**ANNEX I**

**Work Plan**

**I. Summary Project Information**

**1. Project Title**

|  |
| --- |
| Modelling of Reactor Core Behaviour under Severe Accident Conditions. Melt formation, relocation and evolution of molten pool |

**2. Project Manager**

|  |  |  |  |
| --- | --- | --- | --- |
| **Name:** | Mikhail S. Veshchunov | | |
| **Title:** | Dr., Professor | **Position:** | Head of laboratory |
| **Street address:** | B.Tulskaya Street, 52 | | |
| **City:** | Moscow | **Region:** |  |
| **ZIP:** | 115191 | **Country:** | Russian Federation |
| **Tel.:** | +7 (095) 955-2232 | **Fax:** | +7 (095) 958-0040 |
| **E-mail:** | vms@ibrae.ac.ru | | |

**3. Participating Institutions**

***3.1. Leading Institution***

|  |  |  |  |
| --- | --- | --- | --- |
| **Short reference:** | NSI RAS (IBRAE) | | |
| **Full name:** | Nuclear Safety Institute of Russian Academy of Science (IBRAE) | | |
| **Street address:** | 52, B.Tulskaya | | |
| **City:** | Moscow | **Region:** |  |
| **ZIP:** | 115191 | **Country:** | Russian Federation |
| **Name of Signature Authority:** | Leonid A. Bolshov | | |
| **Title:** | Dr., Professor | **Position:** | Director |
| **Tel.:** | +7 (095) 952-2421 | **Fax:** | +7 (095) 958-0040 |
| **E-mail:** | bolshov@ibrae.ac.ru | | |
| **Governmental Agency:** | Russian Academy of Sciences | | |

***3.2. Other Participating Institutions***

**4. Foreign Collaborators**

***4.1. Collaborators***

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution:** | Joint Research Centre, Institut for Transurane (ITU), | | |
| **Street address:** | P.O. Box 2340 | | |
| **City:** | Karlsruhe | **Region/State:** |  |
| **ZIP:** | D-76125 | **Country:** | European Union |
| **Person:** | Paul David William Bottomley | | |
| **Title:** | Doctor | **Position:** | Group leader |
| **Tel.:** | +49 (0)7247/951364 | **Fax:** | +49 (0)7247/951593 |
| **E-mail:** | bottomley@itu.fzk.de | | |

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution:** | Korea Atomic Energy Research Institute (KAERI) | | |
| **Street address:** | 150 Dukjin-dong, Yasong-gu, P.O. Box 105 | | |
| **City:** | Taejon | **Region/State:** |  |
| **ZIP:** | 305-600 | **Country:** | Republic of Korea |
| **Person:** | Young Suk Kim | | |
| **Title:** | Doctor | **Position:** | Program manager |
| **Tel.:** | 82+42+8682296 | **Fax:** | 82+42+8631289 |
| **E-mail:** | yskim1@nanum.kaeri.re.kr | | |

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution:** | Institut de Radioprotection et de Surete Nucleaire | | |
| **Street address:** | B.P.3 | | |
| **City:** | Cadarache | **Region/State:** | Saint Paul-Lez-Durance Cedex |
| **ZIP:** | F- 13115 | **Country:** | European Union |
| **Person:** | Bernard Adroguer | | |
| **Title:** | Doctor | **Position:** | Program manager |
| **Tel.:** | +(33) 4 42 25 23 34 | **Fax:** | (+33) 4 42 25 29 29 |
| **E-mail:** | bernard.adroguer@irsn.fr | | |

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution:** | Forschungszentrum Karlsruhe GmbH | | |
| **Street address:** | P.O. Box 3640 | | |
| **City:** | Karlsruhe | **Region/State:** |  |
| **ZIP:** | D-76021 | **Country:** | European Union |
| **Person:** | Alexei Miassoedov | | |
| **Title:** | Doctor | **Position:** | Group leader |
| **Tel.:** | +49 (0)7247/822253 | **Fax:** | +49 (0)7247/822095 |
| **E-mail:** | alexei.miassoedov@iket.fzk.de | | |

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution:** | Forschungszentrum Karlsruhe GmbH | | |
| **Street address:** | P.O. Box 3640 | | |
| **City:** | Karlsruhe | **Region/State:** |  |
| **ZIP:** | D-76021 | **Country:** | European Union |
| **Person:** | Th. Walter Tromm | | |
| **Title:** | Doctor | **Position:** | Program manager |
| **Tel.:** | +49 (0)7247/825509 | **Fax:** | +49 (0)7247/825508 |
| **E-mail:** | walter.tromm@psf.fzk.de | | |

**5. Project Duration**

|  |
| --- |
| 36 months |

**6. Project Location and Equipment**

|  |  |
| --- | --- |
| **Institution** | **Location, Facilities and Equipment** |
| Leading Institution | Main building, workstations "SUN", PC Pentium 4 |

**II. Specific Information**

**1. Introduction and Overview**

Processes of reactor core degradation represent the most significant factor of severe accident development since they provide the initial conditions for ex-vessel phenomena and determine the fission product and hydrogen source term [1]. The investigation of in-vessel melt behaviour is of paramount importance with respect to reactor materials oxidation kinetics, possible reflooding of the core and reactor pressure vessel failure analysis. The main aspects concerning physico-chemical behaviour of the reactor core melt are:

* dynamics of melt formation,
* variation of core geometry in the course of melt relocation,
* hydrogen generation due to core materials oxidation,
* behaviour of the molten pool in the lower plenum of the reactor pressure vessel.

Presently a large set of experimental data concerning physico-chemical properties of reactor core materials, melt formation and relocation, molten pool behaviour is available [2-24]. On the other hand, the models for melt behaviour that are being used in the existing codes are based on oversimplified assumptions (parametric models with user-defined parameters, gravity driven axially symmetrical film flow, etc.), and do not use all the advantages of the experimental data at hand [7, 25].

During the last 10 years the project team has performed original investigations and developed a set of advanced models giving detailed physically grounded description of the following key core melting phenomena: dissolution of ZrO2 and UO2 by molten Zircaloy [26-29], oxidation of U-Zr-O melts [30, 31], Zr cladding mechanical behaviour and oxide shell failure [32-34], melt relocation in the form of drops and rivulets (candling process) [35-39], oxidation and downward relocation with massive coolant channel blockage (slug) [40-41], behaviour of molten pool (3-d non-stationary turbulent hydrodynamics) [42-51, 55-64].

The general objective of the proposed project is to perform the detailed analysis of the available and new experimental data, to update, improve and verify the developed models and to prepare them for benchmarking of simplified models and for implementation in the existing system codes such as ICARE/CATHARE, MELCOR, or ASTEC. Thus the proposed project will contribute to the reactor core degradation modelling. Tight connection and information exchange with other European projects (e.g. SARNET, LIVE, RASPLAV) will be carried out in the course of the Project realization.

**2. Expected Results and Their Application**

|  |  |  |
| --- | --- | --- |
| **№** | **Expected Result** | **Result Application** |
| 1 | Model of melt formation and onset of melt relocation | SVECHA/MELT code |
| 2 | Numerical module S\_CANDL | SVECHA/MELT code |
| 3 | Numerical module S\_SLUG | SVECHA/MELT code |
| 4 | SVECHA/MELT code | Analysis of experimental data |
| 5 | Analytical support of the ITU tests | ITU, COLOSS program |
| 6 | Mathematical model and numerical module of molten pool | Code CONV |
| 7 | Numerical and analitical support of the numerical module | Code CONV |
| 8 | Numerical module of molten pool at high Ra number | Code CONV |

**3. Meeting ISTC Goals and Objectives**

The proposed project provides weapons scientists opportunities to redirect their talents to peaceful activities, promotes integration of Russian scientists into the international scientific community, supports basic research and technology development for peaceful purposes in the field of nuclear safety.

**4. Scope of Activities**

Task 1: Modelling of melt formation and onset of melt relocation

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 1. Modelling of melt formation and onset of melt relocation  1.1. Improvement and implementation in the SVECHA code of the models for dissolution of ZrO2 and UO2 by molten Zircaloy, U-Zr-O melt oxidation and release from the cladding breach. Performance of verification calculations. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Model of melt formation and onset of melt relocation | |

Task 2: Modelling of candling process

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 2. Modelling of candling process  2.1. Development and implementation in the SVECHA code of the model for the candling process. Performance of verification calculations. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Numerical module S\_CANDL | |

Task 3: Modelling of slug relocation

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 3. Modelling of slug relocation  3.1. Development and implementation in the SVECHA code of the model for the slug relocation. Performance of verification calculations. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Numerical module S\_SLUG | |

Task 4: SVECHA/MELT code verification

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 4. SVECHA/MELT code verification  4.1. Verification of the newly developed SVECHA/MELT code against available experimental data. Preparation of the newly developed modules for the implementation in the system codes such as ICARE/CATHARE, MELCOR, or ASTEC. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | SVECHA/MELT code | |

Task 5: Modelling of molten pool behaviour

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 5. Modelling of molten pool behaviour  5.1. Analytical support for the ITU tests on irradiated and MOX fuel dissolution by molten Zr and U-Zr-O melting points determination. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Analytical support of the ITU tests | |

Task 6: Development of a three-dimensional code and adaptation to the LIVE project

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 6. Development of a three-dimensional code and adaptation to the LIVE project  6.1. The adaptation of the three-dimensional CONV code (within Boussinesq approximation) for the LIVE project conditions. Development and implementation in the CONV code of the thermal-hydraulic model with a variable density (without Boussinesq approximation). | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Mathematical model and numerical module of molten pool | |

Task 7: Theoretical analysis and code validation

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 7. Theoretical analysis and code validation  7.1. The numeric-theoretical analysis of the flows in a boundary layer adjacent to cooled boundaries. Validation of the developed flow models using experimental data, including experiments with a heat generating fluid such as LIVE, COPO, SIMECO. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Numerical and analytical support of the numerical module | |

Task 8: Thermal-hydraulic model taking account of the crust formation

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| 8. Thermal-hydraulic model taking account of the crust formation  8.1. Development of models and code for numerical simulation of flows at high Rayleigh numbers under conditions of crust formation on a cooled surface. Testing of the developed models on experimental data with crust formation using RASPLAV tests. | | NSI RAS (IBRAE) (Leading) |
| **Description of deliverables** | | |
| 1 | Numerical module of molten pool at high Ra number | |

**5. Role of Foreign Collaborators**

ITU (Karlsruhe, Germany) will provide experimental data from tests on irradiated and MOX fuel dissolution by molten Zr and tests on U-Zr-O mixture melting point determinations (COLOSS program), in order to extend the fuel dissolution model to the analysis of irradiated and MOX fuel liquefaction.

FZK(Karlsruhe, Germany) will provide experimental data from the bundle QUENCH and CORA tests, in which liquefaction of the core materials was observed. The measured data on local molten pools formation (at higher bundle elevations), their oxidation and interactions with pellets and downward relocation, will be presented for analytical treatment.

FZK will also provide experimental data from LIVE (Late In-Vessel phase Experiments) project concerning 3-d heat flux distribution to the lower head and possible resulting crust formation, gap formation between the vessel wall and the melt crust, the influence of the melt relocation mode to the lower head on melt pool formation and heat flux distribution.

IRSN/DPAM (Cadarache, France) will collaborate in benchmarking of the simplified models against the advanced models produced by the project, in order to have a benefit for the ICARE/CATHARE and ASTEC codes involved in the modelling/validation effort in SARNET.

The four institutes: ITU, FZK, IRSN/DPAM and KAERI (Republic of Korea) will participate in information exchange, cross-checks of results obtained in the course of project implementation and in technical monitoring of project activities performed by ISTC staff; provide comments to the technical reports, submitted by project participants to the ISTC.

**6. Technical Approach and Methodology**

Implementation of the developed modules in the SVECHA code [32-34, 52-54] is of great practical importance with respect to their comprehensive verification.

Firstly, SVECHA code gives the detailed solution of the heat exchange problem and allows accounting for the heat effects of different processes (oxidation, dissolution, etc.) and their mutual influence. When describing melt relocation the temperature evolution of the system will be self-consistently determined by the code. In particular, it will be possible to account for the heat transfer by relocating melt that gives one of the most important contributions to the total heat transfer at the later stages of core degradation. This effect cannot be appropriately modelled by the stand-alone module. A similar statement is true for the mass exchange due to melt oxidation and surrounding rods dissolution at the second stage of melt relocation.

Secondly, within the framework of the SVECHA code the modules describing different stages of melt relocation will be coupled with each other in a quite natural way: results of one module calculations represent the initial conditions for the other module. Thus, the newly developed SVECHA/MELT code will be able to describe *distributed* melt relocation, when at the same time different melt relocation regimes (melt formation, drop/rivulet flowing down, slug relocation) take place at different elevations and affect each other. Such situation seems to be very typical for the core degradation and needs to be treated adequately.

Below the models under the consideration and the SVECHA code are briefly described.

1. Melt formation, onset of melt relocation

*1.1 Model for simultaneous dissolution of ZrO2 crust and UO2 fuel (fresh and irradiated) by molten Zircaloy and U-Zr-O melt oxidation*

On the base of the previously developed models based on separate dissolution of UO2 and ZrO2 by molten Zry, a new model for simultaneous dissolution of these materials was developed at IBRAE for the mechanistic code SVECHA [28]. The model considers interactions of solid materials with the convectively stirred melt during the two stages of interaction: saturation and precipitation, and self-consistently describes either erosion (dissolution) or corrosion (growth) of ZrO2 layer during these interactions. The system of equations includes mass balances for three components (U, Zr, O) as well as flux matches (solid diffusion and melt convection) at two solid/melt interfaces. The model was successfully validated against various crucible dissolution tests [3, 4, 13], including recently performed (within COLOSS Project of 5th Framework Programme, with analytical support of IBRAE) RIAR (Dimitrovgrad) tests on simultaneous dissolution of UO2 and ZrO2 by molten Zry [23, 24].

Additionally, a new model for oxidation of molten U-Zr-O mixtures was developed in collaboration with JRC and FZK, in order to analyse and explain the H2 peak production during the quenching of degraded rods [30, 31]. The developed model of oxidation of U-Zr-O melts in steam is based on the qualitative results of post-test observations of the melts in the FZK bundle tests CORA and QUENCH. The model explains the emergence of the ceramic precipitates under non-equilibrium conditions induced by the temperature difference between the wall and the melt, and predicts continuous oxidation/precipitation process after attainment of the saturated state of the melt. As a result, the model predicts a close to linear time law for the rate of the (U,Zr)O2 ceramic phase (oxide layer + precipitates) growth during U-Zr-O melt oxidation that corresponds to a much faster kinetics of melt oxidation and hydrogen generation in comparison with the standard (parabolic) rate.

On the basis of the performed analysis, it is anticipated that dissolution of UO2 fuel by the U-Zr-O melt is also strongly influenced by the temperature difference between heated fuel pellets and melt. The new mechanism provides a natural qualitative explanation of the early fuel destabilisation/dissolution and enhanced melt oxidation accompanied with the ceramic phase precipitation. Implementation of this mechanism in the fuel dissolution model for quantitative analysis of the bundle test observations (e.g. in Phebus FP tests) is foreseen in the proposed ISTC Project.

The model will be also extended to consideration of irradiated and MOX fuel liquefaction on the base of analysis of the JRC/ITU tests.

*1.2 Model for oxide shell crust failure*

The model describes the behaviour of the oxide scale under interaction with the molten Zr accounting for the oxide scale and metal phases thickness, oxygen concentration in the molten Zr and oxygen flux on the cladding surface. The model takes into consideration the competitive processes of the oxide scale dissolution (erosion) and oxidation (corrosion) by molten Zircaloy. In particular, the model predicts the corrosion behaviour after Zr melting at low heating rates and erosion of the outer oxide scale at high heating rates. In the case of corrosion, through-wall crack formation takes place leading to "flowering" mode of oxide scale failure. Erosion leads to a local dissolution of cladding oxide shell and release of the molten Zr from the cladding breach. The model is successfully validated against FZK tests on cladding oxide shell failure [29] and applied to interpretation of various bundle test observations.

*1.3 Model for release of U-Zr-O mixture from the cladding breach*

The model to be developed should determine the initial flow regime (separate droplets or a rivulet) depending on the volume of released mixture, dimensions of considered mesh and nature of cladding breach.

2. Candling model: flowing down in the form of drops and rivulets during the first stage of melt relocation

The model is based on the system of differential equations obtained by the integration of the hydrodynamical Navier-Stokes equations over the volume of the moving liquid element with taking into account boundary conditions on the liquid-solid and liquid-gas interfaces [39].

The model allows taking into account:

* capillary effects (contact angle hysteresis, contact line resistance to displacement, wetting of the fuel rod surface) and introduce capillary scale;
* viscous effects (viscous drag force, laminar/turbulent regimes);
* heat exchange influence (melting/solidification process, temperature dependence of viscosity, surface tension, etc.).

The model allows for description of:

* various types of downward flow (drops, rivulets of different length, films);
* transient processes (drop-rivulet transitions);
* non-stationary heat exchange of the liquid mixture with arbitrary temperature distribution along the fuel rod.

The model also describes the gap candling process - flowing down inside the gap formed by cylindrical structures (cladding/fuel pellet).

3. Model for massive melt oxidation and downward relocation in the course of the second stage of melt relocation process (slug model)

On the base of the analysis on melt relocation in the CORA tests [11, 12], it was determined that a massive blockage of the coolant channels (slug) slowly relocates downward and extensively oxidises and simultaneously dissolves UO2 pellets and ZrO2 scales of the cladding [40,41]. It is just these chemical interactions that make the main contribution to the molten materials oxidation process.

The model describes simultaneous relocation and oxidation of a slug. The model is based on the mass and heat balance relations. The slug model describes:

* mass exchange due to slug oxidation and chemical interaction with the neighbouring rods,
* mass exchange due to drops and rivulets joining from the upper elevations,
* heat exchange of the slug with surrounding media.

The model accounts for the heat effects of oxidation and dissolution. The basic data relative to oxidation and dissolution (components mass flows) are to be provided by SVECHA modules for oxidation and dissolution coupled with the slug relocation module in the time step.

The model allows self-consistent calculation of the slug relocation velocity and thus gives the complete description of slug relocation and oxidation.

4. The SVECHA code

The computer code SVECHA was developed in the Nuclear Safety Institute (IBRAE) of Russian Academy of Sciences on the basis of FZK experiments (QUENCH program) for the detailed modelling of fuel rod behaviour under severe accident conditions [32-34].

The SVECHA code includes tightly coupled modules for the description of:

* Heat exchange inside the rod,
* Heat and mass exchange in the surrounding channel,
* Zr oxidation,
* Hydrogen behaviour,
* Cladding mechanical behaviour (to be updated and improved within the framework of the proposed project),
* UO2 and ZrO2 dissolution (to be updated and improved within the framework of the proposed project).

Heat exchange module uses axially non-uniform multi-layer cylindrical structure (fuel pellets/gap/cladding). The module is based on the 2-D finite differences numerical scheme with adaptive grid. Heat exchange module accounts for the layers thickness variation due to oxidation, for different thermal properties of the various layers and for the heat release due to oxidation. Typical number of nodes in the radial direction is 50, in the axial direction - 100-150.

Channel heat and mass exchange module self-consistently determines heat exchange rates under different thermal-hydraulic conditions, calculates chemical composition and temperature distribution of the channel gas (up to a 4-gas mixture: argon, steam, hydrogen, oxygen), provides effective treatment of steam starvation conditions and hydrogen uptake/release. Typical number of axial meshes - 30-100.

Zr oxidation module considers multi-layer oxygen diffusion problem with moving boundaries in terms of partial differential equations, and accounts for non-equilibrium evolution of boundary oxygen concentrations and for radial temperature gradient. Typical number of nodes per layer (in the radial direction) - 40, typical number of axial meshes - 30-100.

Hydrogen behaviour module describes hydrogen uptake and release by oxidising cladding in steam/hydrogen atmosphere. This module is tightly coupled with Zr oxidation one and uses similar nodalisation scheme.

Mechanical behaviour module accounts for the effects of  phase transition, tetragonal-to-monoclinic phase transition, and temperature gradient on the stress state of the oxidised cladding, crack formation and different modes of cladding destruction. Mechanical behaviour module is to be modified within the framework of the proposed project in order to give the most adequate description of the oxide crust shell failure (see above).

5. CONV code system

During the last ten years, 3D unified thermal-hydraulic technique for simulation of heat and mass transfer processes in complex domains is being developed in IBRAE [42-51, 55-64].

The developed technique will be improved during the project in the following directions:

* The methods, algorithms and software for automatic generation of orthogonal/Cartesian grids with local refinement near to solid-state borders,
* The methods and algorithms for solving of heat and mass transfer incompressible CFD problems for research of 3D thermal hydraulic phenomena,
* The turbulence simulation approaches.

Moreover, the developed calculated complex will be adapted with reference to the LIVE experimental facility during of project works.

5.1 For construction of calculated grid in an area, representing LIVE experimental facility, the developed automatic technology of grid generation using CAD system for designing of calculated domains, is planned to usage. For generation of the structured orthogonal/Cartesian grids with a local refinement near solid-state boundaries special pre-processor program supplied by a user-friendly interface and permitting to build calculated grids and to set the boundary conditions will be developed.

5.2 To solve computational fluid dynamics problems in the domain of arbitrary shapes including the variable properties of materials the new effective finite-volume numerical algorithm for the heat and mass transfer equations (i.e. Navier-Stokes equations with energy equation) in the primitive variables formulation will be used and to receive the further development. The numerical technique is based on the developed algorithms with small scheme diffusion, for which the discrete approximations are constructed using finite-volume methods and fully staggered grids.

* Decomposition on physical processes will be used to construct operator-splitting schemes. The momentum equation operators will be splitting on two parts. The first part is associated with the velocity transport by convection/diffusion, whereas the second part deals with pressure gradient. The numerical implementation of the constructed scheme will be performed as the predictor-corrector procedure. To supply momentum equations by pressure correction is allowed to transform it to the well-known Poisson equation and velocity correction equation.
* The energy equation will be decomposed into two parts associated with the enthalpy transfer and temperature diffusion. Fully implicit scheme will be used for solving of unsteady equation of temperature diffusion.
* For solving of transfer equation the developed regularizated non-linear monotonic operator-splitting scheme will be used.
* To deal with irregular computing areas the developed fictitious domain method (FDM) will be used.
* It is planned also to use the modified Richardson Method with Fast Fourier Transformation (FFT) as pre-conditioner for a solution of the pressure equation. In this case, an acceleration more than a ten times in comparison with standard Preconditioned Conjugate Gradient Methods (PCGM) of incompressible CFD problems can be reached.
* The elaborated technique has a high degree of efficiency and today allows CFD calculations to be carried out on a grid with a total number of 107 nodes using a PC with P4-2.0GHz processor and 1.5Gb-RAM. For simulation of the single-phase flows fast actions of 10-5 second per node and time step are possible.

5.3. Existing three-dimensional CONV code will be adapted with respect to the LIVE experimental facility for modelling of three-dimensional flows in a Boussinesq approximation for buoyancy on Cartesian grids with a local refinement. The model for calculation of flows with a variable density without of Boussinesq approximation will be included in CONV code also. Necessary modification of numerical algorithm for a fast solution of the pressure correction equation with taking into account of FFT algorithm and verification of the modified software on such experiments as LIVE, RASPLAV, COPO, SIMECO will be carried out. Comparison to Boussinesq approximation model for such parameters as 3D heat flux distribution on the cooled boundary and possible crust formation depending on the power density and the external cooling is planned.

5.4. For convection analysis in conjunction with crust formation phenomenon a self consistent approach is used. This approach allows simulating of melting/solidification front behaviour under external cooling modes. Validation of approach will be carried out on RASPLAV experiments, on Gau and Viskana's experiments with melting of pure gallium and on Voller's benchmark.

5.5. The calculation of natural convection and heat flux distribution will be supplemented during the project by the theoretical analysis of major phenomena such as boundary layers formation, with the analysis of energy balance in a heat generating fluids. Theoretical dependences will be compared with the results of calculations.

5.6. Heat generating fluids exhibit temperature stratification depending upon boundary conditions at the top (isothermal or adiabatic). Corresponding theoretical assessments for the heat transfer and their dependence upon dimensionless parameters such as Rayleigh number will be compared with numerical results.

5.7 For the modelling of 3D turbulent single-phase flows algebraic turbulence model will be applied. Use of this model needs choice of parameters, which will be defined from the set of test problems. For modelling of convection flows simultaneously with heat exchange to cooled boundary and crust formation at high Rayleigh numbers LES (large eddy simulation) approach is planned also to usage.

Algorithms, methods and software, elaborated on basis of the above computational methods and schemes will be validated during project on a wide class of experiments.

**References**

1. *P.Hofmann*, Current knowledge on core degradation phenomena, a review, J. Nucl. Mater. 270 (1999) 194.
2. *P.Hofmann, D.K.Kerwin-Peck*, J. Nucl. Mater. 124 (1984) 80.
3. *P.Hofmann et al.* Dissolution of solid UO2 by molten Zircaloy and its modelling, in: International Symposium on Severe Accidents in Nuclear Power Plants, Sorrento, Italy, March 1988.
4. *K.T.Kim, D.R.Olander*, J. Nucl. Mater. 154 (1988) 85.
5. *P.Hofmann, S.Hagen, G.Schanz, A.Skokan*, Nucl.Technol. 87 (1989) 146.
6. Special issue on materials interactions and temperatures in the TMI-2 core, Nucl.Technol. 87/1 (1989) 13-326.
7. *S.R.Kinnersly, J.N.Lillington, A.Porracchia, K.Soda, K.Trambauer, P.Hofmann, Y.Waarenpera, R.A.Bari, C.E.L.Hunt and J.A. Martinez*, In-Vessel Core Degradation in LWR Severe Accidents: A State of the Art Report to CSNI, January 1991”, NEA/CSNI/R(91)12, November 1991
8. *R.R.Robbins, D.A.Petti, D.J.Osetek, D.L.Hagrman*, Nucl.Technol. 95 (1991) 287.
9. *C.Gonnier, G.Geoffroy, B.Adroguer*, PHEBUS SFD programme, main results, in: ANS Proceedings, ANS Meeting, Portland, 1991, p. 76.
10. *W.Hering, P.Hofmann*, Material interaction during severe LWR accidents: Summary of separate-effect test results, Kernforschugszentrum Karlsruhe KfK-5125, 1994.
11. *S.Hagen, P.Hofmann, V.Noack, G.Schanz, G.Schumacher and L.Sepold*, Test Results of Experiment CORA W1, Kernforschugszentrum Karlsruhe KfK 5212, 1994.
12. *S.Hagen, P.Hofmann, V.Noack, G.Schanz, G.Schumacher and L.Sepold*, Results of Experiment CORA W2, Kernforschugszentrum Karlsruhe KfK 5363, 1994.
13. *P.J.Hayward, I.M.George*, J. Nucl. Mater. 208 (1994) 35.
14. *P. Von der Hardt, A.Jones, C.Lecomte, A.Tattegrain*, Nucl. Safety 35 (1994) 2.
15. Post-test Examination of the VVER-1000 Fuel Rod Bundle CORA-W2, Ed. by L.Sepold, FZKA 5570 (1995).
16. *M.Firnhaber, L.Yegorova, U.Brockmeier, S.Hage, P.Hofmann, K.Trambauer*, OECD/NEA-CSNI International Standard Problem ISP36, CORA-W2 Experiment on Severe Fuel Damage for a Russian Type PWR, Comparison Report, GRS-120, FZKA 5711, OCDE/GD(96)19, ISBN 3-923875-81-9, February 1996
17. *T.Haste, B.Adroguer, U.Brockmeier, P.Hofmann, K.Mueller, M.Pezzilli*, In-vessel core degradation in LWR severe accidents, European Union Report 16695, 1996.
18. *T.Haste, B.Adroguer, R.O.Gauntt, J.A.Martinez, L.J.Ott, J.Sugimoto, K.Trambauer*, In-vessel core degradation code validation matrix, OCDE/GD (96) 14 (1996).
19. *R.W.Wright*, Nucl. Sci. Technol. 24 (1996) 283.
20. *P.Hofmann, S.Hagen, V.Noack, G.Schanz, L.Sepold*, Nucl.Technol. 118 (1997), 200.
21. *G.Bandini et al.*, Molten material relocation into the lower plenum: A status report, OECD/NEA Report (1997), NEA/CSNI/R (97) 34 (1998).
22. *B.Adroguer* et al., Corium Interections and Thermochemistry, CIT Project, FISA 2001, EUR 19532 EN, Lux., Nov. 1999.
23. *B.Adroguer* et al., Final Summary Report, INV-CIT(99)-PO41 IPSN/DRS/SEMAR 00/89, September 2000.
24. *B.Adroguer* et al., Core loss during a severe accident (COLOSS), FISA 2001, EU Research in Reactor Safety, EUR 20281 EN, Lux., Nov. 2001.
25. SCDAP/RELAP5 Independent Peer Review, 1994, Los Alamos National Laboratory, LA-12481.
26. *M.S.Veshchunov, P.Hofmann and A.V.Berdyshev*, Critical evaluation of UO2 dissolution by molten Zircaloy in different crucible tests. J.Nucl.Mater, 231 (1996) 1.
27. *M.S.Veshchunov, P.Hofmann*, Dissolution of solid UO2 by molten Zircaloy. J.Nucl.Mater, 209 (1994) 27.
28. *M.S.Veshchunov and A.V.Berdyshev*, Modelling of chemical interactions of fuel rod materials at high temperatures. Part I. Simultaneous dissolution of UO2 and ZrO2 by molten Zr in an oxidising atmosphere. J.Nucl.Mater, 252 (1998) 98-109.
29. *P.Hofmann, J.Stuckert, A.Miassoedov, M.S.Veshchunov, A.V.Berdyshev, A.V.Boldyrev*, ZrO2 dissolution by molten Zircaloy and cladding oxide failure. New experimental data and modelling. FZKA 6383, 1999 (ISSN 0947-8620).
30. *M.S.Veshchunov, J.Stuckert, A.V.Berdyshev,* Modelling of Zr-O and U-Zr-O Melts Oxidation and New Crucible tests. Report FZKA 6792, SAM-COLOSS-P040, Karlsruhe, Germany, December 2002.
31. *M.S.Veshchunov, A.V.Berdyshev,* Final Report on U-Zr-O Melt Oxidation Model. JRC Technical Note No. P. 02. 84, SAM-COLOSS-P039, Petten, August 2002.
32. *P.Hofmann, V.Noack, M.S.Veshchunov, A.V.Berdyshev, A.V.Boldyrev, L.V.Matweev, A.V.Palagin, V.E.Shestak*, Physico-Chemical Behavior of Zircaloy Fuel Rod Cladding Tubes During LWR Severe Accident Reflood, FZKA 5846, 1997 (ISSN 0947-8620).
33. *P.Hofmann, A.Miassoedov, L.Steinbock, M.Steinbrueck, M.S.Veshchunov, A.V.Berdyshev, A.V.Boldyrev, A.V.Palagin, V.E.Shestak*, Quench Bechaviour of Zircaloy Fuel Rod Cladding Tubes. Small-Scale Experiments and Modeling of the Quench Phenomena, FZKA 6208, 1998 (ISSN 0947-8620).
34. *A.V.Berdyshev , A.V.Boldyrev, A.V.Palagin, V.E.Shestak, M.S.Veshchunov*, SVECHA/QUENCH Code for The Modeling of Reflooding Phenomena in Severe Accidents Conditions. Proceedings of the Ninth International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-9)*,* paper Log\_19 (CD-ROM edition), San Francisco, California, 1999.
35. *A.V.Palagin*, On the flowing down the fuel rod of Zr-U-O liquefied mixture during severe accident at Nuclear Power Plant, Preprint NSI-1-93, Nuclear Safety Institute, Moscow, 1993.
36. *A.V.Palagin, M.S.Veshchunov*, Relocation of molten materials during core degradation (candling), Report NSI-SARR-04-94, Nuclear Safety Institute, Moscow, 1994.
37. *A.V.Palagin* “Relocation of molten materials during core degradation (candling)”, Transactions of SMiRT-13 Conference, Vol.1, pp.139-144, 1995.
38. *A.V.Palagin* “SVECHA Project Candling Model: Description of Melt Relocation During Core Degradation” Proceedings of the 31-th National Heat Transfer Conference, Severe Accidents Fundamentals Session, Houston, USA, Vol.1, 1996.
39. *A.V.Palagin*, Physical model for molten materials relocation at the first stage of core degradation, Izvest. Acad. Nauk, Energetics, 4 (2002) 93 (in Russian).
40. *M.S.Veshchunov and A.V.Palagin*, Modelling of chemical interactions of fuel rod materials at high temperatures. Part II. Investigation of downward relocation of molten materials. J. Nucl.Mater, 252 (1997) 110.
41. *A.V.Palagin*, Physical model for molten materials relocation at the second stage of core degradation, Izvest. Acad. Nauk, Energetics, 6 (2002) 52 (in Russian).
42. *A.E. Aksenova, V.V. Chudanov, A.G. Churbanov, A.G. Popkov, V.F. Strizhov, P.N. Vabishchevich,* Molten pool behavior in the lower head. In Proc. of the OECD/CSNI/NEA Workshop on Large Molten Pool Heat Transfer, (Eds. M.Ortiz and J.M.Seiler), March 9-11, 1994, Grenoble, France, pp. 321-344.
43. *V.V. Chudanov, A.G. Churbanov, A.G. Popkov, V.F. Strizhov, P.N. Vabishchevich*, Numerical simulation of heat and mass transfer ptocesses at severe accidents of nuclear reactors. In Programming and Mathematical Techniques in Physics (Eds. Yu.Yu.Lobanov and E.P.Zhidkov), pp.186-188, World Scientific, Singapure, 1994.
44. *A.E. Aksenova, L.A. Bolshov, V.V. Chudanov, V.F. Strizhov, P.N.* *Vabishchevich,* Some Aspects of Parametric Model of Molten Corium Behaviour. In Proceedings of the 1995 JOINT ASME/JSME PRESSURE VESSELS \& PIPING CONFERENCE, HONOLULU, HAWAII, JULY 23-27, 1995 pp. 169-175.
45. *A.E. Aksenova, L.A. Bolshov, V.V. Chudanov, V.F. Strizhov, P.N.* *Vabishchevich,* Parametric Numerical Investigation of Natural Convection in a Heat-generating Fluid with Phase Transitions. In Proceedings of the 7th International Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-7), Session 6-11, Saratoga Springs, NY USA, September 10-15, 1995, NUREG/CP-0142, vol. 2, pp.864-874.
46. *A.E. Aksenova, V.V. Chudanov, A.G. Churbanov, V.A. Pervichko, P.N. Vabishchevich*, Numerical methods for solving a diffusion/convection problem with regard to melting using a fictitious domain procedure. In Proceedings of 16th International Conference on numerical methods in fluid dynamics, Arcachon, France, 6th-10th July, 1998.
47. *A.E. Aksenova, V.V. Chudanov, A.G. Churbanov, V.A. Pervichko, V.F. Strizhov, P.N. Vabishchevich*, Current status and validation of CONV2D\&3D code. In Proceedings of the OECD/CSNI/NEA WORKSHOP on in-vessel core debris retention and coolability, Garching near Munich, Germany, Nuclear Safety NEA/CSNI/R(98) 18, February 1999, pp.223-235.
48. *V.V. Chudanov, A.E. Aksenova, S.F. Krylov, V.A. Pervichko, I.G. Plotnikova, V.V.* *Varenkov,* A new approach to CFD problems in complex geometries. In Proceedings of the 9th International Topic Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-9), San Fancisco, California, 1999. CD-ROM edition, paper log326.
49. *A.E. Aksenova, V.V. Chudanov, V.A. Pervichko, V.N. Semenov, V.F. Strizhov*, Development and application of the CONV Codes. In Proc. RASPLAV Seminar 2000, Munich, November 2000. CD. Session 3: Theoretical analysis. 18p.
50. *V.V. Chudanov, A.E. Aksenova, V.A. Pervichko, V.F. Strizhov*, Development and application of software for simulation of the processes at a late stage of severe accidents on NPPs, to be published in Proc. of branch conference "Safety issues NPP with VVER", St.-Petersburg, 2000.
51. *V.V. Chudanov, A.E. Aksenova, V.A. Pervichko*, 3D unified CFD approach to thermalhydraulic problems in safety analysis. In Proc. of IAEA Technical Meeting on Use of Computational Fluid Dynamics (CFD) Codes for Safety Analysis of Reactor Systems, Including Containment, University of Pisa, Italy, 11-14 November, 2002.
52. *M.S.Veshchunov, A.V.Palagin, A.M.Voltchek, N.V.Yamshchikov, A.V.Boldyrev,* Code package SVECHA: Core degradation at severe accidents, Transactions of SMiRT-13 Conference, Vol.1, pp.159-163, 1995.
53. *M.S.Veshchunov, A.E.Kisselev, A.V.Palagin* et al. Code package SVECHA: modeling of core degradation phenomena at severe accidents. Proceedings of the 7th International Meeting on Nuclear Reactor Thermal-Hydraulics NURETH-7 (USA), Vol.3, pp. 1914-1929, 1995.
54. *L.Sepold, P.Hofmann, C.Homann, W.Leiling*, A.Miassoedov, D.Piel, G.Schanz, L.Schmidt, U.Stegmaier, M.Steinbrueck, H.Steiner, A.V.Palagin, A.V.Boldyrev, A.V.Berdyshev, V.E.Shestak, M.S.Veshchunov, Investigation of an Overheated PWR-Type Fuel Rod Simulator Bundle cooled down by steam, FZKA 6412, 2002 (ISSN 0947-8620).
55. *L.A.Bolshov, P.S.Kondratenko, V.F.Strizhov*, Qualitative estimates of convective heat transfer in a volumetrically heated fluid, International Symposium on Transient Convective Heat Transfer, Cesme, Turkey, 19-23August, 1996. Begell House, 1997, PP.103-116.
56. *L.A.Bolshov, P.S.Kondratenko, V.F.Strizhov*, A semi-quantitative theory of convective heat transfer in a heat generating fluid, Int. J. Heat and Mass Transfer, Vol.41 (1997), № 10, pp.1223-1227.
57. *L.A.Bolshov, P.S.Kondratenko, V.F.Strizhov,* Free convection of Heat Generating Fluid in a Constrained Volume and the Conditions Governing Characteristics of Shape during Experimental simulation of Heat Transfer in Slice Geometry,Proc. of OECD/CSNI Workshop on In-vessel Core debris Retention and Coolability, Garching, 1998, NEA/CSNI/R (98) 18, 1999, pp. 235-242.
58. *L.A.Bolshov, P.S.Kondratenko,* Boundary layers and peculiarities of heat transfer distribution from a heat generating fluid, Proceedings of the 2-d Russian National Conference on Heat Exchange, 26-30 October 1998, Moscow, v.3 pp. 50-53 (in Russian).
59. *L.A.Bolshov, P.S.Kondratenko, V.F.Strizhov*, Peculiarities of heat transfer from a cooling down fluid without internal heat sources and heat transfer from a heat generating fluid, 9-th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-9), San Francisco, 1999. CD, paper Log305.
60. *L.A.Bolshov, P.S.Kondratenko, V.F.Strizhov*, Asymptotic characteristics of heat transfer from cooling fluid and the possibility to use it for the experimental modeling of the heat transfer from corium. Thermal Physics Conference, Obninsk 1999 (in Russian).
61. *L.A.Bolshov, P.S.Kondratenko,* Limiting angular characteristics of heat transfer and stratification in a heat-generating fluid, International Journal of Heat and Mass Transfer, Vol.43 (2000), № 20, pp.3897-3905.
62. *P.S.Kondratenko, D.V.Nikolski*, On the applicability of film approximation in the theory of buoyancy-induced laminar boundary layer. Teplofizika visokih temperatur v. 38(2000), №5, pp. 845-848 (In Russian).
63. *L.A.Bolshov, P.S.Kondratenko, V.F.Strizhov*. Buoyancy-induced convection of heat generating liquid. Uspehi Fiz. Nauk Vol.171(2001), №10, pp.1051-1070.
64. *D.G.Griroruk, P.S.Kondratenko, D.V.Nikolski***,** Geometrical aspects in free convection of heat-generating fluid. The 10-th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-10), Seoul, Korea, October 5-9, 2003. CD, paper A00103.

**7. Technical Schedule**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Quarter 1** | **Quarter 2** | **Quarter 3** | **Quarter 4** | **Quarter 5** | **Quarter 6** | **Quarter 7** | **Quarter 8** | **Quarter 9** | **Quarter 10** | **Quarter 11** | **Quarter 12** | **Person\* Days** |
| **Task 1** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  | Model of melt formation and onset of melt relocation |  |  |  |  |  |  |  |  | 997 |
| **Person\*Days** | 256 | 247 | 247 | 247 |  |  |  |  |  |  |  |  | 997 |
| **Task 2** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  | Numerical module S\_CANDL |  |  |  |  |  | 741 |
| **Person\*Days** |  |  |  |  | 247 | 247 | 247 |  |  |  |  |  | 741 |
| **Task 3** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  |  |  |  | Numerical module S\_SLUG |  |  | 741 |
| **Person\*Days** |  |  |  |  |  |  |  | 247 | 247 | 247 |  |  | 741 |
| **Task 4** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  |  |  |  |  |  | SVECHA/MELT code | 494 |
| **Person\*Days** |  |  |  |  |  |  |  |  |  |  | 247 | 247 | 494 |
| **Task 5** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  |  |  |  |  |  | Analytical support of the ITU tests | 420 |
| **Person\*Days** | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 420 |
| **Task 6** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  | Mathematical model and numerical module of molten pool |  |  |  |  |  |  |  |  | 839 |
| **Person\*Days** | 215 | 208 | 208 | 208 |  |  |  |  |  |  |  |  | 839 |
| **Task 7** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  |  | Numerical and analitical support of the numerical module |  |  |  |  | 832 |
| **Person\*Days** |  |  |  |  | 208 | 208 | 208 | 208 |  |  |  |  | 832 |
| **Task 8** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  |  |  |  |  |  | Numerical module of molten pool at high Ra number | 831 |
| **Person\*Days** |  |  |  |  |  |  |  |  | 208 | 208 | 208 | 207 | 831 |
| **TOTAL** | **506** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **489** | **5895** |

**8. Personnel Commitments**

**8.1. Individual participants**

**Leading Institution: NSI RAS (IBRAE)**

***Category I (weapon scientific and technical personnel)***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth Year** | **Scientific Title** | **Weapon Expertise Ref.** | **Function in project** | **Daily Rate**  **(US $)** | **Total days** | **Total grants (US $)** |
| Sarkissov А.А. | 1924 | professor | 4.9 | Development of models | 32 | 340 | 10880 |
| Palagin A.V. | 1962 | doctor | 4.9 | Project sub-manager | 34 | 443 | 15062 |
| Aksenova A.E. | 1969 | doctor | 5.1 | Development of models | 33 | 330 | 10890 |
| Pervichko V.A. | 1967 | no | 5.1 | Development of models | 33 | 330 | 10890 |
| Chudanov V.V. | 1958 | doctor | 4.9 | Project sub-manager | 33 | 330 | 10890 |
| Kalantarov V.E. | 1958 | doctor | 5.2 | Development of models | 24 | 302 | 7248 |
| Evstratov Е.V. | 1961 | doctor | 4.9 | Validation of models and codes | 32 | 340 | 10880 |
| Bolshov L.А. | 1946 | professor | 4.9 | Development of models | 32 | 66 | 2112 |
| Veshchunov M.S. | 1956 | professor | 4.9 | Project Manager | 35 | 443 | 15505 |
| Kondratenko P.S. | 1939 | professor | 4.9 | Development of models | 32 | 46 | 1472 |
| Aroutyunian R.V. | 1954 | professor | 4.9 | Development of models | 32 | 340 | 10880 |
|  |  |  |  |  | **Total:** | 3310 | 106709 |

***Category II (other scientific and technical personnel)***

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth Year** | **Scientific Title** | **Function in project** | **Daily Rate**  **(US $)** | **Total days** | **Total grants (US $)** |
| Boldyrev A.V. | 1963 | no | Development of models | 33 | 443 | 14619 |
| Shestak V.E. | 1963 | no | Validation of models and codes | 33 | 442 | 14586 |
| Kuzmicheva | 1964 | no | Validation of models and codes | 24 | 440 | 10560 |
| Shpinkova L.G. | 1960 | doctor | Validation of models and codes | 24 | 244 | 5856 |
| Medved Yu.I. | 1965 | no | Validation of models and codes | 24 | 453 | 10872 |
|  |  |  |  | **Total:** | 2022 | 56493 |

***Category III (supporting personnel)***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | **Birth Year** | **Function in project** | **Daily Rate**  **(US $)** | **Total days** | **Total grants (US $)** |
| Karyukina T.V. | 1966 | Engineering support | 20 | 240 | 4800 |
|  |  |  | **Total:** | 240 | 4800 |

***Category IV (personnel, who will spend less than 22 days per year on the project)***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily Rate**  **(US $)** | **Total days** | **Total grants (US $)** |
| 7 | Engineering support | 19 | 323 | 6137 |
|  |  | **Total:** | 323 | 6137 |

**8.2. Managerial responsibilities**

**M.S.**

**Veshchunov**

**Project manager**

The laboratory of

condensed state

theory

Tasks

1

-

5

The laboratory of

computational heat

-

and hydrodynamics

Task

s

6

-

8

The organisational structure of the project and the managerial responsibilities.

**9. Financial Information**

**TABLE 1**

**Estimated Aggregated Expenditures by Recipient**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Category** | **Quarters 1 & 2** | | **Year 1** | | **Year 2** | | **Year 3** | | **Total** | |
|  |  |  | **(1)** | **(2)** | **(1)** | **(2)** | (1) | (2) | (1) | (2) | **(1)** | **(2)** |
| **1** |  | **Grant Payments:** |  |  |  |  |  |  |  |  |  |  |
|  | 1.1 | Category I |  | 18054.4 |  | 35786.4 |  | 35464 |  | 35464 |  | 106714.4 |
|  | 1.2 | Category II |  | 9555.48 |  | 18943.32 |  | 18775.68 |  | 18775.68 |  | 56494.68 |
|  | 1.3 | Category III |  | 800 |  | 1600 |  | 1600 |  | 1600 |  | 4800 |
|  | 1.4 | Category IV |  | 1026 |  | 2052 |  | 2052 |  | 2033 |  | 6137 |
|  |  | *Total Grant Payments* |  | **29435.88** |  | **58381.72** |  | **57891.68** |  | **57872.68** |  | **174146.08** |
| **2** |  | **Equipment:** |  |  |  |  |  |  |  |  |  |  |
|  | 2.1 | Capital Equipment |  |  |  |  |  |  |  |  |  |  |
|  | 2.2 | Non-Capital Equipment |  |  |  |  |  |  |  |  |  |  |
|  |  | *Total Equipment* |  |  |  |  |  |  |  |  |  |  |
| **3** |  | **Materials/Supplies** |  |  |  |  |  |  |  |  |  |  |
| **4** |  | **Bank Fees** |  |  |  |  |  |  |  |  |  |  |
| **5** |  | **Other Direct Costs:** |  |  |  |  |  |  |  |  |  |  |
|  | 5.1 | Technological Energy |  | 100 |  | 200 |  | 200 |  | 200 |  | 600 |
|  | 5.2 | Communications |  | 30 |  | 60 |  | 60 |  | 60 |  | 180 |
|  | 5.3 | Subcontracts/Seminars |  |  |  |  |  |  |  |  |  |  |
|  | 5.4 | Logistics/Customs |  |  |  |  |  |  |  |  |  |  |
|  | 5.5 | Other |  |  |  |  |  |  |  |  |  |  |
|  |  | *Total ODC* |  | **130** |  | **260** |  | **260** |  | **260** |  | **780** |
| **6** |  | **Travel:** |  |  |  |  |  |  |  |  |  |  |
|  | 6.1 | Internal \*\*\* |  |  |  |  |  |  |  |  |  |  |
|  | 6.2 | Outside CIS | 5000 |  | 5000 |  | 4000 |  | 4000 |  | 13000 |  |
|  |  | *Total Travel* | **5000** |  | **5000** |  | **4000** |  | **4000** |  | **13000** |  |
|  |  | **Overhead/Retainage** |  |  |  |  |  |  |  |  | **5379.51** |  |
|  |  | ***Subtotals*** | **5000** | **29565.88** | **5000** | **58641.72** | **4000** | **58151.68** | **4000** | **58132.68** | **18379.51** | **174926.08** |
|  |  | **Totals** | **34565.88** | | **63641.72** | | **62151.68** | | **62132.68** | | **193305.59** | |

Remarks: \* (1)-Cash flow through Recipient Account

\*\* (2)-Cash flow through ISTC

\*\*\* Include Local and inside CIS travel

**TABLE 1-1**

***Estimated Aggregated Expenditures by Leading Institution: NSI RAS (IBRAE)***

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Category** | **Quarters 1 & 2** | | **Year 1** | | **Year 2** | | **Year 3** | | **Total** | |
|  |  |  | **(1)** | **(2)** | **(1)** | **(2)** | (1) | (2) | (1) | (2) | **(1)** | **(2)** |
| **1** |  | **Grant Payments:** |  |  |  |  |  |  |  |  |  |  |
|  | 1.1 | Category I |  | 18054.4 |  | 35786.4 |  | 35464 |  | 35464 |  | 106714.4 |
|  | 1.2 | Category II |  | 9555.48 |  | 18943.32 |  | 18775.68 |  | 18775.68 |  | 56494.68 |
|  | 1.3 | Category III |  | 800 |  | 1600 |  | 1600 |  | 1600 |  | 4800 |
|  | 1.4 | Category IV |  | 1026 |  | 2052 |  | 2052 |  | 2033 |  | 6137 |
|  |  | *Total Grant Payments* |  | **29435.88** |  | **58381.72** |  | **57891.68** |  | **57872.68** |  | **174146.08** |
| **2** |  | **Equipment:** |  |  |  |  |  |  |  |  |  |  |
|  | 2.1 | Capital Equipment |  |  |  |  |  |  |  |  |  |  |
|  | 2.2 | Non-Capital Equipment |  |  |  |  |  |  |  |  |  |  |
|  |  | *Total Equipment* |  |  |  |  |  |  |  |  |  |  |
| **3** |  | **Materials/Supplies** |  |  |  |  |  |  |  |  |  |  |
| **4** |  | **Bank Fees** |  |  |  |  |  |  |  |  |  |  |
| **5** |  | **Other Direct Costs:** |  |  |  |  |  |  |  |  |  |  |
|  | 5.1 | Technological Energy |  | 100 |  | 200 |  | 200 |  | 200 |  | 600 |
|  | 5.2 | Communications |  | 30 |  | 60 |  | 60 |  | 60 |  | 180 |
|  | 5.3 | Subcontracts/Seminars |  |  |  |  |  |  |  |  |  |  |
|  | 5.4 | Logistics/Customs |  |  |  |  |  |  |  |  |  |  |
|  | 5.5 | Other |  |  |  |  |  |  |  |  |  |  |
|  |  | *Total ODC* |  | **130** |  | **260** |  | **260** |  | **260** |  | **780** |
| **6** |  | **Travel:** |  |  |  |  |  |  |  |  |  |  |
|  | 6.1 | Internal \*\*\* |  |  |  |  |  |  |  |  |  |  |
|  | 6.2 | Outside CIS | 5000 |  | 5000 |  | 4000 |  | 4000 |  | 13000 |  |
|  |  | *Total Travel* | **5000** |  | **5000** |  | **4000** |  | **4000** |  | **13000** |  |
|  |  | **Overhead/Retainage** |  |  |  |  |  |  |  |  | **5379.51** |  |
|  |  | ***Subtotals*** | **5000** | **29565.88** | **5000** | **58641.72** | **4000** | **58151.68** | **4000** | **58132.68** | **18379.51** | **174926.08** |
|  |  | **Totals** | **34565.88** | | **63641.72** | | **62151.68** | | **62132.68** | | **193305.59** | |

Remarks: \* (1)-Cash flow through Recipient Account

\*\* (2)-Cash flow through ISTC

\*\*\* Include Local and inside CIS travel

**10. Equipment and Materials Summary**

***10.1. Equipment Summary***

**TABLE 2*10.2. Materials Summary***

**TABLE 3*10.3. Single Equipment/Materials Items***

|  |  |  |
| --- | --- | --- |
| **DATA FOR A SINGLE EQUIPMENT/MATERIALS ITEM**  Project Agreement # 2936    (#1) | | |
| INSTRUCTIONS: | YOUR ATTENTION IS DRAWN TO THE IMPORTANCE OF COMPLETING AND ATTACHING THIS FORM, FOR EARCH EQUIPMENT ITEM REQUESTED THAT: |  |
|  | (a) a particular make be supplied | |
| Technical name of instrument and any necessary attachments: | Institute name: NSI RAS (IBRAE) | |
| 1. Tehnological Energy | Date needed (quarter): 1,2,3,4,5,6,7,8,9,10,11,12 | |
|  | Total estimated cost in USD: 600 | |
| Detailed technical specifications regarding performance and other relevant information of primary importance (reference to one specific make, although useful, is not sufficient): | | |
|  | | |
| Purpose for which instrument is to be used (please indicate reasons influencing or governing the selection of a specific type or size, etc.): | | |
|  | | |
| If this item should be compatible, interchangeable with existing equipment or maintenance services available for the Project, please describe that equipment and specify the manufacturer(s) and location of the nearest service: | | |
|  | | |
| Relevant facilities and infrastructure available for the equipment to be installed for the Project: | | |
| Building #  Room #  Person responsible: | | |
| Environmental conditions: Any unusual environmental conditions regarding temperature, humidity, altitude, etc., which must be considered in selecting equipment. (If air conditioning is available, how reliable is it? Is it shut off during the night or at certain times of the year? If so, specify.). Other factors that may cause delays or prevent implementation of the project as proposed above. | | |
|  | | |
| Any special custom formalities, which must be taken into account. | | |
|  | | |

***Form PR-2E of 3/98***

|  |  |  |
| --- | --- | --- |
| **DATA FOR A SINGLE EQUIPMENT/MATERIALS ITEM**  Project Agreement # 2936    (#2) | | |
| INSTRUCTIONS: | YOUR ATTENTION IS DRAWN TO THE IMPORTANCE OF COMPLETING AND ATTACHING THIS FORM, FOR EARCH EQUIPMENT ITEM REQUESTED THAT: |  |
|  | (a) a particular make be supplied | |
| Technical name of instrument and any necessary attachments: | Institute name: NSI RAS (IBRAE) | |
| 2. Communications | Date needed (quarter): 1,2,3,4,5,6,7,8,9,10,11,12 | |
|  | Total estimated cost in USD: 180 | |
| Detailed technical specifications regarding performance and other relevant information of primary importance (reference to one specific make, although useful, is not sufficient): | | |
|  | | |
| Purpose for which instrument is to be used (please indicate reasons influencing or governing the selection of a specific type or size, etc.): | | |
|  | | |
| If this item should be compatible, interchangeable with existing equipment or maintenance services available for the Project, please describe that equipment and specify the manufacturer(s) and location of the nearest service: | | |
|  | | |
| Relevant facilities and infrastructure available for the equipment to be installed for the Project: | | |
| Building #  Room #  Person responsible: | | |
| Environmental conditions: Any unusual environmental conditions regarding temperature, humidity, altitude, etc., which must be considered in selecting equipment. (If air conditioning is available, how reliable is it? Is it shut off during the night or at certain times of the year? If so, specify.). Other factors that may cause delays or prevent implementation of the project as proposed above. | | |
|  | | |
| Any special custom formalities, which must be taken into account. | | |
|  | | |

***Form PR-2E of 3/98***

***10.4. Other Direct Costs Summary***

**TABLE 4**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| OTHER DIRECT COSTS SUMMARY | | | | | | |
| **EQUIPMENT SUMMARY**  for Project Agreement #2936  To be provided in kind [ X ]  To be purchased by recipient [ ] | | | | | | |
|  | | | | | | |
| **Detailed breakdown of Other Directs Costs to include planned activities under items 5.1, 5.2, 5.3, 5.4, 5.5 from Table 1 of the Project Agreement** | | | | | | |
| **Item**  **No.** |  | **DESCRIPTION OF ITEM** | **Date needed (quarter)** | **Qty** | **Unit cost**  **(USD)** | **Amount**  **(USD)** |
| ***Leading Institution: NSI RAS (IBRAE)*** | | | | | | |
| 5.1 | X | 1. Tehnological Energy | 1-12 | 12 | 50 | 600 |
| 5.2 | X | 2. Communications | 1-12 | 12 | 15 | 180 |
| 5.3 |  | 3. Subcontracts/Seminars | 1 | 1 | 0 | 0 |
| 5.4 |  | 4. Logistics/Customs | 1 | 1 | 0 | 0 |
| 5.5 |  | 5. Other | 1 | 1 | 0 | 0 |
| Subtotal: | | | | | | 780 |
| Estimated TOTAL COST: | | | | | | 780 |

**Form PR-1OD of 3/04**

**TABLE 4-1**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| OTHER DIRECT COSTS SUMMARY | | | | | | |
| **EQUIPMENT SUMMARY**  for Project Agreement #2936  To be provided in kind [ ]  To be purchased by recipient [ X ] | | | | | | |
|  | | | | | | |
| **Detailed breakdown of Other Directs Costs to include planned activities under items 5.1, 5.2, 5.3, 5.4, 5.5 from Table 1 of the Project Agreement** | | | | | | |
| **Item**  **No.** |  | **DESCRIPTION OF ITEM** | **Date needed (quarter)** | **Qty** | **Unit cost**  **(USD)** | **Amount**  **(USD)** |
| ***Leading Institution: NSI RAS (IBRAE)*** | | | | | | |
| 5.1 |  | 1. Tehnological Energy | 1 | 1 | 0 | 0 |
| 5.2 |  | 2. Communications | 1 | 1 | 0 | 0 |
| 5.3 |  | 3. Subcontracts/Seminars | 1 | 1 | 0 | 0 |
| 5.4 |  | 4. Logistics/Customs | 1 | 1 | 0 | 0 |
| 5.5 |  | 5. Other | 1 | 1 | 0 | 0 |
| Subtotal: | | | | | | 0 |
| Estimated TOTAL COST: | | | | | | 0 |

**Form PR-1OD of 3/04**