence of neutron irradiation and post-irradiation thermal annealing at 454°C. One of the A 302 grade B (modified) steels was given the Gleeble treatment, irradiated at 288°C to about 0.8×10^{19} n/cm (>1 MeV) and given a thermal annealing treatment at 454°C for 168 h. Charpy impact testing was conducted on the material in both the irradiated and irradiated/annealed conditions, as well as in the as-received condition. The results show that, although the material exhibited a relatively small Charpy impact 41-J temperature shift, the heat-affected zone-simulated material did exhibit significant intergranular fracture in the post-irradiation annealed condition

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

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

(Milestone 3.2.B) Neutronics Analysis of the IAR/UCSB Irradiation Capsules (I. Remec, E. D. Blakeman, and C. A. Baldwin). The report entitled, *Characterization of the Neutron Field in the HSSI/UCSB Irradiation Facility at the Ford Nuclear Reactor*, by I. Remec, E. D. Blakeman, and C. A. Baldwin, NUREG/CR-6646 (ORNL/TM-1999/140) was submitted to the NRC in September 1999.

(Milestone 3.2.C) Previously irradiated, annealed, and reirradiated specimens of HSSI Weld 73W were reinserted into the IAR facility at the FNR to accumulate additional fluence. The results obtained from tests of some of the reirradiated specimens showed a much lower transition temperature shift than expected. The target total fluence for the specimens is about 4×10^{19} n/cm^2.

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

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

(Milestone 3.3.A) The testing of the JRQ specimens from the Paul Scherrer Institute, previously placed on hold primarily due to the need for repair of the servohydraulic machine, is now scheduled to begin in mid-February.

Task 4: Validation of Irradiated and Aged Materials (R. K. Nanstad)

The purpose of this task is to validate the assessment of the effects of neutron irradiation on the fracture-toughness properties of typical RPV materials obtained in the previous HSSI (L1098) Program, tasks 2 and 3 of this program, and retired RPVs. This will be accomplished through the examination of the effects of neutron irradiation on the fracture toughness (ductile and brittle) of the HAZ of welds and of typical plate materials used in RPVs. The irradiated materials from retired RPVs will be machined and tested in the Irradiated Materials Examination and Testing (IMET) hot cells. The feasibility of reconstitution for CVN and 0.5T C(T) and aging of stainless steel welds will also be explored in this task. Other issues to be address include foreign interactions and technical assistance to the NRC.

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

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

(Milestone 4.1.2.B) The NUREG report (ORNL/TM-2000/343), *Attenuation of Charpy Impact Toughness Through the Thickness of a JPDR Pressure Vessel Weldment*, by S. K. Iskander with major contributions from J. T. Hutton, L. E. Creech, M. Suzuki, K. Onizawa, E. T. Manneschmidt, R. K. Nanstad, T. M. Rosseel, and P. S. Bishop, was submitted to the NRC at the end of January for publication as part of an Office of Research Operational Milestone. The abstract of that report is provided below:

> The attenuation of Charpy impact toughness through the wall of a reactor pressure vessel (RPV) was determined from testing 42 irradiated full-size Charpy specimens. The Charpy specimens were machined from eight irradiated trepans from the axial weld of the decommissioned Japan Power Demonstration Reactor (JPDR). Although the results show no attenuation through the 75-mm-thick RPV, the data are not adequate to show significant agreement or disagreement with predictions of U.S. Nuclear Regulatory Commission *Regulatory Guide 1.99*, Revision 2 (RG 1.99-2) because of the relatively small measured Charpy shifts and the relatively small RPV thickness. These small shifts were due to the relatively low exposure of the vessel to neutron irradiation. Thus, although the results are important in the overall context of through-thickness attenuation studies, they cannot be used independently to draw more definitive conclusions regarding the RG 1.99-2

attenuation predictive equation. The irradiation-induced shifts, however, do appear to be reasonable with regards to whether they originated from the core (beltline) or the remote-from-core regions of the vessel, and also whether they were from the inside or outside regions of the vessel wall. This report gives detailed results of testing the 42 JPDR Charpy specimens machined from the irradiated weld metal. This type of testing would be impossible without facilities that enable such machining of irradiated materials. The machining of the Charpy specimens from the JPDR weld trepans is described as an example of the capabilities of the Oak Ridge National Laboratory Heavy-Section Steel Irradiation Program to machine irradiated materials.

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

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

No work is currently funded in this subtask.

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

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

(Milestone 4.3.B) The report, *The Effect of Aging at 343°C on the Microstructure and Mechanical Properties of Type 308 Stainless Steel Weldments*, by D. J. Alexander, K. B. Alexander, M. K. Miller, and R. K. Nanstad, NUREG/CR-6628 (ORNL/TM-13767), was published in November 2000. However, ORNL has not received any copies of the report.

Subtask 4.4: Foreign Interactions (R. K. Nanstad)

The purpose of this subtask is to provide technical support and continued collaboration for a number of cooperative relationships with foreign institutions in the area of radiation effects on RPV steels. Collaborative relationships may be developed during the course of this program and will be developed with the cognizance of NRC. Current relationships are:

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

2. Cooperation with SCK-CEN in Belgium regarding the supply of well-characterized materials and comparison of test results, including dynamic PCVN testing for development of RPV testing standards.

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

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

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

6. Collaboration with PSI in Switzerland on reirradiation.

7. Information and data exchange with all of the above and other countries, especially regarding RPV surveillance data and comparisons of fracture toughness and Charpy impact data.

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

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

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

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

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

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

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

(Milestone 4.5.B) The letter report on RPV materials available for irradiation studies is in progress.

(Milestone 4.5.F) Testing of unirradiated specimens has continued with the high-copper weld given varying time/temperature postweld heat treatments. A Charpy impact energy versus temperature curve has been obtained for each condition to evaluate toughness as a function of PWHT. If funding can be realized, atom probe tomography will be used to determine the matrix copper contribution as a function of PWHT. A presentation of progress on this study was made at the IGRDM meeting in September in Leuven, Belgium. A letter report will be prepared following completion of all testing and evaluation. An abstract has been submitted and accepted for the Tenth International Conference on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, to be held August 5-9, 2001, in Lake Tahoe, Nevada.

A draft white paper, *Issues Regarding Irradiation Effects on Reactor Vessel Steels*, was prepared by R. K. Nanstad, G. R. Odette, and G. E. Lucas and submitted to the NRC for review.

Task 5: Modeling & Microstructural Analysis (R. E. Stoller and T. M. Rosseel)

This task shall determine the microstructural basis for radiation-induced property changes in RPV materials to aid in understanding and applying the experimental results obtained in Tasks 2 through 4. The subtasks comprise two major components: (1) theoretical modeling and data analysis, and (2) experimental investigations. The modeling work focuses on the development of an improved description of primary-damage formation in irradiated materials, and the further development and use of predictive models of radiation-induced microstructural evolution and its impact on the mechanical behavior of RPV materials. The experimental component consists of special-purpose irradiation experiments to isolate particular irradiation variables (neutron-flux level and energy spectrum), and detailed microstructural characterization of RPV materials in relevant conditions using atom probe and transmission electron microscopy techniques. These conditions include: long-term, thermally-aged, irradiated, post-irradiation mitigation (IA), and reirradiated (IAR). The information obtained from the experiments and microstructural characterization will be used to support validation of the theoretical models. Further model verification will be carried out through extensive use of the commercial-reactor surveillance data and test-reactor data contained in the NRC-funded Embrittlement Database (EDB), and data generated in other experiments coordinated by this task.

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

Subtask 5.1: Modeling of Damage Evolution (R. E. Stoller and T. M. Rosseel)

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

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

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

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

(Milestone 5.2.A). The analysis of the atom probe tomography characterization of the radiation-sensitive pressure-vessel-steel weld, KS-01 is continuing. The anomalously high shift in the ductile-to-brittle transition temperature of 170°C for this high-copper (0.37 wt% Cu) material may be due to the presence of microstructural features found in the preliminary analysis of the atom probe data. That analysis revealed a high number density (> 10^{24} m^{-3}) of ~2-nm-diameter Cu-, Mn-, Ni-, and Si-enriched cluster/precipitates in the matrix. Some phosphorus clusters were also observed. The atom probe will be unavailable during the next reporting period because it will be moved to a new lab.

A draft NUREG report entitled, *Effect of Reirradiation Rate on The Charpy Properties of an Irradiated/Annealed High Copper Reactor Pressure Vessel Weld HSSI 73W*, has been prepared that incorporates the atom probe tomography results on weld 73W specimens.

The NUREG report entitled, *Atom Probe Tomography Characterization of the Solute Distributions in a Neutron-Irradiated and Annealed Pressure Vessel Steel Weld*, NUREG/CR-6629, (ORNL/TM-13768), was published by the NRC in November.

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

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

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

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

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

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

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

(Milestone 6.1.A) Irradiation of the ORNL specimens in the HSSI-IAR 1 and 2 irradiation facilities continued during this reporting period.

After more than two years of operating the HSSI-IAR facilities, FNR personnel continue to provide excellent service to the ORNL experimenters and strictly adhere to all ORNL supplied procedures. This can be seen in the plot (under Milestone 6.2A) of the most recent start up, which is a time-temperature thermal couple plot of a typical startup of the HSSI facilities at the FNR.

The HSSI-IAR irradiation facilities continued to operate without incident during this reporting period. During this period, the HSSI-IAR facilities were irradiated for 9.9 days of reactor half-cycle 454A and ~8.3 days of half-cycle 454B.

During the 9.9 days of reactor half-cycle 454A, the IAR irradiation facilities received a total of 238 EFPH (effective full power hours). During the 8.3 days of reactor half-cycle 454B, the facilities received an additional 200 EFPH. During this reporting period, the HSSI-IAR irradiation facilities received a total of 438 EFPH.

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 4666 EFPH. At the end of this reporting period, the second group of specimens had been irradiated for a total of 5104 EFPH. The facilities themselves had been in service for a total of 9432 EFPH.

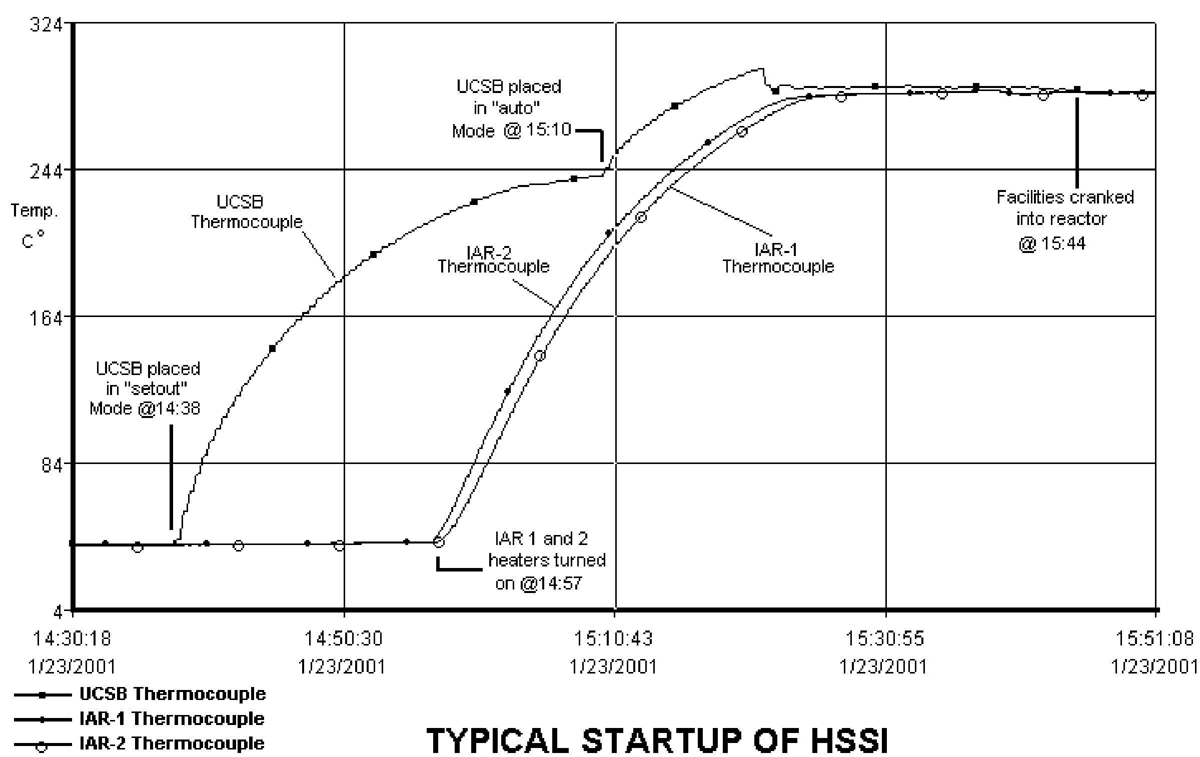
(Milestone 6.1.B) The draft NUREG report on the reusable irradiation facilities has been delayed in order to evaluate other test reactor options as possible alternatives for using the FNR.

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

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

(Milestone 6.2.A) Irradiation of the UCSB specimens in the HSSI-UCSB irradiation facility continued during this reporting period.

After more than four years of operating the HSSI-UCSB facility, the FNR personnel continue to provide excellent service to the ORNL experimenters and strictly adhere to all ORNL supplied procedures. This can be seen in the plot of the most recent start up, which is a time-temperature thermal couple plot of a typical startup of the HSSI facilities at the FNR.



TYPICAL STARTUP OF HSSI FACILTIES AT FNR

One thermocouple each was chosen from the UCSB, IAR-1 and IAR-2 irradiation facilities to monitor the process. The standard startup procedure states that the HSSI-UBSB facility should be started first by placing it in the "setout" mode, which applies a fixed amount of electrical power to all heater zones in order to heat up the facility. This occurred at 14:38 hours.

The procedure then states that the IAR-1 and IAR-2 facility heaters should be turned on ~20 minutes after the UCSB facility is placed in the "setout" mode. In this case, the IAR facility heaters were turned on at 14:57 hours. The procedure requires that the HSSI-UCSB facility be left in the setout mode for ~30 minutes, after which, it is placed in the "auto" mode. For this example, the HSSI-UCSB facility was placed in the "auto" mode at 15:10 hours.

To complete the normal startup procedure the facilities are cranked into the face of the reactor after the facilities are at the normal operating temperature and under steady control. For this case, the facilities were cranked into the reactor at 15:44 hours to begin a complete FNR half-cycle of irradiation. A normal half-cycle of operation at FNR is 10 days.

The HSSI-UCSB irradiation facility continued to operate without incident during this reporting period. During this period, the facility was irradiated for 9.9 days of reactor half-cycle 454A and ~8.3 days of half-cycle 454B

During the 9.9 days of reactor half-cycle 454A the HSSI-UCSB irradiation facility received a total of 238 EFPH (effective full power hours). During the 8.3 days of reactor half-cycle 454B, the facility received an additional 200 EFPH. During this reporting period, the HSSI-UCSB irradiation facility received a total of 438 EFPH of irradiation time.

At the beginning of this reporting period, the HSSI-UCSB facility and original specimen compliment had been irradiated for a total of 16479 EFPH. At the end of this reporting period, the facility and original specimen compliment had been irradiated for a total of 16917 EFPH. The latest irradiation plan received from the UCSB experimenters indicated that the final specimens would be removed from the HSSI-UCSB facility after 13,500 EFPH. Additional specimen irradiations have been added to the original plan and at the end of this reporting period the UCSB irradiation program had obtained 125% of the original desired irradiation time.

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

This task was until March 1, 1999, the Embrittlement Data Base (EDB) and Dosimetry Evaluation Program, JCN: 6164. The objectives of the two subtasks listed below have been reduced but the focus remains the same. Nuclear radiation embrittlement information from radiation embrittlement research on nuclear RPV steels and from power-reactor surveillance reports will be maintained in a data base to be published on a periodic basis. The information will assist the Office of Nuclear Reactor Regulation and the Office of Nuclear Regulatory Research to effectively monitor current procedures and data bases used by vendors, utilities, and service laboratories in the pressure vessel irradiation surveillance program. It will also provide technical expertise and analysis to the NRC regarding dosimetry and transport calculations and methodologies.

<u>Subtask 7.1: Embrittlement Data Base</u> (J.-A. Wang)

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

(Milestone 7.1.B) The completed UPDATE-11 of PR-EDB was transmitted to the US NRC technical program monitor in July.

Subtask 7.2: Dosimetry Evaluation (I. Remec)

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

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

3. MEETINGS AND TRIPS:

On January 21-25, 2001, R. K. Nanstad and M. A. Sokolov traveled to Reno, Nevada, to participate in the Fourth Symposium on Small Specimen Test Techniques. M. A. Sokolov was the Symposium Chairman and R. K. Nanstad was a Session Chairman.

4. PRESENTATIONS, REPORTS, PAPERS, AND PUBLICATIONS:

D. J. Alexander, K. B. Alexander, M. K. Miller, and R. K. Nanstad, *The Effect of Aging at 343°C on the Microstructure and Mechanical Properties of Type 308 Stainless Steel Weldments",* by NUREG/CR-6628 (ORNL/TM-13767), November 2000.

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, *Attenuation of Charpy Impact Toughness Through the Thickness of a JPDR Pressure Vessel Weldment,* was submitted to the NRC.

R. K. Nanstad, D. E. McCabe, M. A. Sokolov, C. A. English, and S. R. Ortner, *Investigation of Temper Embrittlement in Reactor Pressure Vessel Steels Following Thermal Aging, Irradiation, and Thermal Annealing*, has been submitted in final form to ASTM for publication in Effects of Radiation on Materials: 20th International Symposium, *ASTM STP 1405.*

5. PROPERTY ACQUIRED:

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

Item	**Cost ($)**
None	

6. PROBLEM AREAS:

The HSSI Program Manager was notified that the cost of the neutrons provided by the FNR would increase by a factor of 2.5 beginning March 1, 20001, due the University of Michigan's requirement of full-cost recovery for the extended operating time provided on behalf of the Program. In response, a cost growth letter will be submitted to the NRC that reflects the anticipated increase in costs. Additionally, unless long-term support for the facility is identified, the FNR will be shut down by June 30, 2004 and prepared for decommissioning.

The repair of the 100-kip MTS servo-hydraulic machine in the IMET hot cell # 3 has been completed. To conduct tests above room temperature, a test oven was installed and a cell entry has been scheduled for mid-February to make the electrical connection. The entry delay is due to the installation of a new 5-ton crane in January and the unanticipated repairs to equipment in the adjacent cell #2.

Reductions in DOE programmatic support for the IMET hot cell facility are expected to result in a reduced operating schedule during FY 2001.

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: 12/25/00-1/28/01

		Current Month	Fiscal Year to Date	Cumulative Project to date
I.	Direct Staff Effort	8 MM	3.3 MY	33.1 MY
II.	A. Direct Lab Staff Effort ($)			
	Direct Salaries	61,067	266,980	3,282,685
	Materials and Services	722	2,346	378,302
	ADP Support	61	244	2,029
	Subcontracts	-7,870	5,832	368,250
	Travel	825	10,799	127,408
	Indirect Labor Costs	0	0	0
	Other: NRC-PO Tax	4,000	8,000	146,500
	General and Administrative	26,116	114,713	1,493,935
	Total UT-Battelle Costs	84,921	408,914	5,799,109
	B. DOE Federal Access Costs	2,548	12,267	12,267
	TOTAL PROJECT COSTS	87,469	421,181	5,811,376
	Percentage of available cumulative funds costed		97	
	Percentage of available current FY funds costed		73	
	Funds Remaining		158,624	
	Commitments:		21,154	
	BA Remaining		137,470	
	BA Remaining Less Projected FAC		132,849	

III. Funding Status

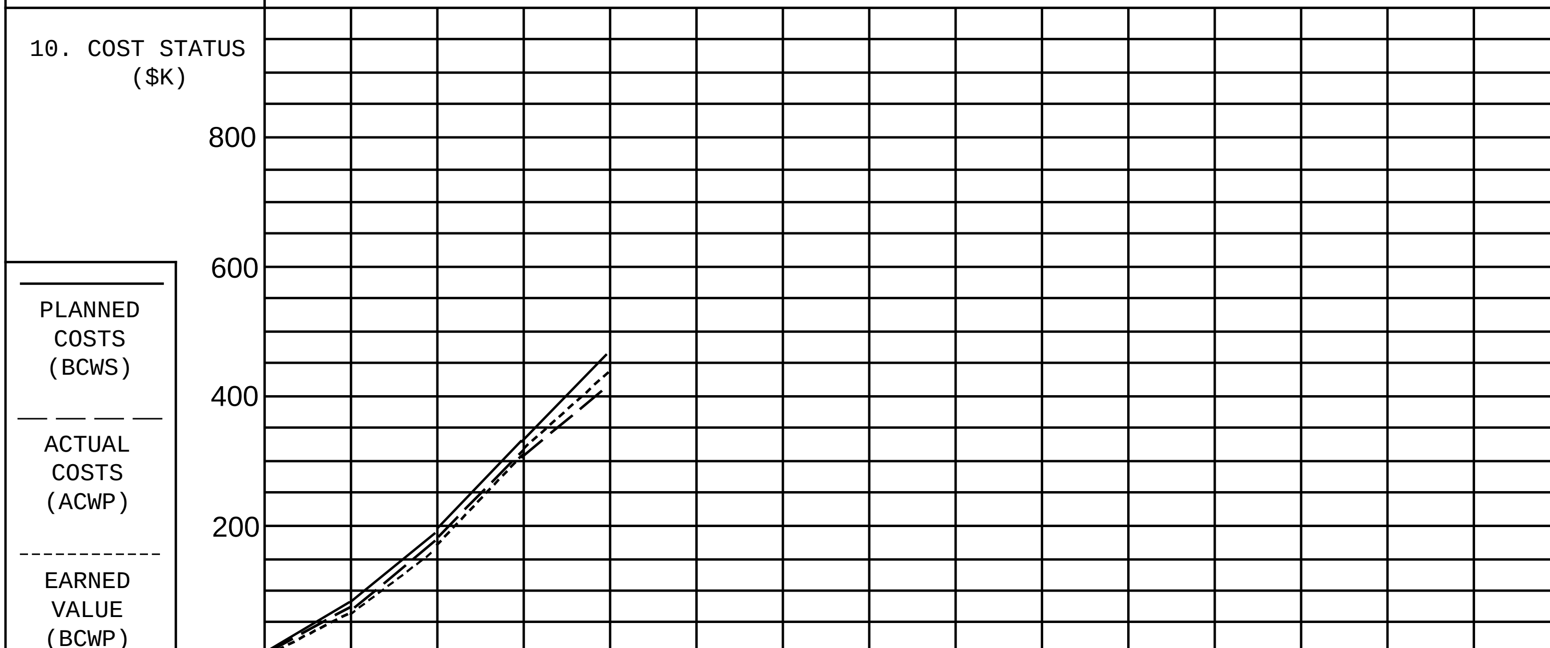
Prior FY Carryover	FY 01 Projected Funding Level	FY 01 Funds Received to Date	FY 01 Funding Balance Needed	Cumulative Amt. Obligated	Cumulative Amt. Costed
279,802	1,450,000	300,000	1,150,000	5,970,000	5,811,376

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

1. CONTRACT REPORTING ELEMENT **HSSI - Heavy-Section Steel Irradiation Program**	2. REPORTING PERIOD **12/25/00 - 01/28/2001**	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 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)



COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 563

ELEMENT COSTS FOR PRIOR FYS ($K): 280

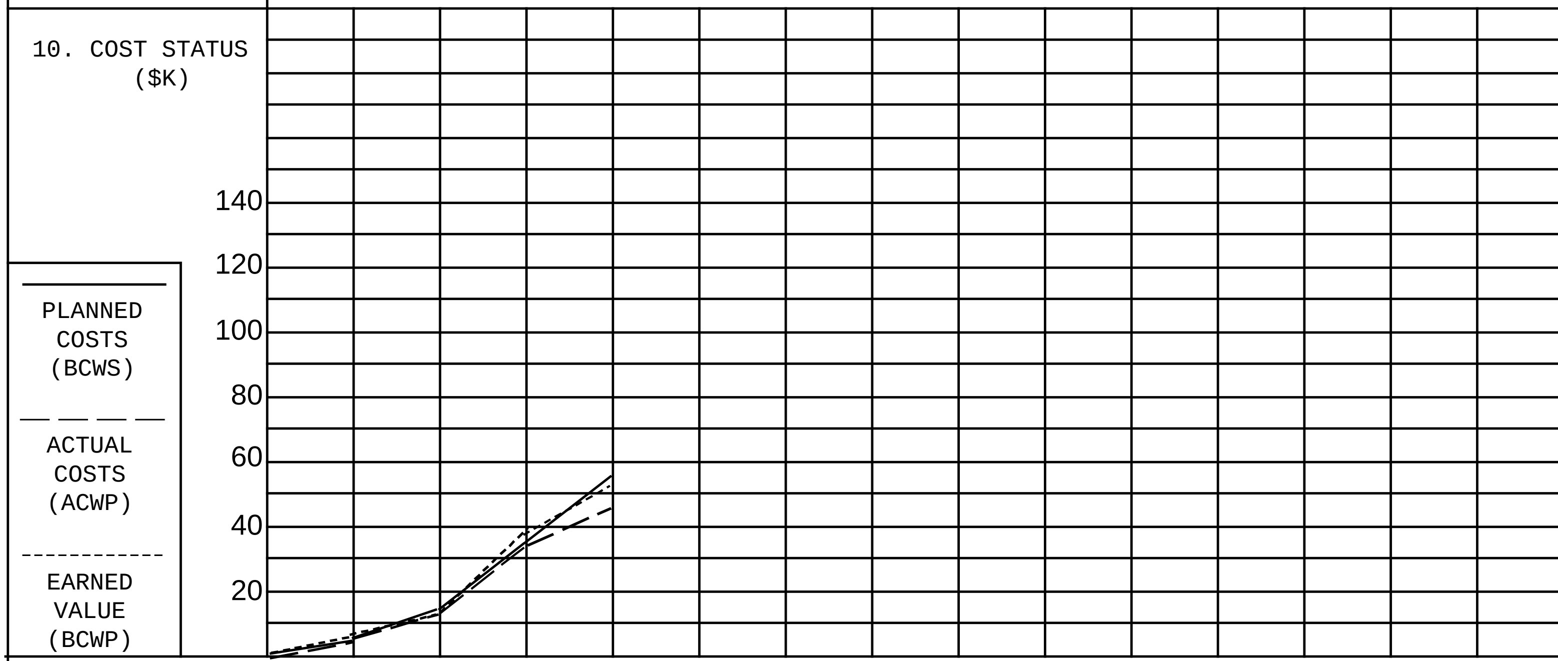
ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	78	103	154	118											
ACTUAL	77	113	134	85											
EARNED	76	87	164	114											
CUM. PLAN.	77	181	335	453											
CUM. ACT.	77	190	324	409											
CUM. EARN.	76	162	326	440											

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

1. CONTRACT REPORTING ELEMENT **HSSI - 1. Program Management**	2. REPORTING PERIOD **12/25/00 - 01/28/2001**	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 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)



COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 60

ELEMENT COSTS FOR PRIOR FYS ($K): 10

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	4	10	20	20											
ACTUAL	4	10	20	11											
EARNED	5	9	20	17											
CUM. PLAN.	4	14	34	54											
CUM. ACT.	4	14	34	45											
CUM. EARN.	5	14	34	51											

11. REMARKS:

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 2. Fracture Toughness Transition and MC Methodology	**12/25/00 - 01/28/2001**	**W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)

COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 214

ELEMENT COSTS FOR PRIOR FYS ($K): 117

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	20	33	75	40											
ACTUAL	20	33	75	40											
EARNED	13	17	73	40											
CUM. PLAN.	20	53	128	168											
CUM. ACT.	20	53	128	168											
CUM. EARN.	13	30	103	143											

11. REMARKS:

1. CONTRACT REPORTING ELEMENT **HSSI - 3. Irradiation Embrittlement of RPV Steel**	2. REPORTING PERIOD **12/25/00 - 01/28/2001**	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 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)

COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 133

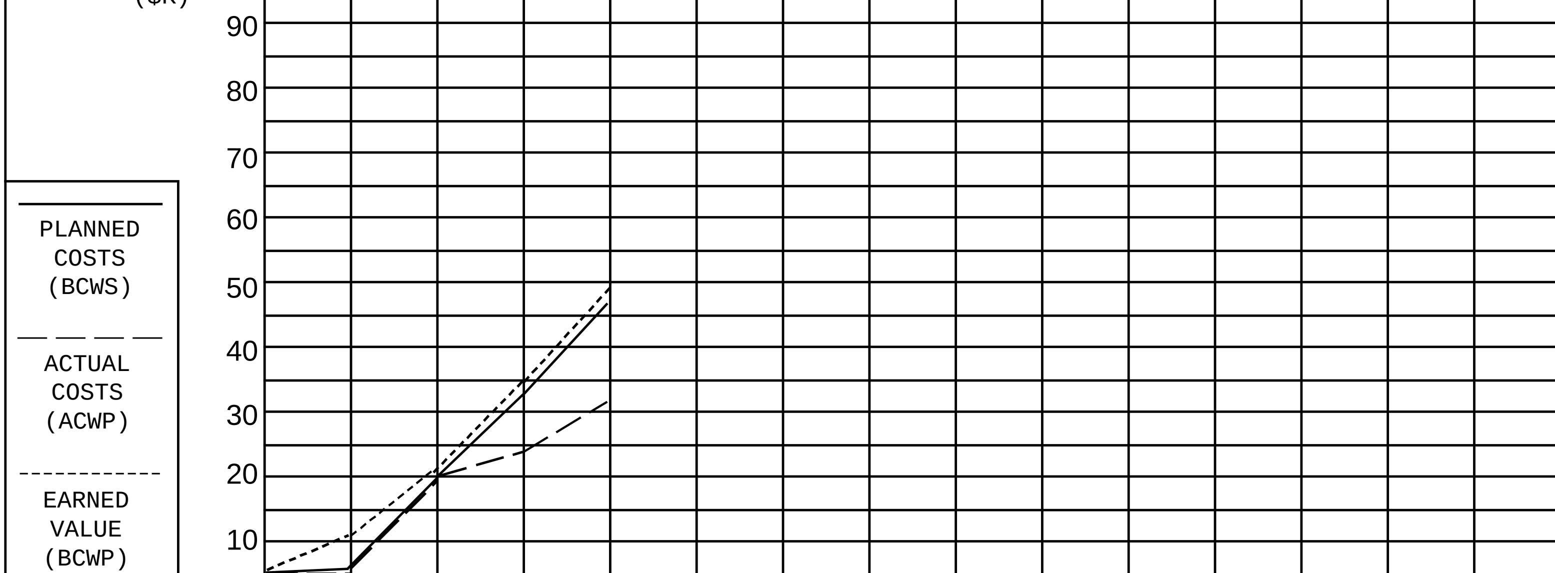
ELEMENT COSTS FOR PRIOR FYS ($K): 98

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	32	26	19	20											
ACTUAL	32	26	9	2											
EARNED	28	34	35	18											
CUM. PLAN.	32	58	77	97											
CUM. ACT.	32	58	67	69											
CUM. EARN.	28	62	97	115											

11. REMARKS:

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 4. Validation of Irradiated and Aged Materials	**12/25/00 - 01/28/2001**	**W6953**
4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NUMBER
OAK RIDGE NATIONAL LABORATORY	**FY 1999-2003**	**41 W6 95 3W 1**
P.O. BOX 2008	7. NRC B&R NO.	8. DOE B&R NO.
OAK RIDGE, TN 37831	**860 15 21 20 05**	**40 10 01 06**

10. COST STATUS ($K)



COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 63

ELEMENT COSTS FOR PRIOR FYS ($K): 18

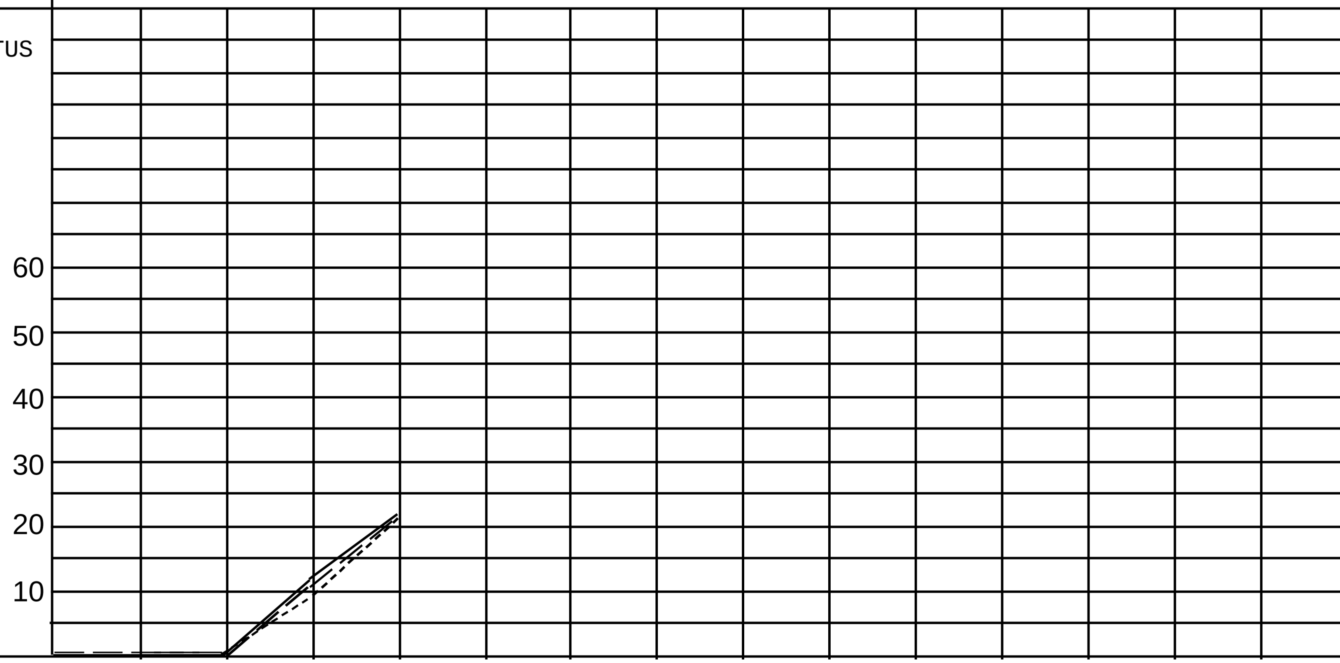
9. MONTHS	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
ACCRUED COSTS ($K) PLANNED	2	18	12	14											
ACTUAL	2	18	3	9											
EARNED	11	10	14	14											
CUM. PLAN.	2	20	33	47											
CUM. ACT.	2	20	23	32											
CUM. EARN.	11	21	35	49											

11. REMARKS:

1. CONTRACT REPORTING ELEMENT **HSSI - 5. Modeling and Microstructural Analysis**	2. REPORTING PERIOD **12/25/00 - 01/28/2001**	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 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)



PLANNED COSTS (BCWS) ———

ACTUAL COSTS (ACWP) — — — —

EARNED VALUE (BCWP) ------------

COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 22

ELEMENT COSTS FOR PRIOR FYS ($K): 2

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	0	0	12	11											
ACTUAL	0	0	12	9											
EARNED	0	0	8	13											
CUM. PLAN.	0	0	12	23											
CUM. ACT.	0	0	12	21											
CUM. EARN.	0	0	8	21											

11. REMARKS:

1. CONTRACT REPORTING ELEMENT **HSSI - 6. Irradiation Coordination**	2. REPORTING PERIOD **12/25/00 - 01/28/2001**	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 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)

PLANNED COSTS (BCWS) ———

ACTUAL COSTS (ACWP) — — — —

EARNED VALUE (BCWP) ------------

COST PLAN DATES: 01/02/01

PLANNED COSTS FOR ELEMENT ($K): 68

ELEMENT COSTS FOR PRIOR FYS ($K): 38

ACCRUED COSTS ($K)	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PLANNED	19	16	16	13											
ACTUAL	19	26	16	14											
EARNED	19	16	14	12											
CUM. PLAN.	19	35	51	64											
CUM. ACT.	19	45	61	75											
CUM. EARN.	19	35	49	61											

11. REMARKS:

1. CONTRACT REPORTING ELEMENT **HSSI - 7. Embrittlement DB & Dosimetry Evaluation**	2. REPORTING PERIOD **12/25/00 - 01/28/2001**	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 1999-2003** 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. MONTHS: O N D J F M A M J J A S O N D

10. COST STATUS ($K)

400
300
200
100

PLANNED COSTS (BCWS)

ACTUAL COSTS (ACWP)

EARNED VALUE (BCWP)

COST PLAN DATES

01/02/01

PLANNED COSTS FOR ELEMENT ($K)

-4

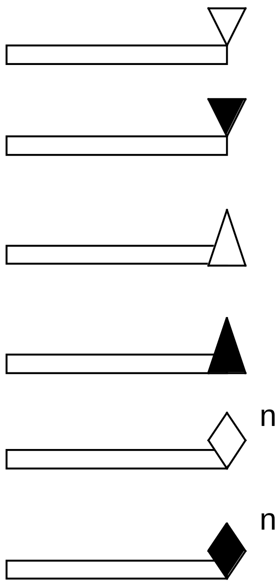
ELEMENT COSTS FOR PRIOR FYS ($K)

-4

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

11. REMARKS:

Milestone Symbology



Intermediate milestone planned

Intermediate milestone completed

Major milestone planned

Major milestone completed

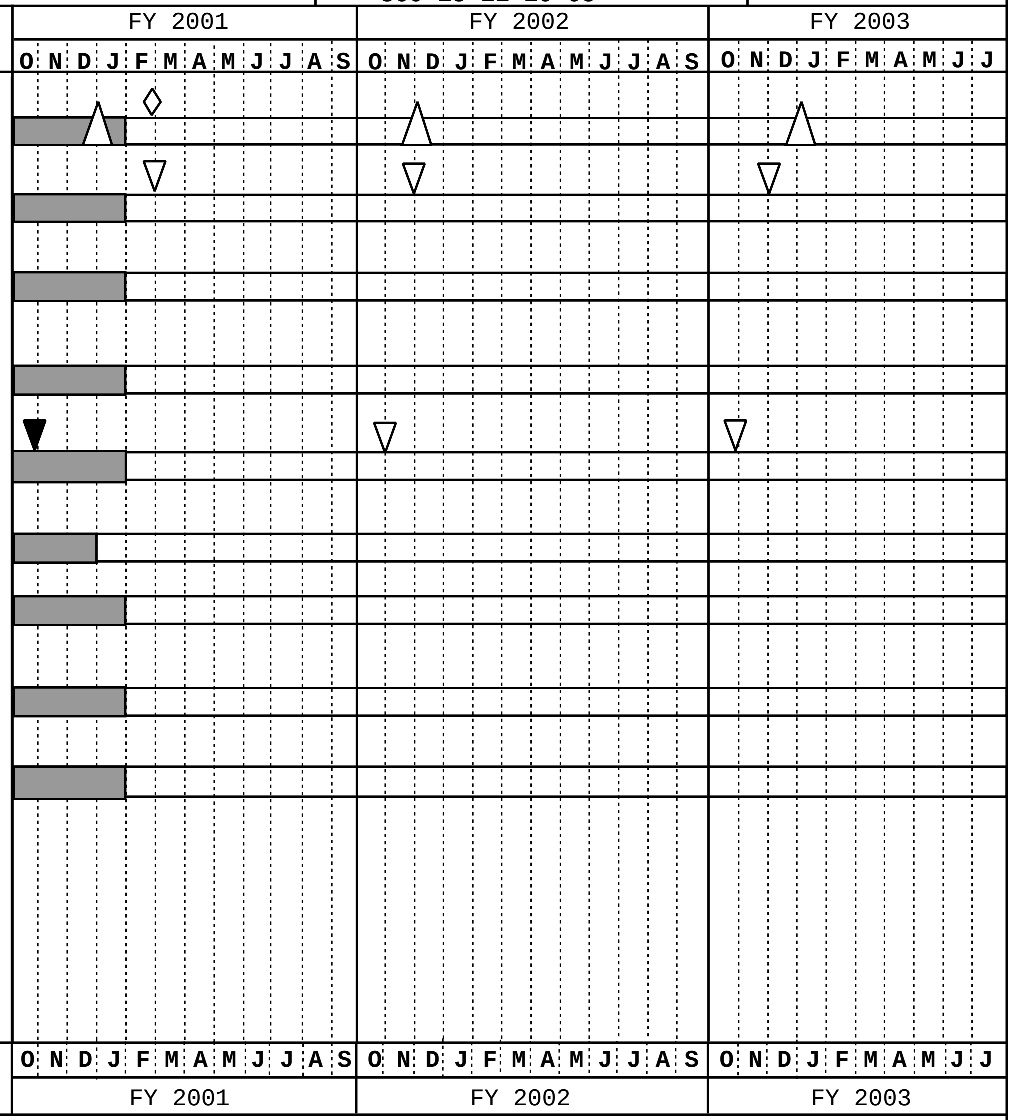
Rescheduled milestone planned

Rescheduled milestone completed

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

1. CONTRACT REPORTING ELEMENT **HSSI - 1. Program Management**	2. REPORTING PERIOD **12/25/00 - 01/28/01**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NO. **41 W6 95 3W 1** 8. DOE B&R NO. **40 10 01 06**

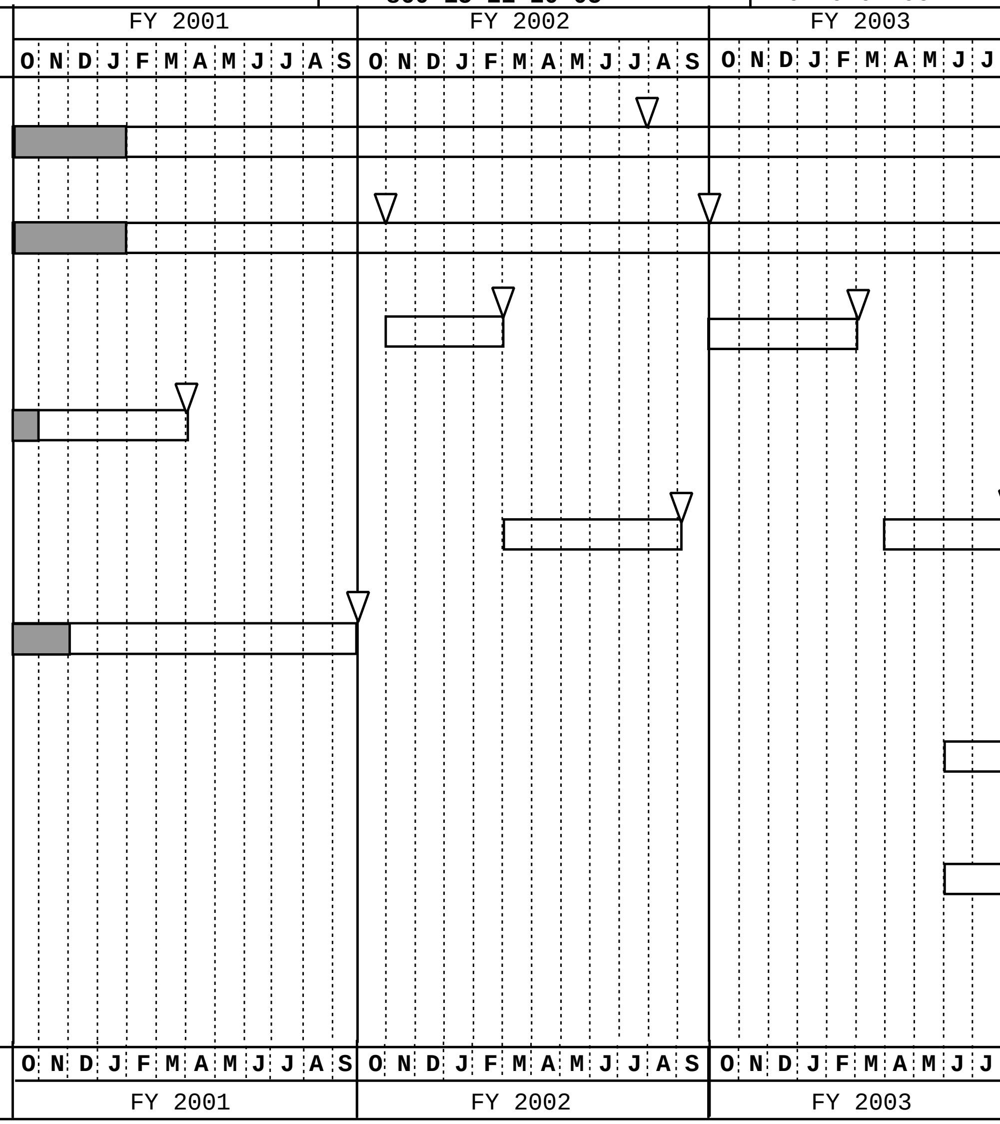
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
1.1.A.	Issue Project & Budget Proposal
1.1.B.	Select and Administer Subcontracts
1.2.A.	Issue Earned Value Based Monthly Management Reports (by the end of subsequent month)
1.2.B.	Ensure QA Requirements are met
1.3.A.	Participate in NRC-Sponsored Meeting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



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 2. Fracture Toughness Transition & MC Methodology**	2. REPORTING PERIOD **12/25/00 - 01/28/01**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003**	6. ACTIVITY NO. **41 W6 95 3W 1**
	7. NRC B&R NO. **860 15 21 20 05**	8. DOE B&R NO. **40 10 01 06**

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

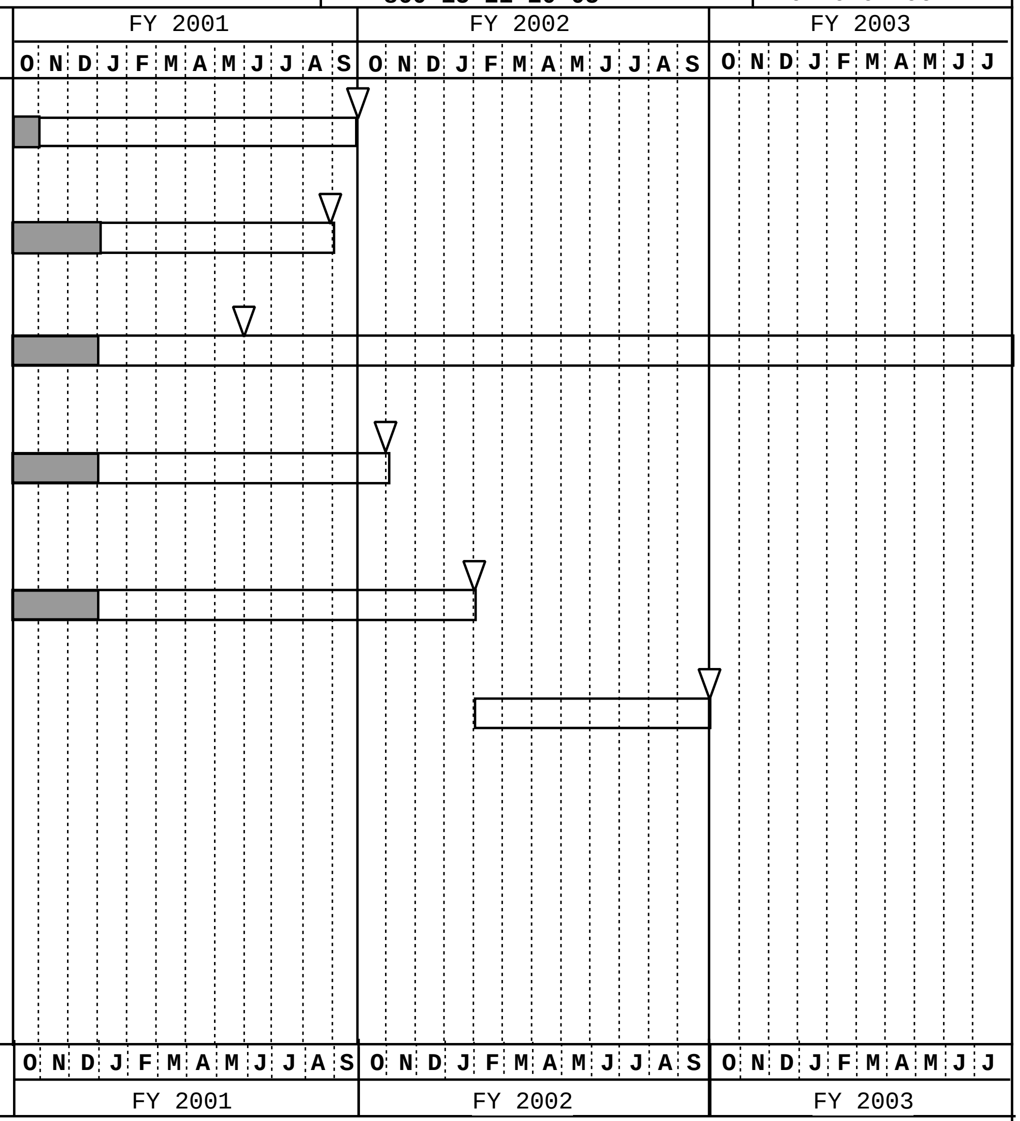


11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 2. Fracture Toughness Transition & MC Methodology	**12/25/00 - 01/28/01**	**W6953**

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

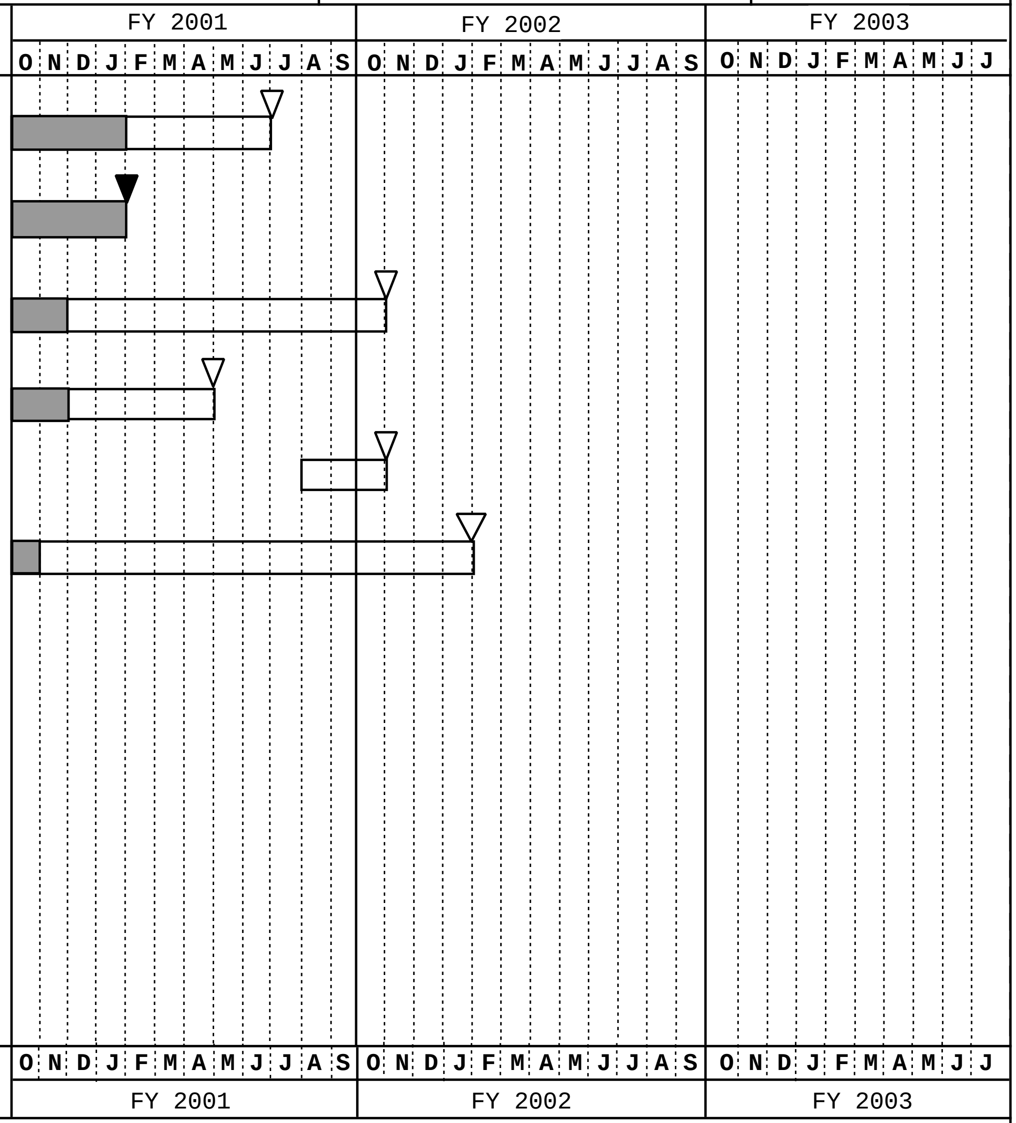
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
2.5.A.	Complete Crack Arrest NUREG Report
2.6.E.	Fractography and Final IGF Report
2.7.B.	Complete Testing of Subsize Specimens
2.7.C.	Complete NUREG Report on Results of Subsize Specimen Fracture Toughness Tests
2.7.E.	Test and Analyze A302B PCVN
2.7.F.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



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 3. Irradiation Embrittlement of RPV Steel**	2. REPORTING PERIOD **12/25/00 - 01/28/01**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NO. **41 W6 95 3W 1** 8. DOE B&R NO. **40 10 01 06**

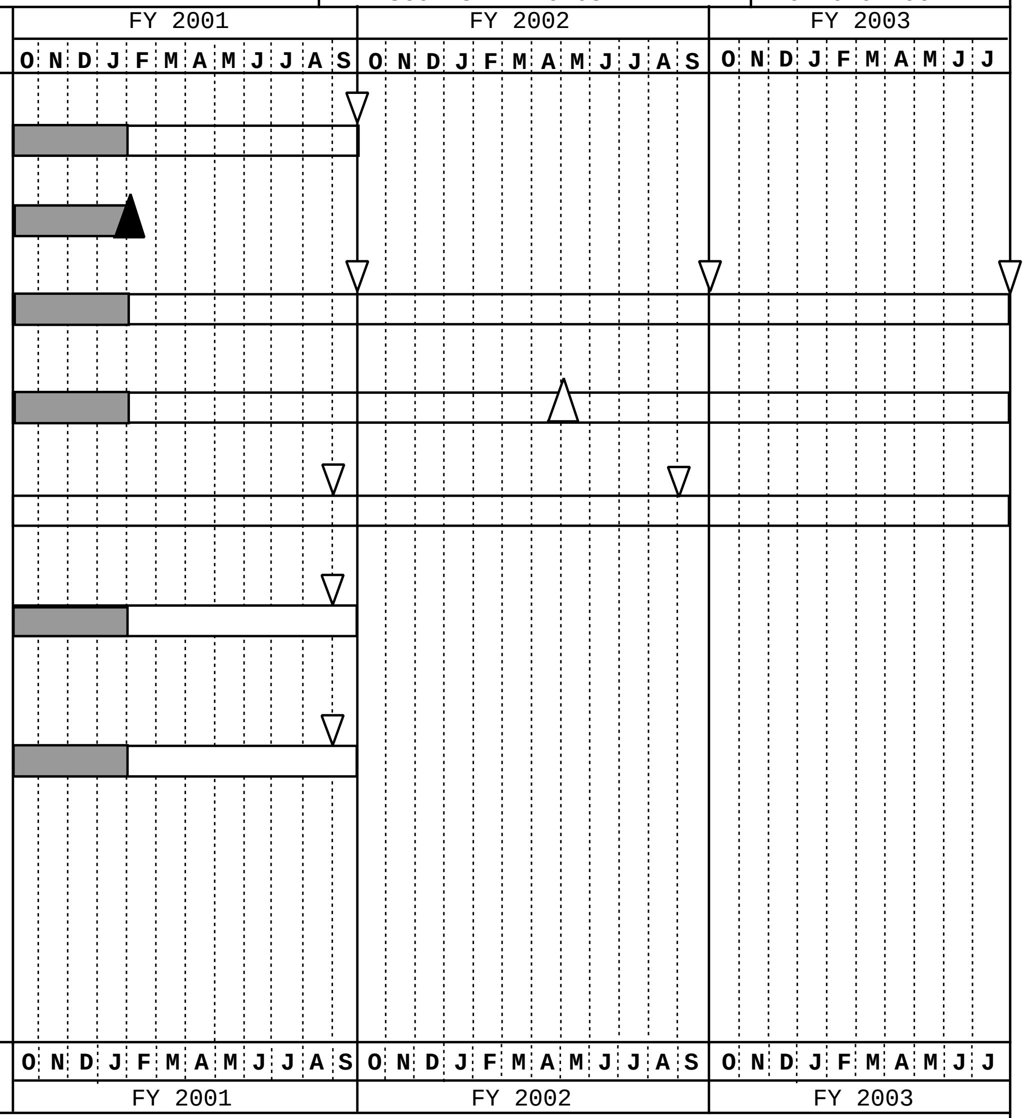
9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
3.1.G.	HAZ NUREG Report
3.1.H.	Evaluate Need for Additional Specimen Testing
3.2.C.	NUREG on 30 CVNs (IAR)
3.3.C.	Complete JRQ Charpy Testing
3.3.D.	Complete PCVN Testing
3.3.E.	Complete Draft NUREG Report on IAR Results of JRQ



11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 4. Validation of Irradiated and Aged Materials**	2. REPORTING PERIOD **12/25/00 - 01/28/01**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NO. **41 W6 95 3W 1** 8. DOE B&R NO. **40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
4.1.1.A.	Information Exchange with JAERI
4.1.1.C.	NUREG Report
4.4.A.	Complete Preparation of List of Anticipated Foreign Travel
4.4.B.	Participate in Periodic Meetings of IGRDM
4.4.C.	Complete Progress Reports of Collaboration Activities
4.5.B.	Complete Letter Report Regarding RPV Materials Available for Irradiation Study
4.5.D.	Complete Letter Report on Test results from MEA Capsule



11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 4. Validation of Irradiated and Aged Materials	**12/25/00 - 01/28/01**	**W6953**

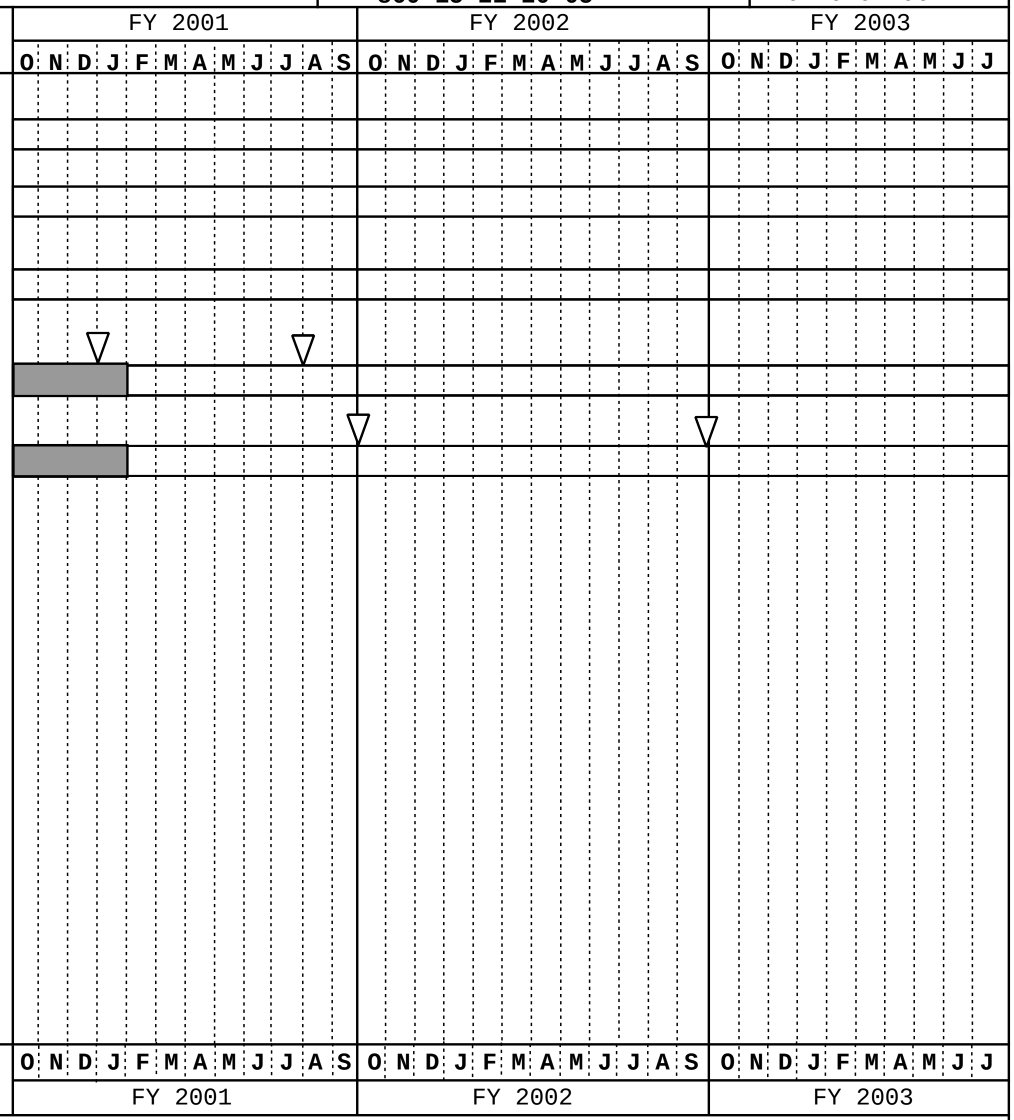
4. CONTRACTOR (NAME AND ADDRESS)	5. CONTRACT PERIOD	6. ACTIVITY NO.
OAK RIDGE NATIONAL LABORATORY **P.O. BOX 2008** **OAK RIDGE, TN 37831**	**FY 1998-2003**	**41 W6 95 3W 1**
	7. NRC B&R NO.	8. DOE B&R NO.
	860 15 21 20 05	**40 10 01 06**

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION	FY 2001	FY 2002	FY 2003
		O N D J F M A M J J A S	**O N D J F M A M J J A S**	**O N D J F M A M J J**
4.5.B.	Complete Letter Report Regarding RPV Materials Available for Irradiation Study			
4.5.D.	Complete Letter Report on Test results from MEA Capsule			

11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 5. Modeling & Microstructural Analysis**	2. REPORTING PERIOD **12/25/00 - 01/28/01**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NO. **41 W6 95 3W 1** 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
5.1.B.	Model Validation and Data Analysis
5.2.A.	Coordinate and Analyze APFIM/SANS/FEGSTEM Round Robin Experiment
5.2.B.	APFIM Characterization
5.4	Administration of Task Activities



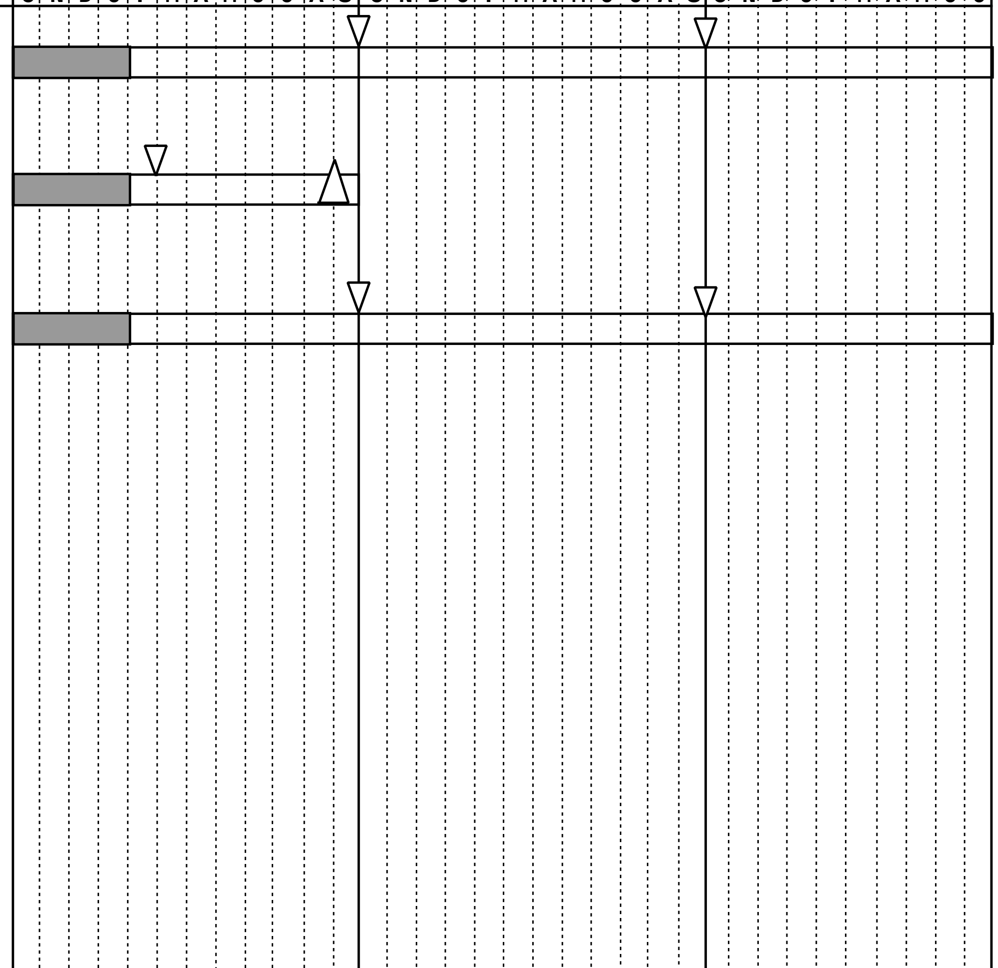
11. REMARKS

1. CONTRACT REPORTING ELEMENT **HSSI - 6. Irradiation Coordination**	2. REPORTING PERIOD **12/25/00 - 01/28/01**	3. JCN NO. **W6953**
4. CONTRACTOR (NAME AND ADDRESS) **OAK RIDGE NATIONAL LABORATORY** **P.O. BOX 2008** **OAK RIDGE, TN 37831**	5. CONTRACT PERIOD **FY 1998-2003** 7. NRC B&R NO. **860 15 21 20 05**	6. ACTIVITY NO. **41 W6 95 3W 1** 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
6.2.A.	Coordinate the Operation, Data Collection, and Maintenance of the UCSB Irrad. Facility

FY 2001 | FY 2002 | FY 2003

O N D J F M A M J J A S | O N D J F M A M J J A S | O N D J F M A M J J



O N D J F M A M J J A S | O N D J F M A M J J A S | O N D J F M A M J J

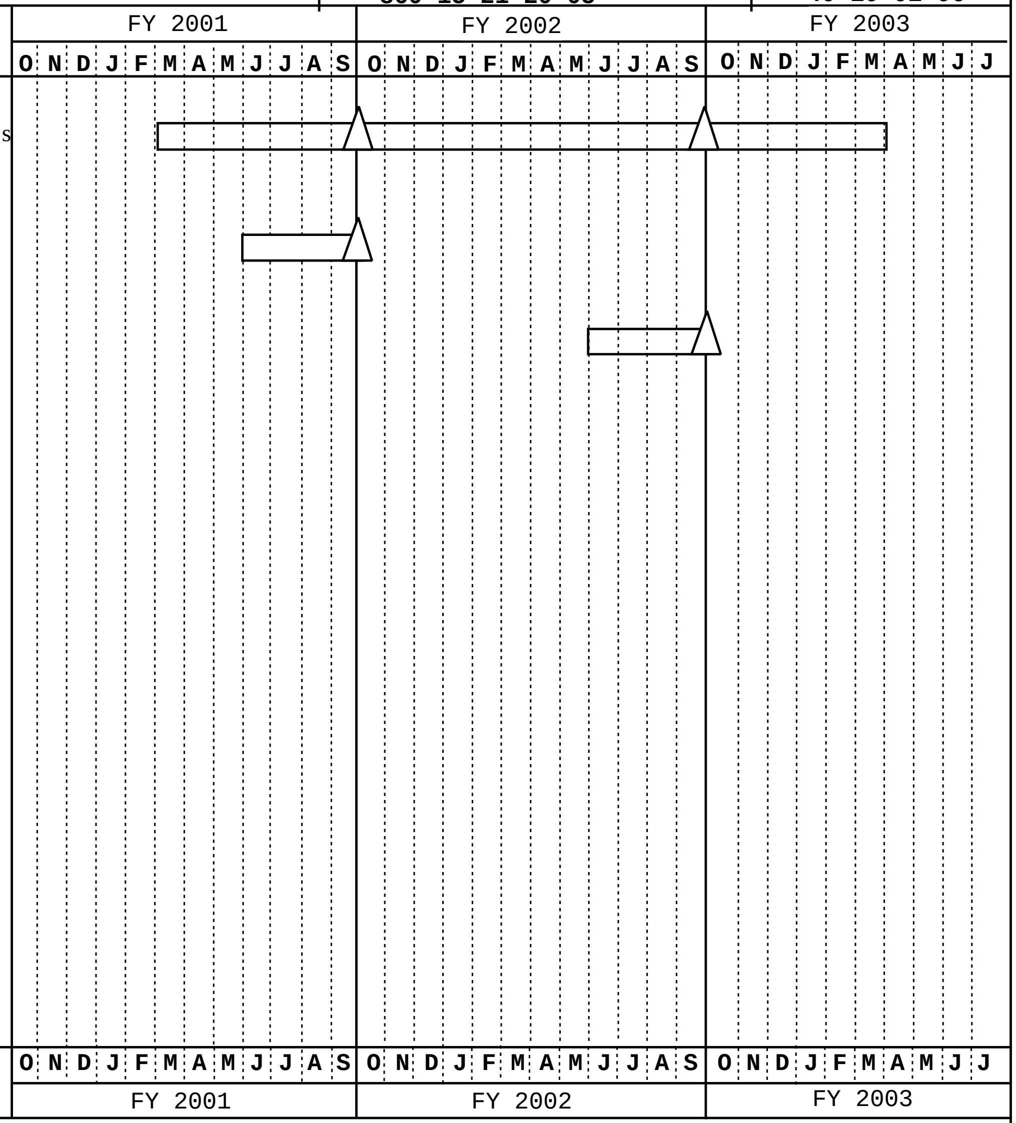
FY 2001 | FY 2002 | FY 2003

11. REMARKS

1. CONTRACT REPORTING ELEMENT	2. REPORTING PERIOD	3. JCN NO.
HSSI - 7. Embrittlement DB & Dosimetry Evaluation	**12/25/00 - 01/28/01**	**W6953**

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

9. MILESTONE IDEN. NO.	10. MILESTONE DESCRIPTION
7.1.A.	Evaluate and Input Surveillance Reports into Embrittlement Database
7.1.B.	Complete Update 12
7.1.C.	Complete Update 13



11. REMARKS