INTERAGENCY AGREEMENT

1. IAA NO. 31310019F0047

PAGE 1 OF 5

2. ORDER NO.

3. REQUISITION NO. RES-19-0315

4. SOLICITATION NO.

5. EFFECTIVE DATE 09/09/2019

6. AWARD DATE 09/05/2019

7. PERIOD OF PERFORMANCE 09/09/2019 TO 05/28/2024

8. SERVICING AGENCY
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9. DELIVER TO
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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

15. PROJECT TITLE
FAST FUEL PERFORMANCE CODE DEVELOPMENT AND ASSESSM

16. ACCOUNTING DATA
2019-X0200-FEEBASED-60-60D003-60B302-1145-11-6-174-252A-11-6-174-1145

17. ITEM NO.	18. SUPPLIES/SERVICES	19. QUANTITY	20. UNIT	21. UNIT PRICE	22. AMOUNT
	Agreement No. 31310019N0001 Task Order No. 31310019F0047 The NRC and PNNL hereby enter into this Agreement for the task order titled, "Fast Fuel Performance Code Development and Assessment." The period of performance for this task order is September 9, 2019 – May 28, 2024 Consideration and Obligations: (A) The Authorized Ceiling for the required work Continued ...				

23. PAYMENT PROVISIONS

24. TOTAL AMOUNT $800,000.00

25a. SIGNATURE OF GOVERNMENT REPRESENTATIVE (SERVICING)

26a. SIGNATURE OF GOVERNMENT REPRESENTATIVE (REQUESTING)

25b. NAME AND TITLE

25c. DATE

26b. CONTRACTING OFFICER JILL E. DALY

26c. DATE 09/18/2019

to be accomplished under this task order, exclusive of the Optional Tasks identified in the attached Statement of Work, is $1,244,417.00

(B) The amount presently obligated with respect to this task order is $800,000.00. When and if the amount(s) paid and payable to the DOE Laboratory hereunder shall equal the obligated amount, the DOE Laboratory shall not be obligated to continue performance of the work unless and until the NRC Contracting officer shall increase the amount obligated with respect to this DOE Agreement. Any work undertaken by the DOE Laboratory in excess of the obligated amount specified above is done so at the DOE Laboratory’s sole risk.

SCHEDULE OF REQUIRED TASKS:

Task 1: Perform Targeted Code Assessment Activities
Subtask 1.1: FAST Fission Gas Release (FGR) Model
Subtask 1.2: FAST LOCA Integral Effects, Halden Hotel Cell LOCA Testing and SCIP IV LOCA Testing
Subtask 1.3: High Burnup Fuel End of Life Parameters
Subtask 1.4: Chromium-coated Zirconium Alloy Cladding

Task 3: Complete Literature Reviews and Perform Subsequent Evaluations
Subtask 3.1: Analyze and Assess Advanced Cladding Mechanical Properties and Corrosion Behavior
Subtask 3.2: Analyze and Assess Advanced Fuel Properties and Models
Subtask 3.3: Analyze and Assess Properties foe Fuel with Higher Burnups
Subtask 3.4: Analyze and Assess Properties for Fuel with Higher Enrichments

Task 4: Maintain Knowledge of State of Practice and Awareness of Meaningful Advancement in Fuel Performance or Fuel Behavior Research Findings

Task 5: Create Design Specific Input Files

Task 6: Maintain and Update the Database of

Continued ...

Reports and References Used to Develop FAST's Integral Assessment, Code Description and Material Library

Task 7: Develop Advanced Modeling of LOCA Phenomena
Subtask 7.1: Analyze, Propose and Implement Axial Fuel Relocation New Model
Subtask 7.2: Analyze, Assess, and Implement Improved Rod Ballooning Model with Cable Guidance

Task 8: Perform a Gap Analysis for TRISO Fuel

Task 9: Document Potential TRISO Fuel Failure Modes

Task 11: Improve Metallic Fuel Models in FAST
Subtask 11.1: Analyze, Propose, and Implement Zirconium Redistribution New Model
Subtask 11.2: Analyze, Propose, and Implement Improved Fission Gas Release Model
Subtask 11.3: Analyze, Propose, and Implement Improved Plenum Heat Transfer and Sodium Filing Models

Task 12: Document Potential Metallic Fuel Failure Modes

Task 13: Quantify Uncertainties in Metallic Fuels Models in FAST

Task 14: Expand Unit and Integration Testing for Existing Code, Starting with the Heat Transfer Models

Task 15: Provide Periodic Training

Task 16: Issue New Code Versions and Documentation

Task 17: User Group Reporting and Updates

Task 18: Provide On-Call Assistance

Task 19: Assist in Transferring the Source Code Repository from GitHub to GitLab

Task 20: Maintain FAST's NQA-1 2018 Compliant Software Quality Assurance Plan

Continued ...

TOTAL AUTHORIZED CEILING OF REQUIRED TASKS……$1,244,417

The Government may require the delivery of the optional tasks/subtasks identified below at the cost stated in the Schedule. The Contracting Officer will issue a modification to the Agreement to authorize the optional tasks/subtasks.

SCHEDULE OF OPTIONAL TASKS/SUBTASKS

Subtask 1.5: Reactivity Initiated Accident Performance
Subtask 1.6: Flexible Operations
Subtask 1.7: ATF Performance

Task 2: Develop Modeling of ATF Fuel Design Phenomena and Proprietary Options of FAST

Task 10: Implement TRISO Fuel Operations and Properties and Perform Targeted Code Assessment

Task 21: Develop Recommendations Related to Implementing Advanced Solvers in The FAST Code and Propose Code Development Requirements for Non-LWR Designs

Task 22: Provide Support for Code Modifications Arising from Licensing Audits

TOTAL OF OPTIONAL TASKS/SUBTASKS……
($200,479)

The following document is hereby made a part of this Agreement:

Attachment No. 1: Statement of Work

This agreement is entered into pursuant to the authority of the Energy Reorganization Act of 1974, as amended (42 U.S.C 5801 et seq.). This work will be performed in accordance with the NRC/DOE Memorandum of Understanding dated November 24, 1998. To the best of our knowledge,

Continued ...

the work requested will not place the DOE and its contractor in direct competition with the domestic private sector.

[X] Non-fee Recoverable Work

[redacted]

NRC COR: Michelle Bales, michelle.bales@nrc.gov, 301-415-1763

DUNS: 040535809 TAS: 31X0200.320 ALC: 31000001
Master IAA: 31310019N0001

STATEMENT OF WORK (SOW)

NRC Agreement Number 31310019N0001	**NRC Agreement Modification Number**	**NRC Task Order Number (If Applicable)** 31310019F0047	**NRC Task Order Modification Number (If Applicable)**
Project Title FAST Fuel Performance Code Development and Assessment			
Job Code Number	**B&R Number**	**DOE Laboratory** Pacific Northwest National Laboratory (PNNL)	
NRC Requisitioning Office Office of Nuclear Regulatory Research (RES)		**Period of Performance** September 9, 2019 – May 28, 2024	
NRC Form 187, Contract Security and Classification Requirements ☐ Applicable ☒ Not Applicable		☒ Involves Proprietary Information ☐ Involves Sensitive Unclassified	
☒ Non-Fee Recoverable		☐Fee-Recoverable (If checked, complete all applicable sections below)	
Docket Number (If Fee-Recoverable/Applicable)		**Inspection Report Number (If Fee Recoverable/Applicable)**	
CAC		**EPID**	

CONTRACTING OFFICER'S REPRESENTATIVE

Contracting Officer's Representative

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NRC-FURNISHED PROPERTY (GFP)

A number of the tasks listed in Section 3 will utilize information furnished by the NRC. The following information will be provided to Pacific Northwest National Laboratory (PNNL) by the NRC:

- The Symbolic Nuclear Analysis Program (SNAP) code
- APT Plot software
- Halden, Studsvik Cladding Integrity Program (SCIP), Cabri International Project (CIP), and fuel modelling in accident conditions (FUMAC) data
- Results from research programs that have investigated the stated loss-of-coolant accidents (LOCA) phenomena
- Results from vendor experiments involving accident tolerant fuel

--- End of Executive Summary ---

STATEMENT OF WORK (SOW)

Contents

DESCRIPTION/SPECIFICATIONS/WORK STATEMENT

1.0 BACKGROUND

The NRC has sponsored the development of the FRAPCON and FRAPTRAN fuel performance codes for predicting steady state and transient fuel behavior, respectively. These codes have recently been combined into one code, Fuel Analysis under Steady-state and Transients (FAST).

FAST is a computer code that calculates the steady-state and response of light-water reactor fuel rods during long-term burnup. The code calculates the temperature, pressure, and deformation of a fuel rod as functions of time-dependent fuel rod power and coolant boundary conditions. The phenomena modeled by the code include: 1) heat conduction through the fuel and cladding to the coolant; 2) cladding elastic and plastic deformation; 3) fuel-cladding mechanical interaction; 4) fission gas release from the fuel and rod internal pressure; and 5) cladding oxidation. FAST is used to perform independent calculations for regulatory evaluation of fuel performance under normal operation, anticipated operational occurrences (AOOs), and hypothetical accidents such as Loss-of-Coolant Accidents (LOCAs), anticipated transients without scram, and reactivity-initiated accidents (RIA). The code is also used to generate initial fuel rod conditions that are needed for the evaluation of fuel performance under transient conditions.

2.0 OBJECTIVE

FAST code assessment, development and maintenance drive a significant portion of the fuel research activities and the tools are used in a substantial number of regulatory products. Given the centrality of the FAST code to the effectiveness of fuel research, it is critical to assess, develop and maintain this. NRC is issuing this agreement to accomplish assessment, development and maintenance activities for the FAST code. The work will include activities designed to support a variety of strategic objectives for FAST code development and builds on the work completed in contract NRC-HQ-25-14-D-0001, task order NRC-HQ-60-16-T-0009. These objectives are characterized by five main themes:

- Ensuring FAST maintain state-of-the-art features, material properties and fuel performance models.
- Making FAST easier and more efficient to use and more reliable.
- Developing new capabilities required to perform more sophisticated analysis of in-reactor transient fuel response as well as analysis related to spent fuel storage.
- Developing new capabilities required to perform analysis of new fuel designs, including accident tolerant fuel (ATF) and non-Light Water Reactor (non-LWR) fuel.
- Supporting an active and engaged peer community through the FAST User Group.

3.0 SCOPE OF WORK/TASKS

Task 1: Perform Targeted Code Assessment Activities

PNNL shall examine the following seven properties and models using experimental data from on-going research projects to perform targeted assessments of FAST for high burnup fuel and evolutionary accident tolerant fuel concepts. The COR will provide reports and presentations containing the Halden, (SCIP)[1], CIP,[2] and the International Atomic Energy Agency (IAEA)'s FUMAC data needed for the activities below.

Subtask 1.1: FAST Fission Gas Release (FGR) Model

Halden gas puncture measurements may produce FGR data during power ramps, PCMI, and fuel thermal performance (i.e., IFA-720.3). Test samples are Cr-doped fuel (i.e., ADOPT) and UO2 fuel of moderately high burnup. FGR data measurements from these experiments shall be compared to FAST FGR models and evaluate FAST's ability to predict FGR of doped and additive fuels.

Subtask 1.2: FAST LOCA integral effects, Halden Hot-Cell LOCA Testing, and SCIP IV LOCA Testing

Halden's IFA-650 series experiments will include measurements of many parameters of regulatory interest. IFA-650.15 will include metallography on cladding. Results from IFA-650 shall be modeled to verify that FAST is able to predict parameters of regulatory interest. Hot-cell LOCA testing will also be performed as part of the 2018-2020 Halden work. Several hot-cell LOCA tests will be performed on near-term ATF concepts such as Cr-doped fuel (i.e., ADOPT), FeCrAl cladding and Cr-coated opt. ZIRLO cladding. Finally, SCIP IV will consist of several LOCA tests (i.e., Subtask 2.2) that will utilize large grain, doped and additive fuels. Rod internal pressure data and cladding outer temperatures will be recorded during testing. A selection of these hot-cell LOCA tests will be identified by the COR and shall be modeled to verify that FAST is able to predict parameters of regulatory interest. For planning purposes, PNNL shall assume 4 LOCA tests will be selected for assessment.

Subtask 1.3: High Burnup Fuel End of Life Parameters

One of the trends in the US Nuclear Industry is the move to higher enrichments and higher burnup. FAST is considered validated to a rod-average burnup of 62 GWd/mtU, but today's fuel vendors are wanting to pursue burnups as high as 70-75 GWd/mtU rod average burnup (with peak burnups in the 80-85 GWd/mtU range). PNNL shall perform an assessment of end of life internal rod pressure and cladding hoop stress for high burnup fuel. The COR will provide relevant experimental data to be used for this assessment.

[1] See http://www.studsvik.com/Projects/SCIP-Project-start-page/

[2] See https://www.oecd-nea.org/jointproj/cabri.html

Subtask 1.4: Chromium-coated zirconium alloy cladding

The US Nuclear Industry has expressed interest in licensing new chromium-coated cladding designs. PNNL shall perform an assessment of cladding deformation under steady-state and transient conditions. The COR will provide relevant experimental data to be used for this assessment.

Subtask 1.5: Reactivity Initiated Accident performance [OPTIONAL]

CIP and Japan Atomic Energy Agency (JAEA's) ALPS program are anticipated to produce new data related to reactivity-initiated accident performance (RIA). Particularly, new data that could be used to expand the assessment database for cladding and fuel designs with the following characteristics may become available:

- recrystallized annealed (RXA) cladding
- cladding with barrier liner
- cr-coating cladding
- doped UO2 fuel
- iron-chrome-aluminum (FeCrAl) cladding

If such data becomes available within the program period, this task will be exercised. PNNL shall perform an assessment of fuel enthalpy at cladding failure, FGR for unfailed rods, cladding hoop strain for failed and unfailed rods, and cladding deformation under steady-state and transient conditions. The COR will provide relevant experimental data to be used for this assessment.

Subtask 1.6: Flexible Operations [OPTIONAL]

The Nuclear Energy Agency (NEA) is developing a proposal for a new experiment program aimed at examining fuel performance under flexible operating conditions and Anticipated Operational Occurrence (AOO) conditions. The program may include high burnup fuel and/or ATF concepts. The NRC has not entered into an agreement to participate in the proposed program, however if an agreement is reached then it is envisioned that the program's results would be used to assess FAST. If the NRC joins the NEA's program, this task will be exercised. PNNL shall perform an assessment of fuel centerline melt under flexible operating conditions and AOOs. PNNL shall also perform an assessment of the role of grain size on fuel performance under flexible operating conditions and AOOs. The COR will provide relevant experimental data to be used for this assessment.

Subtask 1.7: ATF performance [OPTIONAL]

The Department of Energy (DOE) is irradiating a number of Accident Tolerant Fuel (ATF) samples in the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL) in order to produce data on steady state fuel performance. In addition, DOE is sponsoring ballooning and burst tests at Oak Ridge National Lab (ORNL) on select ATF designs. It is not yet clear if the

ATR and ORNL data will be sufficiently relevant to proposed vendor fuel designs. If the NRC determines the ATR data is applicable to vendor submittals, this task will be exercised. PNNL shall perform an assessment of basic irradiation fuel performance characteristics (e.g., oxidation, cladding strain, rod internal pressure) and balloon and burst behavior for ATF designs identified by the COR.

The COR will provide relevant experimental data to be used for this assessment. For each of the seven subtasks above, PNNL shall provide the results in a letter report to the COR. Based on the outcome of the subtasks, the COR will identify two of the subtasks for which PNNL shall prepare a conference paper, conference presentation or technical journal article.

Task 2: Develop Modeling of ATF Fuel Design Phenomena and Proprietary Options of FAST [OPTIONAL]

There is a growing interest within the industry to develop ATF. Fuel vendors are planning lead test assembly (LTA) and laboratory tests to quantify mechanical properties and fuel performance characteristics of these new fuel types. In order for the NRC staff to perform confirmatory calculations during licensing reviews for ATF designs, fuel design specific models and correlations may need to be added to the FAST code. The NRC is anticipating a need to evaluate the applicability of existing cladding models or develop new models appropriate for Cr-coated Zirconium, ARMOR, SiC, and FeCrAl. While some data for ATF designs will be generated in international collaborative research projects, where data is shared with all participating parties, it is likely that in order to develop robust fuel design specific models and correlations proprietary data will be needed. Therefore, options to use and protect proprietary information in the FAST code will likely need to be created to capture these new models.

If suitable results from vendor LTA and laboratory tests investigating ATF phenomena are identified, this task will be exercised. The COR will provide PNNL with the proprietary data in a letter report.

Task 3: Complete Literature Reviews and Perform Subsequent Evaluations

It is critical that FAST maintain state-of-the-art features, material properties and fuel performance models so that it can continue to be relied on as an audit tool for licensing reviews. There are four areas that the NRC has identified as important to maintaining state-of-the-art codes; however, it is not clear if there is adequate data to evaluate and address potential deficiencies in these areas. Therefore, PNNL shall complete a literature review in the following four areas (noted as part 1). The COR will provide PNNL with the documents noted in each subtask below. It is expected that PNNL shall be able to identify meaningful data sources in addition to those provided by the COR. This task requires knowledge of fuel behavior research currently being conducted domestically and internationally as well as familiarity with the major peer-reviewed journals where fuel behavior research is published. PNNL shall propose to the COR which literatures reviews provided adequate data. Subsequent to the COR approval of the

adequacy of the data, PNNL shall use the data to complete an evaluation of FAST's accuracy for the subject parameter (noted as part 2). For planning purposes, PNNL shall assume that three of the subtasks will involve the assessment outlined in part 2.

Subtask 3.1: Analyze and Assess Advanced Cladding Mechanical Properties and Corrosion Behavior

- Part 1: PNNL shall perform a literature review to identify data sources for mechanical properties and corrosion behavior for advanced claddings, including Ziron™, HiFi™ and AXIOM™,. The COR will provide access to information from Halden to be included in the review, including results of IFA-741, IFA-785, and IFA-796. This literature review shall supplement work performed under Subtask 5.2 of a previous contract with PNNL, NRC-HQ-60-16-T-0009.
- Part 2: If PNNL determines that there is adequate data, PNNL shall perform an assessment of the existing cladding mechanical properties and corrosion models in FAST to determine if design-specific models are needed for these advanced alloys. The evaluation shall include, but is not limited to, the failure and uniform elongation properties, waterside corrosion and creep models. In instances where the current FAST model is not design specific, PNNL shall assess the model for design-specific bias for each alloy. PNNL shall update the FAST assessment database if significant deviations are identified. If only proprietary data is available, the assessment shall still be performed. If the assessment of cladding models against proprietary data indicates that there is a significant bias for advanced claddings, the feasibility and value of developing a proprietary version of FAST for in-house use shall be evaluated. PNNL shall provide a letter report to the COR to document the assessment.

Subtask 3.2: Analyze and Assess Advanced Fuel Properties and Models

- Part 1: PNNL shall perform a literature review to identify data sources for fuel properties and models for advanced fuels, including at least UO2-Gd2O3 fuel, Chromium-doped UO2, fuel with integral fuel burnable absorbers (IFBA), and ADOPT™ fuel. The COR will provide access to information from Halden to be included in the review, including results from IFA-720.3 and the SCIP IV program (i.e., Subtask 2.1, 2.2, 2.3, and 2.4). This literature review shall supplement work performed under Subtask 5.3 of a previous contract with PNNL, NRC-HQ-60-16-T-0009.
- Part 2: If PNNL determines that there is adequate data, PNNL shall perform an assessment of the existing fuel properties and models in FAST to determine if design-specific models are needed for these advanced fuels. Specifically, PNNL shall assess the predictions for fuel melting point, thermal conductivity, swelling, FGR behavior and densification. In instances where the current FAST model is not design specific, PNNL shall assess the model for design-specific bias for each fuel design. PNNL shall update the FAST assessment database if significant deviations are identified. If only proprietary data is available, the assessment shall still be performed. If the assessment of fuel properties and models against

proprietary data indicates that there is a significant bias for advanced fuels, the feasibility and value of developing a proprietary version of FAST for in-house use shall be evaluated. PNNL shall provide a letter report to the COR to document the assessment.

Subtask 3.3: Analyze and Assess Properties for Fuel with Higher Burnups

- Part 1: In a previous contract with PNNL, NRC-HQ-60-16-T-0009, PNNL identified the range of burnups for which each model and correlation in FAST has been validated to. PNNL shall perform a literature review to identify high burnup data sources for each of the fuel properties and models that are validated to a burnup less than 80 GWd/MTU.for UO2 fuel.
- Part 2: If PNNL determines that there is adequate data, PNNL shall perform an assessment of the existing fuel properties and models in FAST to determine if model changes are needed for fuel with higher burnup. Specifically, PNNL shall assess the predictions for fuel melting point, thermal conductivity, swelling, FGR behavior and densification. PNNL shall update the FAST assessment database if significant deviations are identified. If only proprietary data is available, the assessment shall still be performed. If the assessment of fuel properties and models against proprietary data indicates that there is a significant bias for fuel with higher burnup, the feasibility and value of developing a proprietary version of FAST for in-house use shall be evaluated. PNNL shall provide a letter report to the COR to document the assessment.

Subtask 3.4: Analyze and Assess Properties for Fuel with Higher Enrichments

- Part 1: PNNL shall perform a literature review to identify data sources for fuel properties and models for UO2 fuel with initial enrichment above 5% U-235.
- Part 2: If PNNL determines that there is adequate data, PNNL shall perform an assessment of the existing fuel properties and models in FAST to determine if model changes are needed for fuel with higher enrichment. Specifically, PNNL shall assess the predictions of radial power profile. PNNL shall update the FAST assessment database if significant deviations are identified. If only proprietary data is available, the assessment shall still be performed. If the assessment of fuel properties and models against proprietary data indicates that there is a significant bias for fuel with higher enrichment, the feasibility and value of developing a proprietary version of FAST for in-house use shall be evaluated. PNNL shall provide a letter report to the COR to document the assessment.

Task 4: Maintain knowledge of state of practice and awareness of meaningful advancement in fuel performance or fuel behavior research findings.

In order to maintain knowledge of the state-of-practice and awareness of meaningful advancement in fuel performance or fuel behavior research findings, PNNL's principle investigators shall attend internationally recognized conferences on the subject of fuel performance or fuel behavior research programs. This includes some combination of the

Global/Top Fuel Meeting (for 2019 see http://globaltopfuel.ans.org/, location rotates), Light Water Reactor Fuel Performance Meeting (LWRFPM, location rotates), and the Studsvik Cladding Integrity Program Group Meeting (Sweden), Fuel Safety Research Meeting (FSRM, Japan) and DOE/EPRI Advanced Fuel / Accident Tolerant Fuel Update meetings. The annual selection of conferences that PNNL shall attend will be defined by the COR. PNNL shall write a trip report after each meeting, documenting any new data or analytical methodologies presented at the conference, how the data or methodologies compare to those used in FAST, as well as recommendations for utilizing any new data for code assessment or code development activities. As appropriate, in discussion with the COR, PNNL shall write one to two papers per year on code development and assessment activities performed in the last 12 months and submit to conferences and/or journals. PNNL shall provide all presentations and papers to the COR for review at least one week prior to the submittal deadline. In addition, as appropriate and in discussion with the NRC COR, the contractor may write one to two white papers to the SCIP joint program, DOE ATF program or NEA WGFS during the contract term to propose new experiments, develop PIE plans or design experimental instrumentation that will provide particular value to validate analytical tools and methods.

Task 5: Create Design Specific Input Files

PNNL shall develop three fuel design specific FAST input files that contain the fuel rod design information. The first fuel design shall be ATRIUM11; the other two designs will be determined based on COR direction. The input files shall contain all of the information except for the operating specific inputs – namely, coolant conditions, rod power and axial power shapes. Any assumptions made on these specific input files (i.e., on geometry) shall be recorded and documented, including the technical basis of each assumption. This feature may be used by the NRC staff to quickly generate an input file with proprietary vendor data.

Task 6: Maintain and Update the Database of Reports and References used to develop FAST's Integral Assessment, Code Description and Material Library

PNNL shall continue to maintain and update as needed a database of all of the reports, data and calculation notebooks used to develop FAST, MatLib, and the Integral Assessment Documents. This database shall be organized in a manner that makes it easily searchable (rather than simply placing all files one folder containing hundreds of references) and accessible by NRC staff. If PNNL can't find specific references, the COR shall work with the NRC's Technical Library to see if the reference can be obtained.

Task 7: Develop Advanced Modeling of LOCA Phenomena

There is a growing interest within the industry to develop best-estimate analysis and address important fuel performance phenomenon mechanistically. There are two LOCA phenomena that the NRC identified as candidates for either a more mechanistic modeling approach or confirmation of best-estimate predictions. This is a continuation of efforts conducted under a previous contract with PNNL, NRC-HQ-60-16-T-0009; however, additional work is needed to refine these models and implement them in the code. The COR will provide PNNL in a letter

report, the results from research programs that have investigated these three LOCA phenomena; however, it is expected that PNNL shall be able to identify meaningful data sources in addition to those provided by the COR. This requires knowledge of fuel behavior research currently being conducted domestically and internationally as well as familiarity with the major peer-reviewed journals where fuel behavior research is published. It is desirable to approach each of the three LOCA phenomena in stages where the sub-task begins with data collection (part 1), proceeds to model development only if sufficient data exists (part 2) and concludes with implementation in FAST only if the modeling approach is determined to be reasonably best-estimate or mechanistic (part 3). For planning purposes, PNNL should assume that both of the tasks will proceed through all three parts. The two LOCA phenomenon are:

Subtask 7.1: Analyze, Propose, and Implement Axial Fuel Relocation New Model

- Part 1: Axial fuel relocation has been shown to occur following the ballooning of cladding during a LOCA. Axial fuel relocation may lead to increased heat load in this area. PNNL shall perform a literature review to identify measurements that quantify the characteristics of relocation, such as the packing fraction of the relocated fuel and cladding temperature rise in the balloon node due to relocated fuel. PNNL shall also review existing relocation models in other transient performance codes.
- Part 2: If PNNL determines that there is adequate data to substantiate an axial fuel relocation model, PNNL shall propose an axial fuel relocation model to the COR by outlining its features, defining how it can be validated, and how it can be integrated into the computational scheme of the FAST code. PNNL shall clearly identify the mechanistic and empirical features of the model in the proposal. The proposal for the new model shall be documented in a letter report to the COR.
- Part 3: If the COR determines that PNNL's proposal is viable, PNNL shall add the model to FAST. PNNL shall write a report to document the new model, including results of fuel performance predictions compared to measurements for experiments where fuel relocation was observed.

Subtask 7.2: Analyze, Assess, and Implement Improved Rod Ballooning Model with Code Guidance

- Part 1: The ballooning model in FRAPTRAN has some restrictions that are not clearly outlined in the FRAPTRAN Code Description, including the fact that ballooning is limited to one node, while the node size is completely up to the user. PNNL shall complete a literature review to identify data sources for balloon length and axial strain profile from LOCA integral tests. PNNL shall evaluate the experimental methodology for each data source to determine if the balloon shape should be considered representative of in-reactor fuel behavior.
- Part 2: If PNNL determines that there is sufficient and appropriate balloon length data available, the implications of small and large ballooning nodes shall be assessed. The assessment shall include evaluation of the impact of balloon node size on the amount of fuel predicted to be available for dispersal from the balloon region.

- Part 3: If PNNL determines that the current ballooning model logic significantly misrepresents scenarios where small or large ballooning nodes are expected, PNNL shall develop and implement an improved balloon model that more accurately reflects the size of the ballooned region. If PNNL determines that no changes to the ballooning model are feasible at this time, PNNL shall develop guidance to be added to the code description document to communicate the ballooning model restrictions.

Task 8: Perform a Gap Analysis for TRISO Fuel

The current fuels code was designed to work with the UO_2/Zirconium LWR fuel system. More recently, new models have been added to support other fuel types due to interest in non-LWR concepts. However, there are no models for TRISO fuel behavior in FAST. This task will be focused on what information is available for TRISO fuel behavior and what code updates will be needed to ensure FAST is ready to analyze TRISO fuel. PNNL shall perform a gap analysis to determine what additional physics and models are necessary to analyze TRISO fuel behavior under steady-state and anticipated transients. The gap analysis shall consider both the behavior within the TRISO particles and in the graphite matrix that binds the particles in a fuel compact. In addition, this review should determine what codes (e.g. PARFUME), data (e.g. AGR test series) and assessment information are available.

Task 9: Document Potential TRISO Fuel Failure Modes

PNNL shall perform a literature survey to determine the potential failure modes for TRISO fuels. Example failure modes include thermal creep and fission product chemical attack. PNNL shall identify limits associated with each failure mode (e.g. fission product concentration limits in the SiC layer).

Task 10: Implement TRISO Fuel Correlations and Properties and Perform Targeted Code Assessment [OPTIONAL]

In a follow on to Task 10, this task is focused on performing code updates needed to ensure FAST is capable of performing confirmatory analyses of TRISO fuel concepts. This task is broken into two parts: the first part is focused on code material and model updates, while the second is focused on assessing the code against previously generated data from test programs such as AGR. This work is contingent on NRC implementation of new solvers for spherical geometry in FAST. If NRC successfully implements these solvers, this task will be exercised.

- Part 1: PNNL shall develop and assess material behavioral models related to UCO fuel, the pyrolytic carbon and silicon carbide coating layers, and the graphite matrix.
- Part 2: PNNL shall perform a target number of code assessments that cover the range of burnups and operating conditions expected for high temperature gas-cooled reactor (HTGR) and fluoride salt-cooled high temperature reactor (FHR) concepts.

Task 11: Improve Metallic Fuel Models in FAST

FAST currently has the ability to analyze metallic fuels. However, recent code assessments have identified potential areas of improvement to the metallic fuel models. NRC has identified three potential areas for improvement. It is desirable to approach each of the three areas of improvement in three stages where the sub-task begins with data collection (part 1), proceeds to model development only if sufficient data exists (part 2) and concludes with implementation in FAST only if the modeling approach is determined to be reasonably best-estimate or mechanistic (part 3). For planning purposes, PNNL should assume that one out of the three subtasks shall terminate at part 1 and the remaining two will proceed through part 2 and 3. The three potential areas of improvement are:

Subtask 11.1: Analyze, Propose, and Implement Zirconium Redistribution New Model

- Part 1: Post-irradiation examinations of metallic fuel from the Experimental Breeder Reactor-II (EBR-II) and from the Fast Flux Test Facility (FFTF) have shown that zirconium migrates within the U-Pu-Zr fuel slugs. This Zr redistribution can affect the fuel thermal properties, radial power profile, and clad-fuel eutectic interactions. PNNL shall perform a literature survey to identify zirconium redistribution models that could be implemented in FAST and to identify available experimental data to validate the redistribution model.
- Part 2: If PNNL determines that there is adequate data to substantiate a zirconium redistribution model, PNNL shall propose a zirconium redistribution model to the COR by outlining its features, defining how it can be validated, and how it can be integrated into the computational scheme of the FAST code. PNNL shall clearly identify the mechanistic and empirical features of the model in the proposal. The proposal for the new model shall be documented in a letter report to the COR.
- Part 3: If the COR determines that PNNL's proposal is viable, PNNL shall add the model to FAST. PNNL shall write a report to document the new model, including results of fuel performance predictions compared to applicable experimental data.

Subtask 11.2: Analyze, Propose, and Implement Improved Fission Gas Release Model

- Part 1: FAST assumes a constant fission gas release rate for U-Pu-Zr fuel. While this is a good approximation at higher burnups, it significantly overestimates releases for low burnup metal fuels. PNNL shall perform a literature survey to identify potential improvements to the fission gas release model.
- Part 2: If PNNL determines that there is adequate data to substantiate an improved fission gas release model, PNNL shall propose an improved fission gas release model for U-Pu-Zr fuel to the COR by outlining its features, defining how it can be validated, and how it can be integrated into the computational scheme of the FAST code. PNNL shall clearly identify the mechanistic and empirical features of the model in the proposal. The proposal for the new model shall be documented in a letter report to the COR.
- Part 3: If the COR determines that PNNL's proposal is viable, PNNL shall add the model to FAST. PNNL shall write a report to document the new model, including results of fuel performance predictions compared to fission gas release results from EBR-II and FFTF.

Subtask 11.3: Analyze, Propose, and Implement Improved Plenum Heat Transfer and Sodium Filling Models

- Part 1: Metallic fuel used in sodium fast reactors typically includes liquid sodium as a fuel-cladding gap fill material. As fuel expands, the sodium bond in the gap flows into the upper plenum. Heat transfer between the sodium, the gas space, and the cladding in the upper plenum impacts fuel rod internal pressure. PNNL shall perform a literature survey to identify applicable experimental data that could be used to validate upper plenum heat transfer and sodium fill models for metallic fuels.
- Part 2: If PNNL determines that there is adequate data to substantiate improved upper plenum models, PNNL shall propose improved upper plenum heat transfer and sodium fill models by outlining its features, defining how it can be validated, and how it can be integrated into the computational scheme of the FAST code. PNNL shall clearly identify the mechanistic and empirical features of the model in the proposal. The proposal for the new model shall be documented in a letter report to the COR.
- Part 3: If the COR determines that PNNL's proposal is viable, PNNL shall add the model to FAST. PNNL shall write a report to document the new model, including results of fuel performance predictions compared to available experimental data.

Task 12: Document Potential Metallic Fuel Failure Modes

PNNL shall perform a literature survey to determine the potential failure modes for metallic fuels. Example failure modes include thermal creep and fuel-cladding eutectic formation. PNNL shall identify limits associated with each failure mode (e.g. fuel-cladding eutectic temperature, which could potentially be affected by Zr redistribution as discussed in Task 11). PNNL shall also identify potential specified acceptable fuel design limits (SAFDLs) that would preclude metallic fuel failure during normal operations and anticipated operational occurrences.

Task 13: Quantify Uncertainties in Metallic Fuels Models in FAST

Preliminary assessments of FAST's metallic fuel models demonstrate that FAST can adequately model metallic fuels. However, additional assessments are needed to quantify the uncertainty in the phenomena of interest in FAST (e.g. fission gas release rates, peak centerline temperature, etc.) PNNL shall perform assessments to quantify uncertainties in FAST's metallic fuel models using data from EBR-II and FFTF.

Task 14: Expand Unit and Integration Testing for Existing Code, Starting with the Heat Transfer Models

PNNL shall expand upon the existing unit testing to ensure the functionality of the code is behaving as expected. A number of integration tests shall be developed that test the code's behavior as a whole when these correlations would be used. Both the unit and integration tests shall be built into the CMake build system. PNNL shall develop additional unit tests on sensitive code areas after discussion with the COR.

Task 15: Provide Periodic Training

PNNL shall provide biennial training to NRC staff on the use of FAST. This training may also be open to FAST users outside of NRC, if approved by the COR. Each training course shall take place over two days. This training shall demonstrate to users how to do the following:

a) Develop an input file using SNAP
b) Run the code through SNAP
c) Visualize the data using FRAPlot, APT Plot and ParaView

Task 16: Issue New Code Versions and Documentation

PNNL shall release new code versions (e.g. FAST 1.x) periodically as new models are added to the code. The timing of new releases will be discussed with and accepted by the COR.

Each time a new code version is produced, PNNL shall update the Code Description Documents, Material Properties Document and Integral Assessment Documents. These documents shall be written in LaTeX. PNNL shall provide Draft versions of the reports to the COR for a 4 week review prior to PNNL submitting the final document for publication. PNNL shall re-run the integral assessment for all cases, ensuring that the cases are updated with the latest code features, and provide the inputs to the NRC.

Task 17: User Group Reporting and Updates

A FRAPCON/FRAPTRAN/FAST User Group is organized and administered by PNNL and adds significant value to the code development and maintenance tasks listed above. Periodically, the NRC staff have reporting or tracking obligations related to the code distribution aspect of User Group. In addition, there are occasions where a new NRC requirement or protocol must be implemented in the administration or documentation of the User Group. The contractor shall assist the NRC staff in reporting, tracking and update activities, specifically:

- PNNL shall maintain a list of current Non-Disclosure Agreements (NDA's) and provide the list to the NRC staff when needed.
- PNNL shall respond to NRC inquiries related to the User Group
- PNNL shall complete updates to the User Group Website requested by the NRC staff.
- PNNL shall distribute license files to registered code users, using the node locking software distributed with FAST.

Task 18: Provide On-Call Assistance

On-call assistance represents a continuing effort that should not exceed 10 percent of the total activity for this project. This on-call assistance task is for PNNL to provide technical assistance to NRC staff who use the FRAPCON/FRAPTRAN/FAST codes. Technical assistance entails

answering and resolving NRC staff questions via phone or email. This assistance is separate from the assistance provided to User Group Members in Task 17.

Activities under this task should be reported in the Monthly Letter Status Report.

Task 19: Assist in Transferring the Source Code Repository from GitHub to GitLab

Previously, NRC used GitHub for hosting the FAST source code. NRC will now be switching the source code repository to GitLab. PNNL shall assist NRC is moving files and information from GitHub to GitLab.

Task 20: Maintain FAST's NQA-1 2018 Compliant Software Quality Assurance Plan

In merging FRAPCON and FRAPTRAN into FAST, the software quality assurance plans for both codes have been combined into a single document for FAST. The software quality assurance plan is now NQA-1 certified according to the 2018 standard. PNNL shall maintain FAST's software quality assurance plan and shall continue to ensure that it is NQA-1 compliant.

Task 21: Develop recommendations related to implementing advanced solvers in the FAST code and propose code development requirements for non-LWR designs [OPTIONAL]

The NRC is in the process of preparing for the review of non-LWR fuel designs. Some of the non-LWR fuel designs feature non-cylindrical fuel geometry. Some of the non-LWR fuel designs will be characterized by complex feedback relationships between the fuel and coolant. In order to model these new non-LWR fuel designs in FAST, advanced solvers will need to be developed and added to the FAST code. The COR is working with other NRC staff as well as a commercial contractor to develop generic advanced solvers. This task is contingent on these generic solvers reaching readiness for application in the FAST code. PNNL shall provide guidance to the COR on the requirements and approach for implementing these advanced solvers into the FAST code. This task may require PNNL to coordinate with additional NRC staff and/or other NRC contractors.

Task 22: Provide support for code modifications arising from licensing audits [OPTIONAL]

The Office of Nuclear Reactor Regulation (NRR) is responsible for the review and approval of fuel vendor fuel performance codes that parallel the functionality of the FAST code. The NRR staff frequently conduct audits of fuel vendor fuel performance calculations using the FAST code. In some cases, these calculations require real-time modifications of the FAST code in order to implement fuel specific models developed for the fuel vendor fuel performance code. This task will be exercised through coordination with NRR staff in the event that the NRR staff request support for fuel vendor audit activities. For planning purposes, PNNL shall assume that two vendor audits that require real-time modifications to select fuel performance models in FAST will take place during the contract period.

4.0 LIST OF DELIVERABLES

Acceptance Criteria: For each deliverable described below, PNNL shall deliver written comments or reports in the required format, quality guidelines, and within the schedule established for COR approval and acceptance. In all cases, only electronic deliverables are requested.

For QA documentation, PNNL shall comply with the “FRAPCON/FRAPTRAN Programming Guidelines” document.

Task Number	Deliverable and Acceptance Criteria	Deliverable Format	Due Date
1	Conference paper for at least two subtasks	Microsoft Word	3 years after award date
1.1	Letter Report, new input files	Microsoft Word	3.5 years after award date
1.2	Letter Report, new input files	Microsoft Word	3.5 years after award date
1.3	Letter Report, new input files	Microsoft Word	3 years after award date
1.4	Letter Report, new input files	Microsoft Word	3 years after award date
1.5 (optional)	Letter Report, new input files	Microsoft Word	1 year after option is exercised
1.6 (optional)	Letter Report, new input files	Microsoft Word	1 year after option is exercised
1.7 (optional	Letter Report, new input files	Microsoft Word	1 year after option is exercised

2 (optional)	Updated code documents, updated source code	LaTeX	1 year after option is exercised
3.1	Letter Report, new input file(s) if applicable	Word, .in	2 years after award date
3.2	Letter Report, new input file(s) if applicable	Word, .in	3.5 years after award date
3.3	Letter Report, new input file(s) if applicable	Word, .in	3.5 years after award date
3.4	Letter Report, new input file(s) if applicable	Word, .in	3.5 years after award date
4	Trip reports and conference presentations as agreed upon between PNNL and COR. Conference presentation, conference paper or technical journal article, as agreed upon by the COR.	Word, PowerPoint – as appropriate	To be determined based on selected conferences
5	Input files for each design	.in files	3.5 years after award date
6	Database of reports and data files	.pdf, Excel, Word	Continuous
7	Updated source code, associated QA documentation and Letter Report	Source Code, Word	2 years after award date
8	Letter Report	Word	1 year after award date
9	Letter Report	Word	2 years after award date

10 (optional)	Updated source code, associated QA documentation and Letter Report	Source Code, Word	2.5 years after award date
11.1	Updated source code, associated QA documentation and Letter Report	Source Code, Word	3 years after award date
11.2	Updated source code, associated QA documentation and Letter Report	Source Code, Word	2 years after award date
11.3	Updated source code, associated QA documentation and Letter Report	Source Code, Word	4 years after award date
12	Letter Report	Word	2 years after award date
13	Letter Report, new input file(s) if applicable	Word, .in	3.5 years after award date
14	Updated source code, associated QA documentation and Letter Report	Source Code, Word	2 years after award date
15	Remote accessible video files / Code Methodology Document	At discretion of the COR and compatible with standard browsers in the US, Europe and Asia / LaTeX	2 years after award date
16	Fast 1.x code version(s)	Source code	As necessary
16	Draft documentation for 1.x code version(s)	LaTeX	1 month before release of new code version(s)

16	Final documentation for 1.x code version(s)	LaTeX	Concurrent with release of new code version(s)
17	User Group reporting and updates	At discretion of contractor	Continuous
18	On-all assistance	MLSR	Continuous
19	Source code in new GitLab repository	At discretion of contractor	1/31/2020
20	Updated Software Quality Assurance Plan	Word	3.5 years after award
21 (optional)	On-call assistance	MLSR	Continuous if exercised
22 (optional)	Fast code version, Audit Report Input	Source Code, Word	As defined by licensing need
All	[Per SOW Section 8.1, Monthly Letter Status Reports (MLSRs) Acceptance Criteria: Report contains all required information]	[Microsoft Word or Adobe PDF]	[NLT than 20th of the following month]

5.0 KEY PERSONNEL AND LABOR CATEGORIES AND REQUIREMENTS

5.1 Labor Categories, Requirements and Key Personnel. Personnel working under this task order shall meet the minimum requirements for experience and education, as follows

Labor Category	**Position Minimum Requirements**	**Key Personnel* (yes or no)**
Senior Key Staff [redacted]	• Engineering degree • 10 or more years of experience in the modification and further development of the FRAPCON and FRAPTRAN source code,	*Yes*

	numeric resolution scheme, and code structure. • Demonstrated in-depth knowledge of the FRAPCON and FRAPTRAN models and their supporting database, as well as possession of such a database with the adequate QA in place. This includes knowledge and understanding of the assumptions, simplifications and rationale employed in the empirical models. • Demonstrated in-depth knowledge of the FRAPCON and FRAPTRAN validation database and its data sources, as well as possession of such a database with the adequate QA in place. • 10 or more years of experience using the FRAPCON and FRAPTRAN codes. • Demonstrated in-depth knowledge of nuclear fuel behaviour under steady-state and transient regimes, as well as during storage and transportation. • Proven knowledge and extensive experience in writing code language that conforms to the 2015 Fortran standard, including utilizing the functionality of modules, submodules, and class structures. • Knowledge and experience with LaTex, Perl, GNUPlot and GIT.	
Key Staff	• Engineering degree • 3 or more years of experience in the modification and further development of the FAST/FRAPCON/FRAPTRAN source code, numeric resolution scheme, and code structure. • Demonstrated knowledge of the FAST models and their supporting database. • 3 or more years of experience using the FAST/FRAPCON/FRAPTRAN codes.	*Yes*

	• Demonstrated knowledge of nuclear fuel behaviour under steady-state and transient regimes, as well as during storage and transportation. • Proven knowledge and experience in writing code language that conforms to the 2015 Fortran standard, including utilizing the functionality of modules, submodules, and class structures. • Knowledge and experience with LaTex, Perl, GNUPlot and GIT.	
Support Staff	Ability to distribute the FAST/FRAPCON/FRAPTRAN codes with NRC oversight. This includes expertise and authority to conduct both the export control and counterintelligence reviews required for distributing materials to foreign organizations.	*No*

6.0 CERTIFICATION AND LICENSE REQUIREMENTS

N/A

7.0 MEETINGS AND TRAVEL

A two-day trip to NRC, Rockville, MD by the principle investigator or other key person to participate in work-related meetings and to present the progress of the work. The NRC anticipates this meeting to occur each fiscal year.

One domestic trip to present papers at conferences are anticipated for each fiscal year. Domestic trips may include TOPFUEL and DOE/EPRI Advanced Fuel / Accident Tolerant Fuel Update meetings and the location will vary. Generally, the conferences are 3-4 days and require 5-6 travel days, depending on location. The PNNL staff who attends each conference shall be determined through discussion with the COR.

One to two foreign trips are anticipated each fiscal year. The PNNL staff who attends each conference shall be determined through discussion with the COR. The exact trips will be determined at the start of the fiscal year but will be one or two of the trips listed below. The selection of trips will vary based on the expected subject material of each conference in the given year:

- Studsvik Cladding Integrity Program (SCIP-IV) Program Review Meetings
    - Held twice per year in Sweden.

    - Meeting is typically 3 days. Including travel time, trip is 5-6 days.
- Light Water Reactor Fuel Performance Meeting
    - Held twice out of every 3 years (the third instance in a 3-year period occurs in the US as the TOPFUEL conference)
    - Location rotates between Europe and Asia
    - Meeting is typically 5 days. Including travel time, trip is 6-7 days.
- CABRI International Project (CIP) Meetings
    - Held once or twice per year in France.
    - Meeting is typically 3 days. Including travel time, trip is 5-6 days
- Fuel Safety Research Meeting (FSRM)
    - Held once per year in Japan.
    - Meeting is typically 3 days. Including travel time, trip is 5-6 days

All travel requires prior written approval from the COR.

PNNL will be authorized travel expenses consistent with the Federal Travel Regulation (FTR) and the limitation of funds specified for the travel within this agreement/order. All travel requires prior written approval from the COR.

Foreign travel for the servicing agency personnel requires a 60-day lead time for NRC approval. For prior approval of foreign travel, PNNL shall submit to the COR an NRC Form 445, "Request for Approval of Official Foreign Travel." All foreign travel requires prior written approval from the NRC Executive Director for Operations (EDO).

Travel will be reimbursed in accordance with FAR 31.205-46, "Travel costs" and the General Services Administration's Federal Travel Regulations at: http://www.gsa.gov/portal/content/104790.

No reactor side access is anticipated.

8.0 REPORTING REQUIREMENTS

PNNL is responsible for structuring the deliverables to current agency standards. PNNL must submit deliverables free of spelling and grammatical errors and shall conform to requirements stated in this section.

8.1 Monthly Letter Status Report (MLSR)

PNNL must provide a Monthly Letter Status Report which consists of a technical progress report and financial status report. This report will be used by the NRC to assess the adequacy of the resources utilized by the servicing agency to accomplish the work contained in this SOW and to provide status of PNNL progress in achieving tasks and producing deliverables. The report shall include agreement/order summary information, work completed during the specified period, milestone schedule information, problem identification and resolution, travel plans, and staff hour summary. Copies must be sent to the COR and AMD at ContractsPOT.Resource@nrc.gov.

9.0 REQUIRED MATERIALS, FACILITIES, HARDWARE/SOFTWARE

The following software shall be purchased by PNNL and used in the execution of this contract:

- Intel Parallel Studio XE 2018 (or newer) Professional Edition: $1,649 per license (Renewal) (http://softwarestore.ispfulfillment.com/Store/Product.aspx?skupart=I23SC9)
- Visual Studio Professional 2017 (or newer): $499 per license (Renewal) (https://www.visualstudio.com/products/how-to-buy-vs)

Other software purchases may be required to complete the tasks above. Any software purchases shall be approved by the COR prior to purchase.

PNNL shall provide the following materials, facilities, hardware, or software required for this agreement/order:

- FAST source code
- All working files and digitized capture of data (both experimental and calculated) associated with the FAST assessment databases. This shall also include a write-up of how the code assessments are performed and what file manipulations are required.
- All input files associated with the FAST assessment databases

10.0 APPLICABLE PUBLICATIONS (CURRENT EDITIONS)

The servicing agency shall comply with the following applicable regulations, publications, manuals, and local policies and procedures:

1. “FRAPCON/FRAPTRAN Programming Guidelines” - outlines the format and structure that all developers must follow when making any change to the source code.
2. FRAPCON/FRAPTRAN Code Maintenance Project Configuration Management and Maintenance Plan (CMMP), PNNL-17477 Rev. 1
3. FRAPCON/FRAPTRAN Software Quality Assurance Plan (SQAP) PNNL-17478 Rev.1

11.0 DATA RIGHTS

The NRC shall have unlimited rights to and ownership of all deliverables provided under this agreement/order, including reports, recommendations, briefings, work plans and all other deliverables. All documents and materials, to include the source codes of any software, produced under this agreement/order are the property of the NRC with all rights and privileges of ownership/copyright belonging exclusively to the NRC. These documents and materials may not be used or sold by PNNL without prior written authorization from the CO. All materials supplied to the NRC shall be the sole property of the NRC and may not be used for any other purpose. This right does not abrogate any other Government rights.