AMENDMENT OF SOLICITATION/MODIFICATION OF CONTRACT

1. CONTRACT ID CODE

2. AMENDMENT/MODIFICATION NO.	3. EFFECTIVE DATE	4. REQUISITION/PURCHASE REQ. NO.	5. PROJECT NO. (If applicable)
M0002	See Block 16C	RES-17-0295	

6. ISSUED BY CODE NRCHQ

US NRC - HQ
ACQUISITION MANAGEMENT DIVISION
MAIL STOP TWFN-5E03
ATTN ROB ROBINSON 301-415-0728
WASHINGTON DC 20555-0001

7. ADMINISTERED BY *(If other than Item 6)* CODE NRCHQ

US NRC - HQ
ACQUISITION MANAGEMENT DIVISION
MAIL STOP TWFN-5E03
WASHINGTON DC 20555-0001

8. NAME AND ADDRESS OF CONTRACTOR *(No., street, county, State and ZIP Code)*

PURDUE UNIVERSITY
401 SOUTH GRANT ST
WEST LAFAYETTE IN 479072024

CODE 072051394 FACILITY CODE

(x) 9A. AMENDMENT OF SOLICITATION NO.

9B. DATED *(SEE ITEM 11)*

x 10A. MODIFICATION OF CONTRACT/ORDER NO.
NRC-HQ-13-C-04-0022
NRC-HQ-60-16-T-0001

10B. DATED *(SEE ITEM 13)*
07/12/2016

11. THIS ITEM ONLY APPLIES TO AMENDMENTS OF SOLICITATIONS

☐ The above numbered solicitation is amended as set forth in Item 14. The hour and date specified for receipt of Offers ☐ is extended ☐ is not extended.
Offers must acknowledge receipt of this amendment prior to the hour and date specified in the solicitation or as amended, by one of the following methods: (a) By completing Items 8 and 15, and returning ____________ copies of the amendment; (b) By acknowledging receipt of this amendment on each copy of the offer submitted ; or (c) By separate letter or telegram which includes a reference to the solicitation and amendment numbers. FAILURE OF YOUR ACKNOWLEDGEMENT TO BE RECEIVED AT THE PLACE DESIGNATED FOR THE RECEIPT OF OFFERS PRIOR TO THE HOUR AND DATE SPECIFIED MAY RESULT IN REJECTION OF YOUR OFFER. If by virtue of this amendment you desire to change an offer already submitted , such change may be made by telegram or letter, provided each telegram or letter makes reference to the solicitation and this amendment, and is received prior to the opening hour and date specified.

12. ACCOUNTING AND APPROPRIATION DATA *(If required)*
See Schedule Net Increase: $44,106.00

13. THIS ITEM ONLY APPLIES TO MODIFICATION OF CONTRACTS/ORDERS. IT MODIFIES THE CONTRACT/ORDER NO. AS DESCRIBED IN ITEM 14.

CHECK ONE	
	A. THIS CHANGE ORDER IS ISSUED PURSUANT TO: *(Specify authority)* THE CHANGES SET FORTH IN ITEM 14 ARE MADE IN THE CONTRACT ORDER NO. IN ITEM 10A.
	B. THE ABOVE NUMBERED CONTRACT/ORDER IS MODIFIED TO REFLECT THE ADMINISTRATIVE CHANGES *(such as changes in paying office, appropriation date, etc.)* SET FORTH IN ITEM 14, PURSUANT TO THE AUTHORITY OF FAR 43.103(b).
	C. THIS SUPPLEMENTAL AGREEMENT IS ENTERED INTO PURSUANT TO AUTHORITY OF:
X	D. OTHER *(Specify type of modification and authority)* FAR 52.243-2 and FAR 52.232-22

E. IMPORTANT Contractor ☐ is not. ☒ is required to sign this document and return ____________ copies to the issuing office.

14. DESCRIPTION OF AMENDMENT/MODIFICATION *(Organized by UCF section headings, including solicitation/contract subject matter where feasible.)*

The purpose of this modification is to A) modify the statement of work to include additional work within the scope of the Task Order; B) Increase the total Task Order ceiling in the amount of $33,279.00, thus increasing the total ceiling amount from $173,827.00 to $207,106.00; C) Extend the period of performance end date from 7/11/2017 - 12/31/2017; and D) provide incremental funding in the amount of $44,106.00, thus increasing the total amount obligated from $163,000.00 to $207,106.00.

Accordingly, Section B: Clause, NRCB030A, is revised as follows:

NRCB030A CONSIDERATION AND OBLIGATION—COST-REIMBURSEMENT - NO FEE ALTERNATE I
(a) The total estimated cost to the Government for full performance under this contract is
Continued ...

Except as provided herein, all terms and conditions of the document referenced in Item 9 A or 10A, as heretofore changed, remains unchanged and in full force and effect.

15A. NAME AND TITLE OF SIGNER *(Type or print)*

16A. NAME AND TITLE OF CONTRACTING OFFICER *(Type or print)*
RICHARD W. ROBINSON

15B. CONTRACTOR/OFFEROR
(Signature of person authorized to sign)

15C. DATE SIGNED

16B. UNITED STATES OF AMERICA
[redacted]
(Signature of Contracting Officer)

16C. DATE SIGNED
07/19/2017

NAME OF OFFEROR OR CONTRACTOR
PURDUE UNIVERSITY

ITEM NO. (A)	SUPPLIES/SERVICES (B)	QUANTITY (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)
	$207,106.00. (b) The amount presently obligated by the Government with respect to this contract is $207,106.00. (c) It is estimated that the amount currently obligated will cover performance through December 31, 2017. (d) This is an incrementally-funded contract and FAR 52.232-22 – "Limitation of Funds" applies. Period of Performance: 7/12/2016 - 12/31/2017 (changed) Total Order Ceiling: $207,106.00 (changed) Total Obligated Amount: $207,106.00 (changed) See attached pages for additional information regarding this modification. NEW ACCOUNTING CODE ADDED: Account code: 2017-X0200-FEEBASED-60-60D003-60B301-1147-11-6-213-252A-11-6-213-1147 NEW ACCOUNTING CODE ADDED: Account code: 2017-C0200-FEEBASED-60-60D003-60B301-1147-11-6-213-252A-11-6-213-114 Period of Performance: 07/12/2016 to 12/31/2017				

SPECIFIC CHANGES REGARDING THIS MODIFICATION ARE AS FOLLOWS:

1. Section A.3 “COST/PRICE SCHEDULE” is deleted in its entirety and replaced with the following:

“**A.3 COST/PRICE SCHEDULE**

Period of Performance: July 12, 2016 – December 31, 2017

CLIN	LABOR CATEGORY	% LEVEL OF EFFORT	TOTAL
0001	[redacted]	[redacted]	[redacted]
0002	[redacted]	[redacted]	[redacted]
0003	[redacted]	[redacted]%	[redacted]
0004	[redacted])	[redacted]	[redacted]
0005	[redacted]		[redacted]
0006	[redacted]	[redacted]	[redacted]
0007	[redacted]	-	[redacted]
		GRAND TOTAL	**$207,106.00**

2. Section A.6 “Task/Delivery Order Period of Performance (SEP 2013) is deleted in its entirety and replaced with the following:

“**A.6 NRCF032 TASK/DELIVERY ORDER PERIOD OF PERFORMANCE (SEP 2013)**

This order shall commence on July 12, 2016 and will expire on December 31, 2017.”

3. The Statement of Work is deleted and replaced in its entirety with the following:

“**C.1 <u>Title of Project</u>**

Noncondensable Gas Transport in Piping Systems

This is a non-personal services contract/order to provide experimental data and reports on the noncondensible transport phenomena in piping systems.

C.2 <u>Background</u>

The USNRC's system thermal-hydraulic analysis code TRACE (<u>T</u>RAC <u>R</u>ELAP <u>A</u>dvanced <u>C</u>omputational <u>E</u>ngine) is in active development by the NRC to perform large and small break loss of coolant accident and system transient analyses for a wide range of nuclear plants. This code will be used as an audit tool to analyze transient and accident analyses submitted by the vendors and licensees. The phenomena of noncondensable sweepout will be the focus of this task order, which aims to produce experimental data that will be used to improve and assess the predictive models of the TRACE code. Improvement of the constitutive models in the

TRACE code has been identified as a high priority and is the primary mission of the Thermal Hydraulic Institute contract. This task order will focus on gas transport in piping systems which begin with a horizontal section in stratified two-phase flow and transition to a vertical section. (See Figure 1 below for a conceptual layout of sweeping in a pipe with two bends.) This configuration is common in most piping systems that contain slow-moving or stagnant liquid. As explained below, this experimental program has been designed to leverage existing experimental facilities and instrumentation.

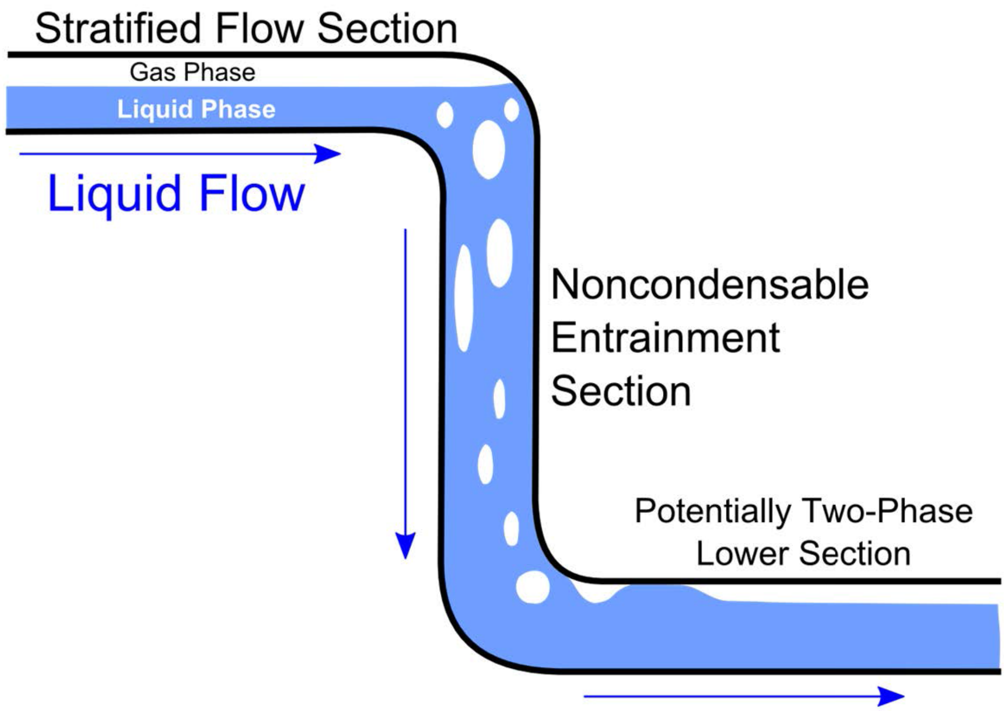

Figure 1. Conceptual model for noncondensable sweeping phenomena

The gas sweeping phenomena can be broken down into several parts. The first, as mentioned above, is horizontal stratified flow. In piping systems with flow that is either slow-moving or stationary, noncondensable gas can accumulate at the high points of the system. Often, this high point is the top of a horizontal section of pipe. When liquid flow in the system is increased, the behavior of the two-phase stratified mixture is a complex and important aspect of the thermal-hydraulics of the system. The configuration of the liquid surface and the relationship between the phases can affect the heat transfer, pressure drop, and indeed the transport of the noncondensable gas phase. TRACE considers several horizontal stratified flow regimes.

1) Stratified Smooth: this pattern only occurs at low liquid and gas velocities, the two phases flow separately with a relatively smooth interface.
2) Stratified Wavy: as the gas velocity is increased, the interface becomes disturbed by waves traveling in the direction of the flow.
3) Plug/Slug Flow: a further increase in the gas velocity causes the waves at the interface to bridge the channel and form a frothy slug that is propagated with a high velocity.
4) Annular/Dispersed: a still higher gas velocity results in the formation of a gas core with a liquid film around the periphery of the pipe. This regime is usually accompanied by the presence of entrained droplets due to the high gas velocity.

5) Dispersed Bubble: this flow pattern is similar to that of vertical flow; at low liquid velocities the gas bubbles tend to travel in the upper half of the pipe, whereas at high liquid velocities the bubbles are dispersed.

Not all of these horizontal flow regimes are explicitly considered by TRACE. The "dispersed bubble" and "annular/dispersed" regimes are treated by their vertical flow analogs, that is, by the bubbly/slug and annular/mist flow regimes. No special alterations to these regimes are made for differences that might occur in horizontal flow. The "stratified smooth" regime is explicitly considered and described by simple interfacial friction models. However, the other two regimes, "stratified wavy" and "plug/slug flow" are not explicitly considered but rather are treated as transition regimes that occur as the flow regime is transitioning from stratified flow to a non-stratified flow pattern.

As additional experimental data on horizontal stratified flow is accumulated, it may be become possible and desirable to replace or improve some of the existing stratified flow models in TRACE. For example, it may become practical to replace the “stratified wavy” and “plug/slug flow” regimes with explicit models based on the flow characteristics rather than simplified transition models. In addition, the experimental data in the current work will be used to assess current and future TRACE stratified flow models up to at least the “plug/slug flow” regime.

The next aspect of the gas sweeping phenomena that needs to be considered is the transport of the noncondensable gas downward into vertical pipe sections. This is arguably the most complicated aspect of the gas sweeping phenomena. The downward transport of the noncondensable gas is related to the Counter Current Flow Limitation (CCFL) phenomenon and the flooding phenomenon, but has some key differences.

Flooding is the situation in which the flow of a fluid in one direction is large enough to inhibit, partially or completely, the flow of a second fluid in the opposite direction and possibly cause a transition to unstable or cocurrent flow. Typically, a gas is flowing upward and a liquid is draining downward. The flow limitation is referred to as Countercurrent Flow Limitation (CCFL) and is experienced under a number of reactor conditions. The flooding phenomenon can prevent sufficient coolant flow into the reactor core or other reactor components.

The noncondensable entrainment that will be studied in the current experiments resembles the flooding phenomenon. However, instead of an upward flowing gas inhibiting the downward draining liquid, it is a downward flow of liquid that inhibits the upward flow of a gas. Recall that the flow configuration of interest is a horizontal section of pipe, starting in stratified flow, followed by a bend to a vertical section. In the sweeping scenario, the increasing flowrate of the liquid phase in the horizontal section imparts sufficient momentum via interfacial drag to the gas phase to start pulling it in the same direction. The resulting cocurrent flow results in the gas phase traveling downward with the liquid into the vertical section. The downward flow of the gas phase is in opposition to its otherwise upward buoyancy-driven flow.

The entrainment of the gas phase into the downward liquid flow is a complex and dynamic event. Often, there is substantial recirculation near the pipe bend that must be considered. The gas entrainment is also often accompanied by a kinematic shock front. Kinematic waves (or continuity waves) occur when the one-dimensional flow rate of some quantity depends on the "density" of that quantity. Here, the mixture density of the downward flowing two-phase mixture can vary considerably along the length of the pipe. A kinematic shock is characterized by the point where the mixture density changes abruptly, accompanied by a corresponding change in individual phase velocity.

Pipes are typically modeled in TRACE as a simplified 1-D component. The behavior of the two-phase flow structures are modeled using analytical models and correlations that do not fully consider the complex fluid dynamics phenomena like those described above. Improved models, based on experimental data like that obtained in the current study, will allow for a better global approximation of the flow dynamics within horizontal and vertical pipe sections containing noncondensable gas mixtures.

An example of the importance of understanding the noncondensable sweeping phenomena is the transport of gas pockets into the ECCS pumps of a PWR during emergency operation. The most significant impact of gas intrusion is on pump performance and operability. Gas intrusion into a pump can result in mechanical damage to the pump as well as loss in performance. The test facility that will be used to perform the current experiments is uniquely designed to study this specific process. The test facility incorporates a double-bend geometry: an initial horizontal section with a stagnant gas pocket is followed by a vertical downward section which then transitions again to a horizontal section representing the intake to a pump.

C.3 Objective

The objective of this contract is to perform noncondensable gas transport experiments in the existing double-bend gas transport test facility. The experiments will be performed with a range of pipe sizes, flowrates, and initial noncondensable gas volumes. Additionally, the experiments will be performed under quasi steady-state and adiabatic conditions. The data from these experiments will be used by the NRC to update and improve the gas transport predictive models of the TRACE code.

General requirements of the test facility and test matrix are as follows.

- Pipe diameters ranging from 4 inches to 12 inches (10.16 cm to 40.48 cm)
- Void fractions up to at least 20% in the upper horizontal pipe
- Atmospheric pressure
- Instrumentation for:
    - Liquid level and/or void fraction measurement in the upper horizontal pipe
    - Void fraction measurement in the vertical pipe
    - Void fraction measurement in the lower horizontal (pump inlet) section
    - Pressure drop over the horizontal stratified and vertical pipe sections
    - Visual observation (video) of the sweeping phenomena

Previous gas transport experiments have focused on the transient phenomena that occurs then the liquid phase is rapidly accelerated, sweeping the gas phase. However, because of the many possible transient conditions, it is impractical to replicate all of them. Therefore, in these experiments, the contractor shall concentrate on the quasi steady-state condition. This may be accomplished by gradually and slowly increasing the flowrate of the liquid phase until the onset of significant gas transport. It may also be necessary to maintain a gas flow into the horizontal section to maintain a level during the quasi steady-state experiments.

C.4 Scope of Work/Tasks

The contractor shall provide all resources necessary to accomplish the tasks and deliverables described in this Statement of Work (SOW). The contractor shall provide experimental data and reports on the noncondensable transport phenomena in piping systems.

Task 1: Test section design, instrumentation plan, and test matrix

Because the contractor will be using an existing test facility, there should be minimal modifications necessary to perform the required experiments. The first task will be for the contractor to prepare a design report that details the existing capabilities of the facility that are applicable to quasi steady-state and adiabatic experiments over a range of pipe sizes. The facility shall leverage existing instrumentation as much as practical and any new or modified instrumentation should be noted in particular. A proposed test matrix that encompasses the required range of test conditions will also be provided by the contractor.
Specific requirements are as follows.

Test Section Design and Instrumentation Plan

The contractor shall deliver a report that describes the test facility design and instrumentation plan for the gas transport experiments. The report shall detail the existing facility design and any modifications that will needed to accommodate the current experiments. The report shall discuss the instrumentation that will be used for the experiments, including all relevant ranges and uncertainties. The test facility shall be capable to performing experiments with the following characteristics.

- Pipe diameters ranging from 4 inches to 12 inches (10.16 cm to 40.48 cm)
- Instrumentation for:
    - Liquid level and/or void fraction measurement in the upper horizontal pipe
    - Void fraction measurement in the vertical pipe
    - Void fraction measurement in the lower horizontal (pump inlet) section
    - Pressure drop over the horizontal stratified pipe section
    - Pressure drop over the vertical pipe
    - Visual observation (video) of the sweeping phenomena, both for the behavior of the stratified flow in the upper horizontal section and the countercurrent/cocurrent behavior of the swept gas in the vertical section

The test section design and instrumentation plan shall be approved by the NRC before performance of the gas transport experiments.

Test Matrix

The contractor shall deliver a proposed test matrix for the gas transport experiments. The test matrix shall cover as much of the range of test conditions provided below as possible.

- Pipe diameters ranging from 4 inches to 12 inches (10.16 cm to 40.48 cm)
- Void fractions up to at least 20% (larger if possible) in the upper horizontal pipe
- Adiabatic
- Atmospheric pressure

- Flowrates sufficient for the entrainment of noncondensable gas into the vertical and lower horizontal pipe sections

The test matrix shall be approved by the NRC before performance of the gas transport experiments.

Deliverables	Level of Effort	Completion Date
Test Section Design and Instrumentation Plan	3 Staff Months	3 months after award
Test Matrix	0.5 Staff Months	3 months after award

The test section design and instrumentation plan and test matrix will be reviewed by the NRC before test section modificaitons are to be performed. The COR will approve or provide changes to the test matrix and plan within 15 days of delivery.

Task 2: Test Section Preparation

Based on the test section design and instrumentation plan, there may be some minor maintenance or modification necessary to perform the required experiments. In this task, the contractor shall perform any necessary preparation or modification of the test section and instrumentation as approved by the NRC. The contractor shall prepare a letter report detailing the results of these changes and any deviations from the test section design and instrumentation plan provided in Task 1.

Deliverables	Level of Effort	Completion Date
Letter report describing the preparation of the flow loop	3 Staff Month	6 months after award

The letter report will be reviewed by the NRC and the COR will provide comments, if any, within 30 days of delivery.

Task 3: Gas transport experiments

After the test section design and instrumentation plan and the test matrix have been approved by the NRC, the contract shall perform the gas transport experiments as determined by the approved test matrix. Upon conclusion of the experiments, the contractor shall prepare a data report on the results of the experiments. The data report shall summarize the results of the experimental tests and shall discuss any relevant trends and experimental limitations and problems. The report shall be accompanied by the experimental data.

The experimental data shall include:

- Void fraction and/or liquid level of the top horizontal pipe
- Void fraction measurements of the vertical pipe section
- Pressure drop measurements of the top horizontal and vertical pipe sections

- The liquid flowrate that results in the onset of noncondensable gas entrainment in the vertical section and/or carryover of gas into the lower pipe section
- Video of the stratified flow in the top horizontal pipe section
- Video of the noncondensable gas sweeping into the vertical pipe section

All electronic data shall be provided by external media purchased under contract and provided to the NRC by mail.

Deliverables	**Level of Effort**	**Completion Date**
Data report on noncondensable sweeping experiments	3 Staff Months	12 months after award
Experimental data in electronic format	3 Staff Months	12 months after award

The NRC will review the final report and deliverables and the COR will provide comments, if any, within 21 days from delivery. Any changes will be incorporated, by the contractor, into the final report.

Task 4: Model Development

Using the void fraction and pressure drop data generated in Task 3 of this Task Order, the contractor shall either select or develop an updated model for interfacial drag in pipes of the configuration tested. This shall include an analytical model for interfacial drag in the horizontal flow section, the downward-facing elbow, the downward vertical section, and (if the data supports it) the lower pipe elbow. The model shall cover the range of two-phase flow conditions in the test matrix and over the range of pipe diameters from 4 to 8 inches.

Prepare a draft and final letter report describing the proposed interfacial drag models for pipe flow undergoing the gas transport phenomena.

Deliverables	**Level of Effort**	**Completion Date**
Draft letter report on the interfacial drag models developed for pipes undergoing the gas transport phenomena	160 staff-hours	11/31/2017
Final letter report on the interfacial drag models developed for pipes undergoing the gas transport phenomena	24 staff-hours	12/31/2017

The Government will provide feedback on the draft letter report, if any, on the delivered reports within 2 weeks. The provided feedback shall be incorporated by the contractor into the final report by the end of the contract period.

C.5 Reporting Requirements

C.5.1 Monthly Letter Status Report (MLSR)

The contractor shall provide a Monthly Letter Status Report which consists of a technical progress report and financial status report. This report will be used by the Government to assess the adequacy of the resources proposed by the contractor to accomplish the work contained in this SOW and provide status of contractor progress in achieving tasks and producing deliverables. The report shall include contract/order summary information, work completed during the specified period, milestone schedule information, problem resolution, travel plans, and staff hour summary.

C.5.2 Intermediate and Final Reports

The contractor shall provide a two intermediate reports and one final report to the COR in electronic format. A test section design and instrumentation plan shall be delivered 3 months after contract award. A letter report detailing the test section describing the preparation of the flow loop shall be delivered 6 months following the contract award. A final report summarizing the work performed and the results and conclusions under this contract/order shall be delivered 12 months after award.

C.6 List of Deliverables

Section #	Deliverable	Due Date	Format	Submit to
C.5.1 MLSR	1 [Monthly Report]	20th of the following month	Word Document	CO/COR
C.4 Task 1	2 [Test Section Design and Instrumentatin Plan]	3 months after contract award	Word Document	COR
C4 Task 1	3 [Test Matrix]	3 months after contract award	Word/Excel or other	COR
C4 Task 2	4 [Letter report describing the preparation of the flow loop]	6 months after contract award	Word Document	COR
C4 Task 3	5 [Data report on noncondensable sweeping experiments]	12 months after contract award	Word Document	COR
C4 Task 3	6 [Experimental data in electronic format]	12 months after contract award	Various	COR
C4 Task 4	7 [Draft letter report on interfacial drag models]	11/31/17	Word Document	COR

C4 Task 4	8 [Final letter report on interfacial drag models]	12/31/17	Word Document	COR

C.7 <u>Required Materials, Facilities, Hardware/Software</u>

N/A

C.8 <u>Release of Publications</u>

Any documents generated by the contractor under this contract/order shall not be released for publication or dissemination without CO and COR prior written approval.

C.9 <u>Place of Performance</u>

The work to be performed under this contract/order will be primarily performed at Purdue University.

C.10 <u>Contractor Travel</u>

No contractor travel will be required for this contract.

C.11 <u>Data Rights</u>

The NRC shall have unlimited rights to and ownership of all deliverables provided under this contract/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 contract/order are the property of the Government with all rights and privileges of ownership/copyright belonging exclusively to the Government. These documents and materials may not be used or sold by the contractor without prior written authorization from the CO. All materials supplied to the Government shall be the sole property of the Government and may not be used for any other purpose. This right does not abrogate any other Government rights."

ALL OTHER TERMS AND CONDITIONS REMAIN UNCHANGED

[END of M0002]