ORDER FOR SUPPLIES OR SERVICES

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

BPA NO.

1. DATE OF ORDER: 09-04-2007

2. CONTRACT NO. (If any): **NRC-04-07-094**

3. ORDER NO.: **NRC TASK ORDER 002**

MODIFICATION NO.

4. REQUISITION/REFERENCE NO.: RES-07-094; RES-07-251 (FFS Commitment #)

5. ISSUING OFFICE (Address correspondence to):
U.S. Nuclear Regulatory Commission
Div. of Contracts
Attn: H. (Eddie) Colón, Jr.
Mail Stop T-7-I-2
Washington, DC 20555

6. SHIP TO:

a. NAME OF CONSIGNEE: U.S. Nuclear Regulatory Commission

b. STREET ADDRESS: Office of Nuclear Regulatory Research
Attn: Joseph M. Kelly Mail Stop: T10-K8

c. CITY: Washington

d. STATE: DC

e. ZIP CODE: 20555

f. SHIP VIA

7. TO:

a. NAME OF CONTRACTOR: PURDUE UNIVERSITY (DUNS #: 072051394)

b. COMPANY NAME: ATTN: KENNETH W. SUTER
YOUNG HALL

c. STREET ADDRESS: 302 WOOD STREET

d. CITY: WEST 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

☒ b. DELIVERY
Except for billing instructions on the reverse, this delivery 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: 76015111205 N6164 252A 31X0200.760

OBLIGATE: $70,000.00

10. REQUISITIONING OFFICE: RES
RES/DRASP/NRCA

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: Destination

13. PLACE OF
a. INSPECTION
b. ACCEPTANCE

14. GOVERNMENT B/L NO.

15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date): As stated in SOW

16. DISCOUNT TERMS: NET 30

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)
	TASK ORDER NO. 002 entitled "**INTERFACIAL AREA TRANSPORT IN ROD BUNDLES**", under ID/IQ Contract No. NRC-04-07-094 In accordance with Section G.4, Task Order Procedures, this action definitizes TASK ORDER NO. 002. This effort shall be performed in accordance with the Statement of Work (Enclosure 1) and the terms and conditions of Contract No. NRC-04-07-094. TASK ORDER NO. 002 shall be effective 09/04/2007 - 02/28/2010 with a total cost ceiling of $366,962.00. This order confirms the verbal authorization provided to PURDUE on 9/4/2007 to commence work under this effort, effective September 4, 2007, with a temporary Not-to-Exceed (NTE) amount of $70,000.00. Reference is made to your revised email proposal dated 8/27/07 in response to this effort.					

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
Div. of Contracts, Mail Stop T-7-I-2

b. STREET ADDRESS (or P.O. Box): Attn: (**NRC-04-07-094-T002**)

c. CITY: Washington

d. STATE: DC

e. ZIP CODE: 20555

17(h) TOTAL (Cont. pages)

17(i). GRAND TOTAL: NTE $366,962.00

22. UNITED STATES OF AMERICA BY (Signature)

23. NAME (Typed): Heriberto Colón, Jr.
Contracting Officer

TITLE: CONTRACTING/ORDERING OFFICER

ADDITIONAL TASK ORDER TERMS AND CONDITIONS

A.1 CONSIDERATION AND OBLIGATION--TASK ORDER

(a) The total estimated amount of this Task Order (ceiling) for the products/services ordered, delivered, and accepted under this contract is **$366,962.00**.

(b) The amount presently obligated with respect to this Task Order is **$70,000.00**. This obligated amount may be unilaterally increased from time to time by the Contracting Officer by written modification to this contract. The obligated amount shall, at no time, exceed the Task Order ceiling as specified in paragraph (a) above. When and if the amount(s) paid and payable to the Contractor hereunder shall equal the obligated amount, the Contractor shall not be obligated to continue performance of the work unless and until the Contracting Officer shall increase the amount obligated with respect to this contract. Any work undertaken by the Contractor in excess of the obligated amount specified above is done so at the Contractor's sole risk.

STATEMENT OF WORK FOR TASK ORDER NO. 002

CONTRACT NO. NRC-04-07-094 ENTITLED "THERMAL-HYDRAULIC EXPERIMENTAL AND MODEL DEVELOPMENT SUPPORT FOR TRACE"

Task Order No. 002 Title:	"Interfacial Area Transport in Rod Bundles"
Contractor:	Purdue University
Site:	Purdue University
Principal Investigator:	M. Ishii (765-494-4587) Ith@ecn.purdue.edu T. Hibiki (765-496-9033) hibiki@ecn.purdue.edu
NRC project Manager:	Joseph M. Kelly (301-415-6852) 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. To improve the numerical model for two-phase flow used by TRACE, the USNRC initiated the interfacial area transport (IAT) program. The primary focus of this task is the generation of IAT data and models specific to a rod bundle geometry. However, two other efforts have been piggy-backed onto this to allow for the generation of data for the assessment and improvement of current TRACE models for interfacial drag and two-phase pressure losses in rod bundles. Specifically, this task has three objectives: 1) generate the database and models for interfacial area transport in rod bundles, 2) generate high void fraction data for rod bundles (70-90%), and 3) generate data and models for two-phase loss coefficients at grid spacers. The background for each of these is presented below.

Large oscillations in the core void fraction were observed in calculations of advanced passive light water reactors (ALWRs), especially during the low pressure long-term cooling phase. These oscillations were numerical in nature and served to limit the accuracy as well as the credibility of the calculations. One of the root causes of these unphysical oscillations was determined to be flow regime transitions caused the usage of static flow regime maps (Kelly, 1996). To address this, the interfacial area transport program was initiated by the USNRC in a previous Thermal-Hydraulic Institute contract to develop a new approach for modeling two-phase flow that provides for the time and length scales over which flow regime transitions occur. Recently, the IAT program was endorsed by the thermal-hydraulic technical advisory group (TAG-T/H).

Previous research successfully developed the foundation of the interfacial area transport equation and the experimental techniques needed for the measurement of interfacial area, bubble diameters and velocities. An extensive database was then generated for adiabatic air-water conditions in vertical upward bubbly-slug flows in pipes. Using this database, mechanistic models for the creation (bubble breakup) and destruction (bubble coalescence) of interfacial area were developed for the bubbly-slug flow regime transition. Neither the effect of phase change nor complicated geometry transitions, such as occur in rod bundles with grid spacers, was included in these models.

Under the previous THI contract, an air/water two-phase flow rod bundle test loop was constructed and generation of the necessary database initiated. However, at the high flow conditions typical of the transition from the churn-turbulent to the annular flow regime, the acrylic rods used in the test section were subject to flow induced vibrations that limited the range of experimental conditions that could be realized. This task provides for rebuilding the rod bundle test section to withstand both higher flow rates and higher pressures so that the needed database can be completed. Then, models for the processes that govern the creation and destruction of interfacial area in a rod bundle will be developed.

The second area of investigation in this task is to generate a database for void fraction in rod bundles at high values (70-90%). Advanced boiling water reactor designs and power uprates have pushed the core exit void fraction for the high power assemblies into this range where limited data is available. This task will generate the data necessary to assess the current TRACE interfacial drag model for this regime, which corresponds to the transition from churn-turbulent to annular flow.

Finally, the third area of investigation is the development of a database for two-phase pressure losses at spacer grids. Currently, TRACE applies a single-phase loss coefficient to two-phase flow by applying it separately to each phase. This approach is ad hoc and has never been assessed for the pressure drop caused by spacer grids. The resulting modeling uncertainties may be inconsequential for conventional plants where large driving forces are available. However, for passively cooled plants, where the flows are driven by gravity induced pressure gradients, these two-phase losses may become appreciable. The necessary instrumentation for void fraction and pressure drop are available in the air-water rod bundle test facility. In addition to the generation of the database for IAT described above, two-phase grid spacer pressure drop data will be generated and used to assess the TRACE formulation.

II. OBJECTIVES

The primary objective of this Task Order is the generation of interfacial area transport data and models specific to a rod bundle geometry. Also, two other efforts have been piggy-backed onto this task to allow for the generation of data for the assessment and improvement of current TRACE models for interfacial drag and two-phase pressure losses. Specific objectives are:

1. To augment the existing rod bundle void fraction database with new air-water data that extends into the transition region between the bubbly/slug and annular/mist regimes;
2. To assess the TRACE interfacial drag model for rod bundles against this database;
3. To generate a database of grid spacer two-phase pressure losses suitable for the assessment of the current TRACE model or the development of a new model;
4. To generate an IAT database for rod bundle geometry that includes the effects of the grid spacers on the two-phase flow;
5. To improve the IAT model by developing sink and source term models for interfacial area concentration, and bubble drag models for upwards two-phase flow in rod bundles with grid spacers.

III. WORK REQUIREMENTS

Task 1: Test Section Fabrication and Shakedown Testing

The contractor shall fabricate, install and perform shakedown testing of a new rod bundle test section. The new test section shall be designed to withstand both flow induced vibrations at high flow rates and pressures up to 0.3 MPa. Furthermore, it should have approximately the same dimensions as the previous acrylic test section, have grid spacers with a prototypic flow area blockage ratio, be compatible with the current bubble injector system, and provide for non-uniform inlet air injection with at least two different zones.

Adequate instrumentation shall be provided to:

- Provide for the measurement of loop flow parameters: inlet air and water flow rates, inlet temperature, inlet and exit pressures.
- Provide for the measurement of bundle averaged void fractions up to values of 90%.
- Provide for the measurement of grid spacer two-phase pressure losses.
- Provide for the measurement of the IAT data (interfacial area, bubble diameter, bubble velocity, etc.) necessary to develop the models for interfacial area transport in a rod bundle with grid spacers.

The test section design and instrumentation plan shall be proposed by the contractor in a letter report and concurred upon by the NRC project manager. Shakedown tests shall be conducted to demonstrate the performance of the void fraction measurement system and to characterize the single-phase loss coefficients for the bundle and the grid spacers. The shakedown tests shall be documented in a letter report.

Deliverables	**Est. Completion Date**
Design & Instrumentation Plan.	1 month after award.
Letter report on shakedown tests.	6 months after award

Task 2: Void Fraction and Grid Loss Database

Perform experiments to augment the void fraction database generated in the previous THI contract with data from the new test section. This database will include the measurement of bundle average void fractions up to values of 90%. Concurrent with the void fraction measurements, the axial two-phase pressure losses shall be measured both for spans with and without grid spacers. Furthermore, experiments shall be conducted at two pressure levels and, to the degree possible, the range of mass flow rates investigated should encompass that of BWR operating conditions to nearly stagnant flow associated with boil-off conditions expected in a SBLOCA or during long term cooling in an advanced passive design. The test matrix shall be proposed by the contractor in a letter report and concurred upon by the NRC project manager.

Prepare a letter report describing the experimental results for both the void fraction and pressure drop measurements. Transmit the data to the NRC in an electronic format agreed to by the NRC project manager.

Deliverables	Est. Completion Date
Proposed test matrix.	6 months after award
Letter report and data in electronic format.	12 months after award

Task 3: Assessment of TRACE Interfacial Drag Models

The contractor shall assess the predictive capability of the TRACE code to calculate bundle average void fractions and two-phase grid pressure losses using the database generated in Task #2 above. This TRACE assessment shall be performed with a version of TRACE provided by the NRC project manager and shall use the AVScript tool. Results shall be compared to the experimental data and documented in a report written in Framemaker using a template to be provided by the Technical Monitor. All figures present in the Framemaker assessment report shall exist as separate files and be linked using the "import by reference feature" of Framemaker. Exceptions to this requirement, where it makes sense, shall be approved by the NRC TRACE code caretaker.

The development of all assessment input problems shall be accompanied by the development of a calculation notebook that justifies the use of every value provided in the model. For every value, the calculation notebook should answer the questions "what is it?", "why was it chosen?", "what did you have to assume?", "how was it calculated?", and/or "where did it come from?". The calculation notebook will be prepared in an electronic format using a template to be provided by the NRC.

A letter report shall be prepared documenting the results of this assessment. In addition, the calculation notebook, all of the TRACE input models and AVScripts necessary to repeat this assessment will be delivered to the NRC.

Deliverables	Est. Completion Date
Assessment report, calculation notebook, input models, and AVScripts.	14 months after award

Task 4: Generate Interfacial Area Transport Data

The contractor shall run air-water experiments to generate interfacial area concentration, bubble velocity, and bubble size data for the 8x8 rod bundle test section over a wide range of flow conditions. The test matrix shall include at least two pressure levels, mass fluxes ranging from pool conditions up to 1000 kg/m^2-s and void fractions up to 80%. The test matrix shall be proposed by the contractor in a letter report and concurred upon by the NRC project manager.

Add the new data to the database generated in the previous THI contract.

Deliverables	Est. Completion Date
Data in electronic format.	26 months after award

Task 5: Interfacial Area Transport Model Development

Using the interfacial area data generated in Task 4 of this Task Order, the contractor shall benchmark the existing interfacial area transport equation models. Using these results, the contractor shall identify the differences of bubble behavior between tubes and rod bundles and develop mechanistic models for interfacial area concentration source and sink terms, and bubble drag models for two-phase flow in rod bundles. The IAT models developed under this task shall be compatible with the two-phase flow model and numerical scheme employed by the TRACE code.

Prepare a final letter report describing the experimental results and detailing the proposed interfacial area and bubble drag models for rod bundles. The quality of this final report shall be such that it is suitable for publishing as a NUREG/CR.

Deliverables	Est. Completion Date
Final letter report.	28 months after award

IV. RESEARCH QUALITY

The quality of NRC research programs are assessed each year by the Advisory Committee on Reactor Safeguards. Within the context of their reviews of RES programs, the definition of quality research is based upon several major characteristics:

- Results meet the objectives (75% of overall score)
  - Justification of major assumptions (12%)
  - Soundness of technical approach and results (52%)
  - Uncertainties and sensitivities addressed (11%)

- Documentation of research results and methods is adequate (25% of overall score)
  - Clarity of presentation (16%)
  - Identification of major assumptions (9%)

It is the responsibility of the contractor to ensure that these quality criteria are adequately addressed throughout the course of the research that is performed. The NRC project manager and technical monitor will review all research products with these criteria in mind.

V. REPORTING REQUIREMENTS

1. Monthly Letter Status Report (MLSR)

   A MLSR should be submitted to the NRC Project Manager by the 20th of the month following the month to be reported with copies provided to the following:

   Project Manager/Technical Monitor (Joseph M. Kelly, Mail Stop T-10K08)
   Division Management Analyst, (Sharon Haggerty, Mail Stop T-10E50)
   Contracting Officer, (Heriberto Colón, Jr., Mail Stop T-712)

   The MLSR shall identify the title of the project, the job code, the Principal Investigator, the period of performance, the reporting period, summarize each month's technical progress, list monthly spending, total spending to date, and the remaining funds. Any administrative or technical difficulties which may affect the schedule or costs of the project shall be immediately brought to the attention of the NRC project manager.

VI. DELIVERABLES AND DELIVERY SCHEDULE

1. Letter report on the test section design and instrumentation plan to be delivered one month after the award date.

2. Letter report on the shakedown tests to be delivered six months after the award date.

3. Letter report on the proposed test matrix to be delivered six months after the award date.

4. Letter report describing the experimental results for both the void fraction and pressure drop measurements from Task #2 and the data in an electronic format agreed to by the NRC project manager to be delivered 12 months after the award date.

5. Assessment report on TRACE interfacial drag models, calculation notebook, test input models and AVScripts, to be delivered 14 months after the award date.

6. Interfacial area transport data generated under Task #4 in an electronic format agreed to by the NRC project manager to be delivered 26 months after the award date.

7. Final letter report describing the interfacial area transport data and detailing the proposed interfacial area and bubble drag models for rod bundles with grid spacers to be delivered 28 months after the award date.

VII. MEETINGS AND TRAVEL REQUIREMENTS

For domestic travel, the contractor is expected to attend an annual meeting at the NRC in Rockville, MD, for research review and a national conference. The trips will be of approximately two days duration. All trips have to obtain approval from the NRC project manager in advance.

VIII. TECHNICAL DIRECTION

Technical direction will be provided by the Project Manager (Joseph M. Kelly), who can be reached at:

> U.S. Nuclear Regulatory Commission
> Mail Stop: (T-10K08)
> Washington, D.C. 20555-0001
> Phone: (301) 415-6852
> Fax: (301) 415-5160
> Email: (jmk1@nrc.gov)

IX. NRC Furnished Material

The NRC project manager will furnish a version of the TRACE code to perform the assessment called for in Task #3. The NRC project manager will also provide a Framemaker template to be used to document the assessment results and for the calculation notebook.

References

1) J.M. Kelly, 1996, "Thermal-Hydraulic Modeling Needs for Passive Reactors," *OECD/CSNI Specialist Meeting on Transient Thermal-Hydraulic and Neutronic Codes Requirements*, Annapolis, MD.