| INTERAGENCY AGREEMENT | 1. IAA NO. NRC-HQ-60-15-T-0008/M0012 | PAGE 1 OF 2 |
|---|---|---|

| 2. ORDER NO. | 3. REQUISITION NO. | 4. SOLICITATION NO. |
|---|---|---|
| | RES-18-0292 | |

| 5. EFFECTIVE DATE | 6. AWARD DATE | 7. PERIOD OF PERFORMANCE |
|---|---|---|
| 07/17/2018 | 07/17/2018 | 05/08/2015 TO 12/31/2019 |

**8. SERVICING AGENCY**
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**12. ISSUING OFFICE**
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WASHINGTON DC 20555-0001

**13. LEGISLATIVE AUTHORITY**
Energy Reorganization Act of 1974

**14. PROJECT ID**
PNNL - EWA

**15. PROJECT TITLE**
SEE BLOCK 18

**16. ACCOUNTING DATA**
2018-X0200-FEEBASED-60-60D001-60B102-1032-11-6-154-253D-11-6-154-1032

| 17. ITEM NO. | 18. SUPPLIES/SERVICES | 19. QUANTITY | 20. UNIT | 21. UNIT PRICE | 22. AMOUNT |
|---|---|---|---|---|---|
| | Task Order Title: Technical Assistance for Primary water Stress Corrosion Testing of Nickel-Base Alloys and Welds<br><br>Agreement No. NRC-HQ-25-14-D-0001<br>Task Order No.: NRC-HQ-60-15-T-0008<br><br>Master IAA: NRCHQ2514D0001<br>Title: Technical Assistance for Primary Water Stress Corrosion Cracking Testing of Nickel-Base Alloys and Welds<br><br>Continued ... | | | | |

| 23. PAYMENT PROVISIONS | 24. TOTAL AMOUNT |
|---|---|
| | $630,000.00 |

| 25a. SIGNATURE OF GOVERNMENT REPRESENTATIVE (SERVICING) | 26a. SIGNATURE OF GOVERNMENT REPRESENTATIVE (REQUESTING) |
|---|---|
| | Sandra R. Nesmith |

| 25b. NAME AND TITLE | 25c. DATE | 26b. CONTRACTING OFFICER | 26c. DATE |
|---|---|---|---|
| | | SANDRA R. NESMITH | 8/9/10 |

SUMMARY OF CHANGES:

The purpose of this modification is to (1) add additional within scope tasks; (2) increase the authorized ceiling by $742,128.00 from $3,255,678.00 to 3,997,806.00; (3) extend the period of performance by 12 months; and (4) provide incremental funding in the amount of $630,000.00.

Accordingly this task order is modified as follows:

1. Reference to the "Statement of Work," is hereby deleted in its entirety and replaced with the following Statement of Work attached to this Modification No. 12.

2. The new authorized ceiling is $3,997,806.00

3. The period of performance has changed from 5/8/15 - 12/31/18 to 5/8/15 - 12/31/19.

4. Incremental funding in the amount of $630,000.00, is provided, increasing the total obligations from $3,104,490.00 to $3,734,490.00.

All other terms and conditions remain unchanged.

Attachment: Statement of Work

[redacted]

NRC COR: Margaret Audrain, 301-415-2133

DUNS: 040535809 TAS: 31X0200.320
ALC: 31000001

## STATEMENT OF WORK

| NRC Agreement Number | NRC Agreement Modification Number | NRC Task Order Number (If Applicable) | NRC Task Order Modification Number (If Applicable) |
|---|---|---|---|
| NRC-HQ-25-14-D-0001 | | NRC-HQ-60-15-T-0008 | M0012 |

| Project Title |
|---|
| Technical Assistance for Primary Water Stress Corrosion Cracking Testing of Nickel-Base Alloys and Welds |

| Job Code Number | B&R Number | DOE Laboratory |
|---|---|---|
| 1032 | 11-6-154 | PNNL |

| NRC Requisitioning Office |
|---|
| RES |

| NRC Form 187, Contract Security and Classification Requirements | |
|---|---|
| ☐ Applicable<br>x Not Applicable | ☐ Involves Proprietary Information<br>☐ Involves Sensitive Unclassified |
| x Non Fee-Recoverable | ☐ Fee-Recoverable (If checked, complete all applicable sections below) |
| **Docket Number (If Fee-Recoverable/Applicable)**<br>N/A | **Inspection Report Number (If Fee Recoverable/Applicable)**<br>N/A |
| **Technical Assignment Control Number (If Fee-Recoverable/Applicable)**<br>N/A | **Technical Assignment Control Number Description (If Fee-Recoverable/Applicable)**<br>N/A |

## 1.0 BACKGROUND

Primary water stress corrosion cracking (PWSCC) in nickel-base alloy primary pressure boundary components is a degradation mechanism that can affect the operational safety of pressurized water reactors (PWRs). PWSCC preferentially occurs in components that operate at high temperatures and pressures, including steam generator tubes, reactor vessel head penetrations, nozzles, and dissimilar metal piping welds. PWSCC can be promoted by fabrication and welding processes, such as weld repairs, that leave high residual stresses and strains in the material. The narrow cracks, which are often located in complex structures within or adjacent to welds, can be difficult to detect and characterize during in service inspections.

At the time of plant construction, the primary nickel-base alloys used in PWRs included alloy 600 base metal and alloy 82 or 182 weld metal. The composition of these alloys includes about 14 to 22 percent chromium. PWSCC was first observed in thin-walled steam generator tubes in the 1970s and 1980s, but did not become apparent in thick-section nozzles and welds until the 1990s and early 2000s. Examples of operational experience include circumferential cracking of a hot leg dissimilar metal piping weld at V.C. Summer in 2000 (ML003762257), cracking of reactor pressure vessel head penetrations at North Anna (ML030140545) and Arkansas Nuclear One (ML011350195) in 2001 and circumferential cracking of a pressurizer surge nozzle at Wolf Creek in 2006 (ML070240159). Most notably, PWSCC of a control rod drive mechanism nozzle at Davis-Besse and subsequent boric acid leakage led to significant wastage of the reactor pressure vessel head in 2002 (ML022760172). In response to the operational experience for PWSCC in alloys 600, 82, and 182, the industry began to replace or repair nickel-base components and welds with alloys 690, 52, and 152, which are thought to be more corrosion resistant because of a higher chromium content in the range of 28 to 31 percent. Actions included replacing reactor pressure vessel heads and overlaying welds with more resistant material.

In-service inspection requirements for nickel-base alloys in the primary system are found in Section XI of the ASME Boiler and Pressure Vessel Code, referenced in Title 10 of the Code of Federal Regulations, Part 50.55a, as well as approved Code Cases. The technical bases for the inspection requirements are, in part, derived from laboratory measurements of the PWSCC growth rates of the materials in simulated PWR conditions. The inspection requirements reflect the higher corrosion resistance of alloys 690, 52, and 152 relative to alloys 600, 82, 182 by allowing longer inspection intervals. To date, there is no experience of in-service cracking of the more resistant materials. In light of the positive performance of the materials in service and apparently very low crack growth rates of as-received alloy 690 and predominantly low crack growth rates in alloy 52 and 152 measured in laboratory testing, industry is currently seeking further reductions in the inspections requirements for alloys 690, 52, and 152.

For over the past 10 years, NRC has maintained an active research program to generate confirmatory crack growth rate data for independent safety evaluations of proposed industry Code actions and inspection relief requests. This program has provided important insights on parameters that affect PWSCC susceptibility, such as the effects of material microstructure, cold work, and welding parameters. Nevertheless, given the complexity of the degradation phenomena, NRC staff recognize that key knowledge gaps remain, particularly for potential reactor operation up to 80 years. Therefore, the additional research within this scope of work is warranted.

## 2.0 OBJECTIVE

The objective of this task order is to allow PNNL to provide assistance to NRC staff in performing PWSCC growth rate testing of alloys 690, 52, and 152 to support the technical bases of safety evaluations for operating reactors and new reactor licensing actions related to pre-service inspections, in-service inspections, and component integrity analyses. Testing shall be focused on specific knowledge gaps that have been identified in previous research programs, such as the effects of compositional dilution near weld/base-metal interfaces, welding repairs, welding flaws, and welding parameters (ML13330A009, ML14338A109). The tests shall be performed on materials and specimens determined to be representative of in-service plant components, including reactor pressure vessel head penetrations, dissimilar metal piping welds, and weld overlays, onlays, and inlays.

## 3.0 SCOPE OF WORK

PNNL shall provide all resources necessary to accomplish the tasks and deliverables described in this statement of work (SOW).

PNNL shall perform PWSCC growth rate testing on alloy 690, 52, and 152 materials using equipment and test methodologies established in programs previously funded by the NRC (ML11277A230, ML11294A228, ML12114A011). These include a total of five test machines capable of simulating PWR water chemistry, temperature, and pressure, which were acquired by NRC under previous contacts (Job Codes N6007, N6782, and N6925). The materials to be tested will be determined by the NRC Contract Officer's Representative (COR) with a preliminary matrix described in further detail in Section 4.0 of this SOW.

PNNL shall acquire and/or fabricate the specimens needed to perform the tests required in this activity. The acquisition of test specimens may require logistical arrangements to be made with third parties such as the Electric Power Research Institute (EPRI), the U.S. Navy nuclear program, or other national and international entities. The fabrication of specimens may require the replication of techniques used for actual plant components, including the understanding of welding and repair processes.

PNNL shall perform the pre-test and post-test characterization of test materials which is required to understand the cracking phenomenology. This includes microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques.

PNNL shall document the progress of the project in Monthly Letter Status Reports and support monthly status update teleconferences with the NRC COR.

PNNL shall prepare the deliverables described in Section 5.0 of this SOW. PNNL is responsible for conformance to NRC standards for the publication of NUREG/CR reports, including technical editing and preparing the final "camera-ready" copy for publication.

PNNL staff shall travel to and participate in meetings, workshops, and conferences where NRC COR determines that there is a programmatic need to disseminate the results of research findings and engage with the technical community.

## 4.0 SPECIFIC TASKS

This Section describes the current status and proposed changes for the specific tasks within the scope of work for this SOW. A summary table of the changes is given at the end of this section. For some tasks, the number of tests is lower than what was required in Modification 8 of this Task Order (M0008). This does not represent a reduction in the level of effort because the duration of the tests or the extent of characterization may have proportionally increased. In the task descriptions, tests described as being within the current scope of work are those which could be performed within the period of performance and budget of M0008. Tests described as being within the additional scope of work are those which could only be performed if the Task Order period of performance and budget are modified. Unless explicitly modified here, the task requirements given in M0008 shall remain in effect.

### Task 1 – Testing of Alloy 182 for Initiation Test Program

NRC recently began a research program at PNNL to investigate PWSCC initiation to obtain confirmatory data for the Extremely Low Probability of Rupture (xLPR) probabilistic fracture mechanics code. Initiation tests will be performed on heats of alloy 182. To investigate the relative PWSCC susceptibility of different heats of alloy 182, crack growth rate tests will be performed. The activities required for this task are:

Task 1.1 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of four compact tension (CT) specimens, one from each of four heats that were identified for the initiation test program. The objective of the testing is to achieve a stable measurement of the SCC growth rate under constant stress intensity conditions. It is expected that measurements can be made at several different amounts of crack extension on a single specimen using appropriate crack extension and SCC transitioning schemes. Following standard PNNL testing methodology, two specimens shall be tested in series if there is no detrimental influence on the quality of the SCC evaluations. [Note: For Tasks 1 through 7, the term "standard PNNL testing methodology" refers to the process for measuring crack growth rate by direct current potential drop, as described in NUREG/CR reports previously prepared by PNNL (ML11277A230, ML11294A228, ML12114A011).] The duration of testing for each specimen is anticipated to be four months.

Task 1.2 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques.

*As of February 2017, Task 1 is complete***.**

**<u>Task 2</u> – Testing of Weld Dilution Zones**

The region near the fusion line in alloy 52 or 152 joined to low alloy steel or stainless steel may be locally diluted in chromium content relative to the nominal bulk composition of the alloy. The reduction in chromium content may make this dilution zone susceptible to primary water stress corrosion cracking (PWSCC). Limited alloy 52/152 to low alloy steel dilution zone testing has been performed with some results from Argonne National Laboratory (ANL) indicating high crack growth rates in a weld of alloy 152 to low alloy steel [1]. Isolated tests of alloy 52/152 to stainless steel dilution zone regions have been performed at PNNL and have not shown any enhanced susceptibility. Additional testing is needed to understand the effects of material composition and microstructure on PWSCC growth rates in dilution zones. The activities required for this task are:

Task 2.1 – Acquire and/or Fabricate Material for Dilution Zone Testing

PNNL shall acquire material or fabricate welds to make dilution zone test specimens. The source of the materials and/or the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. Primary consideration shall be given to welds which are representative of those found in plant components. A total of five welds are required for this task, including (1) two alloy 152 to low-alloy steel welds, (2) one alloy 152 to stainless steel weld, (3) one alloy 52 to low-alloy steel weld, and (4) one alloy 52 to stainless steel weld. Two alloy 152 to low alloy steel welds are proposed due to higher crack growth rates having been seen in this variant. [Note: For Tasks 2 through 7, unless otherwise specified, the use of the designations “alloy 52” and “alloy 152” in the task description includes variants of those alloys (e.g., alloy 52M), which may be used by PNNL for the testing described therein.]

*As of February 2017, Subtask 2.1 is complete.*

Task 2.2 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of ten dilution zone CT specimens, two from each of the five welds described in Subtask 2.1. The objective of the testing is to achieve a stable measurement of the crack growth rate under constant load conditions. It is expected that multiple constant load measurements can be made at differing amounts of crack extension in at least one dilution-zone region on each specimen using appropriate crack extension and SCC transitioning schemes. Dilution zones will likely exist within isolated regions along the crack trajectory and detailed characterization will be required before specimen machining. Since it is unlikely that any two specimens will have dilution zones at the same crack depths, these specimens will likely be tested in tandem a pure weld metal specimen. The duration of testing for each dilution zone specimen is anticipated to be eight to twelve months.

Modification 8 specified that PNNL shall perform tests on three additional dilution zone specimens for a total of eight rather than the ten initially planned. The duration of testing for each specimen is anticipated to be seven to ten months. Two of those three specimens shall be considered to be within the original scope of work given in Revision 0 of the SOW. These include one specimen from the ANL mockup weld with a stainless steel to low-alloy steel to alloy 152 triple interface and one specimen from the EPRI V-groove weld along the allow 52M to stainless steel interface. One specimen from the EWI repair weld along the alloy 52M to low-alloy steel interface was considered additional scope of work for Mod. 8.

*No changes to Subtask 2.2*

Task 2.3 – Material Characterization

PNNL shall perform the pre-test characterization of test materials that is required to determine the dilution zone microstructure and composition variations for CT specimen machining and to establish the testing approach. Post-test examinations shall also be performed to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques

*No changes to Subtask 2.3*

**Task 3 – Testing of Overlays, Inlays and Onlays**

PWSCC of susceptible alloy 82 and 182 dissimilar metal welds can be mitigated by the placement of a resistant alloy 52 or 152 overlay, inlay or onlay. Component integrity analyses may require the consideration of a scenario in which a crack propagates across or along the interface between the overlay, inlay or onlay and the low-chromium weld material. Some testing of overlays, inlays, and onlays has been performed to date [2], but additional tests are needed to address realistic configurations and materials. The activities required for this task are:

Task 3.1 – Acquire and/or Fabricate Overlays, Inlays or Onlays

PNNL shall acquire or fabricate weld overlays, inlays, or onlays to make CT specimens. The source of the material and/or the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. A total of three welds are required for this task, preferably one each for an overlay, inlay and onlay configuration. Primary consideration shall be given to welds which are representative of those found in plant components.

Modification 8 reduced the number of required welds from three to two.

*Subtask 3.1 is complete.*

Task 3.2 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of eight specimens, two from each of the inlay and onlay welds described in Subtask 3.1 and four each from the overlay welds. For the overlay weld, two specimens shall be aligned to observed crack growth into the overlay from the alloy 82/182 material while the other two specimens shall be aligned to observe SCC response along the interface between the overlay and the alloy 82/182 substrate. The objective of the testing is to achieve a stable measurement of the SCC growth rate under constant stress intensity conditions. It is expected that multiple measurements can be made on a single specimen at several different amounts of crack extension using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be eight to twelve months.

Modification 8 specified that PNNL shall perform tests on six weld overlay specimens, rather than the eight initially planned for the overlays, inlays, and onlays. Those specimens included three from both of the NNL and EWI mockup welds. For each of the welds, one specimen shall be aligned to observe crack growth from alloy 182 directly into the alloy 52M overlay, one specimens shall be aligned to observe crack growth parallel to the interface between alloy 182 and alloy 52M, and one specimen shall be aligned to observe crack growth parallel to the interface between alloy 52M and stainless steel. Five of these tests are completed or ongoing

and one test remains to be performed. Additional testing in this area is needed to investigate the potential for enhanced SCC along DM interfaces. One test shall be an alloy 52M overlay on alloy 182 and one test shall be an altered notch position test from alloy 182 toward alloy 52M interface. The duration of testing for each specimen is anticipated to be seven to ten months. These tests shall be considered as additional scope of work for this modification.

Task 3.3 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to identify the most appropriate locations for SCC testing and understand the final cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques

*No changes for Subtask 3.3..*

**Task 4 – Testing of Weld Repairs**

Welds in which defects are detected may be repaired by methods that include the removal of material by grinding followed by repair weld passes. Weld repairs have the potential to impart high residual stresses that could promote PWSCC. Limited testing has been performed on repaired welds [3] and additional data are needed to understand their susceptibility. The activities required for this task are:

Task 4.1 – Acquire and/or Fabricate Material for Weld Repair Testing

PNNL shall acquire material or fabricate welds to make CT specimens. The source of the material and/or the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. Primary consideration shall be given to welds which are representative of those found in plant components. A total of three welds are required for this task, including an alloy 52M temper bead weld with 20% through-wall inner diameter repair, to be acquired from EPRI, and two additional welds that shall be acquired or fabricated.

In Modification 8, PNNL was directed to acquire material or fabricate a total of three repair welds, one of which was an alloy 52M temper bead weld with 20% through-wall inner diameter repair, to be acquired from EPRI. The source of the two other welds was not identified.

As of May 2018, the following materials were acquired or are in the process of acquisition by PNNL: (1) the EPRI 20% through-wall inner diameter repair weld mockup and (2) a 20% and

40% through-wall inner diameter double repair weld mockup under contract for fabrication by EPRI.

*This Subtask 4.1 is considered complete*.

Task 4.2 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of six specimens, two from each of the three welds described in Subtask 4.1. The objective of the testing is to achieve a stable measurement of the crack growth rate under constant load conditions. It is expected that multiple constant stress intensity crack growth rate measurements can be made at different locations with the weld on a single specimen using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be eight to twelve months.

As of May 2018 a test on one specimen from the EPRI repair weld mockup has been completed, designated as Specimen CT134. No other tests have been started.

In Modification 8, PNNL was directed to perform PWSCC testing on two additional specimens, one each from the EWI repair weld and the second EPRI repair weld. This modification specifies that PNNL shall perform tests on two additional repair weld specimens from the EPRI double repair weld mockup. The duration of testing for each specimen is anticipated to be seven to ten months. Both of these specimens shall be considered as additional scope of work for this modification.

Task 4.3 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques

*No changes to Subtask 4.3.*

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**<u>Task 5</u> – Testing of Welds with Defects**

High-chromium, nickel-base alloys are susceptible to various types of defects that may form during welding, including ductility dip cracking (DDC) and hot cracking. Previous tests on welds known to have these defects have not provided a clear understanding of their effect on PWSCC

susceptibility. Therefore, additional data are needed to determine if weld defects enhance the PWSCC growth rate. The activities required for this task are:

Task 5.1 – Acquire and/or Fabricate Material for Testing of Welds with Defects

PNNL shall acquire material or fabricate welds to make CT specimens. The source of the material and/or the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. Primary consideration shall be given to welds which are representative of those found in plant components. A total of two alloy 52 or 152 welds are required for this task, including one with DDC of known orientation and one with hot cracks of known orientation.

As of February 2017, the following materials were acquired or are in the process of acquisition by PNNL: (1) a section of a weld mockup from EPRI designated as EPRI DDC-52-LAS, and (2) a section of a weld mockup from EPRI designated as WRTC 52M-316L-1.

NRC and EPRI have discussed procuring at least one additional weld mockup with defects, and various options are under consideration. This modification specifies that PNNL shall support the ongoing discussions with EPRI and, if necessary, make arrangements for the procurement of material for testing. If this weld mockup cannot be procured, PNNL shall inform the NRC COR and alternative plans may be made.

Task 5.2 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of four specimens, two from each of the two welds described in Subtask 5.1. The objective of the testing is to achieve a stable measurement of the crack growth rate under constant load conditions. It is expected that multiple constant stress intensity crack growth rate measurements can be made at different microstructural locations on a single specimen using appropriate crack extension and SCC transitioning schemes. The challenging nature of testing specific regions within the specimen may require testing these specimens in tandem with a nominal weld metal specimen. The duration of testing for each specimen is anticipated to be eight to twelve months.

In Revision 0 of the Task Order, PNNL was directed to perform PWSCC testing on a total of four specimens, two from each of the two welds described in Subtask 5.1. Two of these tests have been completed, one specimen from the WRTC 52M-316L-1 weld mockup and one specimen from the EPRI DDC-52-LAS weld mockup. Tests of two specimens from a potential new weld mockup with defects have yet to be identified. If the new weld mockup cannot be procured, PNNL shall inform the NRC COR and alternative plans may be made. The duration of testing for each specimen is anticipated to be seven to twelve months.

Task 5.3 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques

*No changes to Subtask 5.3.*

## **Task 6 – Testing of Warm or Cold-Worked Welds**

Welding repairs or other processes impart residual plastic strains in welds that increase the susceptibility to PWSCC. This effect may be investigated by warm or cold working welds to representative levels of residual plastic strain. The specific activities required for this task are:

Task 6.1 – Acquire and/or Fabricate Material for Testing of Warm or Cold-Worked Welds

PNNL shall acquire material and/or fabricate welds to make test specimens. The source of the material and/or the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. Primary consideration shall be given to welds which are representative of those found in plant components. A total of two alloy 52 or 152 welds are required for this task, with different levels of cold or warm work, in the range of approximately 10 to 20 percent.

As of February 2017, PNNL had acquired four 15% cold forged weld mockups: a Mitsubishi Heavy Industries (MHI) alloy 52 weld, an Equipos Nucleares SA (ENSA) alloy 52M weld, an MHI alloy 152 weld, and an IHI alloy 152M weld.

*No additional welds are needed, therefore this modification documents that this Subtask 6.1 is complete.*

Task 6.2 – PWSCC Testing

PNNL shall perform PWSCC testing on four CT specimens, two from each of the two welds described in Subtask 6.1. The objective of the testing is to achieve a stable measurement of the crack growth rate under constant stress intensity conditions. It is expected that multiple SCC growth rate measurements can be made at different amounts of crack extension on a single specimen using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be eight to twelve months. It is recognized that additional testing may be required to adequately establish the effects of cold and warm work on SCC susceptibility.

This modification specifies that the number of tests shall remain at four, but as one from each of the four 15% cold forged welds, rather than two each from two welds. As of May 2018, the tests of the MHI alloy 52 weld, designated as Specimen CT138, the ENSA alloy 52M weld, designated as Specimen CT139, the MHI alloy 152 weld, designated as Specimen CT140, and the IHI alloy 152M weld, designated as Specimen CT141, are completed.

Task 6.3 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques

*No changes to Subtask 6.3.*

## **Task 7 – Testing of Heat-to-Heat Variations in Weld Metals**

Most test data for alloys 52 and 152 indicate a very low crack growth rate. However, ANL reported a higher SCC growth rate in an alloy 152 weld, and other investigators (including PNNL) have noted a high degree of intergranular engagement even for weld specimen that exhibit very low SCC growth rates [4]. These findings indicate that additional testing is needed to understand the key parameters that affect the PWSCC susceptibility in weld metals. The specific activities required for this task are:

Task 7.1 – Acquire and/or Fabricate Material for Alloy 52 and 152 Welds

PNNL shall acquire material or fabricate welds to make CT specimens. The source of the material and/or the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. Primary consideration shall be given to welds which are representative of those found in plant components. A total of three welds are required for this task, one or two of alloy 52 and one or two of alloy 152.

As of February 2017, the following materials were acquired or are in the process of acquisition by PNNL: (1) an ENSA alloy 52 divider plate weld mockup, (2) an MHI alloy 152 weld mockup, (3) an ENSA CRDM mockup with a J-groove weld with alloy 152 butter and alloy 52 filler metal. In addition, a weld with high heat input using alloy 152M butter and alloy 52 filler metal is being fabricated by EPRI under contract to ANL, and will be made available to PNNL for testing. Alloy 52 and 152 can also be tested from portions of weld mockups used procured other tasks, such as the weld repairs or overlays.

*No additional welds are needed, therefore this modification documents that this Subtask is complete.*

Task 7.2 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of six specimens, two from each of the three welds described in Subtask 7.1. The objective of the testing is to achieve a stable measurement of the crack growth rate under constant stress intensity conditions. It is expected that multiple SCC growth measurements can be made on a single specimen using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be eight to twelve months.

As of May 2018, tests have been completed for two specimens from the ENSA alloy 52 divider plate weld mockup, designated as Specimens CT118 and CT137 and 152 weld mockups, and one specimen from the MHI alloy 152 weld mockup, designated as Specimen 135, one specimen from the alloy 52M portion of the NNL overlay mockup, one specimen from the EPRI high heat input weld alloy 52 filler metal, and one specimen from the EPRI high heat input weld alloy 152M butter.

*No additional tests are needed, therefore this modification documents that this Subtask is complete.*

Task 7.3 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques.

*No changes to Subtask 7.3.*

## Task 8 – Testing of Weld Metal Variants (Optional Task)

To resolve challenges with weldability of alloy 52 and 152, industry may propose the use of compositional variants such as alloy 52MSS and 52i. If these alloys will be used in service applications, additional testing will be needed to investigate the crack growth rate behavior. The specific activities required for this task are:

Task 8.1 – Acquire and/or Fabricate Variant Metal Welds

PNNL shall acquire material and/or fabricate welds to make CT specimens. The source of the material and the methodology for fabricating the welds will be reviewed and approved by the NRC COR prior to the expenditure of any funds for procurement. Primary consideration shall be given to welds which are representative of those found in plant components. The type and number of welds required will be determined at the time that it is decided to execute this task, but is not likely to exceed three welds.

Task 8.2 – PWSCC Testing

PNNL shall perform PWSCC testing on the specimens described in Subtask 8.1. The specific number of tests will be determined at the time that it is decided to execute this task, but it is not likely to exceed six. The objective of the testing is to achieve a stable measurement of the SCC growth rate under constant stress intensity conditions. It is expected that multiple SCC growth rate measurements can be made on a single specimen using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be eight to twelve months.

Task 8.3 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques

*No changes to Optional Task 8.*

**<u>Task 9</u> – Testing of NNL 20% CW Alloy 690**

In 2015, NNL published PWSCC growth rate data for 20% cold worked (CW) alloy 690 from a heat designated as 136041 [5]. The reported growth rate was above $10^{-6}$ mm/s, or approximately two orders of magnitude higher than anticipated in alloy 690 at that level of CW based on previous testing by PNNL and other laboratories. This material is of interest to determine if the very high crack growth rate can be attributed to some microstructural condition or other factor. PNNL has acquired a small amount of heat 136041 from NNL for additional testing. The specific activities required for this task are:

Task 9.1 – PWSCC Testing

PNNL shall perform PWSCC testing on a total of two CT specimens from the NNL 20% CW alloy 690 material. The objective of the testing is to achieve a stable measurement of the SCC growth rate under constant stress intensity conditions. It is expected that measurements can be made at several different amounts of crack extension on a single specimen using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be nine to twelve months.

PNNL has performed/attempted to perform PWSCC testing on a total of two CT specimens from the NNL 20% CW alloy 690 material. PNNL has since acquired additional material to be tested. Both of these specimens shall be considered as additional scope of work for this modification. The objective of the testing is to achieve a stable measurement of the SCC growth rate under constant stress intensity conditions. It is expected that measurements can be made at several different amounts of crack extension on a single specimen using appropriate crack extension and SCC transitioning schemes. The duration of testing for each specimen is anticipated to be seven to nine months.

Task 9.2 – Material Characterization

PNNL shall perform the pre-test and post-test characterization of test materials that is required to understand the cracking phenomenology. The characterization techniques will be reviewed and approved by the NRC COR prior to their use, and may include microscopy, mechanical testing, chemical analyses, and other appropriate analytical techniques.

**Task 10 – Testing of Long Range Ordering in Alloy 690 and Alloy 52/52M/152**

The purpose of this task is to determine if long-term aging at PWR service temperatures can produce hardening and an increase in IGSCC susceptibility. This modification specifies that PNNL shall propose a test plan to the NRC COR and, if approved, make arrangements for the procurement of material for testing.

**Task 11 – Participation in EPRI Alloy 690 Expert Panel**

EPRI has organized a panel of PWSCC experts to review currently available crack growth rate data for alloys 690, 52 and 152 to support the development of disposition curves similar to those for alloys 600, 82 and 182 in the MRP-55 and MRP-115 reports. The panel is structured such that one group of experts, referred to as the Data Group, evaluates testing and data acquisition methodologies to determine the quality of the data. A second group of experts, referred to as the Applications Group, will develop a statistical disposition curve by determining which of the data are most relevant for plant components.

NRC has an interest in the Data Group evaluation process, as it will help the staff to identify data gaps relevant to safety evaluation review and to determine future testing needs. Therefore, NRC and EPRI entered into a Memorandum of Understanding in which NRC and EPRI agreed to allow the participation of PNNL staff in the Expert Panel to provide insights from their years of testing experience.

One staff member from PNNL shall attend meetings of the Alloy 690 Expert Panel to provide input on testing results, materials characterization, data interpretation, or other technical information requested by the NRC COR. It is anticipated that there will be two meetings per year, of two days each, along with approximately bi-monthly group teleconferences. Meeting summaries, scheduling notes, and other work performed for the Expert Panel will be documented in the Monthly Letter Status Report.

## Task 12 – Preparation of Technical Reports

| Summary of Task Status and Changes | | | |
|---|---|---|---|
| **Task** | **Status** | **Activities to be Completed Under Original Work Scope** | **Summary of Modification** |
| Task 1 – Testing of Alloy 182 for Initiation Test Program | Finished | None | Documented as completed. |
| Task 2 – Testing of Weld Dilution Zones | Finished | None | Documented as completed |
| Task 3 – Testing of Overlays, Inlays, and Onlays | In progress | Test one specimen from weld overlay mockup | Test two specimens from weld overlay mockups |
| Task 4 – Testing of Weld Repairs | In progress | None | Test two specimen from EPRI double repair weld mockup |
| Task 5 – Testing of Welds with Defects | In progress | Test two specimens from potential new weld mockup with defects | None |
| Task 6 – Testing of Warm or Cold-Worked Welds | In progress | None | None |
| Task 7 – Testing of Heat-to-Heat Variations in Weld Metals | Finished | None | Documented as completed |
| Task 8 – Testing of Weld Metal Variants | Optional task | None | To be determined |
| Task 9 – Testing of NNL 20% CW Alloy 690 | In progress | None | Test two specimens |
| Task 10 – Long Range Ordering | New Task | None | Propose test plan and acquire materials |
| Task 11 – Participation in EPRI Alloy 690 Expert Panel | In progress | Activities as needed. | Renumbered from Task 10 to Task 11 |
| Task 12 – Preparation of | In progress | Preparation of NUREG/CR-7103, Volumes 4 and 5 | Renumbered from Task 11 to Task 12. |

| | | | |
|---|---|---|---|
| Technical Reports | | | |

## 5.0 DELIVERABLES AND/OR MILESTONES SCHEDULE

In the Revision 0 of the Task Order, PNNL was directed to prepare three NUREG/CR reports during the period of performance for this task order, summarizing the details of the test methods, results, and analyses of the data. The first of the three reports has already been published as NUREG/CR-7103, Volume 3: "Stress Corrosion Cracking of Cold Worked Alloy 690." As of May 2018, Volume 4 of NUREG/CR-7103 is in concurrence and will address testing of alloy 52 and 152 weld metals. The subject matter for Volume 5 of NUREG/CR-7103 is yet to be determined. The table below documents the new deliverable schedule to be effective with this Modification. This Modification does not change the anticipated level of effort.

| **Task Order Deliverables – Updated Schedule** | | |
|---|---|---|
| **Deliverable Number** | **Description** | **Date** |
| 1 | NUREG/CR-7103, Volume 3: "Stress Corrosion Cracking of Cold Worked Alloy 690* | Completed July 2016 |
| 2 | Draft of NUREG/CR-7103, Volume 4 | Completed December 2017 |
| 3 | Final of NUREG/CR-7103, Volume 4 | July 1, 2018 |
| 4 | Draft of NUREG/CR-7103, Volume 5 | August 1, 2019 |
| 5 | Final of NUREG/CR-7103, Volume 5 | December 31, 2019 |

## 6.0 TECHNICAL AND OTHER SPECIAL QUALIFICATIONS REQUIRED

No changes.

## 7.0 KEY PERSONNEL

Key personnel assigned to this task order include the following:

[redacted]

## 8.0 MEETINGS AND TRAVEL

The travel anticipated for this task order is listed in the table below for planning purposes only. All travel is subject to the availability of funds and requires written Government approval from the Contracting Officer (CO), unless otherwise delegated to the COR. Foreign travel for the PNNL personnel requires a 60-day lead time for NRC approval. For prior approval of foreign travel, PNNL shall submit an NRC Form 445, "Request for Approval of Official Foreign Travel." NRC Form 445 is available in the MD 11.7 Documents library and on the NRC Web site at: http://www.nrc.gov/reading-rm/doc-collections/forms/. Foreign travel is approved by the NRC Executive Director for Operations (EDO).

The table below has been revised to list the travel anticipated through the end of the new period of performance. Three new trips were added with this modification. All other travel was included in M0008.

| Task Order Anticipated Travel | | | |
|---|---|---|---|
| **Location** | **Purpose** | **Travelers** | **Dates** |
| Tampa, FL | NRC-EPRI Alloy 690 Research Collaboration Meeting | 1 | December, 2018 (4 days) |
| *Boston, MA | International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors | 1 | August 18-22, 2019 |
| *Taiwan | Meeting of International Cooperative Group for Environmentally Assisted Cracking (ICG EAC) | 1 | Spring, 2019 (5 days) |
| *Tampa, FL | NRC-EPRI Alloy 690 Research Collaboration Meeting | 2 | December, 2019 (4 days) |
| *Added with this Modification | | | |

## 9.0 REPORTING REQUIREMENTS

PNNL is responsible for structuring the deliverable to follow agency standards. The current agency standard is Microsoft Office Suite 2010. The current agency Portable Document Format (PDF) standard is Adobe Acrobat X Professional. Deliverables must be submitted free of spelling and grammatical errors and conform to requirements stated in this section.

### *9.1 Monthly Letter Status Reports*

In accordance with Management Directive 11.7, NRC Procedures for Placement and Monitoring of Work with the U.S. Department of Energy, PNNL must electronically submit a Monthly Letter Status Report (MLSR) by the 20th day of each month to the COR with copies to the CO and the Office Administration/Division of Contracts to ContractsPOT.Resource@nrc.gov. If a project is a task ordering agreement, a separate MLSR must be submitted for each task order with a summary project MLSR, even if no work has been performed during a reporting period. Once NRC has determined that all work on a task order is completed and that final costs are acceptable, a task order may be omitted from the MLSR.

The MLSR must include the following: agreement number; task order number, if applicable; job code number; title of the project; project period of performance; task order period of performance, if applicable; COR's name, telephone number, and e-mail address; full name and address of the performing organization; principal investigator's name, telephone number, and e-mail address; and reporting period.

### *9.2 NUREG/CR Reports*

PNNL must prepare NUREG/CR reports in accordance with the standards described in Section 15.0.

## 10.0 PERIOD OF PERFORMANCE

The period of performance for this task order is May 8, 2015 – December 31, 2019.

## 11.0 CONTRACTING OFFICER'S REPRESENTATIVE

Primary COR

Margaret Audrain
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Mail Stop T10-A36
Washington, DC 20555-0001
E-Mail: margaret.audrain@nrc.gov
Phone: 301-415-2133

The Backup COR shall be changed to the following individual:

Backup COR

Eric Focht
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Mail Stop T10-A36
Washington, DC 20555-0001
E-Mail: eric.focht@nrc.gov
Phone: 301-415-2094

## 12.0 MATERIALS REQUIRED

Revision 0 of the Task Order directed PNNL to allocate approximately 10 to 15 percent of the project budget for the procurement of weld mockups for performance of the tasks described in Section 4.0. These funds were utilized for the acquisition of the overlay and repair weld mockups from EWI.

This modification specifies that no additional funds shall be expended for the procurement of test material without the approval of the COR, except for nominal expenses associated with shipping and handling of material otherwise provided at no cost.

## 13.0 NRC-FURNISHED PROPERTY/MATERIALS

No changes.

## 14.0 RESEARCH QUALITY

No changes.

## 15.0 STANDARDS FOR CONTRACTORS WHO PREPARE NUREG-SERIES MANUSCRIPTS

This Modification specifies that for the preparation of NUREG-series manuscripts, PNNL shall follow the new formatting guidance provided by email from Greg Oberson to Stephen Bruemmer, dated December 30, 2016. All other provisions of this Section from Revision 0 of this SOW shall remain in effect.

## 16.0 REFERENCES


1. Alexandreanu, B., Chen, Y., Natesan, K., and B. Shack, “PWSCC Behavior of Cr-Diluted Areas Near the Alloy 152-LAS Interface,” December 2, 2013, Washington, DC, ADAMS Accession Number ML13330A006.

2. Bruemmer, S., Toloczko, M., and M. Olszta. NUREG/CR-7103, Volume 2, “Pacific Northwest National Laboratory Investigation of Stress Corrosion Cracking in Nickel-Base Alloys,” April, 2012, Washington, DC. ADAMS Accession Number ML12114A011.

3. McCracken, S., Tatman, J., and F. Ku, “EPRI EWR Progress Update - ASME Code Case Overview and Status, Partial Arc EWR Mockup and Residual Stress Modeling,“ June 4, 2014, Washington, DC, ADAMS Accession Number ML14163A562.

4. Toloczko, M., Olszta, M., Overman, N., and S. Bruemmer, “ Update of SCC Crack Growth Rate Testing on Alloy 152/52 Welds, DM Welds and Alloy 690 HAZs,” December 2, 2015, Washington, DC, ADAMS Accession Number ML13330A010.

5. Moss, T., Morton, D, and H. Mohr, “Evaluation of the Temperature Dependence of Alloy 690 and Alloy 690 Weld Metal SCC Growth in Hydrogenated Water.,” Proceedings of the 17th International Conference on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors, Ottawa, Canada, August 9-13, 2015.