ORDER FOR SUPPLIES OR SERVICES

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

BPA NO.

1. DATE OF ORDER: 9/25/06
2. CONTRACT NO. (If any): NRC-04-03-048
3. ORDER NO.: T010
   MODIFICATION NO.:
4. REQUISITION/REFERENCE NO.: RES-03-048
5. ISSUING OFFICE (Address correspondence to):
   U.S. Nuclear Regulatory Commission
   Division of Contracts
   Mail Stop: T-7-I-2
   Contract Management Branch 2
   Washington, DC 20555

6. SHIP TO:
   a. NAME OF CONSIGNEE: U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research
   b. STREET ADDRESS:
   c. CITY: Washington
   d. STATE: DC
   e. ZIP CODE: 20555
   f. SHIP VIA:

7. TO:
   a. NAME OF CONTRACTOR: PURDUE UNIVERSITY
   b. COMPANY NAME:
   c. STREET ADDRESS: SPONSORED PROGRAM SERVICES, 302 WOOD ST. (YOUNG HALL)
   d. CITY: W LAFAYETTE
   e. STATE: IN
   f. ZIP CODE: 479072108

8. TYPE OF ORDER
   - [ ] a. PURCHASE
     Reference your ____
     Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheet, if any, including delivery as indicated.
   - [X] b. DELIVERY
     Except for billing instructions on the reverse, this delivery/task order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA
   66015111205 Y6589 252A 31X0200.660
   FFS# RES-C06-383 OBLIGATE: $100,843.00

10. REQUISITIONING OFFICE: RES
    Ofc. of Nuclear Regulatory Research

11. BUSINESS CLASSIFICATION (Check appropriate box(es))
   - [ ] a. SMALL
   - [ ] b. OTHER THAN SMALL
   - [ ] c. DISADVANTAGED
   - [ ] g. SERVICE-DISABLED VETERAN-OWNED
   - [ ] d. WOMEN-OWNED
   - [ ] e. HUBZone
   - [ ] f. EMERGING SMALL BUSINESS

12. F.O.B. POINT: N/A

13. PLACE OF
   a. INSPECTION:
   b. ACCEPTANCE:

14. GOVERNMENT B/L NO.:

15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date): SEE TASK ORDER

16. DISCOUNT TERMS:

17. SCHEDULE (See reverse for Rejections)

ITEM NO. (A)	SUPPLIES OR SERVICES (B)	QUANTITY ORDERED (C)	UNIT (D)	UNIT PRICE (E)	AMOUNT (F)	QUANTITY ACCEPTED (G)
	DUNS: 072051394 ISSUANCE OF TASK ORDER NO. 010 UNDER NRC-04-03-048 TITLE: VOID FRACTION IN LARGE DIAMETER PIPES PERIOD OF PERFORMANCE: AWARD DATE THROUGH JUNE 30, 2007 TOTAL ESTIMATED REIMBURSABLE COSTS: $100,843.00 TOTAL OBLIGATED: $100,843.00 THIS TASK ORDER IS FULLY FUNDED. SEE ATTACHED PAGE 2 OF 2 FOR DESCRIPTION OF TASK ORDER					

18. SHIPPING POINT:
19. GROSS SHIPPING WEIGHT:
20. INVOICE NO.:

SEE BILLING INSTRUCTIONS ON REVERSE

21. MAIL INVOICE TO:
   a. NAME: U.S. Nuclear Regulatory Commission, Division of Contracts
   b. STREET ADDRESS (or P.O. Box): Mail Stop: T-7-I-2, Attn: NRC-04-03-048 Task Order No. 010
   c. CITY: Washington
   d. STATE: DC
   e. ZIP CODE: 20555

17(h) TOTAL (Cont. pages):
17(i). GRAND TOTAL: $100,843.00

22. UNITED STATES OF AMERICA BY (Signature): [signature]

23. NAME (Typed): Donald A. King
    TITLE: CONTRACTING/ORDERING OFFICER

In accordance with Section G.4, Task Order Procedures (OCT 1999), of contract number NRC-04-03-048, this definitizes Task Order No. 010. The effort shall be performed in accordance with the enclosed Statement of Work.

Task Order No. 010 shall be in effect from the date of award through June 30, 2007, with a total cost ceiling of $100,843.00, for the total estimated reimbursable costs under the task order. Funds in the amount of $100,843.00 are being obligated at this time, therefore, this task order is fully funded.

The following individual is considered to be essential to the successful performance of work hereunder: [redacted] The Contractor agrees that such personnel shall not be removed from the effort under the task order without compliance with Contract Clause H.2, Key Personnel.

The issuance of this task order does not amend any terms or conditions of the subject contract.

Your contacts during the course of this task order are:

Technical Matters:	Shawn Marshall Project Officer (301) 415-5861	Contractual Matters:	Michael Mills Contract Specialist (301) 415-6550

Acceptance of Task Order No. 010 should be made by having an official, authorized to bind your organization, execute three copies of this document in the space provided and return two copies to the Contract Specialist at the address below. You should retain the third copy for your records.

Enclosure: Statement of Work

ACCEPTED: NRC-04-03-048, Task Order No. 010

Rick Evans
NAME

Rick Evans
Assistant Director
TITLE

SEP 28 2006
DATE

STATEMENT OF WORK
TASK ORDER NO. 10
UNDER
CONTRACT NO. NRC-04-03-048

Task Order Title:	Void Fraction in Large Diameter Pipes
Contractor:	Purdue University
Site:	Purdue University
Principal Investigator:	M. Ishii (765-494-4587) lth@ecn.purdue.edu
Period of Performance:	Date of award through June 30, 2007
Total Level of Effort:	8 staff-months
NRC Project Officer:	Shawn Marshall, e-mail: som@nrc.gov
NRC Technical Monitor:	Joseph Kelly, e-mail: jmk1@nrc.gov

I. BACKGROUND

The USNRC's system thermal-hydraulic analysis code TRACE (TRAC RELAP Advanced Computational Engine) is being developed to provide a best-estimate accident analysis capability for both operating pressurized and boiling water reactors as well as the next generation of evolutionary water reactor designs. In partnership with the code development, a comprehensive code assessment activity has been initiated. Results from this assessment have identified a code modeling deficiency for the prediction of void fraction in large diameter pipes. Remediation of this code deficiency has a high priority due to its impact on calculations for the proposed ESBWR design.

In the ESBWR design, a tall chimney region exists above the reactor core to provide the gravity head necessary to drive the natural circulation two-phase flow through the core. For this chimney region, the TRACE code uses the same interfacial drag models as for 1-D vertical pipes. That is, for the bubbly/slug flow regime, the Kataoka-Ishii drift flux model for large diameter pipes is converted to an interfacial friction correlation. For the annular/mist flow regime, the Wallis annular flow interfacial friction model is used for the liquid film. When entrained droplets are predicted to exist, the drop volume fraction is estimated and the associated interfacial drag is added to that for the liquid film. For the transition region between these two regimes, TRACE uses a simple power-law weighting scheme to provide a continuous and smooth transition.

Two sources of data were identified to assess these models for hydraulic diameters of about the same size as the ESBWR chimney: pool data (Wilson & Carrier bubble rise tests) and the Ontario-Hydro transient upflow tests. In the assessment against the pool data, the TRACE code performed quite well up to void fractions of about 50-60%. This is not surprising as these tests were included in the data base used to develop the Kataoka-Ishii drift flux model. However, for the large pipe data, there were a few data points in the void fraction range 60-80% and for which TRACE significantly under-predicted the void fraction.

For the Ontario-Hydro transient upflow tests, two deficiencies were observed in the TRACE assessment calculation. First, similar to the predictions for the pool data mentioned above, the TRACE calculated void fractions compared well up to a value of about 50%. For higher void fractions, however, TRACE progressively began to under-predict the void fraction until for a data value of 78%, the TRACE calculated value was only 67%. To put this into perspective, this means that TRACE could over-predict the liquid inventory in the chimney region by 50% thereby providing a non-conservative initial condition for a LOCA analysis.

A second potential modeling deficiency was observed at the end of the Ontario-Hydro transient test as the mass flux was decreased and the quality approached 90%. In the data, the void fraction was reported to be near unity, whereas in the TRACE calculation, the value was only 80%. This would appear to indicate that TRACE significantly under-predicts the interfacial shear in the transition region between the bubbly/slug and annular/mist regimes. While this conclusion is consistent with the observation from the pool data comparisons, it is tentative due to the uncertain boundary conditions of the Ontario-Hydro tests for the high quality conditions.

In summary, assessment of the TRACE code has revealed a significant under-prediction for the void fraction in large diameter pipes in the transition region between the bubbly/slug and annular/mist regimes. While the existing data is sufficient to indicate the existence of a deficiency in the TRACE interfacial drag model, there is not enough data to permit the selection or development of a new model to address this deficiency. Consequently, this task is being put in place both to generate the needed data and to perform the model selection/development necessary to improve TRACE's ability to predict void fraction in large diameter pipes.

II. OBJECTIVES

This task will allow the contractor, Purdue University (PU), to collect two-phase flow data needed to address a modeling deficiency of the TRACE code for the prediction of void fraction in large diameter pipes. Further, this task includes a model development component to produce a model for ready inclusion in TRACE. The ability of TRACE to accurately predict two-phase flow behavior is essential in nearly any foreseeable audit calculations and in particular for the chimney region of the proposed ESBWR design. Specific objectives are:

1. To establish a database of void fraction measurements for both pool and upflow conditions for a wide range of pipe diameters and flow conditions using published data;
2. To augment this database with new air-water data that extends into the transition region between the bubbly/slug and annular/mist regimes;
3. To either select or develop a model for interfacial shear that significantly improves the ability of TRACE to predict void fraction in large diameter pipes.

III. WORK REQUIREMENTS

The work scope is as follows:

Task 1: Establish Void Fraction Database

Using published data for void fraction measurements in pipes for both pool and upflow conditions, assemble a database in electronic format that can be readily used to assess the accuracy of candidate interfacial drag models. In addition to the data itself, the database shall include all the information needed to simulate each test with the TRACE code. Furthermore, it shall be provided with a calculational tool that facilitates the testing of candidate correlations. For example, an acceptable electronic format would be an MS Excel workbook, with each individual test comprising a worksheet and including a Visual Basic module to calculate the void fraction using the experimental conditions and a user defined function for interfacial drag.

The format of this electronic database will be proposed by the contractor and is subject to approval by the NRC Project Officer.

Deliverables	Level of Effort	Completion Date
Data in electronic format.	2 Staff Months (10% PI, 90% graduate assistant)	6.0 months after task order award date

Task 2: Test Section Fabrication and Facility Modification

Design and fabricate two test sections for air-water void fraction experiments. The smaller diameter pipe test section shall have a diameter in the range of three to four inches. The larger diameter test section shall have an internal diameter of at least six inches. Both test sections shall include adequate instrumentation to measure both the area average void fraction at several elevations and the axial pressure drop at the elevations where the void fraction is measured. Instrumentation will also be provided to accurately specify the inlet and exit boundary conditions. Specifically, the inlet air and water flow rates, temperatures and pressure, and the exit pressure will be measured.

The air-water test facility will be modified to accept the new test sections. Water and air supplies shall be provided to enable operating conditions with mass fluxes from pool conditions to 1000 $kg/m^2/s$ and with void fractions up to 80%. A design and instrumentation review meeting shall be held with the NRC technical monitor prior to test section construction and facility modification.

Deliverables	Level of Effort	Completion Date
Two test sections	2 Staff Months (10% PI, 90% graduate assistant)	5.0 months after task order award date

Task 3: Generate Void Fraction Data

The contractor shall run air-water experiments to generate void fraction and pressure drop data for both the small and large pipe diameter test sections over a wide range of flow conditions. The test matrix shall include at least two pressure levels, mass fluxes ranging from pool conditions to 1000 $kg/m^2/s$ and void fractions up to 80%. The test matrix shall be proposed in a letter report and concurred upon by the NRC Project Officer.

Prepare a letter report detailing the facility and the instrumentation upon the completion of the task. Add the new data to the database generated in task #1 above.

Deliverables	Level of Effort	Completion Date
Letter report and data in electronic format	3 Staff Months (10% PI, 90% graduate assistant)	9.0 months after task order award date

Task 4: Interfacial Drag Model Development

Using the void fraction data base assembled in task #1 and the new air-water data generated in task #3, the contractor shall either select or develop a model for interfacial drag in vertical pipes for inclusion in the TRACE code. The proposed model must cover the entire void fraction range from bubbly flow to annular flow and be suitable for inclusion in a two-fluid model. Furthermore, the accuracy of the proposed model should be demonstrated to be equal to or superior to the existing TRACE model over all flow regimes and provide a substantial improvement in modeling performance for the transition regime.

Prepare a letter report detailing the proposed interfacial drag model for vertical pipes.

Deliverables	Level of Effort	Completion Date
Letter report.	1 Staff Months (10% PI, 90% graduate assistant)	9.0 months after task order award date

V. REPORTING REQUIREMENTS

As stated in the basic contract.

VI. DELIVERABLES AND DELIVERY SCHEDULE

Task 1: Database of published void fraction measurements delivered to the NRC in electronic format - 6.0 months after task order award date.

Task 2: Completion of two test sections fabricated to conduct experiments - 5.0 months after task order award date.

Task 3: Letter report documenting the air-water experiments along with the generated experimental data in electronic format - 9.0 months after task order award date.

Task 4: Letter report documenting the proposed interfacial drag model - 9.0 months after task order award date.

VII. MEETINGS AND TRAVEL

For domestic travel, the contractor is expected to attend a meeting at the NRC in Rockville, MD for research review. The trip will be of approximately two day's duration. All trips have to obtain approval from the NRC Project Officer in advance.

VIII. LEVEL OF EFFORT

9 staff months 10% PI and 90% graduate students

IX. PERIOD OF PERFORMANCE

The period of performance is from the award date through June 30, 2007.

X. TECHNICAL DIRECTION

As stated in the basic contract.

XI. PUBLICATIONS (IF APPLICABLE)

As stated in the basic contract.