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|  | PROJECT PROPOSAL | #  |

## I. Summary Project Information

### 1. Project Title and Taxonomy

|  |  |
| --- | --- |
| **Full title:** | **EXPERIMENTAL INVESTIGATION OF FLOW PULSATION EFFECTS ON BURNOUT IN RPV EXTERNAL COOLING SYSTEM** |
| **Short title:** | **FLOW PULSATION AT REACTOR VESSEL EXTERNAL COOLING (EXPULS)** |
| **Technology area:** | Nuclear reactors FIR-EXP, FIR-MOD, FIR-NSS |
| **Category of technology development:** | Applied research |

### 2. Project Manager

|  |  |
| --- | --- |
| **Name:** | MIGROV Yuri Andreyevich |
| **Title:** | Candidate of Science | **Position:** | Head of Division |
| **Street address:** | NITI |
| **City:** | Sosnovy Bor | **Region:** | Leningrad |
| **ZIP:** | 188540 | **Country:** | Russia |
| **Tel.:** | 7-81369-60703 | **Fax:** | 7-81369-23672 |
| **E-mail:** | migrov@niti.ru |

### 3. Participating Institutions

#### 3.1. Leading Institution

|  |  |
| --- | --- |
| **Short reference:** | NITI |
| **Full name:** | Alexandrov Research Institute of Technology |
| **Street address:** | NITI |
| **City:** | Sosnovy Bor | **Region:** | Leningrad |
| **ZIP:** | 188540 | **Country:** | Russia |
| **Name of Signature Authority:** | VASILENKO Viacheslav Andreyevich |
| **Title:** | Doctor of Science | **Position:** | Director General |
| **Tel.:** | 7-81369-22667 | **Fax:** | 7-81369-23672 |
| **E-mail:** | foton@niti.ru |
| **Governmental Agency:** | Federal Atomic Energy Agency |

#### 3.2. Other Participating Institutions

***No***

### 4. Foreign Collaborators/Partners

#### 4.1. Collaborators

|  |  |
| --- | --- |
| **Institution:** | FORTUM NUCLEAR SERVICES LTD |
| **Street address:** | Keilaniementie 1 |
| **City:** | Espoo | **Region/State:** |  |
| **ZIP:** |  | **Country:** | Finland |
| **Person:** | Olli Kymalainen |
| **Title:** |  | **Position:** | Vice President |
| **Tel.:** | +358 10 453 5388 | **Fax:** | +358-10-453 3403 |
| **E-mail:** | olli.kymalainen@fortum.com |

|  |  |
| --- | --- |
| **Institution:** | KOREA ATOMIC ENERGY RESEARCH INSTITUTE (KAERI) |
| **Street address:** | 150 Deokjin-dong, Yuseong-gu |
| **City:** | Daejeon | **Region/State:** |  |
| **ZIP:** | 305-353 | **Country:** | Republic of Korea |
| **Person:** | Sang-Baik Kim |
| **Title:** |  | **Position:** | Projector Leader |
| **Tel.:** | +82-42-868-8368 | **Fax:** | +82-42-861-2574 |
| **E-mail:** | sbkim2@kaeri.re.kr |

#### 4.2. Partners

***No***

### 5. Project Duration

24 months

### 6. Project Location and Equipment

|  |  |
| --- | --- |
| **Institution** | **Location, Facilities and Equipment** |
| **Leading Institution** | **Address:** Sosnovy Bor, Leningrad region, 188540, NITI, Division of Thermal-Physical Research (building 108, rooms 226, 427, 433; building 102, rooms 101, 104)**Facility:** the “KEDR”thermal-hydraulic natural circulation loop with a heated model of reactor lower head**Equipment:** 1. transformers and electric heaters ВАКГ-12/6-3200 and ВАКГ-12/6-12500;
2. centrifugal pump;
3. heat exchanger;
4. component cooling loop;
5. instrumentation;
6. the “Therm-2” data acquisition system;
7. computers;

managerial aids |

### 7. Total Project Effort

|  |  |
| --- | --- |
| **Total number of participants** | 20 |
| **Number of weapon scientists and engineers** | 13 |
| **Total project effort (person\*days)** | 5650 |
| **Total project effort of weapon scientists and engineers (person\*days)** | 4640 |

### 8. Financial Information

#### 8.1. Estimated Project Costs

|  |  |
| --- | --- |
| **Estimated total cost of the project (US $)** | 184000 |
| *Including:* |  |
| **Payments to Individual Participants** | 143930 |
| **Equipment** | 15000 |
| **Materials** | 1500 |
| **Other Direct Costs** | 1570 |
| **Travel** | 12000 |
| **Overhead** | 10000 |

#### 8.2. Funding Sources

|  |  |
| --- | --- |
| **Estimated total cost of the project (US $)** | 184000 |
| *Financial Sources:* |  |
| **Requested from the ISTC** | 184000 |
| **Other financial source 1** | 0 |
| *Non-Financial Sources:* |  |
| **Non-financial source 1** | 100000 |

### 9. Summary of the project

**Project goal** is to enhance the safety of water-cooled water-moderated nuclear reactors under core-melt accident conditions by improving experimental and theoretical support to the capability of core melt retention within the reactor vessel.

**Project tasks are as follows:**

* to obtain experimental data on burnout processes at the external surface of reactor pressure vessel (RPV) under coolant flow oscillation conditions;
* to verify the computer codes which model the mentioned processes.

To retain core melt within RPV is one of the possible ways to confine a severe accident. This approach is adopted in several VVER, PWR, and BWR NPP designs of unit power up to 1400 MWe.

The main condition for in-vessel core melt retention is prevention of burnout on the outer reactor wall cooled by external water. Burnout experiments were performed in a number of test facilities and their results were generalized and used in numerical analyses. All factors being equal, critical heat flux (CHF) depends on the coolant flow stability/instability. Significant flow oscillations can reduce CHF. Though flow oscillations were observed in some of the experiments, the oscillation rates were apparently too low to reduce CHF. However, no separate analysis of this effect was carried out.

The highest possible natural convection flow rate in RPV external cooling system can be achieved by minimizing the hydraulic resistance in the cooling loop, especially, in its upward part. This condition is also most favorable for maintaining the two-phase flow stability. In some designs, however, minimization of hydraulic resistance is hard to realize. Steam-water flow instability may result from subcooling in the water pool (tank) from which the coolant flows to the downcomer part of the circulation loop. Water temperature in the pool depends on accident scenario. In fact, subcooling can still exist at the time of molten pool formation in RPV lower head.

Obviously, knowledge of the quantitative dependence of CHF on the parameters that determine the coolant flow oscillations rate or delineation of the region where CHF is unaffected by those oscillations would facilitate designing of RPV external cooling systems and/or improve the quality of theoretical support to in-vessel retention concept.

Where external cooling of RPV cannot be realized in natural circulation loop, the only possibility will be gravity water flow from a tank (further referred to as the “top tank”) installed at elevation with respect to RPV. This possible solution is being considered for modernization of VVER-440 plants. Though passive cooling here cannot be maintained but for a limited time, this period is long enough to prepare back-up systems for operation, namely, the coolant water feed or the top tank make-up. Gravity-driven flow is also provided for cooling the in-vessel core catcher in Korean advanced reactor APR1400 design.

The project authors have developed an experimental program for studying the effect of flow oscillations on CHF level. Experiments will be carried out in the KEDR test facility (NITI). The facility was already used to obtain experimental data on natural convection CHF. This data was then compared to CHF measurements made in the forced circulation test facility PETLYA (NITI).

The KEDR test facility is a natural convection loop. The loop is nearly 7 m in height and incorporates an electrically heated 1:1 scale model of VVER-1000 RPV lower head (in slice geometry). Burnout is simulated using the “hot spot” method in two test areas inclined at 30o and 90o to the horizontal, respectively.

Gravity flow in experiments will be achieved by opening the loop seal. Experiments will be carried out with varied hydraulic resistance and water temperature (subcooling) in the top tank. Preliminary calculations will give the variation range for the parameter values determining the flow oscillation rates. Based on the first test results, the experiment matrix may be corrected.

Experimental data obtained will be analyzed and generalized to arrive at correlations between the flow oscillation rate and CHF level. Also, this data will be used for verification of RELAP5MOD3.2 and KORSAR Version 1.1 computer codes.

The project authors have gained much experience in studying the two-phase thermal-hydraulics and burnout effects at low pressures. They have performed a great number of experiments, developed theoretical models, and generalized experimental data in support of in-vessel retention (IVR) concept. Also, they have been developing thermal-hydraulic computer codes such as KORSAR and doing verification calculations for International Safety Problems with RELAP and KORSAR computer codes.

**The expected Project products will be:**

1. Original experiment data on burnout processes under conditions of interest.
2. Correlations between flow oscillation rate and critical heat flux level.
3. Results of RELAP5 MOD3.2 and KORSAR Version 1.1 verification against experiment data obtained.

**The project result can be used in:**

* designing of reactor vessel external cooling system and IVR analyses;
* extension of KORSAR and RELAP5MOD3.2 capabilities;
* verification of other thermal-hydraulic codes such as CATHARE and ATHLET;

**The project activities are broken into 4 tasks:**

Task 1 – Pretest calculations. Preparation of experimental setup. Development of experiment procedure. Description of experiment matrix.

Task 2 – Investigation of burnout in natural circulation loop.

Task 3 - Investigation of burnout under gravity flow conditions.

Task 4 – Verification of the computer codes.

Consistent with the scope of the project proposal, the following scope of collaboration with foreign institutions is proposed:

1. discussion and correction of the experiment matrix, if needed;
2. information exchange in the course of project implementation;
3. discussion of the technical reports for correction of the experiment procedures and verification calculations, if needed;
4. conduction of meetings and seminars;
5. preparation of joint papers

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|  | PROJECT PROPOSAL | # |

## II. Detailed Project Information

### 1. Introduction and Overview

The global project objective is to improve the safety state of water-cooled water-moderated nuclear reactors in a core-melt severe accident by enhancing experimental and theoretical support to the capability of core melt retention in the reactor vessel.

The task of the project is to obtain and summarize experimental data on burnout at the external surface of reactor pressure vessel (RPV) under coolant flow oscillation conditions, and verify the applicable computer codes.

To retain core melt inside RPV is one of the possible ways to confine a severe accident. This approach is adopted in several VVER, PWR, and BWR NPP designs of unit power up to 1400 MWe (VVER-440, VVER-640, the Westinghouse’s AP-600 and AP-1000, the Framatom’s BWR-1000, and KEPCO’s Advanced PWR-1400). The main condition for in-vessel retention of melt is prevention of burnout on the outer reactor wall cooled by external water. A number of large-scale experiments with burnout processes were performed in the following test facilities: ULPU (Loviisa NPP), ULPU-2000 (AP-600 project), ULPU-2400 (AP-1000), “PETLYA” and “KEDR” (VVER-640), SULTAN. The experiment results are described in the papers listed below.

1. Kymalainen O., Tuomisto H., Theofanous T.G. Critical heat flux on thick walls of large, naturally convecting loops //ANS Proceedings. 1992 National Heat Transfer Conference. San Diego, CA, Aug 9-12, 1992. Vol. 6. P.44-50.
2. Theofanous T.G., Syri S., Salmassi T., Kymalainen O., Tuomisto H. Critical heat flux through curved downward facing, thick walls //OECD/CSNI/NEA Workshop on large molten pool heat transfer. NRC Grenoble, France, 9-11 March, 1994.
3. Theofanous T.G., Syri S. The coolability limits of a reactor pressure vessel lower head // Proceedings of 7th International Meeting on Nuclear Reactor Thermal-Hydraulics NURETH-7. New York, Sept. 10-15, 1995. V.1.P.627-647.
4. Theofanous T.G. In-vessel retention as a severe accident management strategy// In-Vessel Core Debris Retention and Coolability. Workshop Proceedings 3-6 March 1998 Garching near Munich, Germany. NEA/CSNI/R(98) 18. February 1999. P. 53-74.
5. Bonnet J.M., Rouge S., Seiler J.M. Large scale experiments for core melt retention: BALI: Corium pool thermalhydraulics, SULTAN: boiling under natural convection // OECD/CSNI/NEA Workshop on large molten pool heat transfer. NRC Grenoble, France, 9-11 March, 1994.
6. Rouge S. SULTAN test facility for large-scale vessel coolability in natural convection at low pressure //Nuclear Engineering Design. 1997. V. 169. P. 185-195.
7. Rouge S., Dor I., Geffraye G. Reactor Vessel External Cooling for Corium Retention SULTAN Experimental Program and Modelling with CATHARE Code// In-Vessel Core Debris Retention and Coolability. Workshop Proceedings 3-6 March 1998 Garching near Munich, Germany. NEA/CSNI/R(98) 18. February 1991. P. 351-363.
8. Yu.A.Bezrukov, S.A.Logvinov, V.P.Onshin. Investigation of Heat Transfer from Reactor Lower Head in Fuel Melt Accidents // I-st Russian Conference on Heat Transfer. М.: MEI. 1994. Vol. 4, p. 19-25 (in Russian).
9. V.S.Granovski, V.K.Efimov, O.D.Cherny, S.M.Shmelev. Experimental Investigation of Burnout on VVER RPV Lower Head Outside Surface // I- st Russian Conference on Heat Transfer. М.: MEI. 1994. Vol. 4, p. 82-85 (in Russian).
10. V.S.Granovski, V.K.Efimov, O.D.Cherny. Experimental Determination of Critical Heat Flux under RPV External Cooling Conditions // Thermal-Physical Aspects of VVER Safety. Thermal Physics - 95. Proceedings of International Conference. November 21-24, 1995. Obninsk. Vol. 1, p. 190-195 (in Russian).
11. T.N. Dinh, J.P. Tu, T.G. Theofanous. Limits of coolability in the AP1000-related ULPU-2400 configuration V facility // The 10th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-10), Seoul, Korea, October 5-9, 2003.

Results of the above-listed studies were generalized and utilized in numerical safety analyses.

All factors being equal, critical heat flux (CHF) depends on the coolant flow stability. Significant flow oscillations may reduce CHF. Though flow fluctuations were observed in some of the experiments, the fluctuation rate was apparently too low to reduce CHF. However, no separate analysis of this effect was carried out. The said effects are reported in:

1. Theofanous T.G., Liu C., Addition S., Angelini S., Kymalainen O., Salmassi T. In-Vessel Coolability and Retention of a Core Melt//DOE/ID - 10460, V.1, Oct. 1996; Nucl. Eng. Des., 1997, V. 169, p. 1-48.
2. Kymalainen O., Tuomisto H., Theofanous T.G. In-Vessel Retention of Corium at the Loviisa Plant // Nucl. Eng. Des. 1997. V.169. P. 109-130.
3. T.N. Dinh, J.P. Tu, T.G. Theofanous. Two-phase Natural Circulation Flow in AP-1000 In-Vessel Retention Related ULPU-V Facility Experiments // Proceedings of ICAPP’04 Pittsburg, PA USA, June 13-17, 2004, Paper 4242.

The highest possible natural convection flow rate in RPV external cooling system can be achieved by minimizing the hydraulic resistance in the cooling loop, especially, in its upward part. This condition is also most favorable for the two-phase flow stability. In some designs, however, the minimization of hydraulic resistance is hard to realize. This is the case with plant designs in which external cooling of RPV is not originally provided and has to be considered during safety-related modernization. Moreover, steam-water flow instability may be caused by subcooling in the water pool from which the coolant flows to the downcomer part of the cooling loop. Water temperature in the pool depends on accident management program and accident scenario. In fact, subcooling may be maintained for a long period of time including the time needed for a molten pool to form in RPV lower head.

Obviously, knowledge of the quantitative dependence of CHF on the parameters that determine the flow oscillations rate or the region where CHF is unaffected by those oscillations would facilitate designing of RPV external cooling system and/or improve the quality of support to in-vessel retention concept.

Where external cooling of RPV cannot be realized in natural circulation loop, the only possibility will be gravity water flow from a tank installed at elevation with respect to RPV (further referred to as the “top tank”). This possible solution is being considered for modernization of VVER-440 plants. Though in this case passive cooling cannot be maintained but for a limited time, this period is long enough for back-up means of the forced convection cooling system to be prepared for actuation. Gravity-driven flow is also provided for cooling the in-vessel core catcher in Korean advanced reactor APR1400.

The project authors have developed an experimental program for studying the effect of flow oscillations on CHF. Experiments will be carried out in the KEDR test facility (NITI). The facility was already used to obtain experimental data on natural convection CHF. This data was then compared to CHF measurements made in the forced circulation test facility PETLYA (NITI).

The KEDR test facility is a natural convection loop. The loop is nearly 7 m in height and incorporates an electrically heated 1: 1 scale model of VVER-1000 RPV lower head (in slice geometry). Burnout is simulated by “hot spot” method in two test areas inclined at 30o and 90o to the horizontal, respectively. Gravity flow will be provided by making the loop open.

Experiments will be carried out at varied water temperatures (varied subcooling) in the top tank. Preliminary calculations will give the variation range for hydraulic resistance which determines the flow oscillation rate. Based on the first experiment results, the local hydraulic resistance values may be corrected.

The first series of experiments will be performed in a natural circulation loop. Water subcooling in the top tank will be varied over the range of 0...50°С. Loop hydraulic resistance will be also varied to cause the oscillation rate vary from the lowest value to one of an amplitude corresponding to the mean flow rate.

The second series of experiments will be performed under gravity flow conditions at the varied parameters as mentioned above except that subcooling variation in the top tank will be over the range of 40…800C.

To achieve high reliability of experimental results, at least three replica tests should be carried out.

Experimental data obtained will be analyzed and generalized to arrive at correlations between the flow oscillation rate and CHF value. Also, this data will be used for verification of RELAP5MOD3.2 and KORSAR Version 1.1 computer codes. Both thermal-hydraulic characteristics of two-phase flow and CHF in the codes will be verified against experiment data.

The project authors have gained much experience in studying the two-phase thermal-hydraulics and burnout at low pressures. They have performed a great number of experiments, developed theoretical models, and generalized experimental data in support of in-vessel retention (IVR) concept. They have been also developing thermal-hydraulic computer codes such as KORSAR and doing verification calculations for International Safety Problems with RELAP and KORSAR computer codes.

### 2. Expected Results and Their Application

The proposed project is classified as applied research. The expected project results are as follows.

1. Curved-wall burnout data obtained from experiments in RPV lower head large-scale model under both natural circulation conditions and where water is drained from the top tank at varied coolant subcooling value, hydraulic resistance, and, correspondingly, flow oscillation rate.
2. Correlations between amplitude-frequency characteristics of flow oscillation and critical heat flux value.
3. Results of RELAP5 MOD3.2 and KORSAR Version 1.1 verification against experimental data obtained.

The project result can be used in:

* designing of reactor vessel external cooling system and IVR analysis;
* verification of thermal-hydraulic codes such as CATHARE and ATHLET;
* extension of KORSAR and RELAP5MOD3.2 capabilities.

**2.1. Sustainability Implementation Plan**

2.1.1. Results to be promoted

Not expected

2.1.2. Uniqueness of results

No data for the effect of flow oscillations on burnout processes under conditions of interest is reported in open literature.

2.1.3. Demand for results

Potential users of the project results are designers of reactor systems and regulatory organizations in nuclear countries.

2.1.4. Expected income

Not expected

2.1.5. IPR situation

Intellectual property is protected by prevention of disclosure

2.1.6. Additional developments

Not required

2.1.7. Plan of implementation

Commercialization is not planned.

2.1.8. Additional licenses or permits

Not required.

2.1.9. Business network

Not planned.

### 3. Meeting ISTC Goals and Objectives

20 persons including 13 weapon scientists and engineers will be involved in the project activities for the period of 24 months. The project work in full will be done by Alexandrov NITI under Russia’s Federal Atomic Energy Agency.

The project will:

* provide weapon scientists and engineers with the opportunity to redirect their talents to research activities in the civil sector;
* support applied research for peaceful purposes, particularly, in nuclear safety and environmental protection fields;
* promote integration of Russian scientists into the international scientific community.

Therefore, the project fully responds the ISTC goals.

### 4. Scope of Activities

The estimated project duration is two years. The project activities are broken into four tasks. Each task is oriented to achievement of the project objective specified as acquisition of experimental data for the influence of flow oscillations on burnout at RPV outer wall and verification of applicable computer codes.

Task 1 – Pretest calculations. Preparation of experimental setup. Development of experiment procedure. Detailed description of experiment matrix.

Task 2 – Investigation of burnout in natural circulation loop.

Task 3 - Investigation of burnout under gravity flow conditions.

Task 4 – Verification of the computer codes.

Each task is divided into sub-tasks (steps).

#### Task 1

|  |  |
| --- | --- |
| **Task description and main milestones** | **Participating Institutions** |
| Design and description of experimental setup for KORSAR and RELAP calculations, pretest calculations of steam-water flow regimes at varied subcooling and hydraulic resistance; manufacture of components to the experimental setup; development of experiment procedures.Task steps:* 1. Pretest calculations, manufacture of components and assembly of the experimental setup, development of procedure for carrying out Task 2 experiments;
	2. Pretest calculations, manufacture of components and assembly of experimental setup, development of procedure for carrying out Task 3 experiments.
 | 1- NITI |
| **Description of deliverables** |
| 1 | Technical information in Quarter reports |
| 2 | Description of the experimental setup |
| 3 | Minutes of collaborator meetings |

#### Task 2

|  |  |
| --- | --- |
| **Task description and main milestones** | **Participating Institutions** |
| Investigation of burnout in flow-oscillating natural circulation loop with varied burnout region, hydraulic resistance at the outlet of the loop riser part, and water temperature in the top tank representing emergency water poolTask steps:2.1 Conduction of experiment runs2.2 Analysis and generalization of results | 1-NITI |
| **Description of deliverables** |
| 1 | Test reports |
| 2 | Graphic materials |
| 3 | Chapter in Annual Report |

#### Task 3

|  |  |
| --- | --- |
| **Task description and main milestones** | **Participating Institutions** |
| Investigation of burnout under gravity flow conditions for varied burnout regions, hydraulic resistance, and water temperature at the inlet of the heated length and lower head model. Task steps:3.1 Conduction of experiment runs3.2 Analysis and generalization of results | 1-NITI |
| **Description of deliverables** |
| 1 | Test reports |
| 2 | Graphic materials |
| 3 | Chapter in Annual Report |

#### Task 4

|  |  |
| --- | --- |
| **Task description and main milestones** | **Participating Institutions** |
| Verification calculations with RELAP5MOD3.2 and KORSAR Version 1.1 against experiment data.Task steps:4.1 Calculations of Task 2 experiment scenarios 4.2 Calculations of Task 3 experiment scenarios | 1-NITI |
| **Description of deliverables** |
| 1 | Verification results for two-phase flow thermal-hydraulics |
| 2 | Verification results for CHF |
| 3 | Chapter in Annual Report |
| 4 | Project Final Report |

### Tasks interfaces are shown in fig. 1.

# Tasks 1…4 Interfaces


### Fig. 1

Completion of each step (sub-task) will be documented in the format of evaluation report which will be forwarded to collaborators for review and discussion. Based on discussion results, the experiment matrix may be corrected.

After completion of each project year, an Annual report will be issued and discussed at collaborator meetings.

### 5. Role of Foreign Collaborators/Partners

Consistent with the scope of the project proposal as described above, the following scope of cooperation with foreign institutions is proposed:

* discussion and correction of the experiment matrix, if needed;
* information exchange in the course of project implementation;
* discussion of the technical reports for correction of the experiment procedures and verification calculations, if needed;
* conduction of meetings and seminars;
* preparation of joint papers.

### 6. Technical Approach and Methodology

NITI has been involved in experimental, numerical, and theoretical research of burnout effects and steam-water thermal-hydraulics for about 20 years. Since 1990, NITI scientists have been investigating the problem of in-vessel core melt retention. A series of CHF experiments were performed in the PETLYA forced-convection test facility modelling the outer wall of RPV lower head. A process model was proposed and a correlation was developed which generalized experimental data both obtained from NITI experiments and reported in the literature. The PETLYA experiment data was compared to the KEDR natural convection experiment data for a narrow parametric variation range.

The main component of both PETLYA and KEDR facilities is VVER-1000 (VVER-640) reactor lower head model. The model is implemented in slice geometry, 1:1 scale, ? axial section. The model is a curved 25 mm thick steel plate of 90 mm width provided with two 100 x 90 mm milled grooves.The plate thickness in the grooves is 7 mm. They represent “hot spots” where burnout is initiated. The angles of the plate inclination to the horizontal at these spots are ~ 300 and 900. The plate is directly heated by electric current coming through leads from a rectifier unit (maximum current is 12500A, maximum voltage is 12 V).

The plate is held in a duct with bearing sockets to form a curved channel of 100x100 mm section. In the KEDR configuration, this channel is in the bottom part of the loop riser. A free-level tank is installed at the top of the loop and open to pressure of ~ 0.1 MPa. Water temperature in the tank is controlled by in-built heat exchanger. The height of the circulation loop is about 7 m.

Burnout is achieved by increasing power in steps and holding it constant at each step long enough to reach the stable parameter state. The burnout onset is detected from signals of thermocouples placed in the “hot spot” region.

### The main measured parameters:

* pressure (pressure gage Sapfir - 2DI );
* pressure difference (pressure differential gage Sapfir – 2DD);
* water flow rate (induction flow meter IR 61);
* coolant temperature (cable microthermocouples of K type; resistance thermometer of TSP type);
* plate temperature at different locations (cable microthermocouples of K type).

Output circuits of the sensing devices are connected to the PCI-MIO-16XE-50 multi-function input/output unit ( manufacturer: «National Instruments») installed in РС «Pentium-II». Recording and processing of experimental data is performed with «LabVIEW V4.0» program package.

Experiments according to the project work plan will be carried out in the KEDR test facility. The existing measurement system of KEDR may be modified for the experiment purposes. Experiments with gravity flow will be performed in a modified facility configuration: gravity flow will be arranged by opening the natural circulation loop and water flowing from the top (gravity) tank.

The thermal-hydraulic effects in steam-water flow including burnout on heated surface will be calculated with NITI-developed KORSAR code (Version 1.1, RF Gosatomnadzor Certificate of December 23, 2003) and RELAP5MOD3.2 which has been used by NITI scientists for solution of selected International Safety Problems. The both computer codes will be verified against data obtained from the experiments as planned within the proposed Project.

### 7. Technical Schedule

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Quarter 1** | **Quarter 2** | **Quarter 3** | **Quarter 4** | **Quarter 5** | **Quarter 6** | **Quarter 7** | **Quarter 8** | **Person\*days** |
| **Task 1**Pretest calculations. Preparation of experimental setup. Development of experiment procedure. Detailed description of experiment matrix | Meeting with Collaborators |  |  | Meeting with Collaborators |  |  |  |  |  |
| **Person\*days** | **720** |  |  | **300** |  |  |  |  | **1020** |
| **Task 2**Investigation of burnout in natural circulation loop |  |  |  | Annual report |  |  |  |  |  |
| **Person\*days** |  | **480** | **480** | **400** |  |  |  |  | **1360** |
| **Task 3**Investigation of burnout under gravity flow conditions |  |  |  |  |  |  |  | Annual Report |  |
| **Person\*days** |  |  |  |  | **430** | **430** | **430** | **490** | **1780** |
| **Task 4**Verification of computer codes |  |  |  |  |  |  |  | Final ReportMeeting with CollaboratorsPublication |  |
| **Person\*days** | **90** | **200** | **200** | **200** | **200** | **200** | **200** | **200** | **1490** |
| **TOTAL** | **810** | **680** | **680** | **900** | **630** | **630** | **630** | **690** | **5650** |

### 8. Personnel Commitments

#### 8.1. Individual participants

### Leading Institution: NITI

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth****Year** | **Scientific Title** | **Weapon****Expertise Ref.** | **Function in project** | **Daily rate****(US$)** | **Total days** | **Total grants****(US$)** |
| Migrov Yuri Andreyevich | 1946 | Cand. Sc | 4.9 | Project Manager | 35 | 400 | 14000 |
| Verbitski Yuri Grigorievich | 1964 |  | 4.9 | Calculations | 30 | 400 | 12000 |
| Gudoshnikov Andrey Nikolayevich | 1960 |  | 4.9 | Calculations | 30 | 400 | 12000 |
| Efimov Vladimir Kazimirovich | 1951 | Cand. Sc. | 4.9 | Experiments | 30 | 400 | 12000 |
| Granovsky Vladimir Semenovich | 1941 | Cand. Sc | 4.9 | Theoretical studies and experiments | 30 | 400 | 12000 |
| Sulatsky Andrey Nikolayevich | 1960 | Cand. Sc. | 4.9 | Theoretical studies | 30 | 400 | 12000 |
| Cherny Oleg Dmitriyevich | 1964 |  | 4.9 | Experiments | 30 | 400 | 12000 |
| Kuvshinova Olga Vladimirovna | 1975 |  | 4.9 | Calculations | 25 | 400 | 10000 |
| Malikov Timofei Borisovich | 1966 |  | 4.9 | Experiments | 25 | 400 | 10000 |
| Podymaka Nikolay Fedorovich | 1941 |  | 4.9 | Experiments | 25 | 400 | 10000 |
| Shmelev Serguei Mihailovich | 1960 |  | 4.9 | Calculations | 25 | 400 | 10000 |
| Anikina Elena Vasilyevna | 1953 |  | 4.9 | Translations | 20 | 140 | 2800 |
| Philippov Evgueny Mihailovich | 1948 | Cand. Sc. | 4.9 | Patent and information support | 20 | 100 | 2000 |
| **Total:** | **4640** | **130800** |

#### Supporting Personnel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily rate****(US$)** | **Total days** | **Total grants****(US$)** |
| 4 | Material support | 13 | 350 | 4550 |
| 2 | Experiment work | 13 | 510 | 6630 |
| 1 | Office work | 13 | 150 | 1950 |
| **Total:** | **1010** | **13130** |

#### 8.2. Managerial responsibilities

The managerial responsibilities diagram is shown below


### 9. Financial Information

### 9.1. Estimated Project Costs (US $)

|  |  |
| --- | --- |
| **Estimated total cost of the project** | **184000** |
| **Leading Institution** | **184000** |

#### 9.1.1. Payments to Individual Participants (US $)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Institution** | **Category I** | **Category II** | **Supporting personnel** | **Total** |
| **Leading Institution** | **130800** | 0 | **13130** | **143930** |
| ***Subtotal:*** | **143930** |

#### 9.1.2. Equipment

|  |  |  |
| --- | --- | --- |
| **Institution** | **Equipment description** | **Cost (US $)** |
| **Leading Institution** | Sensors, computer, printer, scanner, notebook, monitor | 15000 |
| ***Subtotal:*** | 15000 |

#### 9.1.3. Materials

|  |  |  |
| --- | --- | --- |
| **Institution** | **Materials description** | **Cost (US $)** |
| **Leading Institution** | - Raw materials- Expendable materials- Spare materials | 500500500 |
| ***Subtotal:*** | **1500** |

#### 9.1.4. Other Direct Costs

|  |  |  |
| --- | --- | --- |
| **Institution** | **Direct costs description** | **Cost (US $)** |
| **Leading Institution** | - Reports/ Publishing- Communications- Admin. Supplies- Bank Fees- Other | 150300150600370 |
| ***Subtotal:*** | **1570** |

#### 9.1.5. Travel costs (US $)

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution** | **CIS travel** | **International travel** | **Total** |
| **Leading Institution** | 1200 | 10800 | **12000** |
| ***Subtotals:*** | 1200 | 10800 | **12000** |

#### 9.1.6. Overhead (US $)

|  |  |  |
| --- | --- | --- |
| **Institution** |  | **Amount** |
| **Leading Institution** |  | **10000** |
| ***Subtotal:*** | **10000** |

### 9.2. Funding Sources

|  |  |
| --- | --- |
| **Estimated total cost of the project (US $)** | **184000** |

#### 9.2.1. Financial Sources

|  |  |  |
| --- | --- | --- |
| **Financial Source** | **Written confirmation (Y/N)** | **Amount****(US $)** |
| **Requested from the ISTC** |  | **184000** |
| Other financial source 1 | - | - |

#### 9.2.2. Non-Financial Sources

|  |  |  |  |
| --- | --- | --- | --- |
| **Source** | **Short description of contribution** | **Written confirmation (Y/N)** | **Estimated****amount****(US $)** |
| NITI | Facilities and equipment. Payment of equipment maintenance costs. Transport services. | Y | **100000** |

#### 9.2.3. Submitted for Funding to Program Beside the ISTC

###### No

### 10. Intellectual Property Statement

The rights for intellectual property that are generated during the course of the project will be regulated by the laws of the Russian Federation and by the procedures, which have been developed by the ISTC.

The general conditions on Intellectual Property Rights as described in the Model Project Agreement will be observed.

### 11. Monitoring and Auditing Statement

In accordance with Article VIII of the ISTC Agreement, project recipients will give to the Center and to each Party which wholly or partly finances a project the right of access to carry out on-site monitoring and audit of all activities of the project. Project agreements will specify the portions of facilities, equipment, documentation, information, data systems, materials, supplies, personnel, and services which will concern the project and therefore will be made accessible for monitoring and audit. Project recipients shall have the right to protect those portions of facilities that are not related to the project.

### 12. Supporting Information

The list of published papers on the project topic by the key project authors is presented below.

1. Sulatskii A.A., Chernyi O.D., Efimov V.K., Granovskii V.S. Burnout on the External Surface of a VVER Reactor Vessel //Thermal Engineering. 1998. V.45. №11. P. 913-918.
2. Rogov M.F., Logvinov S.A., Granovskii V.S., Kovtunova S.V., Khabenskii V.B., Bezlepkin V.V., Kukhtevich I.V. Analyzing the Possibility of Retaining the Corium in the Vessel of a VVER-640 Reactor in a Severe Accident with a Damage Core//Thermal Engineering. 1996. V. 43. № 11. P. 888-892.
3. S.N.Volkova, V.S.Granovski, V.K.Efimov, O.V.Kuvshinova. Thermal-Hydraulic Aspects of Reactor External Cooling in Support of VVER In-Vessel Core Melt Retention // Minatom Conference «Fluid Dynamics and NPP Safety», Obninsk, September 28-30, 1999, p. 237-239 (in Russian).
4. Migrov Yu.A.,Volkova S.N., Yudov Yu. V., Danilov I.G., Korotaev V.G., Kutyin V.V., Bondarchik B.R., Benedictov D.V. KORSAR: A new generation computer code for numerically modeling dynamic behavior of nuclear power installations. ICONE-9, Rep.№545, Book of Abstracts, v.2. pp. 546-547, France, Nice, April 8-12, 2001.
5. Vasilenko V.A., Migrov Yu. A., Volkova S.N., Yudov Yu.V., Danilov I.G., Korotaev V.G., Kut′in V.V., Bondarchik B.R., Benediktov D.V. Experience in Creating the Thermohydraulic Computer Code of the New Generation KORSAR and Its Main Characteristics// Thermal Engineering. 2002. V. 49. №11. Р. 888-894.
6. Sulatskii A.A., Chernyi O.D., Efimov V.K. Investigation of the Crisis of Heat Transfer under Conditions of Boiling on an Inclined Surface Facing Downward // High Temperature. 2002. V. 40. № 6. P. 912-918.
7. Yu. A. Migrov, I. V. Chernov and Yu. V. Yudov. The Results of Verification of the Computational Codes DZHIP and RELAP5 in the ISB-VVER Test Facility on the Basis of Standard Safety Problems SPB-1 and SPB-2// Thermal Engineering. 1999. V.46. No. 3.
8. V.B.Habenski, Yu.A.Migrov, V.K.Efimov. Coolant Flow Patterns and Burnout in Fuel/Clad Gap Model with Bypass at Low Velocities and Downward Flow in Loop// Thermal Engineering. 1991. V.38. No. 11.
9. Yu.A.Migrov, O.V.Tokar, V.B.Habenski, V.K.Efimov. Burnout in Single Channel// Thermal Engineering. 1988. V. 35. No. 12.