March 13, 1998

FOR: The Commissioners

FROM: L. Joseph Callan /s/
Executive Director for Operations

SUBJECT: STATUS OF NRC RESEARCH CONDUCTED BY THE RUSSIAN RESEARCH CENTER (I.V. KURCHATOV INSTITUTE) AND THE INSTITUTE OF NUCLEAR SAFETY OF THE RUSSIAN ACADEMY OF SCIENCES

PURPOSE:

To inform the Commission of the progress made in 1997 on research sponsored by the NRC at the Russian Research Center (the I.V. Kurchatov Institute) and the Institute of Nuclear Safety of the Russian Academy of Sciences. Also, to inform the Commission of the staff's plan to continue these arrangements in 1998 provided that research results continue to be of value to the NRC and that measurable progress is being made. We will inform the Commission annually of these programs.

SUMMARY:

For the past several years, the Russian Research Center and the Russian Academy of Sciences have performed research work for the NRC under bilateral agreements. This work is funded by the Office of Nuclear Regulatory Research and has involved research in code development and assessment, hydrogen combustion experiments, evaluation of high burnup fuel test data,

in-vessel debris coolability experiments, evaluation of reactor pressure vessel surveillance capsule data, uncertainty analysis and development of concrete containment failure criteria. The results of this work have led to code improvements, expanded databases and confirmatory research information. This work has also helped the Russians become familiar with USNRC analytical tools, safety issues and Western approaches to safety. It is intended to continue these programs in 1998, although at a much reduced level from that in 1997. The proposed agreements for the 1998 work are attached to this paper.

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BACKGROUND:

In SECY-91-375, "Proposed Arrangement with the I.V. Kurchatov Institute for Atomic Energy of the U.S.S.R. on Severe Accident Experiments," SECY-92-015, SECY-93-350, SECY-95-021, SECY-96-036, and SECY-97-050, "Status of NRC Research... Sciences," the staff provided descriptions of the NRC research programs being conducted in Russia and recommended to the Commission that continued research cooperation between the NRC and the Russian Research Center and the Institute of Nuclear Safety of the Russian Academy of Sciences was in the best interest of the NRC. The Commission endorsed the staff recommendation.

Currently, the work being performed for the NRC by the Russian Research Center is described in the Implementing Agreement on Severe Accident Research between the USNRC and the Russian Research Center (RRC). A copy of Addendum 1 to this Implementing Agreement describing the work in 1997 was enclosed with SECY-97-050. The 1997 work covered by the Addendum consisted of:

- Model development, calculations and experiments on hydrogen combustion
- Evaluation of high burnup fuel test data
- Investigation of mechanisms for in-vessel cooling of molten core debris

The FY 1997 cost to the NRC for this work specified in the Addendum was $400K. In accordance with the Agreement, this was supplemented in August 1997 with another $50K based upon successful demonstration of a 3D reactor physics code (BARS) capable of pin-by-pin steady state and transient analysis and submittal of an acceptable proposal for follow on work to assess and validate the code.

The work being performed for the NRC by the Institute of Nuclear Safety is described in the Implementing Agreement on the Development and Application of Nuclear Safety Analysis Codes between the USNRC and the Institute of Nuclear Safety of the Russian Academy of Sciences (RAS). A copy of Addendum 2 to this Implementing Agreement describing the work in 1997 was also enclosed with SECY-97-050. The 1997 work covered by the Addendum consisted of:

- Model development and assessment for NRC severe accident codes
- Development of concrete containment failure criteria
- PRA uncertainty analysis
- Enhancement of the data base and assessment of NRC thermal-hydraulic codes

The FY 1997 cost to the NRC for this work was $520K.

DISCUSSION:

Discussed below is a summary of the work done in 1997 under the Implementing Agreements and our plans for continuing work in 1998. Attached to this paper are a proposed Addendum 2 to the existing Implementing Agreement covering the 1998 work at the RRC and a proposed Addendum 3 to the existing Implementing Agreement with the RAS covering their 1998 work.

WORK AT THE RRC

Work Completed in 1997

**Hydrogen Behavior**

During 1997, the RRC continued to conduct experiments on hydrogen combustion to provide data on the potential for hydrogen detonation by deflagration to detonation transition (DDT). Eleven tests (which include three preliminary scoping tests) were conducted in the large scale (480 $M^3$ volume) RUT facility to investigate the combustion behavior of hydrogen, air, steam mixtures at elevated temperatures. The findings from these large scale experiments are being used to confirm hydrogen ignitor location and separation criteria and to assess the potential for deflagration to detonation transition in an environment where initial non-uniform hydrogen and steam concentrations exist. These tests were jointly funded by NRC, IPSN (France), and FZK (Germany) with the U.S. contribution being one-third of the total.

**High Burnup Fuel**

Experimental work and data assessment were completed on the IGR test reactor program on reactivity accidents. This work was jointly funded by the NRC and IPSN (France) with the U.S. contribution being one-half of the total. A paper titled "Results of Reactor Tests to Investigate VVER Fuel Element Behavior Under RIA Conditions" was published in the journal, *Nuclear Safety*. Additional work was undertaken in three related areas:

(1) Transient fuel rod analysis for the IGR-tested rods

The NRC's FRAP-T6 fuel rod transient code was used for these analyses and certain models required modification for the stagnant testing conditions in IGR and the Russian Zr-Nb cladding material. Both of these modeling efforts have direct applicability to our work.

(2) 3-D neutronic analysis of plant transients

The BARS kinetics code, which was developed in Russia for analysis of Chernobyl, has been modified for VVERs and LWRs and is being coupled to our RELAP5/MOD3 plant transient code. Validation and development work was done for the code package, and applications for analyses of interest to the NRC will be done next year (see below).

(3) Mechanical properties of high burn up cladding

A round-robin testing exercise was conducted with Argonne National Laboratory (for the NRC) and the Cadarache Center for Nuclear Studies (for the French IPSN) to investigate the effects of variations in testing methods. A series of tests was made on irradiated and unirradiated VVER cladding and reported at the NRC's 25th Water Reactor Safety Information Meeting. A large reference document on mechanical properties of zirconium-niobium alloys was made available to the NRC and has been translated. Efforts are being made to get permission to release this document to the U.S. industry. Zirconium-niobium alloys are being used in new cladding types in the U.S.

**In-vessel Cooling Mechanisms**

During 1997, RRC continued to experimentally measure the thermal resistance in an initially water-filled gap between a solid ceramic crust (simulating core debris) and the reactor vessel (RV) wall. The purpose of these tests is to obtain experimental data on the ability of steam filled gaps between core debris and the reactor vessel wall to remove sufficient heat to maintain RV integrity under high pressure severe accident conditions.

Work Planned for 1998

Attachment I to this paper describes the work planned in 1998 at the RRC. Due to funding constraints it is limited to the areas of high burnup fuel and 3D reactor physics. This work is summarized below:

**High Burnup Fuel**

Based on results of the round-robin tests performed in 1997, improved mechanical properties tests are to be performed on VVER cladding for

temperatures and strain rates applicable to reactivity accidents and loss-of-coolant accidents.

### 3D Reactor Physics

Calculations for a reactivity accident are to be performed using Three Mile Island Unit-1 data with the BARS 3D kinetics code to investigate local variations that cannot be resolved with our present codes. In addition, the BARS code is to be converted to use ENDFB nuclear cross-section data from the U.S.

WORK AT THE RUSSIAN ACADEMY OF SCIENCES (RAS)

Work Completed in 1997

### Model Development for NRC Severe Accident Codes

The RAS has been providing model development and code assessment for NRC's severe accident code, SCDAP/RELAP5. In particular, the RAS has been working on implementation and assessment of improved core degradation models in the code. Specific activities accomplished in 1997 include completion of the development and testing of the following four improved models:

- $UO_2/Zr/ZrO_2$ steam interaction
- fuel/clad candling
- $Zr/UO_2$ dissolution
- cladding mechanical behavior

In addition, a report on the sensitivity of SCDAP/RELAP results to various input parameters and models was completed to help in the prioritization of future work on SCDAP/RELAP. Also, a report on RAS views on the VICTORIA (fission product code) peer review recommendations was completed.

### PRA Uncertainty Analysis

A final report comparing PRA uncertainty techniques used in NUREG-1150 "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants" (using station blackout as an example) versus a RAS developed technique (that accounts for additional factors contributing to the uncertainty) was produced and is currently under review by the staff.

### Development of Concrete Containment Failure Criteria

The purpose of this work was to develop a containment fragility curve for the Kalinin nuclear power plant to be used in the PRA being conducted under Lisbon Initiative-Priority 8. A final report and fragility curve was produced.

### NRC Thermal-Hydraulic Code - Data and Assessment

The objective of this work was to assess the adequacy of the RELAP5 hydrodynamic heat and mass transfer models in low flow regimes and for horizontal tube bundles using Russian experimental data. In effect, this expands the assessment data base for RELAP5 to include data and conditions that were not available in the U.S. and not considered in previous assessments.

In 1997, work continued on utilizing Russian data to assess the RELAP5 code. Three reports were completed in 1997. The first report, "RELAP5 MOD3.2 Assessment Against Loop Seal Clearing Experimental Data," describes the code prediction of experimental data from small and full scale test facilities. The results of calculations for the full scale facilities agree better with the experimental data than those for the small scale test facility. The second report, "RELAP5 MOD3.2 Assessment Against CKTI Flooding Tests in Vertical Tubes," describes the comparison of Wallis and CKTI flooding correlations based on air-water and steam-water data of counter current flow in vertical tubes. The comparison revealed that the CKTI correlation has a much wider range of application than the Wallis correlation.

The third report, "Assessment of RELAP5 MOD3.2 on Experimental Data of Water Level Behavior in VVER-440 Steam Generator in Transient Regimes with Six MCP Tripping and Stopped Feed Water on KOLA NPP," describes the code capability to simulate mass and heat transfer using plant data obtained during two reactor transients. The results of the comparison showed that the RELAP5 code describes flows, pressure, temperature, and collapsed water level in the pressurizer and steam generators within the experimental uncertainty.

Work Planned for 1998

Attachment II to this paper describes the work planned in 1998 at the RAS. The level of work is greatly reduced from that in 1997 due to budget reductions. This work is summarized below:

**Model Implementation for NRC Severe Accident Codes**

Work is planned to implement into the SCDAP/RELAP code the four models developed and tested in 1997, as described above.

Additional work will be considered within the framework of the Agreement provided it is of value to the NRC and can be accommodated within budget constraints. IBRAE is to make a proposal regarding additional work in the following areas:

1) Methods to calculate thermal-hydraulic code uncertainty.
2) Defining interface requirements to couple the consolidated thermal-hydraulic code to a severe accident code, e.g., SCDAP. This activity would involve separating the SCDAP modules from the RELAP5 modules.
3) Feasibility study to consolidate the FRAPTRAN and FRAPCON codes into a single code.
4) Assessing the use of different numerical schemes, e.g., high order differencing and fully implicit schemes, in the NRC consolidated thermal-hydraulic code.
5) Application of containment and uncertainty work to other areas.

Once proposals are received, and reviewed, we may approve additional work in accordance with this agreement provided it provides substantial benefit for the funds expended.

CONCLUSION:

Given the progress to date on the ongoing programs and the expectation that the 1998 work described above can be successfully carried out, we believe that it is in the best interest of the NRC to continue our agreements with the RRC and the RAS. The proposed Addendum 2 to the Agreement with RRC and the proposed Addendum 3 to the Agreement with the RAS are attached for information. I intend to forward these to the RRC and RAS for signature.

RESOURCES:

The cost to the NRC in FY 1998 of the research summarized above would be $200K for the RRC and $20K for the RAS. These costs do not include the cost of travel, which will be paid for by the RRC and RAS or by NRC through invitational travel. Funds for this research work are in the FY 1998 RES budget. Additional funds for any follow-on research work would be provided separately.

COORDINATION:

This paper has been coordinated with the Office of the Chief Financial Officer, which has no resource objection, and the Office of the General Counsel, which has no legal objection.

I will continue to keep the Commission informed of progress on the NRC sponsored research at the RRC and the RAS.

L. Joseph Callan
Executive Director for Operations

Attachments: I. Addendum 2 to the Agreement with RRC
II. Addendum 3 to the Agreement with RAS

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ATTACHMENT I

ADDENDUM 2 TO THE IMPLEMENTING AGREEMENT
BETWEEN
THE UNITED STATES NUCLEAR REGULATORY COMMISSION (USNRC)
AND
THE RUSSIAN RESEARCH CENTER (RRC)
FORMERLY THE I.V. KURCHATOV INSTITUTE FOR ATOMIC ENERGY (IAE)
ON SEVERE ACCIDENT RESEARCH

Considering that,

1. In accordance with Article VII, D of the Implementing Agreement on Severe Accident Research between the United States Nuclear Regulatory Commission and the Russian Research Center (hereinafter referred to as the Implementing Agreement), the parties have agreed to this Addendum to the Implementing Agreement.

2. The USNRC and RRC have cooperated in the field of severe accident research under a five year Implementing Agreement signed on February 23, 1996.

3. The RRC has performed extensive research in the area of hydrogen combustion and detonation at conditions representative of severe reactor accident, analysis and examination of high burnup fuel experiments, measurement of gap conductance representative of severe accident conditions and annealing of reactor pressure vessel steels. The USNRC and RRC are presently cooperating in this research program under Addendum 1 of the Implementing Agreement.

ARTICLE I - PROGRAM COOPERATION

The cooperative program includes (1) evaluating data and analyzing the results of tests in the IGR reactor on high burnup fuel, and (2) developing and demonstrating a 3D reactor transient physics code. The NRC program will consist of technical assistance and cash contributions to permit defraying some of the cost of conducting the above described program.

ARTICLE II - SCOPE OF THE ADDENDUM

A. USNRC Scope of Responsibility

The USNRC shall provide over the duration of this Addendum the following specified goods and services related to nuclear reactor severe accident research:

1. Limited technical assistance and advice will be provided during the conduct of the high burnup fuel and reactor physics evaluation programs; the extent of such assistance to be mutually agreed to prior to the start of the program.
2. Financial Support - Subject to the availability of funds, the NRC will provide to RRC the sum of $200K in FY98. The RRC will provide a detailed work plan on the research to be conducted and the expected completion dates. The funds will be used to conduct the necessary analyses to define the experiments and to defray some of the costs associated with: (1) evaluating high burnup fuel test data, and (2) developing and demonstrating 3D transient reactor physics capability. $150K will be designated for the high burnup fuel evaluations and $50K for the reactor physics work.

   A work plan acceptable to both sides describing the work in items II.B.1 and II.B.2 should be completed and agreed to within 60 days after signature of this Addendum. Upon USNRC approval of the workplan and receipt of RRC invoices, payments will be made as follows, subject to U.S. government rules and regulations:

   - $100,000 U.S. dollars upon approval of the work plan,
   - $100,000 U.S. dollars in July 1998.

B. RRC Scope of Responsibility

The RRC shall provide over the duration of this Addendum the following specific goods and services:

1. High Burnup Fuel - The RRC is to complete the analysis of IGR test data and to initiate related follow up work:

   Work in 1998 is organized in 3 tasks:

   - Complete all work on the data reports describing 1996 and 1997 IGR test reactor results and publish the reports.
   - Prepare a report on modification to NRC's FRAP-T6 for analysis of Zr-1%Nb clad fuel.
   - Perform improved and expanded mechanical properties tests on irradiated Zr-1%Nb cladding under conditions applicable to RIA and LOCA.

2. Reactor Neutronic Code - The RRC is to complete development of the BARS 3D reactor physics code and perform specified analyses:

   Work in 1998 is organized into 3 tasks:

   - Convert the BARS code to use ENDFB data files and assess the code against suitable benchmarks.
   - Perform plant calculations for TMI-1 using the BARS code for a reactivity insertion accident and compare results with U.S. (TRACM/PARCS calculations at BNL) and French calculations.
   - Perform plant calculations for TMI-1 using the BARS code for a steam-line break accident and compare results with USNRC calculations for an OECD standard problem.

   The cost of this work is to be shared equally between France (IPSN) and the USNRC. The cost specified in this Addendum is for the USNRC portion only.

3. Reporting and Meetings - The RRC will prepare quarterly technical and financial status reports for all programs, and provide final technical reports for each program at the completion of the work described in this Addendum. Periodic technical meetings may be called for by either party to discuss programmatic or technical issues that might arise during the duration of the program described here.
4. Audit and Record Requirements - The RRC shall maintain complete accounting records of all funds provide to it by the USNRC under this Addendum in accordance with accounting principles generally accepted in the Russian Federation. The accounting records shall be maintained for a period of no less than three years after the expiration of this Addendum. The USNRC, or other authorized U.S. Government officials, shall have full access to the accounting record for the purposes of financial audit during the period of this Addendum and, after its expiration, for a period of no less than three years.

III. FINAL PROVISIONS

Duration and Termination - The work described in this Addendum shall begin upon signature by the parties and is expected to be completed on or before December 31, 1998. The work described in this Addendum may be terminated by mutual consent or by either party's withdrawing from the present Implementing Agreement after providing the other party written notice 6 months prior to its intended date of withdrawal.

All terms and conditions of the Implementing Agreement will apply to this Addendum. The parties further agree to modify or extend the activities described in this Addendum within the intended scope of this Addendum upon written agreement of its Administrators.

In witness whereof this Agreement has been entered into the day and year last written.

**FOR THE UNITED STATES NUCLEAR REGULATORY COMMISSION**

BY: _____

L. JOSEPH CALLAN

TITLE: _____

Executive Director for Operations

DATE: _____

PLACE: Rockville, Maryland, USA

**FOR THE RUSSIAN RESEARCH CENTER (RRC), FORMERLY THE I.V. KURCHATOV INSTITUTE OF ATOMIC ENERGY**

BY: _____

VLADIMIR ASMOLOV

TITLE: DIRECTOR FOR RESEARCH AND DEVELOPMENT

DATE: _____

PLACE: _____

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ATTACHMENT II

ADDENDUM 3 TO THE IMPLEMENTING
AGREEMENT ON THE DEVELOPMENT AND
APPLICATION OF NUCLEAR SAFETY ANALYSIS CODES
BETWEEN
THE UNITED STATES NUCLEAR REGULATORY COMMISSION (USNRC)
AND
THE NUCLEAR SAFETY INSTITUTE (IBRAE)
OF THE RUSSIAN ACADEMY OF SCIENCES (RAS)

Considering that,

1. In accordance with Article VII.D of the Implementing Agreement on the Development and Application of Nuclear Safety Analysis Codes between the United States Nuclear Regulatory Commission and the Nuclear Safety Institute of the Russian Academy of Sciences (hereafter referred to as the Implementing Agreement), the parties have agreed to this Addendum to the Implementing Agreement.
2. The USNRC and IBRAE/RAS have cooperated in the field of nuclear safety analysis codes under a five year Implementing Agreement signed on January 31, 1995.
3. The IBRAE/RAS has performed extensive research in the areas of model development for NRC severe accident codes, the development of probabilistic risk assessment techniques, the development of containment failure criteria and thermal-hydraulic code model assessment and validation. The USNRC and IBRAE/RAS are presently cooperating in this research program under the original Agreement.

ARTICLE I - PROGRAM COOPERATION

The cooperative program includes (1) implementation of improved models for NRC severe accident codes, (2) thermal-hydraulic code model assessment and validation, (3) application of probabilistic risk assessment techniques, and (4) refinement of containment failure criteria. The USNRC program will consist of technical assistance and cash contributions to permit defraying some of the cost of conducting the above described program.

ARTICLE II - SCOPE OF THE ADDENDUM

A. USNRC Scope of Responsibility

The USNRC shall provide over the duration of this Addendum the following specified goods and services related to code and analysis research:

1. Limited technical assistance and advice will be provided during the code model and analytical methods development; the extent of such assistance to be mutually agreed to prior to the start of the program.

2. Financial Support - Subject to the availability of funds, the USNRC will provide to IBRAE/RAS the sum of $20K in FY98. The IBRAE/RAS will provide a detailed work plan on the research to be conducted and the expected completion dates. The funds will be used to implement into SCDAP/RELAP

IBRAE/RAS developed computer code models.

A work plan acceptable to both sides describing the work in item II.B.1a below, should be completed and agreed to within 60 days after signature of this Addendum. Upon NRC approval of the workplan and receipt of an IBRAE/RAS invoice, payment will be made as follows, subject to U.S. government rules and regulations:

$20,000 U.S. dollars upon approval of the workplan

Subject to availability, additional funds may be provided for the work described below in II.B.1.b, II.B.2, I.B.3 and II.B.4, subject to NRC review and approval of a detailed work plan.

B. IBRAE/RAS Scope of Responsibility

The IBRAE/RAS shall provide over the duration of this Addendum the following specific goods and services related to code modelling, analysis methods development and application:

1. Model Development and Application for NRC Severe Accident Codes

a. Implement the following improved models into the SCDAP/RELAP code:

- $U0_2/Zr/Zr0_2$ steam interaction
- fuel/clad candling
- $Zr/U0_2$ dissolution
- cladding mechanical behavior

b. Additional funding for model development, assessment and implementation may be provided based on the results of 1(a) above or upon NRC review of other severe accident code work completed in 1997 (i.e., VICTORIA review and SCDAP/RELAP sensitivity study).

2. Thermal-Hydraulic Code Assessment and Validation

Based upon NRC review of work completed in 1997 on the assessment of RELAP, additional funding may be provided to extend the assessment to cover additional data or improve RELAP calculational techniques.

3. Application of Probabilistic Risk Assessment Techniques

Based upon NRC review of work completed in 1997 on the development of a technique to model various sources of uncertainty in probabilistic risk assessment, additional funding may be provided to extend this technique to areas where uncertainties need more complete assessment.

4. Refinement of Containment Failure Criteria

Based upon NRC review of work completed in 1997 on the development of a containment fragility curve for the Kalinin nuclear power plant, additional funding may be provided to extend this work to other containment types (i.e., reinforced concrete and steel shell).

5. Reporting and Meetings

The IBRAE/RAS will prepare quarterly technical and financial status reports for all programs, and provide final technical reports for each program at the completion of the work described in this Addendum. Either party may call for periodic technical meetings to discuss programmatic or technical issues that might arise during the duration of the program described here.

6. Audit and Record Requirements

The IBRAE/RAS shall maintain complete accounting records of all funds provided to it by the USNRC under this Addendum in accordance with accounting principles generally accepted in the Russian Federation. These accounting records shall be maintained for a period of no less than three years after the expiration of this Addendum. The USNRC, or other authorized U.S. government officials, shall have full access to the accounting records for the purposes of financial audit during the period of this Addendum and, after its expiration, for a period of no less than three years.

III. FINAL PROVISIONS

Duration and Termination - The work described in this Addendum shall begin upon signature by the parties and is expected to be completed on or before December 31, 1998. The work described in this Addendum may be terminated by mutual consent or by either party's withdrawing from the present Implementing Agreement after providing the other party written notice 6 months prior to its intended date of withdrawal.

All terms and conditions of the Implementing Agreement apply to this Addendum. The parties further agree to modify or extend the activities described in this Addendum within the intended scope of this Addendum upon written agreement of its Administrators.

In witness whereof this Agreement has been entered into the day and year last written.

**FOR THE UNITED STATES NUCLEAR REGULATORY COMMISSION**

BY: _____

L. Joseph Callan

TITLE: Executive Director for Operations

DATE: _____

PLACE: Rockville, Maryland, USA

**FOR THE INSTITUTE OF NUCLEAR SAFETY OF THE RUSSIAN ACADEMY OF SCIENCES**

BY: _____

Leonid A. Bolshov

TITLE: Director, Nuclear Safety Institute, RAS

DATE: _____

PLACE: _____