APR 1 9 2002

MODIFICATION NO. 12 TO COOPERATIVE AGREEMENT NO. NRC-04-98-051

BETWEEN

UNIVERSITY OF CALIFORNIA AT SANTA BARBARA

AND THE

U.S. NUCLEAR REGULATORY COMMISSION

The purpose of this modification is to (1) correct a typographical error made in the Total Funding Agreement Amount of "$1,029,932.00" Modification No. 11, Block 16. Total Funding Agreement to read $1,024,932" and increase the total funding amount by $100,000.00 from $1,024,932.00 to $1,124,932.00 (2) Add additional work as described in the attached proposal (3) Provide incremental funds in the amount of $100,000.00 thereby increasing the obligated and ceiling amount by $100,000.00 from $1,024,932.00 to $1,124,932.00 and (4) extend the period of performance through December 31, 2002. Accordingly, the following changes are hereby made:

1. In Block No. 13, Accounting & Appropriation Data, the following is added to the information previously found there:

"APPN. NO:	31X0200.260
B&R NO:	26015120127
Job Code:	6605
BOC NO:	4110
Amount Obligated:	$ 100,000.00
RES ID NO:	RES-C02-020

2. Block No. 15, NRC Obligation of Funds, is deleted in its entirety and replaced with the following:

This Cooperative Agreement Action	$ 100,000.00
Previous Obligation	$ 1,024,932.00
Total	$ 1,124,932.00

TEMPLATE—ADM001

ADM02

3. Block No. 16, Total Funding Agreement, is deleted in its entirety and replaced with the following:

NRC:	$ 1,124,932.00
Cooperator:	$ - 0 -
Total:	$ 1,124,932.00

All other terms and conditions remain the same and in full force and effect.

EXECUTED:

UNIVERSITY OF CALIFORNIA @
SANTA BARBARA

BY: [signature]

NAME: Lore L. Dobler

TITLE: Sponsored Projects Officer

DATE: APR 19 2002

UNITED STATES OF AMERICA
U.S. NUCLEAR REGULATORY COMMISSION

BY: Robert Webber

NAME: for Mary H. Mace

TITLE: Contracting Officer

DATE: 4/2/02

US NRC's CENTER OF EXCELLENCE AT UCSB
MULTIPHASE FLOW, SAFETY AND RISK MANAGEMENT

OVERALL VISION

Maintain readiness in Severe Accidents in LWRs; enhance Thermal/Hydraulics (T/H) and Severe Accidents (SA) understanding in specific areas as needed; prepare flexible capability for assessing specialized Thermal/Hydraulic and Severe Accident issues in Advanced Reactors; provide tie-in of all of the above with Risk Informed Regulation.

EXPLANATION/MOTIVATION

1. **Readiness in Severe Accidents** is needed because we don't know what the next rare event will be (internationally), and what time frame will be available for decisions. An example is the Tokai-Mura criticality accident that went on for too long, while the people over there were basically "in the dark". We at CRSS are in a unique position to most efficiently maintain such readiness. Having resolved all key (and contested) severe accident issues, we have a comprehensive understanding, as well as a complete set of the specialized tools needed (α-mode failure, Mark I Liner attack, Direct Containment Heating, In-Vessel Retention, Lower Head Integrity under Steam Explosion Loads). Also, we will have a Severe Accident Risk Management Manual, presently in production and to be kept as a living document. So, it is straightforward to maintain this capability, basically without any "overhead". Moreover, this capability can be enhanced and be used to contribute to significant future efforts, such as the OECD MCCI coolability program at ANL and the EUROSAFE program about to begin in Europe. Further, our extensive capability on In-Vessel Retention (including the worldwide-unique facilities, ULPU and ACOPO) will be readily available in NRC's review of Westinghouse's AP1000 design, anticipated to begin next year.

2. **Enhancement of Understanding** is needed in specific areas, and more such needs "pop up" still. One example of an old "issue" is ex-vessel coolability. We have some ideas on a new way to approach this. Another, more recent example is the consideration of Large Early Release Frequency in connection with Pressurized Thermal Shock risk-informed regulation. In a matter of two months we were able to apply our MuSiC code, and obtain very important results that there are no mechanisms for containment failure (due to vessel rupture in a PTS event). Another still more recent example is some work we did on Thermal Mixing during reactor shutdown/startup. Importantly, the tools available from the PTS work were not reliable enough for this very special purpose, but the basic understanding we had from the earlier work allowed us to approach this problem in an extraordinarily

efficient manner. We did so by building up a new ½-scale experiment and applying our MuSiC code to scale from ½ to full scale. Incidentally, it is important to note that through this experience we learned of some operating procedures (technical specifications) that may be good to revisit. The potential problem is that these do not give adequate credit to natural circulation, and "inundate" the system with very high injection rates of cold water from LPSI.

Another example is the CSNI initiative to see if we can finalize closure of steam explosion issues internationally. At this time, ours (CRSS) are the only major assessments of steam explosions published, peer reviewed and made for practical use by licensing. The initial impetus actually for MuSiC was provided by our own experiences in this area that pointed to certain needed improvements in the computational platform. Thus, MuSiC makes the best of PM-ALPHA and ESPROSE.m, while at the same time expands the horizon in the key area of robust numerics and the tracking of large-scale discontinuities. Both of these are critical to a more basic description of premixing. A related need is to find out, at the basic level again, whether Oxidic Melts can explode. Our SIGMA-3000 experiment is uniquely suited to address this question, and we are working on this now.

3. **Flexible TH/SA capability for Advanced Reactors** is needed because suddenly the future seems to be looking at many, some of them exotic, designs (for example, boiling water pebble-bed cores). If there are specialized needs, that is beyond the usual systems codes, for existing LWRs, one can readily imagine what will happen when radically new designs (such as AP1000, the supercritical water reactor, the IRIS, or any of the various High Temperature Gas Cooled designs being worked on by DOE) begin to come in. To this part of the vision, we bring our MuSiC code, extensive technology in Laboratory experiments and instrumentation, including operations at large scale. We also bring experience with "advanced reactors" based on our extensive work (actually done for the NRC) for the Liquid Metal Fast Breeder Reactor (FFTF, CRBR), and the High Temperature Gas-Cooled Reactor (Fort St. Vrain).

An interesting point to be made here is how basic understanding, gained through good research helps one face efficiently new, seemingly disparate situations. For example, in our Fort St. Vrain work, we (and the staff) were concerned about hot plumes rising into the upper plenum and locally overheating the liner in a loss of flow accident. This work provided a perfect entrée, some 5 years later, in immediately seeing how to approach the Thermal Mixing problem for PTS – this led to our REMIX code. Another example is our work for the FFTF on how to "retain" melts, which gave us the hint to pursue what became the in-vessel retention for Loviisa, the AP600, and now it appears for the AP1000. Such flexibility can be obtained at high quality only through fundamentals, and what we mean by it specifically is described further below under such a heading **"Important Basic Areas"**.

4. **Tie-in between TH/SA and Risk.** This is an integration issue, and to be addressed well one must have extensive experience on both ends (to "straddle the fence"). We showed how this can be done in our addressing of PTS and Severe Accident issues, as mentioned above. There will be a huge need for this in the present climate and the pursuit of advanced reactors. For example, the PBMR is talking about no exclusion boundary, no emergency plans, and "license by test". Again, different designs will have different needs, and one must be prepared on the basic grounds. An early step would be to prepare a white paper on Pebble-Bed reactor severe accident risks.

STRATEGY

Because of its strong fundamental component, our vision is very open to synergisms. This is good, too, in present limited budgets because of leveraging of resources thus made possible. In the past four years, we have shown that this can actually be done. We leveraged NRC funding with NSF, NASA, LLNL, US Army (expected coming fiscal year), KEPRI (Korea), NUPEC (Japan), and INERI (expected), and we got tremendous gains for everybody.

Operationally, our strategy consists of the following key parts.

1. **Intellectual Infrastructure.** We are completing a book on "Principles of Risk Management" and a book on "Principles of Severe Accident Management". We are beginning a book on "Principles of Multiphase Flow". These are to be used for developing human resources in National Labs, NRC/DOE, and, of course, universities.

2. **Human Resources.** We have built a "core capability" of "permanent" employees that consists of the Center Director, T.G. Theofanous, a computational group (three individuals) and an experiments group (three individuals). Around this core we can expand/contract as needs require, but in every step of the work, technology, know-how, experience, maturity, are retained in the core groups and continuously develop.

3. **Laboratory Facilities.** These include experiments such as the MAGICO, SIGMA, ACOPO, ULPU, ALPHA (this is for LLNL, on drop breakup), BETA (this is for NASA, on boiling), REMIX (this is for Thermal Mixing). In addition, we have extensive instrumentation, including High Speed Video along with Copper Vapor Laser illumination, High Speed Infrared Imaging, Flash X-ray source used for quantitative radiography, Magnetic Resonance Imaging, and extensive nano and micro technology tools we use for surface characterization in our boiling studies.

4. **The MuSiC Code.** This is a comprehensive, flexible package for computing complex (single and multiphase) flows. It is based on several important innovations. First is a new efficient way to couple domains – that is, fluid-fluid, or solid-fluid domains. This makes it ideal for fluid structure interactions, as they arise, for example, in steam explosions, in venting of ruptured vessels, or in vibrations. Second

is a new, very efficient incompressible solver that makes it very competitive for very complex geometries, such as the inter-fuel-pin space in LWRs, or the inter-pebble space in PBMRs. This, combined with our NMR Imaging capability, uniquely employing superpolarized Xenon gas, can allow a very basic and detailed investigation of flow patterns in a pebble-bed core. In this connection it may be interesting to note the very recent results obtained with NMR but for liquid flow in packed beds (chemical reactors), that more than ~50% of the flow is concentrated to under 10% of the flow area, even under what might be considered uniform packing. The numerical approach, based on numerical acoustic relaxation (NAR) makes it ideally suitable for coupling compressible with incompressible regions, and this is important in interfacing high-speed flows with liquid domains – interfaces perhaps breaking up. A good example is in the premixing of steam explosions.

Third is a new numerical approach to solve the multifluid model equations, which for the first time gives robustness to such solutions. Codes like RELAP and TRAC cannot go to small grid spacing because they become unstable – they need the numerical diffusion – and this has been a major criticism. As a result, these codes cannot be used for special purposes to learn about "details" of the flow, such as instabilities, local regions of separation (such as slugging), etc. With MuSiC, we have shown that we can go to the limit a cell size approaching zero as close as we wish. Our solutions are the only ones to compare favorably with the well-known "faucet" benchmark problem.

Finally, the fourth innovation involves a combination of the above towards simulating the internal structure of multiphase flows, such as, for example, following the demarcation between vapor-continuous and liquid-continuous regions. The physics of either side are very different. The physics at the interface (we call this a large-scale discontinuity) are also very important, and in fact they are very special. All these are central features in proper simulations of steam explosions. The same can be used even for melt dispersal in Direct Containment Heating. This capability is very germane also to more "traditional" T/H problems in low-pressure accidents such as relevant to advanced passive plants. Further, this capability will have a myriad of applications in other technologies from oil pipe lines to chemical plants, to fluidized beds.

In addition to the above innovations, MuSiC incorporates a number of state-of-the-art techniques in Direct Numerical Simulations (DNS) and interface tracking, that allow us to compute turbulent flows, as well as include and track gas-liquid interfaces. So, as a last feature, we should mention the overall goal of using MuSiC in a multiscale mode; that is, running DNS locally, and direct the results to updating constitutive laws that describe phase interactions in the multifluid (mixture theory) simulation at the "system" level.

IMPORTANT BASIC AREAS

1. **Critical Heat Flux.** Our findings in this area are really momentous; they will allow us to rewrite "the book" in such basic areas as nucleation and dryout, both being affected profoundly by the surface nanomorphology and chemistry. Also, counter-current flow limitations in pool boiling are absent (this was the "gospel" before), and any role they may have in forced convection is yet to be determined. This is very important for in-vessel retention, especially for larger (than AP600) reactors, because the margins are less and one is not clear about what a prototypic surface is likely to look like, when needed. This would be important, too, in thermal margins of the core, where the fuel cladding is already "aged" by cruding.

2. **Multidimensional Multiphase Flow.** The importance of multidimensionality and the multiregion structure (the large-scale discontinuities mentioned above) has already been established by our work with MAGICO, PM-ALPHA and ESPROSE.m. Now we have the computational platform (MuSiC) to address these realistically (as opposed to our previous bounding-oriented efforts). We have also seen a very important manifestation in ULPU – it is critical to the coolability limits for in-vessel retention. Recently we found that by just streamlining the baffle that simulates the thermal insulation we could increase the critical heat flux by ~30%. There may be other improvements possible, or it may be that certain geometries may be detrimental. Also, this upside-down, turning to vertical geometry, we found to exhibit a multiregion behavior, that in addition is pulsatile – this makes ULPU an ideal test bed to study such behaviors, while at the same time learning something of value to in-vessel retention. In combination with critical heat flux, this area is hugely important to many important industrial and safety tasks, as for example, predicting the response of storage vessels to external fire.

3. **Natural Convection and Mixing.** This area concerns mixing/stratification phenomena as affected by turbulence and buoyancy forces. Pressurized Thermal Shock, Boron Mixing, Shutdown/Startup Cooling, Energy Partition in a volumetrically heated melt pool, mixing of Hydrogen/Steam/Air in containments, Stratification in Pressure Suppression pools, decay heat removal phenomena in Loss of Forced Circulation accidents in Gas Cooled reactors, etc. All these share the same basics. All these can be computed on the same basis with our MuSiC code. Experience gained from one can be applied to the other problems constantly improving capability and readiness to tackle efficiently new, unforeseen situations. We have made pivotal contributions in many of the areas listed above; more can be done.

4. **Runaway Kinetics.** This pertains to nuclear criticality accidents, as well as chemical reactor runaways. Common ingredients include coupling kinetics to thermal hydraulics, and the latter involve highly transient single-phase compression, flashing, two-phase expansion, and ultimately blowdown and/or structural damage. We have calculated the Tokai-Mura criticality, and we discovered the cause of the runaway in the famous Seveso (chemical) accident a long time ago. Work remains to be done in

having confident, a priori, estimations of nuclear disassemblies. This is basic capability that can be readily achieved, to a great benefit, we believe.

COLLABORATIONS/ACCESS

Access to research results and technical expertise is possible for us through several collaborations. On European severe accident research we have access through our collaboration (sanctioned by the NRC) with the ARVI project. Access to Neutronic and structural/materials capabilities we have through our collaboration with LLNL. Access to the latest in Materials science we have through our world-renown Physics and Materials research at UCSB, especially the NSF-supported Materials Research Lab (MRL). Finally, access to all kinds of multiphase expertise we have through the IMuST community.

AGENCY: US Nuclear Regulatory Commission
TITLE: Center of Excellence
PI: T.G Theofanous
PERIOD: 3/15/02 - 12/31/02

A. SALARIES (Actual)					
Dinh, T.N., Assoc. Adjunct Prof.					
9.5 mo @	35%	6,416.67 /mo		$	21,335
Nourgaliev, R. Asst. Adjunct Prof.					
9.5 mo @	30%	5,366.67 /mo		$	15,295
SALARIES TOTAL				$	36,630
B. FRINGE BENEFITS					
Dinh, T.N					
	21335 /mo @	17%		$	3,627
Nourgaliev, R.					
	15295 /mo @	17%		$	2,600
FRINGE BENEFITS TOTAL				$	6,227
C. SUPPLIES AND EXPENSES					
Computer Usage - 13,000 hrs @ $0.88/hr				$	11,440
Miscellaneous Lab Supplies for SIGMA				$	4,740
SUPPLIES/EXPENSES TOTAL				$	16,180
D. EQUIPMENT AND FACILITIES					
1 Development Engr.					
6 mo @ 44 hrs/mo @ $47.61/hr				$	12,569
2 Development Engr.					
6 mo @ 44 hrs/mo @ $49.41/hr				$	13,044
EQUIP/FACILITIES TOTAL				$	25,613

TOTAL DIRECT COSTS:	84,650
MODIFIED TOTAL DIRECT COSTS:	59,037
INDIRECT COSTS* 26% (of Modified Direct Costs)	15,350

TOTAL NRC PROJECT COSTS	$	100,000

E. COST SHARING (UCSB College of Engineering)

1 Office Manager	9,819		
2 Rent	4,920		
		$	14,739

TOTAL PROJECT COSTS	$	114,739

3/18/2002