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|  | PROJECT PROPOSAL | #3936 |

## I. Summary Project Information

### 1. Project Title and Taxonomy

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| **Full title:** | Study of fuel assemblies with boron carbide absorber rods under severe accident conditions in the PARAMETER-SF tests series | | |
| **Short title:** | PARAMETER-SF | | |
| **Technology area:** | | FIR-ENG, FIR-EXP, FIR-MOD, FIR-MAT | |
| **Category of technology development:** | | | Applied Research |
| **Key words:** | VVER-1000, fuel assembly, absorber rod, severe accident, tests, PARAMETER test facility | | |

### 2. Project Manager

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Name:** | | Nalivaev Vladimir Ivanovich | | | | | | |
| **Title:** | Ph.D. | | | | **Position:** | | Division Deputy Director, FSUE SRI SIA “LUCH” | |
| **Street address:** | | | | Zheleznodorozhnaya 24 | | | | |
| **City:** | Podolsk | | | | **Region:** | | Moscow | |
| **ZIP:** | 142100 | | | | **Country:** | | | Russian Federation |
| **Tel.:** | +7 (4967) 69-2792 | | | | **Fax:** | +7 (4967) 54-8589 | | |
| **E-mail:** | | | dvp@luch.podolsk.ru | | | | | |

### 3. Participating Institutions

#### 3.1. Leading Institution

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | FSUE SRI SIA “LUCH” | | | | | | |
| **Full name:** | | | Federal State Unitarian Enterprise “Scientific Research Institute Scientific Industrial Association “LUCH” | | | | | | | | |
| **Street address:** | | | | Zheleznodorozhnaya 24 | | | | | | | |
| **City:** | Podolsk | | | | | | | **Region:** | | Moscow | |
| **ZIP:** | 142100 | | | | | | | **Country:** | | | Russian Federation |
| **Name of Signature Authority:** | | | | | | | Chervyakov Leonid Dmitrievich | | | | |
| **Title:** |  | | | | | | | **Position:** | | Deputy General Director | |
| **Tel.:** | +7 (4967) 69-9449 | | | | | | | **Fax:** | +7 (4967) 54-8589 | | |
| **E-mail:** | | dvp@luch.podolsk.ru | | | | | | | | | |
| **Governmental Agency:** | | | | | | State Atomic Energy Corporation “Rosatom” | | | | | |

#### 3.2. Other Participating Institutions

#### Participant Institution 1

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | IBRAE RAS | | | | | | |
| **Full name:** | | | Nuclear Safety Institute of Russian Academy of Sciences | | | | | | | | |
| **Street address:** | | | | B. Tulskaya 52 | | | | | | | |
| **City:** | Moscow | | | | | | | **Region:** | |  | |
| **ZIP:** | 115191 | | | | | | | **Country:** | | | Russian Federation |
| **Name of Signature Authority:** | | | | | | | Bolshov Leonid Aleksandrovich | | | | |
| **Title:** | Prof., Corresponding member of RAS | | | | | | | **Position:** | | Director | |
| **Tel.:** | (495) 952-2421 | | | | | | | **Fax:** | (495) 958-0040 | | |
| **E-mail:** | | bolshov@ibrae.ac.ru | | | | | | | | | |
| **Governmental Agency:** | | | | | | Russian Academy of Sciences | | | | | |
| **Sub-manager:** | | | | Kisselev Arkadi Evgenievich | | | | | | | |
| **Title:** | Ph.D. | | | | | | | **Position:** | | Head of Department | |
| **Tel.:** | (495) 955-2324 | | | | | | | **Fax:** | (495) 958-1151 | | |
| **E-mail:** | | ksv@ibrae.ac.ru | | | | | | | | | |

#### Participant Institution 2

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | OKB “GIDROPRESS” | | | | | | |
| **Full name:** | | | Joint Stock Company “Experimental and Design Organization “GIDROPRESS” awarded the Order of the Red Banner of Labour and CZSR of Labour” | | | | | | | | |
| **Street address:** | | | | Ordzhonikidze 21 | | | | | | | |
| **City:** | Podolsk | | | | | | | **Region:** | | Moscow | |
| **ZIP:** | 142103 | | | | | | | **Country:** | | | Russian Federation |
| **Name of Signature Authority:** | | | | | | | Mokhov Victor Pavlovich | | | | |
| **Title:** |  | | | | | | | **Position:** | | Chief Designer-Head of Division | |
| **Tel.:** | (495) 502-7910 | | | | | | | **Fax:** | (4967) 542733 | | |
| **E-mail:** | | grpress@grpress.podolsk.ru | | | | | | | | | |
| **Governmental Agency:** | | | | | | State Atomic Energy Corporation “Rosatom” | | | | | |
| **Sub-manager:** | | | | Semishkin Valery Pavlovich | | | | | | | |
| **Title:** | Ph.D. | | | | | | | **Position:** | | Deputy Head of Department | |
| **Tel.:** | (495) 5027918 | | | | | | | **Fax:** | (4967) 542733 | | |
| **E-mail:** | | semishkin@grpress.podolsk.ru | | | | | | | | | |

### 4. Foreign Collaborators/Partners

#### 4.1. Collaborators

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Institution:** | | | | Forschungszentrum Karlsruhe | | | | | | |
| **Street address:** | | | | | Hermann-von-Helmholtz Pl. 1 | | | | | |
| **City:** | Eggenstein-Leopoldshafen | | | | | **Region/State:** | | | |  |
| **ZIP:** | 76344 | | | | | **Country:** | | | Germany | |
| **Person:** | | | Stuckert, Juri | | | | | | | |
| **Title:** | | Ph.D. | | | | **Position:** | | Senior Scientific Officer | | |
| **Tel.:** | (+49) 7247/82-2558 | | | | | **Fax:** | (+49) 7247/82-2095 | | | |
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| **Institution:** | | | | Joint Research Centre, Institute for Transuranium Elements (JRC-ITU) | | | | | | |
| **Street address:** | | | | | Hermann-von-Helmholtz Pl. 1 | | | | | |
| **City:** | Karlsruhe | | | | | **Region/State:** | | | |  |
| **ZIP:** | 76125 | | | | | **Country:** | | | Germany | |
| **Person:** | | | Bottomley, David | | | | | | | |
| **Title:** | | Ph.D. | | | | **Position:** | | Senior Scientific Officer | | |
| **Tel.:** | (49-7247)951-364 | | | | | **Fax:** | (49-7247)951-591 | | | |
| **E-mail:** | | | David.Bottomley@ec.europa.eu | | | | | | | |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Institution:** | | | | Électricité de France (EDF) | | | | | | |
| **Street address:** | | | | | 1 avenue du General de Gaulle | | | | | |
| **City:** | Paris | | | | | **Region/State:** | | | | Clamart |
| **ZIP:** | 92141 | | | | | **Country:** | | | France | |
| **Person:** | | | Lamy, Jean-Sylvestre | | | | | | | |
| **Title:** | |  | | | | **Position:** | | Manager of the Severe Accident R&D Team | | |
| **Tel.:** | +33(1)4765-4059 | | | | | **Fax:** | +33(1) 4765-3499 | | | |
| **E-mail:** | | | Jean-sylvestre.lamy@edf.fr | | | | | | | |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Institution:** | | | | Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) | | | | | | |
| **Street address:** | | | | | Schwertnergasse 1 | | | | | |
| **City:** | Köln | | | | | **Region/State:** | | | |  |
| **ZIP:** | 50667 | | | | | **Country:** | | | Germany | |
| **Person:** | | | Trambauer, Klaus | | | | | | | |
| **Title:** | | Ph.D. | | | | **Position:** | | Senior Scientific Officer | | |
| **Tel.:** | +49(89)32004-436 | | | | | **Fax:** | +49(89)32004-599 | | | |
| **E-mail:** | | | klaus.trambauer@grs.de | | | | | | | |

#### 4.2. Partners

None

### 5. Project Duration

24 months

### 6. Project Location and Equipment

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| --- | --- |
| **Institution** | **Location, Facilities and Equipment** |
| **Leading Institution** | **Building #1**  Room #117 – section for assembly of fuel rod dummies, model fuel assemblies, and inspection tests of technical parameters.  Main equipment:   1. Assembly racks – 2, 2. Argon-arc welding device – 1, 3. Electrocontact welding device – 1, 4. Lathe – 1, 5. Drilling machine – 1, 6. Tool-grinding machine – 1, 7. Electronic scales – 1, 8. Wiring table.   Room #115 – technological systems of PARAMETR facility: water treatment, steam generation, by-pass.  Rooms #115à, 115á – technological systems of PARAMETR facility: containment, gas feeding, systems for commutation of test parameters.  Room #115в – technological systems of PARAMETR facility: high-temperature heat exchanger, mixer, sampler for gas analysis.  Room #211 – technological systems of PARAMETR facility: power supply, system of control of power supply of FA.  Room #304 – technological systems of PARAMETR facility: sampler for gas analysis, chromatograph.  Room #215 – control room. 4 PC computers.  **Material research section:**  Room #210 – X-ray diffractometer.  Room #212 – electronic microscope, optical microscope.  Rooms #301, 303 – sampling section.  Machines: cutting-off machine, pressing machine, grinding machine, polishing machine.  **Building #116/1A**  Rooms #813, 814 – calculation and theoretical department.  Main equipment: 6 PC computers. |
| **Participant Institution 1** | Rooms #301, 302, 304, 306, 308  Main equipment: required computing machinery |
| **Participant Institution 2** | **Building #1**  Rooms # 606a, 608  **Building #2**  Rooms # 502, 505, 615  Main equipment: 10 PC |

### 7. Total Project Effort

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| --- | --- |
| **Total number of participants** | 62 |
| **Number of weapon scientists and engineers** | 33 |
| **Total project effort (person\*days)** | 11937 |
| **Total project effort of weapon scientists and engineers (person\*days)** | 6284 |

### 8. Financial Information

#### 8.1. Estimated Project Costs

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| --- | --- |
| **Estimated total cost of the project (US $)** | **600000** |
| ***Including:*** |  |
| **Payments to Individual Participants** | **362000** |
| **Equipment** | **70000** |
| **Materials** | **54000** |
| **Other Direct Costs** | **19000** |
| **Travel** | **60000** |
| **Overhead** | **35000** |

#### 8.2. Funding Sources

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| **Estimated total cost of the project (US $)** | 600000 |
| *Financial Sources:* |  |
| **Requested from the ISTC** | 600000 |
| Other financial source 1: | 0 |
| *Non-Financial Sources:* |  |
| **Non-financial source 1:** | 0 |

### 9. Summary of the project

Nowadays a serious risk appears all over the world concerning availability of power resources, safe production of energy, changes in climate and quality of the air, therefore there is an increase in the role of nuclear power it could play in the future power systems and energy supply. However the long-term prospects of nuclear power utilization should be considered in general context of assurance of safety, economic competitiveness and risks of proliferation.

Safety assurance is one of the main tasks in designing, construction, operation and decommissioning of NPP. The key role in NPP safety problem is devoted to reliability of nuclear reactor control features. The considerable reliability improvement of control features can be gained by usage of radiation-resistant and high efficient absorbing materials.

For successful and efficient usage of such materials and structures the calculational and experimental verification of their availability is necessary not only for the operation conditions but also for the conditions of postulated design basis accidents (DBA) and initial stages of beyond design basis accidents (BDBA), and the studies are required for the effect of AR structural materials on the core behavior at the initial stage of the severe accident with partial or complete melting of the core components.

In the analysis of accident a special attention should be paid to the interference of fuel rods and absorbing rods (AR) within the FA. Deformation of fuel rod claddings could lead to deformation and blockage of the guiding tube and the AR cladding itself. Melting and relocation of AR components can cause the additional core overheating both due to reaching the state of local criticality and power spike, and due to blockage with melt of flow area of some sells of spacing grids and worsening of the fuel rods cooling conditions.

For detailed study of the core structural components interaction processes the complex bench studies are required for the behaviour of absorbing rods in a set of FA, including fuel rods, spacing grids and guiding channels under the conditions simulating severe accident at VVER reactor plant.

The PARAMETER facility in SRI SIA “LUCH” is the most appropriate for such kind of studies, that allows to conduct the required scope of experimental and material studies with the calculational and methodical support of studies made by specialists of IBRAE RAS, OKB “GIDROPRESS”, VNIINM, RRC “Kurchatov Institute”, SRI SIA “LUCH” and JSC “MZP”.

The studies of AR behaviour under accidents shall include the following:

1. study of AR thermomechanical behaviour under tests of the model FAs using different scenarios of DBA and BDBA;
2. post-test material studies of FA and AR to determine the following:
3. the degree of cladding oxidation over AR length depending on temperature;
4. the degree of metal melting of the cladding, guiding tube and AR materials;
5. the composition of the solidified mixtures after flowing down of melt and formation of solid layer of melted structural materials (corium) that can blocks the coolant cross section;
6. the character of cooling of the model assembly with AR under top flooding.

On the basis of the analysis of indications of measured temperature and using the post-test material studies it is possible to identify the processes and temperature regimes that caused damage and melting of structural components.

The objective of the proposed Project is the study of behaviour of two 18-rods model FAs of VVER-1000 with the guiding tube and the central AR, completed with standard reactor materials (structural materials, fuel pellets and boron carbide absorber rods) under the conditions of the initial stage of severe accident with top flooding.

The studies planned in new Project present a continuation of PARAMETER-SF test series at the PARAMETER test facility started under ISTC Projects # 3194 and # 3690.

The Project will be jointly implemented by the leading organizations of the State Atomic Energy Corporation “ROSATOM” and Russian Academy of Sciences:

1. FSUE SRI SIA “LUCH” – performing the experiments, post-test calculations and material study;
2. IBRAE RAS – making scenarios of experiments, pre-test and post-test calculations;
3. OKB “GIDROPRESS” – making scenarios of experiments, analysis of the experiment model, pre-test and post-test calculations.

The following results are expected during implementation of the Project:

- obtaining and systematization of information on behaviour of the model FA with boron carbide AR under the conditions of severe accident with top flooding;

- study of the degree of the cladding oxidation over AR length depending on temperature and of the degree of metal melting of the cladding, guiding tube and AR materials;

- determination of the composition of solidified mixtures after flowing down of melt;

- extension of database for verification of severe accident codes (SOCRAT/B1, ATHLET, ICARE-CATHARE, etc.).

The obtained results can be used for safety justification of VVER and PWR type reactors.

The scope of the work for 24 months includes preparing and conducting two experiments at PARAMETER test facility on studying two model FAs of VVER-1000 with 18 heated fuel rods and the central boron carbide AR:

1) heating-up of the model assembly in steam-argon flow to maximum temperature of fuel rods before the beginning of flooding ~1250°C (PARAMETER-SF5 experiment);

2) heating-up of the model assembly in steam-argon flow to maximum temperature of fuel rods before the beginning of flooding ~1450°C (PARAMETER-SF6).

In both experiments the top flooding water flow rate is 40g/s.

Following the experiments SF5 and SF6 the post-test material studies of model assemblies will be carried out.

The proposed methodological approach to implementation of the Project is provided by:

- making of a realistic scenario of experiments based on safety justification of VVER using computer codes TECH-M and KORSAR;

- calculational modeling of experiments using the certified computer code package SOCRAT/B1;

- completing the fuel assembly simulator with the standard structural materials of fuel rods and FAs of VVER-1000 (fuel rod claddings of alloy Zr+1%Nb, fuel pellets of uranium dioxide, spacing grids and shell of alloy Zr+1%Nb, boron carbide AR).

The proposed Project meets ISTC objectives and tasks since the defense industry scientists and specialists will be involved in its implementation, and the final results will contribute to improvement of reliability and safety of nuclear power reactors both under operation, and those being designed and constructed.

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|  | PROJECT PROPOSAL | # |

## II. Detailed Project Information

### 1. Introduction and Overview

Nowadays a serious risk appears all over the world concerning availability of power resources, safe production of energy, changes in climate and quality of the air, therefore there is an increase in the role of nuclear power it could play in the future power systems and energy supply. However the long-term prospects of nuclear power utilization should be considered in general context of assurance of safety, economic competitiveness and risks of proliferation.

Safety assurance is one of the main tasks in designing, construction, operation and decommissioning of NPP. The key role in NPP safety problem is devoted to reliability of nuclear reactor control features. The considerable reliability improvement of control features can be gained by usage of radiation-resistant and high efficient absorbing materials.

For successful and efficient usage of such materials and structures of AR the calculational and experimental verification of their availability is necessary not only for the operation conditions but also for the conditions of postulated design basis accidents (DBA) and initial stages of beyond design basis accidents (BDBA), and the studies are required for the effect of AR structural materials on the core behavior at the initial stage of the severe accident with partial or complete melting of the core components.

In the analysis of accident a special attention should be paid to the interference of fuel rods and absorbing rods (AR) within the FA. Deformation of fuel rod claddings could lead to deformation and blockage of the guiding tube and the AR cladding itself. Melting and relocation of AR components can cause the additional core overheating both due to reaching the state of local criticality and power spike, and due to blockage with melt of flow area of some sells of spacing grids and worsening of the fuel rods cooling conditions

Interaction of AR and FA materials due to formation of eutectics takes place at rather low temperatures:

1. formation of eutectic Fe+Zr at temperature 950°C;
2. formation of eutectic B+Fe at 1130-1150°C.

Beginning of the core melting at low coolant pressure (<1 MPa) and at temperature of about 1227°C is appearance of eutectic “steel (or Inconel) – Zr” that occurs in contact of zirconium spacing grid with guiding tube, or in ballooning of AR and contact of its steel cladding with zirconium guiding tube.

For detailed study of the core structural components interaction processes the complex bench studies are required for the behaviour of absorbing rods in a set of FA, including fuel rods, spacing grids and guiding channels under the conditions simulating severe accident at VVER reactor plant.

The PARAMETER facility in SRI SIA “LUCH” is the most appropriate for such kind of studies that allows to conduct the required scope of experimental and material studies with the calculational and methodical support of studies made by specialists of IBRAE RAS, OKB “GIDROPRESS”, VNIINM, RRC “Kurchatov Institute”, SRI SIA “LUCH” and JSC “MZP”.

The studies of AR behaviour under accidents shall include the following:

1. study of AR thermomechanical behaviour under tests of the model FAs using different scenarios of DBA and BDBA;
2. post-test material studies of FA and AR to determine the following:
3. the degree of cladding oxidation over AR length depending on temperature;
4. the degree of metal melting of the cladding, guiding tube and AR materials;
5. the composition of the solidified mixtures after flowing down of melt and formation of solid layer of melted structural materials (corium) that can block~~s~~ the coolant cross section;
6. the character of cooling of the model assembly with AR under top flooding.

On the basis of the analysis of indications of measured temperature and using the post-test material studies it is possible to identify the processes and temperature regimes that caused damage and melting of structural components.

Results of the complex bench studies can be used in safety justification of VVER and PWR type reactors.

At present the vibrocompacted boron carbide (B4C) cores are widely used in VVER ARs of thermal neutron nuclear power reactors.

The objective of the proposed Project is the study of behaviour of two 18-rods model FAs of VVER-1000 with the guiding tube and the central AR, completed with standard reactor materials (structural materials, fuel pellets and boron carbide absorber rods) under the conditions of the initial stage of severe accident with top flooding.

The studies planned in new Project present a continuation of PARAMETER-SF test series at the PARAMETER test facility started under ISTC Projects # 3194 and # 3690.

The Project will be jointly implemented by the leading organizations of the State Atomic Energy Corporation “ROSATOM” and Russian Academy of Sciences:

1. FSUE SRI SIA “LUCH” – performing the experiments, post-test calculations and material study;
2. IBRAE RAS – making scenarios of experiments, pre-test and post-test calculations;
3. OKB “GIDROPRESS” – making scenarios of experiments, analysis of the experiment model, pre-test and post-test calculations.

Competence of the Project participants is confirmed by publications:

FSUE SRI SIA “LUCH”

Deniskin V.P., Nalivaev V.I., Fedik I.I., Ponomarev-Stepnoi N.N., Dragunov Yu.G. Bench simulation of the stages of loss-of-coolant accidents at VVER reactor plant – Atomnaya Energiya, 2004, v. 96, edition 4, p. 247-255.

Deniskin V.P., Ignatiev D.N., Konstantinov V.S., Nalivaev V.I., Soldatkin D.M., etc. Prior investigation of absorber rod Dy2O3×TiO2 behavior after severe accident test. //11th International QUENCH Workshop, Karlsruhe, Germany, 2005.

Nalivaev V.I., Degtyareva L.S., Deniskin V.P., Konstantinov V.S., Parshin N.Ya., Kiselev A.E., Yudina T.A.,   
Semishkin V.P. Experimental trials of VVER FA models at the PARAMETER facility under simulation conditions of different stages of severe coolant loss accidents. International Conference “Nuclear Power Engineering of the Republic of Kazakhstan. NP-2008”, Kazakhstan, Kurchatov, 2008, pp. 54-56.

IBRAE RAS

Veshchunov M.S., Kiselev А.Е., Strizhov V.F. Development of computer code package SVECHA for modeling of in-vessel stage of beyond design-basis accident of water-water reactor // Izvestiya Akademii Nauk. Ser. Energetika. –No. 2. -2004.  
-PP.6-21.

Kiselev A.Ye., Strizhov V.F., Voltchek A.M., Porracchia A., Gonzalez R., Chatelard P.. Assessment of the Modified ICARE2 Code Oxygen Diffusion Model for UO2/Zr (solid)/H2O Interactions. // IAEA Technical Committee on Behavior of LWR Core Materials under Accident Conditions, Dimitrovgrad. IAEA-TECDOC-921. -1995. -PP.217-228.

OKB “GIDROPRESS”

Shchekoldin V.V., Fil N.S., Semishkin V.P., Konstantinov V.S. (FSUE SRI SIA “LUCH”), Parshin N.Ya. (FSUE SRI SIA “LUCH”), Popov E.B. (FSUE SRI SIA “LUCH”) Calculation of experiments at PARAMETR test facility. – Report at the 4-th international Scientific and Technical Conference “Safety Assurance of NPP with WWER”, Podolsk, May 23-24, 2005.

Dragunov Y.G., Shchekoldin V.V., Fedik I.I. (FSUE SRI SIA “LUCH”), Parshin N.Ya. (FSUE SRI SIA “LUCH”). Computational analysis of PARAMETER facility experiments, Proc. of the 11th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Avignon, France, October 2-6, 2005.

### 2. Expected Results and Their Application

The proposed project “Study of fuel assemblies with boron carbide absorber rods under severe accident conditions in the PARAMETER-SF tests series” belongs to the category “Applied Research”.

The following will be done within the framework of the project:

1. Information will be obtained and systematized on behaviour of model FA with boron carbide absorber rods (AR) under the initial stage of severe accident with top flooding.
2. Degree of cladding oxidation over AR length depending on temperature and degree of metal melting of the cladding, guiding tube and AR materials will be studied.
3. Structure of the solidified mixes after a melt refluxing will be received.
4. Database for verification of severe accident codes (SOCRAT/B1, ATHLET, ICARE-CATHARE, etc.) will be broadened.

The obtained results can be used for verification of computer codes used in justification of criterial limits of NPP design and operation.

### 2.1. Sustainability Implementation Plan

#### 2.1.1. Results to be promoted

Scientific and technical reports, reference books (data bases) and papers containing information on behaviour and properties of structural components and materials of VVER-1000 reactor core under bench conditions simulating the initial stage of severe accident.

#### 2.1.2. Uniqueness of results

Uniqueness of results means that such series of experiments are performed for the first time to study the behaviour of VVER-1000 model fuel assemblies completed with standard structural materials, including fuel pellets of uranium dioxide and boron carbide absorbing rods, at the initial stage of severe accident with top flooding.

#### 2.1.3. Demand for results

Potential demand for the results of the project is caused, in the first place, by the fact that while operating VVER type reactors in RF and in a number of Eastern and Western European countries and in Asian countries one should take into consideration the probability of occurrence of accidents, namely, loss-of-coolant accidents. Therefore the experimental data are required in RP designs while considering the methods of reactor core cooling under severe accident in order to develop effective measures to prevent further development of accident and to bring the reactor to the safe state.

#### 2.1.4. Expected income

Income can be expected from using the results of the Project when designing of water-water nuclear power reactors, or when mitigating the consequences of severe accidents at NPP. Recommendations will be developed on the basis of the analysis of Project work results that will be included into the normative-technical and operational documentation. At the given stage of the Project it is not possible to estimate the income in terms of money.

#### 2.1.5. IPR situation

The scientific ideas, originated during execution of the project, will be confidential till elaboration on their basis the technical solutions with patentability criteria. Patentable technical solutions will be protected by obtaining patents in compliance with legislation of RF, standards and rules of ISTC, as well as in compliance with the Patent law of world countries if needed. The scientific and technical reports on the results of work under the Project will be protected as copyright in compliance with the law of RF No. 5351-1 of 09.07.1993. There are no live patents on the design of PARAMETER test facility. The methods of experiments will be developed on the basis of the tasks stated in the agreement. No patents have been revealed that could prevent using the results of the present project from the analysis of patent files of RF and leading foreign countries.

#### 2.1.6. Additional developments

The supposed results of the Project – the experimental data on FA behaviour at WWER reactors, being operated or constructed, under the conditions simulating the initial stage of severe accident with top quenching – are themselves the articles of trade in the world market. The analysis of the project results with issue (development) the recommendations on the use of the analysis results in designing and in normative-technical documentation will considerably increase the value of the project results.

#### 2.1.7. Plan of implementation

One of the main scenarios of getting income from the project results can be licensing of copyrights for the methods of performing the experiments and the results of the experiments that will be stated in scientific and technical reports.

#### 2.1.8. Additional licenses or permits

FSUE SRI SIA “LUCH” has a license for carrying out scientific and technical work with nuclear materials, no other licenses are required for implementation of the project. In addition, the registration of license contracts in Rospatent may be required for implementation of the project results.

#### 2.1.9. Business network

The leading research institutes and organizations of RF in the field of nuclear power engineering are involved in the process of implementation of the project results: OKB “GIDROPRESS”, IBRAE RAS, A.A. Bochvar FSUE VNIINM,   
A.I. Leipunsky SRC RF - IPPE, RRC “Kurchatov institute”, JSC “MZP”, who carry out an analysis of the project results and elaborate recommendations to State Atomic Energy Corporation “ROSATOM”, JSC “TVEL”, etc. on expediency of their application in designing VVER type reactors and in elaboration the normative-technical and operational documentation. Foreign collaborators from FZK, JRC-ITU, GRS (Germany), EdF (France), PSI (Switzerland), AEKI (Hungary), interested in obtaining data on the behaviour of model FAs of VVER at the initial stage of severe accident, are supposed to participate in the Project.

### 3. Meeting ISTC Goals and Objectives

According to ISTC objectives and tasks the implementation of work under the project will allow:

1. to convert for peaceful activities a part of the Russian specialists who formerly were involved in weapons programs;
2. to use the obtained results for safety justification of WWER (PWR) type reactors, as well as for elaboration of methods and means of control and protection system, capable to fulfill their function under accident conditions;
3. to improve reliability and safety of nuclear power reactors both operated, and being design.

### 4. Scope of Activities

The activities under the Project include preparation and performing of two experiments at PARAMETER test facility on studying the two model FAs of VVER-1000 with 18 heated fuel rods and the central boron carbide AR:

1) heating-up of the model assembly in steam-argon flow to maximum temperature of fuel rods before the beginning of flooding ~1250°C (PARAMETER-SF5 experiment);

2) heating-up of the model assembly in steam-argon flow to maximum temperature of fuel rods before the beginning of flooding ~1450°C (PARAMETER-SF6).

In both experiments the top flooding water flow rate is 40g/s.

Following the experiments SF5 and SF6 the post-test material studies of model assemblies will be carried out.

Two main tasks are implemented in the executing the Project:

#### Task 1

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **1. Study of change in the structure of materials of VVER-1000 model FA with AR under initial stage of severe accident with top flooding of the assembly heated to ~1250°C** **(PARAMETER-SF5):**  1.1. Preparing and performing the PARAMETER-SF5 experiment  1.2. Post-test material study  1.3. Processing the results of the PARAMETER-SF5 experiment | | 1-FSUE SRI SIA “LUCH”  2-IBRAE RAS  3-OKB “GIDROPRESS” |
| **Description of deliverables** | | |
| 1 | Specification of the PARAMETER-SF5 experiment | |
| 2 | PARAMETER-SF5 experiment protocol | |
| 3 | Protocol of the material study results of assembly SF5 | |

#### Task 2

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **2. Study of change in the structure of materials of VVER-1000 model FA with AR under initial stage of severe accident with top flooding of the assembly heated to ~1450°C** **(PARAMETER-SF6):**  2.1. Preparing and performing the PARAMETER-SF6 experiment  2.2. Post-test material study  2.3. Processing the results of PARAMETER-SF6 experiment  2.4. Preparing and issue of R&D final report | | 1-FSUE SRI SIA “LUCH”  2-IBRAE RAS  3-OKB “GIDROPRESS” |
| **Description of deliverables** | | |
| 1 | Specification of the PARAMETER-SF5 experiment | |
| 2 | PARAMETER-SF5 experiment protocol | |
| 3 | Protocol of the material study results of assembly SF5 | |
| 4 | R&D final report | |

### 5. Role of Foreign Collaborators/Partners

1. Information exchange in the course of project implementation.
2. Joint review (expertise) of scientific and technical reports.
3. Joint workshops, meetings and consultations.
4. Verification of results with the use of independent methods and/or equipment.
5. Shared use of test materials and specimens.
6. Joint verification of results obtained through the Project.
7. Consultations on the intellectual property rights in case of a joint invention.

### 6. Technical Approach and Methodology

The methodology of implementation of Project tasks includes the following main stages:

• Preparation and performing the experiment:

1. development of the scenario and main goals of the experiment;
2. development of the calculated model and carrying out the calculations of test conditions and parameters of the experiment on the basis of computer codes SOCRAT/B1, PARAM-TG, TECH-M, RELAP/SCADSIM, ICARE – CATHARE;
3. assembling, mounting of model FA and preparation of technological systems of the test facility for performing the experiment;
4. complex preoperational work (functional check of the process and information-measuring systems of the test facility systems, adjustment of testing conditions for the process systems and technical parameters of model FA);
5. performing the experiment.

• Post-test material study:

1. fragmenting of model FA, subjected to tests in the experiment, and preparing of templates;
2. optical and electronic microscopy;
3. X-ray structural analysis.

• Processing the experiment results and issuing the protocol with the results of:

1. measurements of the model assembly parameters monitored in the course of the experiments;
2. post-test metallographic examinations of assemblies.

• Preparation and issuing the R&D final report.

Technical implementation of the Project is tasks is accomplished at PARAMETER test facility of FSUE SRI SIA “LUCH”, intended for studying the behaviour of VVER model FAs under the conditions simulating various stages of LOCA type accidents.

The object of tests is a model fragment of VVER-1000 FA with AR with the following technical characteristics (see   
Table 1):

Table 1

Main design characteristics of the model FA with AR

|  |  |
| --- | --- |
| Number of fuel rods heated | 18 |
| Number of absorber rods | 1 |
| Grid pitch, mm | 12,75 |
| Location of steam/argon inlet (radial), mm | -372 (270°/90°) |
| Location of steam/argon outlet (radial), mm | 1425 (0°) |
| Fuel rod simulators | |
| Outer/inner diameter of fuel rod cladding, mm | 9.13/7.73 |
| Cladding material | Zr-1%Nb |
| Length of fuel rods heated, mm | 3120 |
| Heater material | tantalum |
| Fuel rod heater, mm: | |
| diameter length | 4/1275 |
| location | 0 to 1275 |
| Inside pressure of gas (helium) in fuel rods, MPa | 0.2 |
| Fuel pellets | |
| material | UO2 |
| outer diameter/of central hole /height, mm | 7.6-0.03/4.2+0.15/11±0.1 |
| Absorber rod simulators | |
| Diameter/length, mm | ∅8.2x3120 |
| Material | Vibrocompacted B4C |
| Guiding channel | |
| Material | Alloy E-635 |
| Outer/inner diameter, mm | 13/11 |
| Spacer grid | |
| Material | Zr-1%Nb |
| Height, mm | 20 |
| Number, pcs. | 6 |
| Distance between grids, mm | 255 |
| Location of the upper edge of grids, mm: | |
| of the first (lower) | 30 |
| of the sixth (upper) | 1305 |
| FA shroud | |
| Material | Zr-1%Nb |
| Size: diameter/wall thickness, mm | 70/2 |
| Length, mm | 1450 |
| Thermoinsulation | |
| Material | ZrO2 ZYFB-3 |
| Thickness, mm | 23.15 |
| Length, mm | 1450 |
| Thermoinsulation shroud | |
| Material | Steel 12X18H10T |
| Thickness, mm | 1 |
| Length, mm | 1450 |
| Outer diameter /thickness, mm | 118/1 |

Parameters measured:

1. temperature of fuel rod cladding in various points over the height and cross-section of the assembly;
2. pressure inside fuel rods;
3. temperature of absorber rod cladding in various points over the height and cross-section of the assembly;
4. coolant temperature;
5. coolant flowrate;
6. amount of hydrogen generated;
7. water flowrate for top flooding.

Tests of the model FAs are performed by the scenario, developed on the basis of design calculations on safety justification of VVER reactors using the code TECH-M with calculated modeling of experiments by using the certified computer code complex SOCRAT/B1 (see Tables 2,3).

Parameters and characteristics studied after the experiments:

1. condition of fuel rods, absorber rods and spacer grids;
2. flow area of the assembly in various coordinates over the assembly height;
3. degree of oxidation and hydrogenation of fuel rod cladding and absorber rod cladding.

Table 2

Supposed scenario of the SF5 experiment

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Stage | Stage | Main parameters | | | |
| No. |  | FA  temperature, K | Medium | Heating rate, K/s | Time, s |
| 1 | Joule heating up of FA in argon flow | ~300-670 | Argon flow  at temperature to 720K (argon flow rate - 2 g/s) at the test section inlet | - | 0-2000 |
| 2 | Joule heating up of FA in the flow of steam-argon mixture | 670770 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | - | 2000-4000 |
| 3 | FA heating up to 1470 K | 7701470 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | 0.25 (at the beginning),  0.1 (towards the end) | 4000-8000 |
| 4 | FA pre-oxidation | ~1470 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | - | 8000-12000 |
| 5 | FA heating up to maximum temperature | 1470→1520 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | ~0.4 | 12000-12120 |
| 6 | Assembly top flooding (as soon as FA will reach Tmax=1520 K) | to saturation temperature | Water (flow rate 40 g/s, water temperature ~300 K) | - | As soon as design temperature will be reached |

Table 3

Supposed scenario of the SF6 experiment

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Stage | Stage | Main parameters | | | |
| No. |  | FA  temperature, K | Medium | Heating rate, K/s | Time, s |
| 1 | Joule heating up of FA in argon flow | ~300-670 | Argon flow  at temperature to 720K (argon flow rate - 2 g/s) at the test section inlet | - | 0-2000 |
| 2 | Joule heating up of FA in the flow of steam-argon mixture | 670770 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | - | 2000-4000 |
| 3 | FA heating up to 1470 K | 7701470 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | 0.25 (at the beginning),  0.1 (towards the end) | 4000-8000 |
| 4 | FA pre-oxidation | ~1470 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | - | 8000-12000 |
| 5 | FA heating up to maximum temperature | 1470→1720 | Steam-argon mixture (argon/steam flow rate at the test section inlet - 2/3.5 g/s, at temperature of 720/770K) | ~0.4 | 12000-12500 |
| 6 | Assembly top flooding (as soon as FA will reach Tmax=1720 K) | to saturation temperature | Water (flow rate 40 g/s, water temperature ~300 K) | - | As soon as design temperature will be reached |

### 7. Technical Schedule

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Quarter 1** | **Quarter 2** | **Quarter 3** | **Quarter 4** | **Quarter 5** | **Quarter 6** | **Quarter 7** | **Quarter 8** | **Person\*days** |
| **Task 1** |  | Specification of the PARAMETER-SF5 experiment | PARAMETER-SF5 experiment protocol | Protocol  of the material study results of assembly SF5 |  |  |  |  |  |
| **Subtask 1** |  |  |  |  |  |  |  |  |  |
| **Subtask 2** |  |  |  |  |  |  |  |  |  |
| **Subtask 3** |  |  |  |  |  |  |  |  |  |
| **Person\*days** | **1480** | **1500** | **1500** | **1480** |  |  |  |  | **5960** |
| **Task 2** |  |  |  |  |  | Specification of the PARAMETER-SF6 experiment | PARAMETER-SF6 experiment protocol | Protocol  of the material study results of assembly SF6.  R&D final report |  |
| **Subtask 1** |  |  |  |  |  |  |  |  |  |
| **Subtask 2** |  |  |  |  |  |  |  |  |  |
| **Subtask 3** |  |  |  |  |  |  |  |  |  |
| **Subtask 4** |  |  |  |  |  |  |  |  |  |
| **Person\*days** |  |  |  |  | **1475** | **1490** | **1490** | **1522** | **5977** |
| **TOTAL** | **1480** | **1500** | **1500** | **1480** | **1475** | **1490** | **1490** | **1522** | **11937** |