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|  | PROJECT PROPOSAL | #3345 |

## I. Summary Project Information (EVAN)

### 1. Project Title and Taxonomy

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| --- | --- | --- | --- | --- |
| **Full title:** | Source Term Assessment at Ex-vessel Stage of Severe Accident | | | |
| **Short title:** | | Ex-Vessel Source Term ANalysis (EVAN) | | |
| **Technology area:** | | | ENV-MRA, FIR-EXP, FIR-MOD | |
| **Category of technology development:** | | | | Applied Research |

### 2. Project Manager

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Name:** | | Vladimir Bezlepkin | | | | | | |
| **Title:** | Doctor of Science (Power Engineering) | | | | **Position:** | | SPAEP Deputy Director for R&D | |
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### 3. Participating Institutions

#### 3.1. Leading Institution

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | SPAEP | | | | | | |
| **Full name:** | | | Federal State Unitary Enterprise «Saint Petersburg Research and Design Institute ATOMENERGOPROEKT» (FSUE SPAEP) | | | | | | | | |
| **Street address:** | | | | Suvorovsky, 2A | | | | | | | |
| **City:** | St.Petersburg | | | | | | | **Region:** | | - | |
| **ZIP:** | 191036 | | | | | | | **Country:** | | | Russian Federation |
| **Name of Signature Authority:** | | | | | | | Sergey Onufrienko | | | | |
| **Title:** | Cand. Sc. (Power Engineering) | | | | | | | **Position:** | | SPAEP Director | |
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| **Governmental Agency:** | | | | | | Federal Atomic Energy Agency | | | | | |

#### 3.2. Other Participating Institutions

#### Participant Institution 1

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | IBRAE RAS | | | | | | |
| **Full name:** | | | Russian Academy of Sciences, Nuclear Safety Institute (IBRAE) | | | | | | | | |
| **Street address:** | | | | Bolshaya Tulskaya, 52 | | | | | | | |
| **City:** | Moscow | | | | | | | **Region:** | | - | |
| **ZIP:** | 113191 | | | | | | | **Country:** | | | Russia |
| **Name of Signature Authority:** | | | | | | | Bolshov Leonid | | | | |
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| **Governmental Agency:** | | | | | | Russian Academy of Sciences | | | | | |
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#### Participant Institution 2

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | NITI | | | | | | |
| **Full name:** | | | A.P. Alexandrov Research Institute of Technology | | | | | | | | |
| **Street address:** | | | | - | | | | | | | |
| **City:** | Sosonovy Bor | | | | | | | **Region:** | | Leningrad | |
| **ZIP:** | 188540 | | | | | | | **Country:** | | | Russian Federation |
| **Name of Signature Authority:** | | | | | | | Vyacheslav Vasilenko | | | | |
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| **Governmental Agency:** | | | | | | Federal Atomic Energy Agency | | | | | |
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#### Participant Institution 3

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | JSC «NPO CKTI» | | | | | | |
| **Full name:** | | | Joint Stock Company «I.I.Polzunov Scientific and Design Association on Research and Design of Power Equipment» | | | | | | | | |
| **Street address:** | | | | Atamanskaya, 3/6 | | | | | | | |
| **City:** | St.Petersburg | | | | | | | **Region:** | | - | |
| **ZIP:** | 191167 | | | | | | | **Country:** | | | Russian Federation |
| **Name of Signature Authority:** | | | | | | | Yuri Petrenya | | | | |
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#### Participant Institution 4

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Short reference:** | | | | | FSUE LI VNIPIET | | | | | | |
| **Full name:** | | | Federal State Unitarian Enterprise "Leading Institute "All-Russia Design and Scientific Research Institute for Complex Power Technology" | | | | | | | | |
| **Street address:** | | | | Savushkina st., 82 | | | | | | | |
| **City:** | St.-Petersburg | | | | | | | **Region:** | | - | |
| **ZIP:** | 197183 | | | | | | | **Country:** | | | Russian Federation |
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| **Governmental Agency:** | | | | | | Federal Atomic Energy Agency | | | | | |
| **Sub-manager:** | | | | Vladimir Kritski | | | | | | | |
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### 4. Foreign Collaborators/Partners

#### 4.1. Collaborators

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Institution:** | | | | VTT Technical Research Centre of Finland | | | | | | |
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| **City:** | Jyvaskyla | | | | | **Region/State:** | | | | - |
| **ZIP:** | FIN-02044 | | | | | **Country:** | | | Finland | |
| **Person:** | | | Ari Auvinen | | | | | | | |
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Institution:** | | | | Gesellschaft fur Anlagenund Reaktorsicherheit (GRS) mbH | | | | | | |
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| **City:** | Koln | | | | | **Region/State:** | | | | - |
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Institution:** | | | | Joint Research Centre - Institute for Transuranium Elements (JRC-ITU) | | | | | | |
| **Street address:** | | | | | P.O. Box 2340 | | | | | |
| **City:** | Karlsruhe | | | | | **Region/State:** | | | | - |
| **ZIP:** | D-76125 | | | | | **Country:** | | | Germany | |
| **Person:** | | | Paul David Bottomley | | | | | | | |
| **Title:** | | - | | | | **Position:** | | Senior Scientific Officer | | |
| **Tel.:** | +49 7247 95 1364 | | | | | **Fax:** | +49 7247 95 1593 | | | |
| **E-mail:** | | | bottomley@itu.fzk.de | | | | | | | |

#### 4.2. Partners

No

### 5. Project Duration

36 months (1 phase — 12 months, 2 phase — 24 months.)

### 6. Project Location and Equipment

|  |  |
| --- | --- |
| **Institution** | **Location, Facilities and Equipment** |
| **Leading Institution** | SPAEP, St.Petersburg, Babushkina str., 1, Premises of the safety research department. Personal computers for experimental data processing, modeling, analysis, calculations, and reporting for the Project. |
| **Participant Institution 1** | IBRAE RAS, 52, B.Tulskaya, Moscow, 113191, Russia. Personal computers for experimental data processing, numerical simulation and preparation of Project reports. |
| **Participant Institution 2** | A.P. Alexandrov NITI: 188540, Sosnovy Bor, Leningrad Reg., NITI.  Project location: 188540, Sosnovy Bor, Leningrad Reg., LSK “Radon”.  Premises and facilities: “Rasplav-2” and “Rasplav-3” experimental installations, Bldg. 12, LSK. Information and measuring system, Bldg. 12, LSK. Instruments and analytical facilities (mass spectrometer, X-ray diffractometers and spectrometers, chromatograph, etc.), Bldg. 12, LSK.  Computer facilities and office equipment, Bldg. 12, LSK, Bldg. 11 – Rooms. 404, 405 |
| **Participant Institution 3** | NPO CKTI, SPb, str. Atamanskaya 3/6, str. Politechnicheskay, 24, building of laboratory 102. Facilities for investigation of flow characteristics and heat and mass transfer. Computers and office equipment. |
| **Participant Institution 4** | VNIPIET, St.Petersburg, Dibunovskaya str., 55, premises of the NPP reliability department. Autoclave setup with reagents supply and sampling, analytic and chemical equipment.  NITI, Sosnovy Bor, Leningrad district, premises of the 5 department. RKhM-γ-20 setup, analytic equipment, autoclave setup, setup for separate analysis of non-organic and organic iodine species. |

### 7. Total Project Effort

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| --- | --- |
| **Total number of participants** | 95 |
| **Number of weapon scientists and engineers** | 48 |
| **Total project effort (person\*days)** | 25103 |
| **Total project effort of weapon scientists and engineers (person\*days)** | 12826 |

### 8. Financial Information

#### 8.1. Estimated Project Costs

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| --- | --- |
| **Estimated total cost of the project (US $)** | 1040000 |
| *Including:* |  |
| **Payments to Individual Participants** | 672100 |
| **Equipment** | 157750 |
| **Materials** | 42500 |
| **Other Direct Costs** | 33750 |
| **Travel** | 72600 |
| **Overhead** | 61300 |

#### 8.2. Funding Sources

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| --- | --- |
| **Estimated total cost of the project (US $)** | 1040000 |
| *Financial Sources:* |  |
| **Requested from the ISTC** | 1040000 |
| **Other financial source 1** | - |
| **Other financial source 2** | - |
| *Non-Financial Sources:* |  |
| **Non-financial source 1** | - |
| **Non-financial source 2** | - |

### 9. Summary of the project

9.1 The “Ex-vessel Source Term Analysis” (EVAN) ISTC project includes theoretical and experimental research of the processes affecting the late phase fission product release to the PWR containment atmosphere at the ex-vessel stage of the hypothetical severe accident with core meltdown.

This stage is characterized by corium relocation outside the reactor pressure vessel into the core catcher/reactor cavity and a need for long-term heat removal from the containment (with possible loss of integrity, increased leak rate, and internal overpressure). At this stage, the fission products are released to the containment atmosphere (and thus made available for release to the environment) from the core melt located in the reactor cavity/lower containment compartment, along with various secondary sources like contaminated solution in the containment sump and FP deposited at the surfaces of process equipment and building structures.

Ex-vessel core melt fission products release is affected by design features and the accident management strategy. Partly, the oxidation degree of the melt is important for the low-volatile oxidizing FP release, especially Ru, Ba, and Mo, while water supply onto the melt can effectively reduce FP transport from the melt to the atmosphere but generate a secondary source of soluble FP (Cs, I, Ru) from contaminated solution boiling at the melt surface.

Fission products deposited at the in-vessel stage in the primary circuit (including heat transfer surfaces of steam generators) can be resuspended/revaporized and be an important source in a long-term perspective. Investigation of aerosol transport processes (deposition, resuspension, and revaporization) is of practical interest for characteristic primary circuit geometries (vertical, horizontal sections, tube bends and so on).

For various severe accident management strategies, containment sump solution is often used for long-term heat removal from the melt and from the containment. Investigation on how different chemical species in the sump solution (boric acid, Fe oxides and organic forms) affect concentrations and partitioning of the iodine species is very important for radioiodine source term predictions.

9.2 The project features possibility to obtain data directly applicable to existing VVER-type designs, and data allowing comparison with PWR analogues. Necessary quality of the project is achieved through the combination of intellectual input from competent Russian scientific sub-teams having experience both in EU and ISTC research projects, using unique experimental setups and up-to-date computer codes, elaborated ISTC organizational framework, and constant interaction with foreign collaborators interested in the project outcome.

9.3 Four main work packages are included in the project:

• WP1/Task 1. Analysis of results of severe accident scenarios calculations for various NPP with PWR/VVER. Participants: SPAEP, IBRAE. The goal of the analysis is to determine the representative (envelope) boundary ranges for the fluid parameters in the reactor plant and containment, for the core melt parameters, FP aerosol characteristics, boundary conditions at the surfaces of structures and equipment, sump solution chemical composition, dose rate level, and other parameters necessary for specification of the experimental conditions for WP2-4. Further on, the review of the present modeling capabilities for up-to-date codes (RATEG/SVECHA, ICARE2, ASTEC) is to be performed, and applicability of the obtained experimental results for computer models validation is to be justified.

• WP2: Theoretical and experimental investigations of fission product release from the molten pool/core catcher.

Task 2. Experimental investigations of fission product release from the molten pool/core catcher. Participant: NITI. Tests for model corium compositions are carried out within the approved test matrix, and the following is to be determined: low volatile fission product release from the molten pool during its transition from sub-oxidized to fully-oxidized state and fission product release from the molten pool with water supply onto the melt surface (for pure water and water contaminated with FP species).

Task 3. Theoretical and numerical modeling of fission product release from the molten pool/core catcher. Participant: IBRAE. Computer codes RATEG/SVECHA, appropriate models of ICARE2 (IRSN, France) and, if collaborators provide such an opportunity, RELOS are to be used for numerical estimations.

• WP3. Theoretical-experimental investigations of deposition, transport and revaporization of aerosols in the primary circuit pipes.

Task 4. Experimental investigations of aerosols transport in the primary circuit pipes. Participants: CKTI. Tests for different aerosol types are carried out within the approved test matrix. The experimental programme would take a typical aerosol and examine their deposition and resuspension behavior in horizontal or vertical tubes for the specified Re ranges.

Task 5. Theoretical and numerical modeling of deposition, transport and revaporization of aerosols in the primary circuit pipes. Participants: IBRAE, SPAEP. Aerosol transport calculations are performed with use of the reference models implemented in RATEG/SVECHA code. Cross-validation of results obtained by means of CFD-codes is carried out (SPAEP).

• WP4. Assessment of containment media parameters impact on content and proportioning of the volatile iodine species in the containment atmosphere.

Task 6. Experimental investigations of containment parameters impact on content and proportioning of the volatile iodine species. Participants: VNIPIET (in collaboration with NITI, department 5). Experiments on the effect of impurity complex, coming out into the containment water medium under emergency conditions, on the content of I2 in the solution and volatile iodine species in the gas phase would be performed within the approved test matrix.

Task 7. Theoretical and numerical modeling of containment parameters impact on content and proportioning of the volatile iodine species. Participants: VNIPIET, SPAEP. VNIPIET adapts the iodine species behavior model developed earlier for the containment atmosphere under emergency conditions to the conditions of the experimental tests (task 6) in order to compare calculation results with the experimental ones. VNIPIET performs numerical modeling of the experimental test modes, develops the model for accident environmental radioiodine source term assessment, the algorithm and computer programme for numerical description of the experimental tests. SPAEP analyses results and adapts the iodine species behavior model and computer code to accident environmental radioiodine source term assessment.

9.4 The scope of the project may be extended by additional adaptation and validation of computer models, continuation of experimental programmes and radiological consequences calculation for selected severe accident scenarios.

9.5 The EVAN project is an applied research. Theoretical and experimental research results for assessment of consequences of fission product release to the PWR containment atmosphere at the late stage of severe accidents can be used for safety assessment of both existing and new NPP designs, including probabilistic safety analyses of 2 and 3 level, for development of severe accident management strategies and for emergency planning analysis. The project features possibility to obtain data directly applicable to new designs of NPP with VVER-type reactors, providing severe accident management measures.

9.6 Supporting letters have already been received from collaborators of VTT, GRS, and ITU; if necessary, in addition supporting letters from PSI, CEA and IRSN may be presented. The foreign collaborators are expected to partly provide material for analysis within the WP1/task 1, to participate in developing the text matrices, and in discussions on modeling issues for WP2-4. Also joint publications can be planned, proposals for modifications of models and codes, and for future cooperation.

9.7 The project is implemented with the use of up-to-date computer codes and unique experimental setups applied by organizations-participants. Approved theoretical and experimental base techniques are used.

9.8 The project promotes ISTC goals to let Russian weapon scientists and specialists to apply their knowledge to peaceful applications, to facilitate their integration to the global NPP accident analysis community, and also to support the applied research in the field of environment protection, energy generation, and nuclear safety. The project is also important for nuclear power engineering and complies with the European Framework Programmes goals. The proposed work packages for the project were approved by EU-ISTC CEG-SAM and SARNET experts.

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|  | PROJECT PROPOSAL | # |

## II. Detailed Project Information

### 1. Introduction and Overview

In recent years, after the accidents at Three-Mile-Island NPP in the USA and at Chernobyl NPP, a number of national and international research programmes for investigations of the main processes taking place during severe accidents at NPP with light-water-coolant reactor plant have been carried out. On the basis of results obtained within the scope of these programmes standards and recommendations [1-3] are established and computer codes are developed.

Radiological consequences analysis for severe accidents includes assessment of fission product (FP) release to the containment atmosphere (in-containment source term) and investigation of time dynamics and physical-chemical composition of environmental source term. For these purposes quantitative analysis of the following chemical-chemical processes is to be carried out: fission product accumulation in the irradiated fuel, fission product gap-release and release from fuel matrix during the core heating-up and melting-down, core melt fission product release (in-vessel and ex-vessel), FP transport in the primary circuit (transfer, deposition, resuspension), FP confinement in the containment (transfer, deposition processes at surfaces), fission products transport and release into the containment atmosphere, chemical reactions with FP determining environmental source term.

The initial (in-vessel) stage of severe accidents is considered in detail in recommendations [1-3], in general these recommendations are applicable to existing NPP designs and express the level of technical-scientific knowledge achieved by the time that the recommendations were issued, but according to the modern requirements [4-6], for new NPP with light-water-coolant reactor plant severe accidents shall be taken into account at the stage of NPP design (e.g. [7, 8]). Comprehensive concept for severe accident management shall be developed in design and appropriate technical measures shall be realized. For analysis of severe accident management system probabilistic and deterministic methods and realistic models are used jointly, so that excessive conservatism and cost inefficiency are excluded.

Wide-ranging research programmes of European Community (European Concerted Actions, Framework Programmes, experimental programme “Phebus”) and Russian programmes [9, 10] were realized to support substantiation of designs complying with the new requirements. At present computer codes and background knowledge applicable to realistic substantiation of severe accident management concept are being worked out for new NPP designs.

Assessment of fission product release to the containment atmosphere at the late stage of severe accident is an important stage of environmental source term analysis. This stage of severe accident is characterized by corium relocation outside the reactor pressure vessel into the core catcher/reactor cavity and a need for long-term heat removal from the containment (with possible loss of integrity, increased leak rate, and internal overpressure during the first several days). At this stage, the fission products are released to the containment atmosphere (and thus made available for release to the environment) from the core melt located in the reactor cavity/lower containment compartment, along with various secondary sources like contaminated solution in the containment sump and FP deposited at the surfaces of process equipment and building structures.

New designs of NPP with PWR [7, 8] provide the core catcher containing special sacrificial materials, which interact with the core melt, so that it gets properties necessary for further corium localization and cooling. In this case expected fission product release from the core melt may differ from release under conditions of the melt-concrete interaction considered in [1-3]. In this connection at present theoretical and experimental research of fission product release from molten pool is performed (see, e.g., [11]). Water supply into the reactor cavity (or core catcher) onto the melt surface effectively reduces FP transport from the melt to the containment atmosphere, but generates a secondary source of soluble FP (Cs, I, Ru) from contaminated solution boiling at the melt surface in case there is a recirculation circuit from sump via core melt retention device and to containment atmosphere. In this connection continuation of theoretical and experimental research on fission product release from molten pool taking into account water supply onto the melt surface (including consistent modeling of thermo-hydraulic and chemical-chemical processes in the molten pool) is of practical interest for severe accident ex-vessel stage.

Fission products deposited at the initial stage in the primary circuit (including heat transfer surfaces of steam generators) can be resuspended/revaporized and be an important source in the containment atmosphere. Taking into account FP confinement in the primary circuit at the initial stage may both increase (due to possible additional leakage of deposited FP from the primary circuit to the containment atmosphere at ex-vessel stage) and decrease (due to formation of stable chemical compounds with FP at surfaces of primary circuit equipment) FP release. As it is noted in earlier papers [12], for prediction of FP release rate from surfaces of primary circuit equipment (due to resuspension and revaporization), it is greatly important to know conditions of aerosol deposition from steam-gas turbulent flow onto pipe walls of different diameters. Besides experimental investigation of these processes, it is necessary to carry out joint calculations on gas-dynamical and aerosol models for real geometries of equipment and test particles. Numerical and experimental investigations of local problems related to species deposition, resuspension and deposited FP revaporization from internal surfaces of the primary circuit will allow to make more precise parameters of FP release to the containment atmosphere at severe accident ex-vessel stage.

For fission product release assessment related to different stages of severe accidents estimation of aerosol, volatile and non-volatile iodine species partitioning shall be performed. Content of non-volatile and volatile (including organic forms) iodine species in the water phase is determined not only by pH-level, redox-potential of the medium and ionizing irradiation dose rate, but also by composition of containment sump solution and sludge. Ferric/ferrous ions and some silicate-derivatives can absorb certain iodine species, keeping them in the compound and affecting concentrations and partitioning of gaseous iodine species in the gas phase. Experiments on how these different chemical species affect sophisticated mass transfer process and iodine equilibrium have not been carried out yet. Thermo-radiolysis of organic impurities in the water phase resulting in reduction of pH-level also substantially affects the volatile iodine species production [13]. Investigation on how different impurities in the containment water medium (boric acid, Fe-compounds and organic forms) affect the long-term pH-level prediction and concentrations and partitioning of the iodine species in the gas and water phase is of practical interest for severe accident radioiodine source-term assessment.

References

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2. A simplified approach to estimating reference source terms for LWR design. IAEA-TECDOC-1127, IAEA, Vienna, 1999.

3. Procedures for Conducting Probabilistic Safety Assessments of Nuclear Power Plants (Level 2): Accident Progression, Containment Analysis and Estimation of Accident Source Terms: Safety Series # 50-P-8 IAEA, Vienna, 1995.

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5. Safety Assessment and Verification for Nuclear Power Plants: Safety Guide. NS-G-1.2, International Atomic Energy Agency, Vienna, 2001.

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9. Heat and Mass Transfer Processes in Safety Systems of VVER-640, Annals, St.Petersburg, 1997.

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11. Fission Product Release from Molten Pools (MP). “Nuclear Science and Technology. EU Co-sponsored Research on Reactor Safety/Severe Accidents”. European Commission. EUR 19963 EN. 2003.

12. Steam Generator Tube Rupture Scenarios (SGTR), J. Jokiniemi, H. Tuomisto, S. Guntay, et al., . “FISA-2001. EU Research on Reactor Safety”. European Commission. EUR 20281 EN. 2001.

13. Dutton L.M.C., Grindon E., Handy B.Y. et.al., Iodine Behavior in Severe Accidents. In The Chemistry of Iodine in Reactor Safety (Proceed. of the Fourth CSNI Workshop, Wurenlingen, Switzerland, 1996). NEA/CSNS/R(96) 6, p.615.

### 2. Expected Results and Their Application

The “Ex-vessel Source Term Analysis” (EVAN) ISTC project includes theoretical and experimental research of the processes affecting the late phase fission product release to the PWR containment atmosphere at the late stage of the hypothetical severe accident with core meltdown. The main results expected to be obtained within the framework of the proposed project (total duration is 36 months) are listed below:

1. Experimental data and numerical analysis of core melt fission product release, applicable to different designs of power units, taking into account corium transition from sub-oxidized to fully-oxidized state and water supply onto the melt surface.

2. Experimental data and numerical analysis of processes of aerosol transport and deposition in primary circuit pipelines at different composition and flow conditions of the medium-carrier, aerosol species characteristics and equipment geometry.

3. Experimental data and numerical analysis on how composition of containment sump solution and sludge affects content and partitioning of volatile iodine species in the containment atmosphere at different temperature, irradiation dose, ambient parameters and covering characteristics.

The scope of the project may be extended by additional adaptation and validation of computer models, continuation of experimental programmes and radiological consequences calculation for selected severe accident scenarios.

This research is a sort of applied investigations. Theoretical and experimental research results can be used for computer codes validation for application to new designs, for safety assessment of both existing Russian and foreign NPP designs, including probabilistic safety analyses of 2 and 3 level, for development of severe accident management strategies and for emergency planning analysis. The project features possibility to obtain data directly applicable to new designs of NPP with VVER-type reactors providing severe accident management measures.

Project results may also be applied to ex-vessel source term analysis for Russian designs of power units in Eastern Europe.

Table 1. Russian designs of power units built in Eastern Europe and in the Ukraine

|  |  |  |
| --- | --- | --- |
| NPP | Number and type of reactor plant | Years of comissioning |
| Loviisa, Finland | 2xVVER-440 | 1977-81 |
| Bogunitse, Slovakia | 4xVVER-440 | 1980-85 |
| Mohovtse, Slovakia | 2xVVER-440 | 1998-2000 |
| Dukovany, Czechia | 4xVVER-440 | 1985-87 |
| Temelin, Czechia | 2xVVER-1000 | 2002-2003 |
| Kozloduj, Bulgaria | 4xVVER-440  2xVVER-1000 | 1974-82  1988-93 |
| Paksh, Hungary | 4xVVER-440 | 1983-87 |
| Chmelnitskaya, the Ukraine | 4xVVER-1000 | 1988-indef. |
| Rovenskaya, the Ukraine | 2xVVER-440  2xVVER-1000 | 1981-1982  1987-2002 |
| Yuzhnoukrainskaya, the Ukraine | 4xVVER-1000 | 1983-indef. |
| Zaporozhskaya, the Ukraine | 6xVVER-1000 | 1985-96 |

2.1. Sustainability Implementation Plan

2.1.1. Results to be promoted

During the course of the project the new research results will be obtained allowing to develop new up-to-date computer programs (codes) for nuclear power plants accident analysis. Enhancing the level of safety assessment for new NPP designs with up-to-date computer codes increase the competitiveness of the design at the market. Selling or promoting of the research product obtained during the project is possible within the framework of the cluster of research institutions involved in the applied R&D for NPP safety analysis.

2.1.2. Uniqueness of results

Uniqueness of the project results depends on the novelty of the experimental results to be obtained and modeling analyses to be performed.

2.1.3. Demand for results

Primarily, the Russian and foreign nuclear power engineering research and design institutions are demanding for results of the project. Foreign collaborators having submitted the support letters to ISTC are the main foreign consumers of the future results.

2.1.4. Expected income

Russian participant organizations are financially stable and independent enterprises of various ownership forms allowed by the Russian law; they possess the necessary licenses and permissions for the activity, which will allow them to obtain the expected income out of the project.

2.1.5. IPR situation

Intellectual property objects emerging during the course of the project will be protected according to the requirements of the Russian law, participants’ interests, and international experience applicable by agreement with foreign collaborators.

2.1.6. Additional developments

Later work plan and need for additional developments will depend on effectiveness of co-operation with the main potential end-users of the research results — foreign collaborators.

2.1.7. Plan of implementation

Most probable scenario for gaining income out of the project results will be international contracts for joint activities on safety assessment for nuclear power plants.

2.1.8. Additional licenses or permits

Russian participant organizations possess all the licenses necessary for business carried out at the territory of Russian Federation since the mentioned types of activities are their core business.

2.1.9. Business network

The present business network of the Russian participants is described in the project summary. The present results of the activity of the research teams are provided in the referenced publications.

### 3. Meeting ISTC Goals and Objectives

The project promotes ISTC goals to let Russian weapon scientists and specialists to apply their knowledge to peaceful applications, to facilitate their integration to the global NPP accident analysis community, and also to support the applied research in the field of environment protection, energy generation, and nuclear safety. The project is also important for nuclear power engineering and complies with the European Framework Programmes goals. The proposed work packages for the project were approved by EU-ISTC Contact Expert Group on Severe Accident Management (CEG-SAM) (Minutes of the 7th Meeting, Cologne, Germany, February 28- March 1, 2005).

### 4. Scope of Activities

#### Task 1. Assessment of results of severe accident sequences modeling

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Assessment of results of severe accident sequences modeling**  **Task Stages: 1) Assessment of results of severe accident sequences modeling for different NPP designs with PWR or VVER reactors. Justification of initial data for experimental investigations. 2) Justification of applicability to be obtained experimental data for computer codes validation. Preparation of experimental programs.**  **Tools to solve the task: 1) Results of severe accidents modeling. 2) Computer codes RATEG/SVECHA/HEFEST, CORCAT, DINCOR, KUPOL-M, SCDAP/RELAP, MELCOR. Assessment of results of numerical modeling.** | | 1- SPAEP  2- IBRAE |
| **Description of deliverables** | | |
| 1 | Report on initial data for experimental programs for tasks 2, 4, 6 (stage 2) | |

#### Task 2. Experimental research on FP release from molten pool/core melt catcher

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Experimental research on FP release from molten pool**  **Work stages: 1) Experimental investigations of low-volatile fission products release during molten corium oxidation. Melt characteristics and composition of the FP in question are determined from the results of Task 1. 2) Experimental investigations of low-volatile fission products release during water supply onto the melt surface.**  **Tools for solving the task: 1) A set of “Rasplav” experimental installations, equipped with aerosol sampling system, for studying high-temperature phenomena in molten corium. 2) A complex of instruments and equipment for tests preparation, conducting posttest analyses and processing experimental results. The complex includes XRF spectrometers, microsizer, mass spectrometer, spectrophotometer, auxiliary equipment (crusher, microgrinder, laboratory balance, etc.)** | | 1- NITI |
| **Description of deliverables** | | |
| 1 | Report on experimental study of low-volatile fission products release during molten corium oxidation | |
| 2 | Report on experimental study of low-volatile fission products release from molten corium pool covered by water layer | |

#### Task 3. Analytical investigation of fission products release from molten pool or core catcher.

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Analytical investigation of fission products release from molten pool.**  **Task Stages: 1) Review of modern codes capabilities to simulate FP release from molten pool. Justification of applicability to be obtained experimental data for computer codes validation. 2) Pre tests/post tests simulation (in connection with experimental program performance).**  **Tools to solve the task: High performance computers, analytical and numerical calculation models** | | 1- IBRAE |
| **Description of deliverables** | | |
| 1 | Report on modeling results of fission products release from molten pool | |

#### Task 4. Experimental study of aerosols transport processes in the primary circuit equipment

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Experimental study of aerosols transport processes in the primary circuit equipment**  **Work stages: 1) Final completing and adjustment of experimental facilities. Development of research procedures. Pre-test calculations. 2) Experimental studies of aerosol particles deposition on pipeline surfaces from a turbulent flow and re-entrainment of particles. 3) Experimental studies of Cs deposition and evaporation from primary circuit pipeline surfaces.**  **Tools to solve the task: 1) A test facility for studying aerodynamics of a "dust-laden flow": distributions of velocities, concentrations, turbulent pulsations, and dynamics of deposition of aerosol particles (depending on disperse composition of aerosol) on the channel walls and re-entrainment of particles in the flow, equipped with an online optical monitoring system. A test facility for calibration of the measuring system, adjustment of aerosol particle generators and determination of spectral composition of the particles. 2) A complex of instruments and equipment for experiment preparation, performance of post-test analyses and processing of experimental results. The complex includes: lasers, spectrophotometers, signal analyzers, LDA-processor, 4 PC-based workstations, multimedia projector (to be corrected during further work at the first stage of the task).** | | 1- CKTI |
| **Description of deliverables** | | |
| 1 | Report on results of experimental studies of aerosol particles transport processes in the primary circuit pipelines | |

#### Task 5. Theoretical and computer modeling of aerosol transport in the primary circuit

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| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Theoretical and computer modeling of aerosol transport in the primary circuit.**  **Task Stages: 1) State-of-art review of modeling capabilities of the processes in question by modern computer codes, justification of applicability of the expected experimental results for models validation. 2) Pretest/posttest calculations (according to the test schedule).**  **Tools to solve the task: 1) 2D and 3D CFD codes coupled with mechanistic aerosol models, RATEG/SVECHA/GEFEST code with integral aerosol models. 2) High-performance computers.** | | 1- IBRAE  2- SPAEP |
| **Description of deliverables** | | |
| 1 | Report on modeling results for aerosol particles transport in the primary pipelines | |

#### Task 6. Experimental investigations of containment parameters impact on volatile iodine content and correlation

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| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Experimental investigations of containment parameters impact on volatile iodine content and correlation.**  **Task stages: 1) Completing and adaptation of the experimental researches of sludges effect (oxyhydrates Fe and silicates) on volatile iodine species content and correlation in gas phase. 2) Experimental investigations on effect of organic polymeric paints, cable insulation, organic impurities and their thermoradiolytic products (chloride-ions, organic acids), sludges on content and correlation of the volatile iodine species in the content and correlation of the volatile iodine species in the containment gas phase and the water/gas phase iodine partitioning coefficients.**  **Tools to solve the task: Autoclave installations with sampling for researches of same iodine species and the water/gas phase iodine partitioning coefficients in the impurities present and the temperature range 20-1500C, pressure 0,1-0,8 MPa, γ-irradiation-0-5 kGy/h. Gamma-radiation, facility RChM-γ-20. Methods and sorbents for the determination of iodine species ratio in the water and gas phases. Analytical and chromatographic methods and techniques for the impurities radiolysis products and various iodine species detection; ion-selective and red-ox electrodes, ionometer, spectrometer, gas-liquid-chromatography, gamma-spectrometry, paper chromatography, iodine sensor and other** | | 1- VNIPIET  2- NITI (Department 5) |
| **Description of deliverables** | | |
| 1 | Reports on experimental tests | |
| 2 | Preliminary repot on experimental researches of sludge effects in water phase on iodine volatility (Phase I) | |
| 3 | Report on experimental research results on containment parameters and impurities impact on iodine volatility; and recommendations on choice of numerical models and rate constants for iodine model (for task 7) | |

#### Task 7. Numerical and theoretical modeling of containment parameters impact on volatile iodine species content and correlation

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Numerical and theoretical modeling of containment parameters impact on volatile iodine species content and correlation.**  **Task stages: 1) Iodine model analyses and adaptation, computer codes development, choice of parameters and process constants. 2) Pre-test/post-tests calculation (according to test schedule). 3) Recommendation choice of numerical models and constants for iodine computer code development and assessment of iodine environmental accident source term at late phase accident stage.**  **Tools to solve the task: 1) Containment iodine behavior model under accident conditions, developed by VNIPIET/SPAEP. 2) Computer codes for calculations of pH and Ered-ox in solution; databases on iodine rate and equilibrium constants; published experimental and calculation data; proprietary unpublished data.** | | 1- SPAEP  2- VNIPIET |
| **Description of deliverables** | | |
| 1 | Preliminary report on iodine model adaptation and computer code development | |
| 2 | Pre-test/post-tests calculation results (information) | |
| 3 | Report on iodine model adaptation results correlation with experimental data, and numerical modeling; recommendations on parameters and constant choice | |

### 5. Role of Foreign Collaborators/Partners

Support letters for the EVAN project are already provided by collaborators from VTT, GRS, and ITU; additionally the support letters are expected from PSI, CEA and IRSN. Foreign collaborators provide materials for analysis during Task 1, participate in the test matrices specification, modeling, and analysis for Tasks 2-7. Also joint publications are expected, along with development of proposals for models and computer codes development and future research.

### 6. Technical Approach and Methodology

#### Task 1. Assessment of results of severe accident sequences modeling

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Assessment of results of severe accident sequences modeling**  **Task Stages: 1) Assessment of results of severe accident sequences modeling for different NPP designs with PWR or VVER reactors. Justification of initial data for experimental investigations. 2) Justification of applicability to be obtained experimental data for computer codes validation. Preparation of experimental programs.**  **Tools to solve the task: 1) Results of severe accidents modeling. 2) Computer codes RATEG/SVECHA/HEFEST, CORCAT, DINCOR, KUPOL-M, SCDAP/RELAP, MELCOR. Assessment of results of numerical modeling.** | | 1- SPAEP  2- IBRAE |
| **Description of deliverables** | | |
| 1 | Report on initial data for experimental programs for tasks 2, 4, 6 (stage 2) | |

Participants experience

SPAEP specialists have been leading the research-and-development programs for projects of nuclear power plants (AES-91, VVER-640, and VVER-91/99 with reactors VVER-640, VVER-1000, and VVER-1500) with more than 20 institutions involved and time scale up to 5 years each. Institute has been certified for ISO 9001-2000 quality management system, has necessary licenses for nuclear power plants designing, and has a state accreditation as research institution.

During safety justification of the NPP designs with VVER-640 and VVER 1000 where the severe accident management concept had been implemented, SPAEP specialists analyzed the accident modeling results obtained by the subcontractors’ or co-operating institutions (IBRAE, RRC Kurchatov Institute, SEC NRS of Gosatomnadzor, IVO Engineering), and also were personally involved in the supporting calculations, consulting, and engineering. Based on the results of calculations with integral computer codes the severe accident source terms had been estimated for safety analysis reports and Level 2 probabilistic safety analysis.

Under SPAEP supervision in IBRAE and other co-operating institutions the following computer codes had been developed and validated: thermal hydraulic modules for estimation of parameters within the process circuits and containment compartments (RATEG, KUPOL) and modules for core and reactor internals materials interaction at in-vessel and ex-vessel stages of severe accident (SVECHA, GEFEST, DINCOR). The RATEG/SVECHA/GEFEST program modules are functionally coupled into single integral severe accident code. Additionally, the empirical model similar to CORSOR for in-vessel fission product release from fuel and BONUS program for estimation of FP buildup in fuel and decay heat generation are implemented into this integral code.

Research on safety analysis of the nuclear power facilities is one of the important subject of IBRAE RAS activities. The Institute carries out works on numerical and theoretical analysis and development of computer codes to model NPP at various stages of accidents, as well as verification of the codes.

Verification of the developed codes has been done using experimental data obtained in the frameworks of international and Russian projects, such as SURC-4 (NRS), international program ACE, BETA (KfK), interaction of melt with high temperature concrete (IVTAN), CORINA (CBA IPSN), RASPLAV (Project of RSC "Kurchatov Institute"), PHEBUS B9+ (IPSN), CORA-13 (KfK), CORA-WWER (RRC, KfK), experiment on the quenching of reactor core (FZK, Germany), containment model 1/6 Sandia, full-scale data of Kalinin NPP, etc.

Within the framework of cooperation between IBRAE RAS and IRSN, IBRAE takes part in the IRSN works on development and improvement of codes on NPP safety, including integral severe accident code ICARE2.

List of main publications:

1. Severe accident code RATEG/SVECHA/HEFEST. Methodology of calculations. Part 1. Thermo-hydraulic module RATEG. Report SPAEP No. F-1660.01, 2002.

2. Severe accident code RATEG/SVECHA/HEFEST. Methodology of calculations. Part 2. Description of SVECHA package. Report SPAEP No. F-1660.02, 2002.

3. Severe accident code RATEG/SVECHA/HEFEST. Methodology of calculations. Part 3. Description of HEFEST module. Report SPAEP No. F-1660.03, 2002.

4. Software package «KUPOL-M». Description of software. No. 75687/1, SPAEP.

5. Reference Manual on code DINCOR-DGR, No. # SPAEP F-17579, Obninsk, 2002.

6. Development of codes to simulate a fission products release during in-vessel phase of a beyond design accident. Phase 1. Development and debugging of modules of fission products release and assessment of nuclide composition. R&D Report on Contract No. LYG/593. No. SPAEP F-17696, IBRAE, Moscow. 2002.

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9. Severe Accident Management Measures in VVER-91/99. V.V. Bezlepkin, S.V. Svetlov, Yu.G. Leontiev, 11th International Conference on Nuclear Engineering, Tokyo, JAPAN, April 20-23, 2003, ICONE11-36108.

10. Core Catcher for Tianwan NPP with VVER-1000 reactor. Concept, Design and Justification. S.V. Svetlov, V.V. Bezlepkin, I.V. Kuhtevich, V.S. Granovsky, S.V. Bechta, V.B. Khabensky, V.G. Asmolov, V.B. Proklov, A.S. Sidorov, A.B. Nedorezov, Hua Mign Chuan, V.V. Gusarov, V.F. Strizhov, Yu.P. Udalov, 11th International Conference on Nuclear Engineering, Tokyo, JAPAN, April 20-23, 2003, ICONE11-36102

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15. Kisselev A., Voltchek A., Strizhov V., Derugin A., Parracchia A., Gonzalez R., Jacqu F. Verification of Modified Version of SFD integral Code ICARE2 Against CORA-W2 (ISP-36) Experimental Data. // Heat and Mass Transfer in Severe Nuclear Reactor Accidents. Begell house, Inc., New York, Wallingford. -1996. -P.117-128.

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Methodology and technical approach

SPAEP and IBRAE will analyze the data on the earlier LWR severe accident calculations provided by foreign collaborators and available to participants.

|  |  |  |
| --- | --- | --- |
| Analyzed designs | Data from Russian party | Data from collaborators |
| Western reactors (LWR) | - | + |
| VVER-640 | + | - |
| VVER-1000 | + | + |
| Phebus-FP | - | + |

Comment: ISP-46 (P. Giordano, IRSN), German BWR designs (HJ Allelein, GRS), SARNET PSA-2 and OPTSAM accident analyses (different types of reactors and accident sequences).

The goal of the analysis is to determine the parameter ranges within the reactor plant and containment, core melt parameters, FP aerosol characteristics, surface boundary conditions at structures and equipment, chemical content of containment sump solution, dose rate ranges in the equipment and containment, and other parameters, necessary to develop the final test specification for Tasks 2, 4, and 6. Participants will also analyze the capabilities of physical models for aerosol generation and transport for RATEG/SVECHA/GEFEST, ICARE2, and ASTEC codes (in case the foreign collaborators provide documentation on ASTEC code physical models).

#### Task 2. Experimental research on FP release from molten pool/core melt catcher

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Experimental research on FP release from molten pool**  **Work stages: 1) Experimental investigations of low-volatile fission products release during molten corium oxidation. Melt characteristics and composition of the FP in question are determined from the results of Task 1. 2) Experimental investigations of low-volatile fission products release during water supply onto the melt surface.**  **Tools for solving the task: 1) A set of “Rasplav” experimental installations, equipped with aerosol sampling system, for studying high-temperature phenomena in molten corium. 2) A complex of instruments and equipment for tests preparation, conducting posttest analyses and processing experimental results. The complex includes XRF spectrometers, microsizer, mass spectrometer, spectrophotometer, auxiliary equipment (crusher, microgrinder, laboratory balance, etc.)** | | 1- NITI |
| **Description of deliverables** | | |
| 1 | Report on experimental study of low-volatile fission products release during molten corium oxidation | |
| 2 | Report on experimental study of low-volatile fission products release from molten corium pool covered by water layer | |

Experience of participants

Experimental investigations on the “Rasplav” installation are carried out by the NITI team, involving individual specialists from academic institutes and institutes of higher education, such as ISC RAS, SPbGETU and SPbTU (TI). High professionalism of the NITI staff that matches the standards of the leading scientific schools in the Russian Federation in the sphere of improving NPP safety has been confirmed by the valuable research results recognized both in Russia and abroad.

The NITI team participating in the project has taken part in two EC research projects on the FP release at the NPP severe accident late phase, namely Fission Product Release from Molten Pools - F14SCT960021 and Late Phase Source Term Phenomena – Contract No.FIKS-CT-1999-00005.

The results of investigations performed by the NITI team on the problem of melt retention in the reactor vessel allowed the development, designing and justification of a system for melt retention in the VVER-640 vessel. The design has undergone an examination by experts and a licensing procedure.

Among the team’s recent scientific an technical achievements of significant importance is the development of a concept of core melt retention under the VVER NPP severe accident conditions, scientific and technical justification of the concept, designing of a core melt catcher and implementation of the said concept and device in the design of the new generation NPP with VVER-1000 currently constructed by Russia in China and India. By now, construction of the core melt catcher for the 1st and 2nd power units of the Tianwan NPP in China has been completed. The device of this type is unique in the world. In the course of investigations the team of scientists has created a fundamentally new class of materials with special properties, i.e. sacrificial materials for nuclear engineering. The core melt catcher and the applied materials have been patented in the Russian Federation and undergone examination by experts from Russian and international supervising bodies, namely Federal Inspectorate for Nuclear and Radiation Safety (Gosatomnadzor, or GAN) and IAEA.

The team numbers 20 persons including 1 corresponding member of RAS, 2 professors, 2 Dr. Sci. (Eng.), 1 Dr. Sci. (Chem.), 6 PhDs (Eng.), 1 PhD (Phys.-Math.), researchers, engineers and technicians of various profiles. The research results obtained on the “Rasplav” installation have served as the basis for preparing 3 PhD and 1 Doctoral theses; several more theses are still in progress. Since commissioning the installation in 1988, the team has performed a significant number of unique experimental investigations into the problems of corium.

Main publications by the team on the topic:

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2. S.V. Bechta, V.S. Granovsky, A.A. Sulatsky et al. Water boiling on the corium melt surface. // Proc. of International Workshop on physics and heat exchange at boiling and condensation. May 21-24, 1997, Moscow. (in Russ.)

3. Bechta S.V., Vitol S.A., Krushinov E.V., Granovsky V.S. et al. Water boiling on the corium melt surface under VVER severe accident conditions.// Teploenergetica (Heat-and-power engineering). V.45. No.11. 1998, P. 898-905. (in Russ.)

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5. S.V. Bechta, S.A. Vitol, E.V. Krushiniv et al. Fission Products Release from Molten Pool: Ceramic Melt Tests // Proc. of SARJ meeting 1998, Nov. 4-6, 1998, Tokyo, Japan.

6. S.V. Bechta, V.B. Khabensky, E.V. Krushinov et al. Corium Melt - Zirkonia Concrete Interaction: Oxide Melt Tests // Proc. OECD Workshop on Ex-Vessel Debris Coolability. Karlsruhe, Germany, 15-18 November 1999.

7. K. Froment, B. Duret, J.M. Seiler, S. Hellmann, M. Fischer, S. Bechta, D. Lopukh, A. Pechenkov and S. Vitol. Analysis of Ceramic Ablation by Oxidic Corium // Proc. OECD Workshop on Ex-Vessel Debris Coolability. Karlsruhe, Germany, 15-18 November 1999.

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9. D. Lopukh, S. Bechta, A. Pechenkov, S. Vitol et al. New Experimental Results on the Interaction of Molten Corium with Core Catcher Material // Proc. International Conference ICONE-8, April 2-6, 2000, Baltimore, MD USA

10. I.V. Kukhtevich, V.V. Bezlepkin, V.S. Granovsky, V.B. Khabensky, V.G. Asmolov, S.V. Bechta, A.S. Sidorov, V.M. Berkovich, V.F. Strizhov, M.F. Rogov, V.P. Novak. A concept of molten corium localization at the VVER-1000 NPP severe accident ex-vessel stage. // Proc. of Scientific and Practical Workshop “Problems of the VVER NPP safety”, St.Petersburg, 12-14 September 2000. (in Russ.)

11. Sidorov A.S., Nedorezov A.B., Kukhtevich I.V., Bezlepkin V.V., Khabensky V.B., Granovsky V.S., Bechta S.V.. Melt catcher for the Tianwan NPP. Design and functioning. // Proc. of Scientific and Practical Workshop “Problems of the VVER NPP safety”, St.Petersburg, 12-14 September 2000. (in Russ.)

12. Bechta S.V., Khabensky V.B., Krushinov E.V., Vitol S.A., Granovsky V.S, Sulatsky A.A.,. Lopukh D.B., Petrov Yu.B., Pechenkov A.Yu., Martynov A.P., Kulagin I.V. Water boiling on the oxidic corium melt surface under VVER severe accident conditions // Problems of the VVER NPP safety. Investigation of processes during severe accidents involving core degradation. Proc. of Scientific and Practical Workshop “Problems of the VVER NPP safety”, St.Petersburg, 12-14 September 2000. (in Russ.)

13. Almjashev V.I., Gusarov V.V., Bechta S.V., Khabensky V.B., Saenko I.V. Sacrificial Materials of the Core Catcher as a New Class of Functional Materials. Abstract Book. Gdansk-Jelitkowo. 10-13 September 2001. P1.

14. Gusarov V.V., Bechta S.V., Khabensky V.B., Granovsky V.S., Almjashev V.I., Vitol S.A., Krushinov E.V. Choice of buffer material for the VVER-1000 core melt catcher. // Atomnaya Energiya (Nuclear Energy), 2002. V.92. No.1. P.7-18. (in Russ.)

Methodology and technical approach

A calculated prediction of the main radiation safety objectives during a severe accident requires substantiated data, e.g. coefficients of the radiologically significant radionuclides release from molten fuel into the environment. At present such data are available for the majority of volatile radioactive FP (radioactive noble gases, iodine, Cs, Rb, etc.), which evaporate during the core degradation and molten fuel pool formation. The release of such low-volatile FP as Ba, Sr, La, Ce, isotopes of the platinum group elements (Ru), lanthanoids and actinoids form a high-temperature molten core pool still has not been studied sufficiently due to extremely difficult engineering aspects of experimental investigations.

For suppressing the FP release, protecting the superstructures from heat radiation from the melt surface and increasing the efficiency of corium pool cooling, the core melt catcher (CMC) envisages water feeding onto the melt surface after inversion of the oxidic and metallic layers. The resulting decrease in radionuclides release into the containment is mainly achieved owing to:

- capture of a significant part of aerosols by the water layer at bubbling the gas-aerosol flow through it,

- melt surface temperature decrease at the film boiling of water,

- crust formation at the melt surface.

At present, there does not exist a unified theory that would describe the mechanisms of evaporation from oxidic melts. The complexity of oxidic systems evaporation is that evaporation of few oxide follows one chemical pattern (congruously). The majority of data on evaporation have been obtained by the classical Knudsen’s method (effusion into vacuum), as well as by high-temperature mass spectrometry (a combination of Knudsen’s method with mass spectrometry of the evaporated products) and are available for individual oxides. These data are hardly applicable to the multicomponent oxidic melts and, correspondingly, to the severe accident conditions.

The study FP evaporation from molten corium (Task 2) envisages application of the flow method which belongs to the dynamic methods of steam pressure determination. The essence of the method is in saturation of the carrier gas passing at a constant rate above the melt (water-flooded, too) with vapors of the substance in question. The amount of the transported substance will be determined by means of physicochemical analyses.

The high temperature and chemical activity of the molten ceramic corium place limitations on the application of conventional heating methods and crucible materials. The method of induction melting in the cold crucible (IMCC) in the RF band has been chosen for producing ceramic melts and achieving objectives of the project.

Characteristic features of the method:

- internal power in the melt;

- the presence of a crystallized melt layer (crust) between the melt and the crucible cold wall, which prevents mass transfer of the crucible material to the melt.

This combination of the non-contact heating and the non-contaminating method of oxides melting ensures:

- melt purity as high as that of the initial products;

- melt superheating above Tliq, chemically active oxidic materials included;

- melting and long-term maintenance of an oxidic system in molten state in both neutral and oxidizing atmospheres;

- universality and compactness of the melting device.

The level of experimental investigations is determined to a considerable degree by the available material and technical basis. The backbone of the facility are three experimental installations for the induction melting of corium in which the IMCC technology is realized at different frequencies of the heating current. They allow experimenting with a broad range of corium compositions which differ greatly in electrical conductivity when in molten state. The specification of the experimental installations are given in Tab. 2.

Table 2. Specification of experimental installations.

|  |  |  |  |
| --- | --- | --- | --- |
| Specification | Experimental installation | | |
|  | Rasplav-2 | Rasplav-2/Ñ | Rasplav-3 |
| Molten corium preparation method | Induction melting in the cold crucible (IMCC) | | |
| Installed capacity, kVA | 250 | 250 | 100 |
| Melt mass in crucible, kg | Up to 5 | Up to 10 | Up to 2 |
| Melt temperature, °Ñ | Up to 3000 | | |
| Above-melt atmosphere | Air, nitrogen, helium, argon | Air | Air, nitrogen, helium, argon |
| Melt composition | Oxidized corium | | Unoxidized corium and steel |
| Possible manipulations with melt | Ingot production | Spreading | Ingot production |
| Commissioned, year | 1988 | 1995 | 2002 |

The installations are equipped with modern monitoring instruments, including those for measuring the melt temperature, electrical characteristics of melting, calorimetry of heat fluxes and the process video monitoring. Acquisition, processing and storage of the results of measurements is done using the data acquisition and measuring system IIS-R designed and produced by the NITI specialists. IIS-R incorporates modern software controlled by the Lab View 5.5 software package.

The experimental installations are supported by the laboratory equipped with modern instruments for physicochemical analyses.

Table 3. NITI contribution to the EVAN project: suggested experimental matrix (to be finalised during project agreement preparation).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Test | Test objective | Specifications | Notes | Time |
| Stage 1 | EVAN–FP1 | Study of low-volatile fission products release during molten corium oxidation | Corium composition: UO2 – ZrO2 - Zr, U/Zr(at)=1.2, C-32 (specified according to the results of Tasks 1 and 2)>C-100,  Corium mass: 1-2 kg,  Melt temperature: Tliq+(50-100)C,  FP: Mo, Ce, La, Sr, Ba | Oxidation in air | 2nd quarter |
| Stage 2 | EVAN–FP2 |  |  | Oxidation in steam | 4th quarter |
|  | EVAN–FP3 | Study of low-volatile fission products release at feeding water onto the melt surface | Corium composition: UO2 – ZrO2 (-FeO), U/Zr(at)=1.2, C-100 (specified according to the results of Tasks 1 and 2)  Corium mass: 1-2 kg,  Melt temperature: Tliq+(50-100)C,  FP: Mo, Ce, La, Sr, Ba | Desalted water is fed onto the melt surface | 6th quarter |
|  | EVAN–FP4 |  |  | Water containing dissolved materials from the primary coolant circuit and FP (H3B03, etc.) is fed onto the melt surface. Water composition is to be specified upon coordination with the project collaborators. | 8th quarter |

Notes:

- Determination of the FP release coefficients is carried out using stable FP simulators by the flow method that envisages measurements of FP concentrations in the melt, gas (steam) flow and water layer on the melt surface.

- The Rasplav 2 and 3 installations will be modernized, their aerosol sampling system in particular, in order to reduce the aerosol transport losses and increase representativity of measurements.

- The analytical filters/impactors and techniques used in the FPR MP and LPP project will be adapted to ensure that measurements can be made in steam.

#### Task 3. Analytical investigation of fission products release from molten pool or core catcher.

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Analytical investigation of fission products release from molten pool.**  **Task Stages: 1) Review of modern codes capabilities to simulate FP release from molten pool. Justification of applicability to be obtained experimental data for computer codes validation. 2) Pre tests/post tests simulation (in connection with experimental program performance).**  **Tools to solve the task: High performance computers, analytical and numerical calculation models** | | 1- IBRAE |
| **Description of deliverables** | | |
| 1 | Report on modeling results of fission products release from molten pool | |

Participants' experience

Simulation of the studied processes is being carried out using numerical simulation of processes of heat and mass exchange taking into account aerosol kinetics. IBRAE specialists are experienced in simulation of complex processes of physical and chemical transformations, which occur in the core melt. On this basis, they develop software to solve hydrodynamic problems, including modules for calculation of release of aerosol particles from the melt surface.

List of main publications:

1. Stepnov V.D., Tkachenko A.V., Klementeva E.M., Kazakov V.A. Methodology for assessing releases of iodine compounds into atmosphere at accidents at NPP with VVER-1000 reactors (RB-020-01). Gosatomnadzor of Russia, Moscow, 2001.

2. Kisselev A.E., Nosatov V.N., Strizhov V.F., Tomachik D.Yu. Application of integral codes to simulate emergency regimes of VVER reactors // Izvestiya Akademii Nauk (Bulletin of Academy of Sciences), Series Energy, v. 2. -2004, -p.57-64.

3. Kisselev A.E., Nosatov V.N., Strizhov V.F., Tomachik D.Yu. Simulation of severe accident at VVER-440 reactor (V-230) using MELCOR-1.8.5 code// Izvestiya Akademii Nauk (Bulletin of Academy of Sciences), Series Energy, v.2. -2004. -p.65-71.

Methodology and technical approach

Release of radionuclides and generation of aerosols from the melt surface can be caused by mechanical formation of aerosols and evaporation. The mechanical formation of aerosols results from bursting of gas bubbles rising through the melt and reaching the surface, as well as from breaking of small drops against the melt surface. The rate of FP release will be determined by the speed of gas bubbles “floating-up” to the melt surface and the viscosity of the melt material. Besides, as theoretical investigations have shown, under certain conditions of gas media above the melt surface (while vertical flows form), it is quite possible a generation of waves with crests, which can also cause generation of aerosol particles.

However, the most important mechanism determining fission products release from the melt surface is not the mechanical formation of aerosols, but the process of evaporation. It is supposed, that several particles, which can evaporate (usually, 4 to 10 particles), cluster in one particle, which is taken into account, of which the aerosol is formed. The melt evaporation increases, first of all, nonvolatile fission products release. This can be taken into account by convective members in boundary conditions to the diffusion equations for nonvolatile elements. From this point of view, account of the melt evaporation does not represent methodical difficulties for FP release calculations, and requires only appropriate experimental data on thermodynamic properties of the melt containing fission products. Sufficiently precise problems can be formulated for a liquid film on a flat or cylindrical surface. These problems should include the equations of motion for the liquid film, its energy equation along with equations determining diffusive mass transfer in the film volume to its surface with regard to material evaporation. In this case, it is possible to use the solutions on the liquid flow, known from hydrodynamics, or include the equations of motion into the common system of equations.

By now, many physical models of FP release from the molten pool have been implemented in the computer codes. They are characterized by the various levels of sophistication, from simplest correlation models to mechanistic ones. To do the calculations, it is supposed to use codes RATEG/SVECHA and respective models of code ICARE2 (IRSN, France) (code RELOS, Germany, if provided by counterparts). Experimental data from EU Framework Programme LPP project provided by collaborators could be used for additional analysis.

#### Task 4. Experimental study of aerosols transport processes in the primary circuit equipment

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Experimental study of aerosols transport processes in the primary circuit equipment**  **Work stages: 1) Final completing and adjustment of experimental facilities. Development of research procedures. Pre-test calculations. 2) Experimental studies of aerosol particles deposition on pipeline surfaces from a turbulent flow and re-entrainment of particles. 3) Experimental studies of Cs deposition and evaporation from primary circuit pipeline surfaces.**  **Tools to solve the task: 1) A test facility for studying aerodynamics of a "dust-laden flow": distributions of velocities, concentrations, turbulent pulsations, and dynamics of deposition of aerosol particles (depending on disperse composition of aerosol) on the channel walls and re-entrainment of particles in the flow, equipped with an online optical monitoring system. A test facility for calibration of the measuring system, adjustment of aerosol particle generators and determination of spectral composition of the particles. 2) A complex of instruments and equipment for experiment preparation, performance of post-test analyses and processing of experimental results. The complex includes: lasers, spectrophotometers, signal analyzers, LDA-processor, 4 PC-based workstations, multimedia projector (to be corrected during further work at the first stage of the task).** | | 1- CKTI |
| **Description of deliverables** | | |
| 1 | Report on results of experimental studies of aerosol particles transport processes in the primary circuit pipelines | |

Experience of participants

Specialists of JSC NPO CKTI, during 70s-80s, carried out an R&D programme on studying the mechanism of substance deposition from a gas flow on surfaces of various configurations. The research was performed within a scope of work on designs of magneto-hydro-dynamic electric power generators – MHD generators. For increasing gas conductivity, MHD generators use readily ionized additives (0.1% by weight) for closed-cycle MHD generators, and their salts (~ 1% by weight) for the open cycle. In closed-cycle generators, the working medium is an inert gas (helium or argon) with addition of readily ionized vapors of alkali metals (cesium or potassium). In open-cycle generators, smoke fumes serve as working medium. After the working channel of the MHD unit, before gas feeding to the compressor and the heater (nuclear reactor), the additive must be separated from the flow. This can be achieved by vapor condensation in the cooler. The principal feature of the process is that vapor condensation on a surface involves volume mist formation during cooling of supersaturated vapors mixture. One of the main purposes of said cycle of work was development of a condenser calculation procedure and verification of the procedure by theoretical calculations and experiments. In connection with development of the calculation procedure, great attention was given to physical subjects: baro- and thermal diffusion, mist formation, thermophoresis of fine particles. Furthermore, diffusion coefficients for cesium and potassium vapors in helium and argon, for vapors of zinc and lead in helium, argon and nitrogen were determined experimentally (by Stephen method) as they were necessary for calculations.

Specialists of the condensation team with the NPP equipment research and design department of OAO NPO CKTI have wide experience in modeling of complex flows with chemical physics transformations including kinetics of aerosol particles.

It is planned to perform studies on the test facility for modeling of aerosol transport processes in the primary circuit by efforts of the team of JSC NPO CKTI employees with involvement of individual specialists from institutions of higher education, in particular, St. Petersburg State Polytechnic University and St. Petersburg State Marine Engineering University. Conformity of the team to the category of leading scientific schools of the Russian Federation in the area of research for improvement of NPP safety is confirmed by positive results of research projects that have received acceptance both in Russia and abroad.

The team of the project participants from JSC NPO CKTI took part in an international project for study of thermal processes in Russian fission materials storage facility (RFMS). In particular, aerodynamic and heat-exchange processes for free and mixed air convection in a vertical cylindrical channel were studied. State-of-the-art measuring methods and facilities were widely used in the experiments, for instance, laser Doppler anemometry was applied to determine velocity profile of air containing suspended particles. The process of measurement, information acquirement and processing was fully automated. This experience can be directly used in the work for Task 3.

The team includes 28 persons, among them one academician of MEA, 1 professor, 4 assistant professors, 2 doctors of tech. sc., 6 candidates of tech. sc., researchers and specialists in various engineering and scientific subjects. Results of the research in extraction of ionizing additives have become a basis for 2 candidate dissertations and 1 doctor dissertation already defended, several works being prepared. During the period of operation of the test rig, the team has realized a significant amount of experimental research in the above-said problem.

A list of main publications of project team on the topic of the project

1. K.M.Arefiev, V.M.Borishansky, I.I.Paleev, L.A.Suslova, N.M.Fishman, B.M.Khomchenkov. Coefficients of Cs, K and Na vapors Diffusion in He and Ar., “Transfer phenomena in low –temperature plasma”. “Nauka i technika”, 1969, pp. 186-197.

2. K.M.Arefiev, V.M.Borishansky, T.V.Zablotskaya, N.I.Ivashchenko, O.P.Krektunov, I.I.Paleev, L.A.Suslova, N.M.Fishman, B.M.Khomchenkov. Coefficients of Cs, K and Na vapors Diffusion in He and Ar., High Temperature, 10, #5, 1972, pp. 1112-1114

3. K.M.Arefiev, V.M.Borishansky, T.V.Zablotskaya, N.I.Ivashchenko, O.P.Krektunov, I.I.Paleev, L.A.Suslova, N.M.Fishman, B.M.Khomchenkov. Coefficients of Cs, K and Na vapors Diffusion in He and Ar., High Temperature, 10, #5, Fog initiation effect on Cesium condensation from flow of argon. “Advances on heat transfer and hydraulics of two-phase flows in elements of power equipment”, L., “Nauka”, 1973, pp. 275-283.

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7. M.E.Lebedev, N.G.Ivanov, E.L.Kitanin, V.V.Ris, A.G.Fedorov. Mixed convection in vertical heated tube: computation and comparison with experiment data. Vol.3, M. Moscow State Power Eng. Univ. 2002, pp. 79-82

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9. M.E.Lebedev, S.F.Uras, L.N.Chirkov, M.A.Blinov, A.V.Terentiev. Experimental determination of dynamical characteristics of processes at air natural convection in vertical cylindrical ducts. “Proceedings of Regional science and technology conference “Shipbilding Education and Science – 2003, vol. 2, Saint- Petersburg, SPb State Naval Tech. University, 2003., pp.276-281.

10. Feldberg L.A., Povarov O.A., Semenov V.N., Popov S.A. (1999) Dispersion and Steam Wetness Measurements in the Turbine Using Optical Probe International Conference Steam Chemistry -“Interaction of Chemical Species with Water, Steam, and Materials during Evaporation, Superheating, and Condensation”, No 20, Germany

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15. N. Semidetnov, Experimental Study and Numerical Simulation of Time-of-Flight Anemometer Signals generated by Large Particle, "Proceedings of the international workshop" «Flow Diagnosis Techniques", St-Petersburg: Society “Znanie”- RPO SPALA, 1998, pp. 131-138

16. N. Damaschke, H. Nobach, T. Nonn, N. Semidetnov, C. Tropea, Size and velocity measurements with the Global Phase Doppler Technique, 11th International Symposium on Application of Laser Techniques to Fluid Mechanics. 8 – 11 July 2002, Lisbon, Portugal

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18. N. Damaschke, H. Nobach, N. Semidetnov, C. Tropea, Multidimensional particle sizing techniques for two phase flows,10th International symposium on Flow Visualization August 26-29, 2002, Kyoto, Japan, paper # F0502

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21. N.Semidetnov, C. Tropea, Conversion Relationships for Multidimansional Particle Sizing Techniques, Measurement Science and Technology, issue 15, Institute of Physics, UK 2004, pp. 112-118.

22. N. Damaschke, H. Nobach, N. Semidetnov, C. Tropea, TIME-SHIFT Technique For IN-SITU Particle Sizing in Backscatter, 7th International Congress on Optical Particle Characterization, Doshisha University, Kyoto, Japan, 2004

23. N. Damaschke, H. Nobach, N. Semidetnov, C. Tropea, Cross Sectional Area Difference Method For Backscatter Particle Sizing 12th International Symposium on Application of Laser Techniques to Fluid Mechanics, Lisbon, 12-15 July, 2004

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Methodology and technical approach

Fission products deposited at the initial stage of a severe accident in the primary circuit (including heat-transfer surfaces of steam generators) can in future enter the atmosphere of the containment. Account of FP retention in the primary circuit at the initial stage of the accident may influence the evaluation of accidental release, which can be both overestimated (due to possible additional discharge of deposited FP from the primary circuit to the containment atmosphere at a later stage of the accident) and underestimated (in case of reliable FP localization within the primary circuit). To forecast the rates of FP leaving the primary circuit surfaces (due to resuspension and re-evaporation), it is extremely important to know conditions of aerosol deposition on walls of pipelines of different diameters from the steam-gas turbulent flow. Experimental research of local problems of particles deposition and resuspension, and processes of FP re-evaporation from inside surfaces of the primary circuit will allow more precise definition of characteristics of FP entering the containment atmosphere from the primary circuit late in severe accidents.

Initial stages of the experimental research can be carried out using the available installation that was earlier used in experiments involved in creation of RFMS (see above). In particular, there is a steel cylindrical channel of 98 mm inside diameter, 6.2 m long. It is equipped with an electric heating system and a water jacket that can be used both for heating and cooling. It is possible to vary the heated length and to combine heating and cooling of different sections. 40 thermocouples for wall temperature measurements and 11 gradient heat flux sensors are mounted along the channel. Optical windows for flow scanning by laser Doppler anemometers are located in four cross-sections along the length. Coordinate devices for flow scanning by wire sensors (thermal anemometers and resistance thermometers) are disposed in five cross-sections along the length. All measurements are computer-controlled.

Within the scope of the planned work, it is proposed to study experimentally the influence of physical properties of particles on their coagulation and the structure of the layer of even film formed of them.

Optical methods as applied to the task under consideration can be successfully used both for measuring kinematical characteristics of particles and for fractional analysis of a two-phase flow. This will enable us to determine velocity profiles along the pipe, including the near-wall layer as the most important for migration of particles, and characterizing parameters of turbulence

Table 4. Tentative matrix of NPO CKTI experiments within the scope of EVAN project (to be adjusted during project agreement preparation).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Test | Purposes of experiments | Specification | Note | Time |
| EVAN–AER1 EVAN–AER2 EVAN–AER3 | Study of deposition and re-entrainment of aerosol particles | Vertical and horizontal pipes, Re 400‑10000, composition of particles to be determined on agreement with collaborators | Steam and inert atmosphere | 4-6 qts |
| EVAN–AER4 | Study of deposition and re-evaporation of Cs compounds | Vertical or horizontal pipe, Re 400‑10000, test conditions to be determined on agreement with collaborators | Steam atmosphere | 8 qts |

Kinematical measurements

The use of the laser Doppler method makes it possible to measure, with sufficient accuracy (of the order of several percent):

- carrying phase velocity profile,

- suspended phase velocity profile (for particle size larger than several microns).

The measuring method is absolute and does not require any calibration. The measured velocity range is 0.1…100 m/s. Measurement of both longitudinal and transverse velocity components is possible. Both average and pulsating velocity components are measured. The measurements are performed in an online mode. The time of traversing the channel diameter is about 1 min. Simultaneous measurements in several (up to four) check cross-sections along the pipe length are possible. Flat (or cylindrical) protective glasses must be mounted for measurements. An approximate size of the protective glass for measuring the longitudinal velocity component is 5x10 mm (10 mm along the channel axis).

CKTI has main measuring equipment units, which does not exclude the necessity of adapting them for solution of the problem under consideration.

Fractional analysis

Fractional analysis is understood as measurement of an average size (and, sometimes, also the size distribution function) and the volume concentration of particles. Unlike kinematical measurements, there is not any optical method today which enables measurements throughout the entire required range of particle sizes. Information available at present is not sufficient for final selection of a measuring method. As a first approximation, selection of the spectral transparency method (STM) and the pulse count method (PCM) seems reasonable. A similar solution was used in experiments on the STORM test facility.

Let us note some specific features of optical fractional analysis methods. For measurements in flows with particle sizes of up to several microns, optical constants (refraction indices) of particles must be known.

STM is absolute method and does not require calibrations, but it is integral (that is, it gives an averaged value along the beam path in the medium under study). The use of the method allows measurement of a certain combination of size and volume concentration. In some cases, both parameters can be measured separately. This depends on particle material and size range.

PCM has a high spatial resolution (fractions of a cubic millimeter) and allows measurement of a size distribution function of droplets. Thus, building of a profile of particle size and concentration over the channel diameter is possible. The main drawback of the method is that it is not absolute and requires provision of a calibrating apparatus. The exception is performance of relative measurements (e.g., piecewise concentration of particles).

Engineering implementation of both methods requires mounting of glasses: for the STM 3…5 mm in diameter, and for the PCM the glasses must be somewhat larger.

The STM is limited by particles concentration at the lower boundary while the PCM at the upper boundary.

The STM allows online measurements, and the PCM requires a certain time (not more than a minute) for measurements at a single point.

All the above considerations are stated for an assumption that particles have a spherical shape. In case the particles have large deviations from spherical form, special calculations of light dissipation and additional experiments on a calibration apparatus will be required.

Engineering implementation of the fractional analysis methods under consideration will not require purchase of any special expensive equipment. All optical methods considered allow creation of a fully automated measurement complex including measurement, traversing and processing of results. Combination of kinematical and some fractional measurements in a single measuring device is basically possible. Pressures of up to several atmospheres and flow temperatures of up to several hundred degrees do not present any special difficulties for engineering implementation of the optical methods under consideration.

CKTI has considerable experience both in kinematical measurements of one- and two-phase flows and in fractional analysis of two-phase media (in particular, analysis of high-velocity steam flows with water droplets of a size from hundredth parts to hundreds microns). Respective reports and literature references can be submitted. CKTI has no experience in deposition thickness measurements by optical methods, but such possibility exists and can be realized. The problem requires additional developmental work.

#### Task 5. Theoretical and computer modeling of aerosol transport in the primary circuit

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| **Task description and main milestones** | | **Participating Institutions** |
| **Theoretical and computer modeling of aerosol transport in the primary circuit.**  **Task Stages: 1) State-of-art review of modeling capabilities of the processes in question by modern computer codes, justification of applicability of the expected experimental results for models validation. 2) Pretest/posttest calculations (according to the test schedule).**  **Tools to solve the task: 1) 2D and 3D CFD codes coupled with mechanistic aerosol models, RATEG/SVECHA/GEFEST code with integral aerosol models. 2) High-performance computers.** | | 1- IBRAE  2- SPAEP |
| **Description of deliverables** | | |
| 1 | Report on modeling results for aerosol particles transport in the primary pipelines | |

Experience of participants

Computer modeling of the considered processes is performed by numerical modeling of heat and mass transfer processes with aerosol kinetics. Specialists of computational mechanics group in SPAEP NPP safety research department have extensive experience of modeling the complex flow dynamics with physico-chemical transformations and development of computer codes with appropriate hardware for solving the hydrodynamics problems, including those with coupled aerosol kinetics models. IBRAE performs modeling of aerosol transport with the integral aerosol model implemented in severe accident RATEG/SVECHA/GEFEST code.

1. Within the INTAS projects 93-1916, 94-740 and 96-0235 and RFBR project 97-01-00233 the model and computer code of processes in the plasmochemical reactors had been developed for 1D approach for the problem [1, 2].

2. Within the framework of Russian-Byelorussian SKIF programme the REAF-3D computer code had been developed intended for 3D modeling of the processes in the plasmochemical reactors [3, 4]. Such computer code allows to model flow dynamics of multicomponent gas mixtures with chemical reactions in the reactors with complex geometry.

3. Within the contract with National aeronautical centre (France), contract #715.728/DA,B2/MA the cloud dynamics model with cloud droplet formation had been developed [5].

4. Within the ISTC project #1078 «Mathematical modeling of mesoscale transport of atmospheric pollutants with their transformations: Aerosol formation kinetics in clouds» the aerosol kinetics models had been implemented into numerical models of atmospheric convection [6].

5. Within the ISTC project #2834 «Numerical modeling and estimation of the distribution of the suspended highly particulate particles and gases form ground sources for urban conditions» the models for aerosol transport and kinetics in the urban boundary layer had been developed.

6. In 2001-2002 the participants developed a program package for aerosol kinetics for NPP severe accident conditions [7], which had been coupled with the CUPOL-M code, tested and validated with available experimental data [8]. The model includes calculation of condensation, coagulation and deposition rates for composite aerosol particles.

A list of main publications of project team on the topic of the project

1. Y.E.Gorbachev, M.A.Zatevakhin, I.D.Kaganovich. Modeling of Growth of Amorphous Hydrogenated Silicon Films from HF discharge plasma // Journal of Technical Physics. 1996. vol. 66. issue 12. pp. 89-110.

2. Y.E.Gorbachev, M.A.Zatevakhin, V.V.Krzhizhanovskaya, V.A.Shveygert. Features of Growth of Amorphous Hydrogenated Silicon Films in PECVD-reactors // Journal of Technical Physics. 2000. vol. 70. issue 8. pp. 77-86.

3. Y.E.Gorbachev, M.A.Zatevakhin, A.A.Ignatiev. Numerical modeling of a-Si:H films growth in PECVD reactors // Proceedings of XXII international conference on computational mechanics and modern software application, Vladimir, 30 June - 5 July 2003. - Moscow, 2003. pp. 203-204.

4. Y.E.Gorbachev, M.A.Zatevakhin, V.V.Krzhizhanovskaya, A.A.Ignatiev, V.Kh.Protopopov, N.V.Sokolova, A.B.Witenberg. Distributed Simulation of Amorphous Hydrogenated Silicon Films: Numerical Experiments on a Linux Based Computing Environment // Lecture Notes in Computer Science, Vol. 2073, pp. 483-491. Springer-Verlag Berlin Heidelberg 2001.

5. I.L.Carol, M.A.Zatevakhin, N.A.Ozhigina, Yu.E.Ozolin, R.Ramaroson, E.V.Rozanov, E.N.Stankova. Numerical model of dynamical, microphysical, and photochemical processes in convective cloud // Izv. RAN, Physics of atmosphere and ocean. 2000. vol. 36. #6. pp. 1-16.

6. V.N. Piskunov and M.A. Zatevakhin. Numerical simulation of aerosol particle formation kinetics in large fires // Sixth International Aerosol Conference, Taipei, Taiwan, September 8-13, 2002. p.487-488.

7. M.A.Zatevakhin et al., Computer code for aerosol particles kinetics for beyond design basis accident for nuclear power plants. Technical report #F-17915, SPAEP, St.Petersburg, 2002

8. M.A.Zatevakhin, A.A.Ignatiev, Yu.G.Leontiev, I.M.Ivkov, Development of aerosol kinetics model for containment compartments during severe accidents at NPP with VVER, Power Engineering, April 2004.

9. Stepnov V.D., Tkachenko A.V., Klementeva E.M., Kazakov V.A. Methodology for assessing releases of iodine compounds into atmosphere at accidents at NPP with VVER-1000 reactors (RB-020-01). Gosatomnadzor of Russia, Moscow, 2001.

10. V.V.Bezlepkin, V.G.Sidorov, A.V.Lukin, R.V.Arutyunyan, A.E.Kiselev, V.F.Strizhov, M.S.Samigulin, V.P.Soloviev, V.B.Proklov, D.Yu.Tomaschik. Development of computer codes for in-vessel thermal hydraulic and physico-chemical processes within the framework of integral computer code for NPP severe accident modeling. // Power Engineering, #2. 2004. pp. 5-11

11. V.N.Antropov, V.D.Stepnov, A.V.Tkachenko et al. R&D report: Development of NPP accident consequences map. Topic 3-2-99-2001, #126/24, SEC NRS Gosatomnadzor RF, 2001.

Methodology and technical approach

Fission products deposited at the in-vessel stage of severe accident in the primary circuit (including heat transfer surfaces of steam generators) can be released into containment atmosphere at later stages of the accident. Taking into account FP confinement in the primary circuit at the initial stage may both increase (due to possible additional resuspension/revaporization of deposited FP from the primary circuit to the containment atmosphere at ex-vessel stage) and decrease (due to formation of stable chemical compounds with FP at surfaces of primary circuit equipment) FP release. To predict FP release rate from surfaces of primary circuit equipment (due to resuspension and revaporization), it is greatly important to know conditions of aerosol deposition from steam-gas turbulent flow onto reactor plant pipe walls of different diameters. Partly, of the principal interest are the flow characteristics (laminar and turbulent flow), fluid density and temperature gradients in the near-wall space for analysis of aerosol deposition due to diffusionphoretic and thermophoretic forces. Besides experimental investigation of these processes, it is necessary to carry out joint calculations on gas-dynamical and aerosol models for real geometries of equipment and test particles. While modeling the aerosol transport in the real geometry of the primary circuit it is necessary to employ such thermal hydraulic models that allow to account for Reynolds number change for changing pipeline geometry (e.g. in elbows, and bends). Numerical and experimental investigations of local problems related to FP species deposition, resuspension and deposited FP revaporization from internal surfaces of the primary circuit will allow better prediction of FP release to the containment atmosphere at severe accident ex-vessel stage.

Aerosol kinetics modeling is necessary for correct prediction the accident source term parameters. Also, as was noted above, such modeling is to be done with coupled thermal-hydraulics models. However, the lumped-parameter thermal-hydraulics models cannot provide all the input parameters for up-to-date aerosol models. For example, parameters like turbulent energy dissipation rate or boundary layer width are user-input in many modern computer codes, while it is evident that with just several user-input parameters it is impossible to consider all the processes which may occur in drastically different conditions.

Firstly, the near-wall processes are to be analyzed very closely, since it is those processes which eventually define the aerosol particles deposition efficiency.

Secondly, the aerosol kinetics models are to account for physical properties of the aerosol particles. For severe accident conditions most of aerosol particles are hygroscopic which, in turn, effects the deposition rate in certain conditions.

Thirdly, the hydrodynamics models used are to provide detailed modeling of the turbulent transport processes. Beside the direct turbulent transport calculation, turbulent parameters are necessary for such kinetics processes like turbulent coagulation and also deposition in tubes with changing geometry. In certain conditions such mechanism can contribute to the aerosol particles spectra formation. That is why turbulent parameters are necessary to be calculated for correct modeling of the aerosol particles spectra formation, and also aerosol deposition in the reactor plant coolant circuit for real geometries.

Simple semi-empirical models cannot always provide adequate modeling of the turbulent transport processes in the presence of buoyancy forces. The most promising technique for such problems is large-eddy-simulation method (LES-method) allowing to calculate processes with minimal additional empirical information. Though, such technique is very resource-consuming. Effective realization of such calculation techniques is possible only at modern high-performance computers and special programming methods. Such technique can only be used for relatively simple geometries for single problems (not multi-variant calculations). For large number of calculations, especially with aerosol dynamics models, it is necessary to use simpler models based on semi-empirical turbulence models with their parameters validated with the data obtained by LES-method.

SPAEP NPP safety research department and IBRAE have access to the modern high-performance computers allowing to use complex and resource-consuming computer codes for necessary calculations.

Thus, for Task 5 realization the 2D and 3D hydrodynamics models coupled with aerosol models will be used. External boundary conditions necessary for calculations will be chosen based on the results of Task 1. Task 5 stages are: (I) analysis of the main processes and development of the physico-mathematical model of aerosol spectra formation accounting for evaporation/condensation and turbulent transport; (II) adaptation of logic and computer code for numerical analysis of the developed model at parallel computing systems; (III) calculation with hydrodynamics computer codes and analysis of results; (IV) calculations with aerosol kinetics models coupled with thermal hydraulic codes, sensitivity study for different parameters on final results and producing recommendations for constitutive equations for aerosol deposition models. There will be joint work of IBRAE and SPAEP on cross-validation of aerosol transport models implemented in the integral RATEG/SVECHA/GEFEST code with CFD-codes. Also analysis of experimental date for STORM (JRC Ispra) and PSAERO (VTT) installations is proposed based on data provided by collaborators.

#### Task 6. Experimental investigations of containment parameters impact on volatile iodine content and correlation

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| **Task description and main milestones** | | **Participating Institutions** |
| **Experimental investigations of containment parameters impact on volatile iodine content and correlation.**  **Task stages: 1) Completing and adaptation of the experimental researches of sludges effect (oxyhydrates Fe and silicates) on volatile iodine species content and correlation in gas phase. 2) Experimental investigations on effect of organic polymeric paints, cable insulation, organic impurities and their thermoradiolytic products (chloride-ions, organic acids), sludges on content and correlation of the volatile iodine species in the content and correlation of the volatile iodine species in the containment gas phase and the water/gas phase iodine partitioning coefficients.**  **Tools to solve the task: Autoclave installations with sampling for researches of same iodine species and the water/gas phase iodine partitioning coefficients in the impurities present and the temperature range 20-1500C, pressure 0,1-0,8 MPa, γ-irradiation-0-5 kGy/h. Gamma-radiation, facility RChM-γ-20. Methods and sorbents for the determination of iodine species ratio in the water and gas phases. Analytical and chromatographic methods and techniques for the impurities radiolysis products and various iodine species detection; ion-selective and red-ox electrodes, ionometer, spectrometer, gas-liquid-chromatography, gamma-spectrometry, paper chromatography, iodine sensor and other** | | 1- VNIPIET  2- NITI (Department 5) |
| **Description of deliverables** | | |
| 1 | Reports on experimental tests | |
| 2 | Preliminary repot on experimental researches of sludge effects in water phase on iodine volatility (Phase I) | |
| 3 | Report on experimental research results on containment parameters and impurities impact on iodine volatility; and recommendations on choice of numerical models and rate constants for iodine model (for task 7) | |

Participants experience

VNIPIET has experience of fifteen years of experimental researches on mass transfer and iodine distribution in the system of /water solution/gas phase/polymeric paints/surfaces/, iodine behavior in gas atmosphere, air cleaning from gaseous iodine species, the new absorbing-filtering materials development. Large scope database on rate and equilibrium constants of reaction and processes with iodine participation was accumulated. For the first time a series of constants describing the interaction of iodine with some materials were determined. Research is performed by collaboration of VNIPIET and NITI scientists’ groups. NITI scientist group has long experience in developments of experimental methods for analysis of content and proportions of iodine species in liquid-gas phases, possesses original methods of organic and inorganic iodine species determination and identification, works out methods and sorbents for ventilation air cleaning from radioiodine, has a continually active bench scale apparatus for determination of inorganic and organic volatile radioiodine species correlation and iodine trapping effectiveness with various sorbents and filtering materials. Apparatus was metrologically certified. Methods of radioiodine analysis are used on operating NPPs for the radioiodine environmental releases control, detection of iodine concentration in the room air, iodine radioactivity level in primary circuit coolant and for other purposes. Our groups’ collaboration on iodine behavior research, sorbents and filters for iodine trapping from gas atmosphere has already been carried out for 10 years. Our conformity to top-notch Russian scientific groups level was confirmed by application of our results for new designs of VVER-1000 and VVER-1500 units; by designing, licensing, and producing of iodine filters of new generation; by positive results of recommendations to be used at operating NPPs.

Research group comprises 16 persons, including 2 professors, 6 PhD in technical and chemical sciences, engineering and technical specialists. Chetverikov V.V. is the head of ISTC project on development of production technology of sorbent SILOXIDE. During our long-term cooperation our groups have performed series of new developments, obtained new data and fulfilled large scope of investigations.

List of main publications on theme:

1. Karaseva M.A., Fedorov A.A., Ampelogova N.I., Kritsky V.G. Radioactive iodine behavior in containment under the accidents./ 2 Intern Conf. “Safety, effectiveness and economics of nuclear energy. M., VNIIAES, 2001, P.282.

2. Ampelogova N.I., Kritsky V.G., Karaseva M.A., Fedorov A.A. Behavior of radioactive iodine in containment and suppression methods of volatile iodine species formation under accident DBA type on unity VVER-1000./ Aspects of safety of NPP with VVER./ Proceed. of the scientific-technical seminar. SPB. SPBAEP,2000. v.2, P.207-221.

3. Ampelogova N.I., Petric N.G., Aleksandrov A.B. Molecular iodine species absorption from gas phase with protective paints on NPP./ Atomnaja energia, 1996, V.80, No.6.

4. Aleksandrov A.B., Karaseva M.A., Ampelogova N.I., Kritsky V.G., Petric N.G. /Physico-chemical conditions effect on the molecular iodine absorption with protective paints./Thermoenergetics, 1995, No.12, P.32-36/

5. Kritsky V.G., Ampelogova N.I., Krupennikova V.I. et al. Comparative tests of effectiveness of sorbing-filtering materials for gas wastes cleaning from radioactive iodine./Atomnaja energia, 2004, V.97, No.6, P.457-464.

6. Simanovsky V.M., Kritsky V.G.,Ampelogova N.I. et al. 131I gas-aerosols wastes reduction in aspects of safety improvement exploitation of power blocks NPP with RBMK-1000 under prolongation their use./Thermoenergetics, 2000, No.5, P.39-42.

7. Aleksandrov A.B., Ampelogova N.I., Kritsky V.G. et al. Adsorption of molecular iodine and methyliodide vapors from air./J. appl. Chem. 2000, V.73, No.11, P.1822-1825.

8. Ampelogova N.I., Kritsky V.G., Chetverikov V.V.,Prokopenko V.A. Organic iodine compounds formation under accident on NPP with VVER-1000./ Thes.rep, 3 Russ. Conf.on radiochemistry “Radiochemistry-2000”. SPB,2000, P.180.

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11. Kritsky V.G., Ampelogova N.I., Krupennikova V.I. et al. Formation radioactive iodine exhausts on NPP with RBMK-100./ Atomnaja energie,1997, V.82, No.2, P.125-130.

12. Kritsky V.G., Ampelogova N.I., Krupennikova V.I.et al. Analysis of iodine charcoal adsorbents effectiveness in special ventilation systems of NPP with RBMK-1000./ Atomnaja energia, 1997, V.83, No.1,P.44-49.

13. Ampelogova N.I., Glusckova N.E. Iodine and methyliodide vapors absorbtion with organosilicate paints./Book Rep. “Temperature stable functional paints. SPB.,IChS.,1997, P.1, P.174-176.

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15. Kritsky V.G., Rodionov Yu.A., Ampelogova N.I. Analysis of radioisotopes iodine behavior in KMPC RBMK-1000./ Atomnaja energia. In publ.

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18. Bredikhin V.J., Chetverikov V.V. Organic impurities of water coolant effect on radioiodine activity formation in gas-aerosols exhausts of NPP. / Thes.Rep. Obninsk. Symposium XV Mendel. Congress on general and appl. Chemistry “Radio ecological problems in nuclear energy”Obninsk. 1993, V.1, P.65-66.

Methodology and technical approach

For assessment of NPP radiation safety under reactor accident conditions and for prediction of volatile radioiodine species release it is necessary to have reliable data on main containment parameters and impurities in water phase influence on iodide-ions oxidation rate, iodine-organic compounds formation, on iodine partition coefficients between water/gas phases, volatile iodine species in gas phase accumulation rate, and on the ratio of inorganic/organic gaseous iodine species, particularly during long-term containment conservation (post-accident period).

Among the main factors providing the iodine safety there are the following: supression of gaseous iodine species generation, stability of processes of volatile iodine species fixation and trapping, accounting for containment parameters and impurities effects on iodine state and volatility.

Effect of containment parameters, such as temperature, pH and red-ox-potential of water phase, dose rate of gamma-irradiation, was researched enough and correctly interpreted. So iodide-ion oxidation to molecular iodine (volatile species) under gamma-irradiation of aqueous low-acidic solutions depends on iodide-ion oxidation by radiolysis water products (mainly OH-radicals), and oxidation rate depends on dose rate, solution pH, temperature and iodide concentration. Essential dependence iodide oxidation rate from pH was stipulated by participation of H+-ions in competing reaction of radiolytical oxidation of ion I- and reduction of I2 by radicals of hydrogen peroxide. Ordanic iodine compounds formation and limitation of I2 formation would lead to reducing of generation RI (R- alkyl-, acryl), thus mainly two processes influence the volatile iodine compounds generation and the ratio of iodine volatile/unvolatile species: water radiolysis and organic iodide generation in presence of organic contamination. Binding or trapping of elemental iodine are more effective processes in comparison with methyliodide where trapping is ineffective.

The interaction with surfaces in the containment can influence the iodine volatility due to its temporary hold-up at the surfaces or due to iodine chemical species change-over owing to reactions with surface material components (polymeric paints, steel).

Organic polymeric protective paints can be effective iodine “sinks”; iodine interacts with paints of organic groups and generates iodine-organic volatile species. In the atmosphere of condensing steam I2 conversion to unvolatile species (iodide-ion) takes place, at the same time the rest of organic solvents can be release from paints, where radiolysis products are organic acids, reducing pH of the water medium (condensate). Solution acidation provides favorable conditions for radiolytical oxidation of iodide-ions to I2.

There are still high uncertainty in the domain of iodine interaction with polymeric paints, specifically – on iodine absorption/adsorption kinetics, mechanism and generation rate of organic iodides. There is a need for data on how these processes are effected by paints type, temperature, γ-irradiation dose rate, and condensing steam presence. Besides the direct reactions with iodine, organic materials are leached from polymeric paints and compete with iodine in radical reactions, and also are exposed to radiolysis with generation of organic acids. All these processes require more detailed investigations.

Radiolysis of cable insulation containing chlorine can lead to generation of chlorine-derivative organic compounds and chloride-ions in water phase. Presence of chloride-ions, more chemically active in comparison with iodide-ion, can enhance HOI formation and iodine oxidation, and also of iodine-organic compounds.

In realistic severe accident conditions sludge including ferric oxides and hydroxides, silicates and gel of silicium acid, perhaps boron carbide will be accumulated in the containment sump. These impurities can influence the iodine content in the water phase, as they can adsorb and retain the iodide-ions. So sludges can act as effective iodine “sinks” and reduce iodine concentration in water phase; accordingly, the possibility of iodide-ions oxidation and accumulation of volatile iodine species in the gas phase can decrease.

But these processes have hardly been studied, data on iodine adsorption are scarce, data on iodine sorbing behavior are in general not available. It is noteworthy to mention that iodine chemistry and behavior under increased temperature (up to 150-2000C) have not been studied enough and there were problems in predicting iodine behavior in realistic accident condition.

Experimental programme includes the investigations of influence on iodine volatility : sludges, protective polymeric paints, cable insulation, used at NPPs with VVER – one type of epoxy paint, one type of organosilicate paint, ferric and silicate sludges, impurities of chloride-ions and organic acids.

Ferric oxides sludges impurities are representative for sump water under accident conditions. Ferric ions come into water phase by the various types of steel corrosion (mainly carbon steel) and in a state of aerosols from corium molten pool (core catcher) (sources – “sacrificial” ferric oxide and structure core materials); silicium also can come with aerosols from core catcher (refractory facing) and as impurity from construction materials. It is necessary to determine kinetics and sorption degree of various iodine species for temperature exposure (20-25; 50; 1000C) and gamma-irradiation (0; 3 kGy/h).

It is proposed to investigate influence of type paint, temperature and condensed steam on iodine absorption kinetics and iodine desorption in gas phase (simulation of containment atmosphere) and in liquid phase (simulation of sump solution). There will be also tests performed with gamma-irradiation (dose rate 0-3 kGy/h) in gas/liquid phases. Polymeric cable insulation can contain chlorine, therefore test with supply of chloride-ions in water phase is planned.

It is also planned to perform investigation of influence of combined impurities, characteristic for containment water phases under accident conditions (oils, organic acids, chloride-ions and sludges contained silicates and ferric hydroxides, polymeric paints), on iodine distribution between water/gas phases and iodine volatility.

Proposing matrix of investigations is given in the Table 5. Experiments are performed in autoclave apparatus for researches of iodine mass transfer. Solutions are prepared with high purity water (“nanopure”) and addition of boric acid, KOH and HNO3 (for pH regulation), CsI (KI). Inner volume of autoclave – up to 1 dm3.

Table 5. Proposed matrix of tests on EVAN-project, Task 6 (to be finalised during project agreement preparation).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Test | Testing purpose | Parameters | Analysis scope | Period performing |
| EVAN-T6-I1 | Determination of sludge effect on iodine content and speciation in water/gas phases | Sludge composition: ferric sludges (FeOOH, Fe3O4, Fe2O3); Si-sludges (H2SiO3·nH2O); Fe/Si=10; m/V=0; 1 g/l; 5 g/l. T=25; 50; 100 oC; pH=7-8; H3BO3=0; 16 g/l; CI=10-6-10-7 and <10-8 mol/l; γ-irradiation – 0; 3 kGy/h | Iodine and its species concentration in gas and water phases; pH; Eh; CFe in water phase; T | 3 quart. |
| EVAN-T6-I2 | Determination of organic materials effect on iodine content and speciation in water/gas phases | Organic acids. 10-3 mol/l. Sludges Fe/Si (m/V – on results Test I1); T=25; 50; 100, 150 oC; pH=7-8; H3BO3=0; 16 g/l; CI=10-6-10-7 and <10-8 mol/l; γ-irradiation – 0; 3 kGy/h | Iodine and its species concentration in gas and water phases; pH; Eh; T; P. Organic acids and Cl−concentration | 2 quart. |
| EVAN-T6-I3 | Determination of cable insulation pyrolysis products effect on iodine content and speciation in water/gas phases ( Cl−-ions and organic impurities effect) . | CCl-=10-4-10-3 mol/l; Corganic acid=0; 10-3 mol/l; Sludges Fe/Si; pH=7-8; H3BO3=0; 16 g/l; CI=10-6-10-7 and <10-8 mol/l; γ-irradiation – 0; 5 kGy/h | Iodine and its species concentration in gas and water phases; organic acids and Cl−concentration; pH; Eh; T; P. | 2 quart.. |
| EVAN-T6-I4 | Determination of combined impurities in water phase on iodine content and speciation in water/gas phases | Polymeric paints (1 epoxy, 1 organosilicate), organic acids, 10-3 mol/l; Cl−-ion, 10-3 mol/l; sludges Fe/Si; pH=7-8; H3BO3=0; 16 g/l; CI=10-6-10-7 and <10-8 mol/l; γ-irradiation – 0; 5 kGy/h | Iodine and its species concentration in gas and water phases; concentration of organic acid, Cl−, Fe; pH; Eh; T; P. | 4 quart. |

Separate experiments in presence of paints and impurities and under γ-irradiation can be performed with ampoule methodic. VNIPIET is performing experiments without irradiation, NITI – with irradiation. At iodine low concentrations (<10-8 mol/l) test are performed with 131I. Solution samples are analyzed on iodine total content and ratio of inorganic/organic species. Iodine partition coefficients are calculated from experimental results. Experimental autoclave apparatus would be reconstructed and adapted to experimental matrix conditions. Techniques and analytical instrumental equipment would be checked and adapted to necessary measurement ranges and increased temperatures. Used experimental methods and equipment are given in the Table 6.

New experimental results on volatility and iodine speciation would be used to iodine behavior model for its approximation to realistic accident regimes, also for the assessment of iodine environmental source terms for selected accident scenarios.

Table 6.- Methods of iodine analysis

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| --- | --- | --- | --- |
| Phase | Component | Analytical methods and equipment | Sensibility, mol/l |
| Water phase | I−, Cl− | Ion-selective electrodes: ionometer | 10-6 |
|  | IO3− | Paper chromatography, spectrophotometry | up to 10-8 |
|  | I2, RI | Extraction, spectrophotometry, paper chromatography | 10-6-10-8 |
|  | RI, organic acids | Gas-liquid chromatography | 10-9 |
|  | 131I (I−, I2, IO3−) | Extraction, blowing + γ-spectrophotometry | 10-8-10-11 |
| Gas phase | I2 | On-line: semiconductor iodine sensor | 10-8-10-10 |
|  | I2, RI | Gas chromatography | up to 10-9 |
|  | I2/RI | Trapping of selective sorbents, extraction, spectrophotometry | up to 10-9 |
|  | 131I2/ R131I | Trapping of selective sorbents + γ-spectrometry | 10-10 -10-11 |

#### Task 7. Numerical and theoretical modeling of containment parameters impact on volatile iodine species content and correlation

|  |  |  |
| --- | --- | --- |
| **Task description and main milestones** | | **Participating Institutions** |
| **Numerical and theoretical modeling of containment parameters impact on volatile iodine species content and correlation.**  **Task stages: 1) Iodine model analyses and adaptation, computer codes development, choice of parameters and process constants. 2) Pre-test/post-tests calculation (according to test schedule). 3) Recommendation choice of numerical models and constants for iodine computer code development and assessment of iodine environmental accident source term at late phase accident stage.**  **Tools to solve the task: 1) Containment iodine behavior model under accident conditions, developed by VNIPIET/SPAEP. 2) Computer codes for calculations of pH and Ered-ox in solution; databases on iodine rate and equilibrium constants; published experimental and calculation data; proprietary unpublished data.** | | 1- SPAEP  2- VNIPIET |
| **Description of deliverables** | | |
| 1 | Preliminary report on iodine model adaptation and computer code development | |
| 2 | Pre-test/post-tests calculation results (information) | |
| 3 | Report on iodine model adaptation results correlation with experimental data, and numerical modeling; recommendations on parameters and constant choice | |

Participants experience

Scientists group of VNIPIET NPP reliability department has large experience of simulation of physico-chemical processes in water solutions and development of computer programmes based on these models. Among the developed models are: model and computer code of water radolysis in ITER first wall modules and vacuum chamber; computer model of water radiolysis in VVER-440 primary circuit. The latter was used to determine main features of coolants radiolysis at standard and hydrazine water chemistry and also for numerical simulation of formation and mass transfer of corrosion products.

Chemical composition of impurities in containment water phases under severe accidents conditions were determined, calculation techniques for determination of their mass transfer were developed and numerical modeling of sump water pH dynamics and also of pH effect on iodine volatility was performed. Computer code for pH solution calculation accounting for impurities mass transfer (for reactors VVER-1000 and VVER-1500) has been developed.

For assessment of influence of water phase composition on iodine oxidation-reduction processes, the model of red-ox potential and pH water phase calculation in presence of impurities have been developed. Algorithm of Eh and pH calculation was has been suggested, and on its base computer programme has been developed.

Under contract with SPAEP models and methods for assessment of radioiodine mass transfer and chemical equilibrium in the containment under accident conditions have been developed. This complex of models, methods, and database make it possible to calculate the iodine concentrations dynamics in water/gas phases and to assess the ratio of volatile/non-volatile iodine species in the sump, atmosphere and at the containment surfaces. Partly, these methods were used for assessment of radiation safety of NPP with VVER-1000 (project of Tianwan units) and were peer reviewed by IAEA experts. These results were published and used in joint Russian-American investigation to work out a strategy of 1-st unit of Leningrad NPP decommissioning (contract #235311-A-R-4) for the assessment of radioiodine chemical species in the releases during decontamination of RBMK circulation circuit.

List of main publications on theme:

1. Kritsky V.G., Ampelogova N.I., Bobrov U.G. et al. Development complex of calculated methods, models, programmes for iodine compounds transfer calculation in containment rooms./VNIPIET Report, #0974-66-29.04.2002.

2. Kritsky V.G., Ampelogova N.I., Bobrov Yu.G. et al. Development of iodine module including complex of models, programmes, methods, database for iodine compounds mass transfer calculation under DBA accident./VNIPIET Report, #3353,2003.

3. Ampelogova N.I., Kritsky V.G., Karaseva M.A., Fedorov A.A. Behavior of radioactive iodine in containment and suppression methods of volatile iodine species formation under accident DBA type on unity VVER-1000./ Aspects of safety of NPP with VVER./ Proceed. of the scientific-technical seminar. SPB. SPBAEP,2000. v.2, P.207-221.

4. Karaseva M.A., Fedorov A.A., Ampelogova N.I., Kritsky V.G. Radioactive iodine behavior in containment under the accidents./ 2 Intern Conf. “Safety, effectiveness and economics of nuclear energy. M., VNIIAES, 2001, P.282

5. Kritsky V.G., Bobrov Yu.G., Vasiljev V.N. et al. Assessment of water radiolysis for ITER working conditions/ Report on ITER EDA working meet. on corrosion and water radiolysis. St.-Petersburg,sept.2000.

6. Kritsky V.G., Bobrov Yu.G., Vasiljev V.N. et al. Development of water radiolysis computer code for ITER conditions / ITER EDA Final Report, St.-Petersburg,, 2001.

7. Kritsky V.G., Bobrov Yu.G., Vasiljev V.N. et al. Influence of ions and metal surfaces on water coolant radiolysis NPP. / Rep. on 1st All-Russ. Conf. on applied aspects of high energies chemistry. Nov.2001. M., RchTU,2001.

8. Kritsky V.G., Bobrov Yu.G., Vasiljev V.N. et al. Special features of coolant primary circuit radiolysis for reactors VVER. / Rep. on Conf. on safety NPP with VVER. Nov.2001. Podolsk, OKB”Hydropress”,2001.

9. Kritsky V.G., Bobrov Yu.G., Vasiljev V.N. et al. Assessment of water radiolysis in ITER circuits. / Problems of nucl. science and engineering. Ser. Electro-phys.Apparatus. #2(28), M., 2004, P.102-108.

10. Kritsky V.G., Ampelogova N.I., Bobrov U.G. et al. Development of model and programme pH and red-ox-potential calculation in water solution of containment. / VNIPIET Report #3307, 2002.

11. Kritsky V.G., Ampelogova N.I., Bobrov U.G. et al. Development of model and calculated methods of main impurities formation and mass transfer under accident conditions. / VNIPIET Report #3433,2004.

12. Kritsky V.G., Beresina I.G., Ampelogova N.I., Bobrov U.G. et al. Experimental determination of mass transfer rate in processes iodine adsorption and desorption with polymeric and oiled surfaces under accident conditions oh VVER-1000. / VNIPIET Report #3433, 2004.

Methodology and technical approach

The main computer code is based on developed computer model of iodine mass transfer and chemical iodine species (I-,I2, IO3-, CH3I) permanent partition in systems of /water phase/steam-gas phase/rooms/equipment surfaces/. Calculations are carried out with the available database on rate and equilibrium constants of radiolytical, chemical reactions and iodine mass transfer.

The uncertainty study of the results on volatile iodine species release into containment atmosphere is usually performed on the base of mathematical statistics and probability theory methods. Uncertainty of results is connected with uncertainty of the values used for constants of processes and medium physico-chemical parameters, and also with incompleteness of processes and contaminating substances accounted for. Completeness of considered processes and contaminating substances in gas/water containment phases is to be estimated. It is necessary to range the processes with iodine participation in the containment by their significance for iodine release into gas phase, to determine the confidence intervals for values used and final calculated results, to carry out the correlation analysis of dependence of volatile iodine species release to the containment atmosphere against radiolytical processes with iodine participation and iodine mass transfer rate in the containment.

For pre- and post-tests calculations of effect of water phase impurities on the iodine volatility and iodine speciation in water/gas phases, it is necessary to update the iodine model. Experimental tests are carried out in steady-state condition without mass transfer in other volumes, and at 25 and 500C – without water evaporation and condensation. Types of impurities are also limited. Therefore it is necessary to adapt the iodine model to test conditions. Numerical simulation of reactions and iodine mass transfer under experimental test conditions with database available will be performed. Then the algorithm and computer programme for assessment of iodine concentration and its speciation in water/gas phases and partition coefficients between phases will be developed. Then pre- and post-tests calculations are carried out, from their results the applicability of experimental results for numerical modeling is justified, separate factor sensitivity effect is determied, correctness of iodine model is estimated and degree of uncertainty of used constants is obtained. Then correction of model and computer programme for every tests and for the whole total experimental programme is carried out. Besides the computer model for assessment of radioiodine accident environmental source term is developed and used for model calculation, significance of influence of impurities and containment medium parameters on iodine concentration in gas phase and on iodine accident source term is assessed.

### 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 SPAEP** |  |  |  | Report |  |  |  |  |  |  |  |  |  |
| **Person\*days** | **300** | **300** | **300** | **308** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **1208** |
| **Task 1 IBRAE** |  |  |  | Report |  |  |  |  |  |  |  |  |  |
| **Person\*days** | **170** | **170** | **170** | **170** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **680** |
| **Task 2 NITI (14 dep.)** |  |  |  | Report |  | Protocol |  | Protocol |  | Report |  | Report |  |
| **Person\*days** | **800** | **800** | **800** | **802** | **600** | **600** | **600** | **600** | **600** | **590** | **595** | **598** | **7985** |
| **Task 3 IBRAE** |  |  |  | Report |  |  |  | Report |  |  |  | Report |  |
| **Person\*days** | **125** | **125** | **125** | **125** | **115** | **115** | **115** | **125** | **115** | **115** | **115** | **125** | **1440** |
| **Task 4 CKTI** |  |  | Protocol | Report |  |  |  |  |  |  |  |  |  |
| **Person\*days** | **540** | **540** | **540** | **540** | **450** | **450** | **450** | **455** | **450** | **450** | **450** | **460** | **5775** |
| **Task 5 IBRAE** |  |  |  | Report |  |  |  | Report |  |  |  | Report |  |
| **Person\*days** | **125** | **125** | **125** | **135** | **115** | **115** | **115** | **125** | **115** | **115** | **115** | **125** | **1450** |
| **Task 5 SPAEP** |  |  |  | Report |  |  |  | Report |  |  |  | Report |  |
| **Person\*days** | **150** | **150** | **150** | **150** | **190** | **190** | **190** | **190** | **190** | **190** | **190** | **190** | **2120** |
| **Task 6 VNIPIET** |  |  | Protocol | Report |  | Protocol |  | Protocol |  |  | Protocol | Report |  |
| **Person\*days** | **310** | **360** | **360** | **215** | **160** | **160** | **160** | **160** | **160** | **210** | **210** | **175** | **2640** |
| **Task 7 VNIPIET** |  |  |  | Report |  | Technical Information |  | Technical Information |  |  | Technical Information | Report |  |
| **Person\*days** | **60** | **60** | **30** | **45** | **50** | **50** | **35** | **35** | **60** | **60** | **50** | **70** | **605** |
| **Task 7 SPAEP** |  |  |  | Report |  | Technical Information |  | Technical Information |  |  | Technical Information | Report |  |
| **Person\*days** | **80** | **80** | **80** | **80** | **110** | **110** | **110** | **110** | **110** | **110** | **110** | **110** | **1200** |
| **TOTAL** | **2660** | **2710** | **2680** | **2570** | **1790** | **1790** | **1775** | **1800** | **1800** | **1840** | **1835** | **1853** | **25103** |

Schedule 1. Planned schedule for tasks and leading participants (works scope is adjusted during development of project agreement and workplan)



### 8. Personnel Commitments

#### 8.1. Individual participants

### Leading Institution: SPAEP

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Weapon**  **Expertise Ref.** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Zatevakhin Mikhail | 1953 | candidate of sciences, scientist | 4.9 | Tasks 1, 5. Aerosol transport modeling | 30 | 330 | 9900 |
| Blinova Lidia | 1954 | candidate of sciences | 4.1.,4.8 | Tasks 1, 7. Accident scenario analysis. Radioiodine source term analysis. | 30 | 270 | 8100 |
| Dushin Viktor | 1950 | candidate of sciences | 4.1., 4.3.,4.7.,4.8 | Tasks 1, 7. Accident scenario analysis. Radioiodine source term analysis. | 30 | 110 | 3300 |
| **Total:** | | | | | | **710** | **21300** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Bezlepkin Vladimir | 1958 | doctor of science | Project Manager | 35 | 360 | 12600 |
| Leontiev Yuri | 1971 | - | Sub-manager of the project | 30 | 360 | 10800 |
| Svetlov Sergey | 1966 | candidate of sciences | Tasks 1, 5. Theoretical and calculation modelling. Accident scenarios analysis | 30 | 340 | 10200 |
| Semashko Sergey | 1961 | - | Tasks 1, 5. Theoretical and calculation modelling. Accident scenarios analysis | 30 | 340 | 10200 |
| Frolov Andrey | 1976 | - | Tasks 1, 7. Accident scenario analysis. Radioiodine source term analysis. | 20 | 340 | 6800 |
| Lukin Andrey | 1976 | - | Tasks 1, 5. Accident scenario analysis. Core melt behavior analysis. | 20 | 210 | 4200 |
| Alekseev Sergey | 1965 | - | Tasks 1, 5. Accident scenario analysis. In-vessel processes analysis. | 25 | 228 | 5700 |
| Kharchenko Eugenia | 1976 | - | Tasks 1, 7. Accident scenario analysis. Radioiodine source term analysis. | 20 | 230 | 4600 |
| Ryabova Anastasia | 1976 | - | Tasks 1, 7. Accident scenario analysis. Radioiodine source term analysis. | 20 | 230 | 4600 |
| Krylov Yuri | 1976 | - | Tasks 1, 5. Accident scenario analysis. Containment analysis. Aerosol transport modeling. | 20 | 250 | 5000 |
| Ignatiev Aleksey | 1960 | - | Tasks 1, 5. Computer modelling of aerosol kinetics | 25 | 260 | 6500 |
| Govorkova Veronika | 1958 |  | Tasks 1, 5. Computer modelling of aerosol kinetics | 20 | 230 | 4600 |
| **Total:** | | | | | **3378** | **85800** |

#### Supporting Personnel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| 2 | Computer systems maintenance, technical translations, students’ projects | 20 | 440 | 8800 |
| **Total:** | | | **440** | **8800** |

### Participant Institution 1: IBRAE

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Weapon**  **Expertise Ref.** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Kisselev Arkadi | 1962 | Doctor of science | 4.9 | Deputy Project Manager (Numerical simulation). | 30 | 260 | 7800 |
| Vasiliev Aleksandr | 1962 | Candidate of science | 4.9 | Severe accidents modeling (Code RATEG/SVECHA, ICARE2). Assessment of results | 30 | 160 | 4800 |
| Vinogradova Tatiana | 1947 | Engineer | 4.9 | Severe accidents modeling (Code RATEG/SVECHA, ICARE2). Assessment of results | 20 | 170 | 3400 |
| Nosatov Vladimir | 1965 | Engineer | 4.9 | Severe accidents modeling (Code MELCOR). Assessment of results | 20 | 250 | 5000 |
| Filippov Aleksandr | 1954 | Candidate of science | 4.9 | Severe accidents modeling (Code RATEG/SVECHA, ICARE2). Assessment of results | 30 | 250 | 7500 |
| Kobelev Gennadi | 1957 | Candidate of science | 4.9 | Severe accidents modeling (Code RATEG/SVECHA, ICARE2). Assessment of results | 30 | 250 | 7500 |
| Tarasov Vladimir | 1951 | Candidate of science | 4.9 | Preparation of experimental scenario. Pre and post test modeling. | 25 | 250 | 6250 |
| **Total:** | | | | | | **1590** | **42250** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Fokin Aleksei | 1965 | Engineer | Pre and post test modeling. | 20 | 250 | 5000 |
| Tkachenko Aleksandr | 1951 | Engineer | Pre and post test modeling | 20 | 260 | 5200 |
| Ozrin Vladimir | 1944 | Candidate of science | Review of models for FP release from molten pool. | 25 | 250 | 6250 |
| Korzhov Mikhail | 1964 | Engineer | Review of models for FP release from molten pool. | 20 | 150 | 3000 |
| Semenov Vladimir | 1946 | Doctor of science | Preparation of experimental scenario. Assessment of measured data | 20 | 250 | 5000 |
| Stepnov Vladimir | 1944 | Candidate of science | Preparation of experimental scenario. Assessment of measured data | 30 | 230 | 6900 |
| Tomashik Dmitri | 1969 | Engineer | Assessment of results of experimental programs from point of view their applicability in computer codes. | 20 | 220 | 4400 |
| Kasiyanov Sergei | 1953 | Candidate of science | Preparation of experimental scenario. Assessment of measured data | 20 | 120 | 2400 |
| **Total:** | | | | | **1730** | **38150** |

#### Supporting Personnel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| 1 | Preparation of the report, drawing and graphics | 15 | 250 | 3750 |
| **Total:** | | | **250** | **3750** |

### Participant Institution 2: NITI

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Weapon**  **Expertise Ref.** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Aniskevich Yuri | 1946 | candidate of sciences | 4.9 | Deliverables preparation | 30 | 220 | 6600 |
| Bechta Sevostian | 1961 | candidate of sciences | 4.8 | Task 3 supervisor | 34 | 420 | 14280 |
| Vitol Sergey | 1951 | — | 4.9 | Posttest analyses | 34 | 420 | 14280 |
| Granovsky Vladimir | 1941 | candidate of sciences | 4.9 | Heat exchange calculations | 30 | 370 | 11100 |
| Kaliago Elena | 1952 | — | 4.7 | Experimental data computer processing | 30 | 350 | 10500 |
| Krushinov Evgeny | 1960 | — | 4.3 | Tests preparation and performing | 34 | 420 | 14280 |
| Koulagin Igor | 1943 | candidate of sciences | 4.7 | Measuring results mathematical processing | 30 | 370 | 11100 |
| Gousarov Victor | 1952 | doctor of sc., professor | 4.9 | Posttest analyses | 34 | 370 | 12580 |
| Martynov Valery | 1953 | - | 4.9 | Material studies | 25 | 190 | 4750 |
| Khabensky Vladimir | 1937 | doctor of sc., professor | 4.9 | Theoretical and experimental investigations | 35 | 420 | 14700 |
| Yakushev Michail | 1937 | candidate of sciences | 4.4 | Physicochemical analyses | 25 | 80 | 2000 |
| Granovskaja Nadezhda | 1950 |  | 4.9 | Accounting | 25 | 150 | 3750 |
| Smirnov Sergey | 1957 | candidate of sciences | 4.9 | Thermodynamic modeling | 30 | 140 | 4200 |
| Sabinin Vladimir | 1936 | candidate of sciences | 4.9 | Design work | 30 | 180 | 5400 |
| Blizniuk Valentina | 1950 | - | 4.9 | Physicochemical analyses | 25 | 306 | 7650 |
| Lyssenko Anatoli | 1963 | - | 4.9 | Tests preparation and performing | 30 | 320 | 9600 |
| Sulatsky Andrey | 1961 | candidate of sciences | 4.9 | Thermodynamic modeling | 25 | 390 | 9750 |
| Kamensky Nikolay | 1942 | - | 4.9 | Tests preparation and performing | 25 | 280 | 7000 |
| **Total:** | | | | | | **5396** | **163520** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Kotova Svetlana | 1967 | candidate of sciences | Physicochemical analyses | 25 | 340 | 8500 |
| Shevchenko Evgeny | 1958 | - | Tests preparation and performing | 25 | 280 | 7000 |
| Bouligin Valentin | 1967 | - | High-frequency equipment adjustment | 20 | 320 | 6400 |
| Almjashev Vjacheslav | 1972 | - | Posttest analyses | 20 | 320 | 6400 |
| Peregud Sergey | 1954 |  | Physicochemical analyses | 25 | 240 | 6000 |
| Kaliago Alexdandr | 1950 |  | Design work | 25 | 240 | 6000 |
| Chemeriskin Vladimir | 1953 | candidate of sciences | Electromagnetic heating calculations | 25 | 240 | 6000 |
| Beljaeva Elena M | 1974 |  | Physicochemical analyses | 20 | 276 | 5520 |
| **Total:** | | | | | **2256** | **51820** |

#### Supporting Personnel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| 2 | Translation , technical-organizational work | 20 | 333 | 6660 |
| **Total:** | | | **333** | **6660** |

### Participant Institution 3: CKTI

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Weapon**  **Expertise Ref.** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Krektunov Oleg | 1946 | Ph.D (Reader) | 4.9 | Manager of Task #3. Theoretical and experimental investigations | 33 | 400 | 13200 |
| Lebedev Mikhail | 1946 | Ph.D(Reader) | 4.8 | Deputy manager of Task #3. Theoretical and experimental investigations. Preparation of report documentation | 33 | 400 | 13200 |
| Fokin Boris | 1938 | Doctor of science (tech)- professor | 4.9 | Development of test facility and methods of experimental investigations | 30 | 320 | 9600 |
| Belen’kiy Mikhail | 1944 | Ph.D. (Reader) | 4.9 | Development of test facility design and methods of experimental investigations | 30 | 320 | 9600 |
| Gotovskiy Mikhail | 1940 | Doctor of science (tech) | 4.9 | Thermal dynamics simulation and experimental data analysis | 30 | 320 | 9600 |
| Arefiev Valentin | 1955 |  | 4.9 | Test facility design and experimental investigations | 30 | 600 | 18000 |
| Zavel’skaya Elena | 1954 |  | 4.9 | Participation in experimental investigations performance | 20 | 80 | 1600 |
| Kiseleva Elvira | 1941 |  | 4.9 | Participation in experimental investigations performance | 20 | 80 | 1600 |
| Danilova Galina | 1939 |  | 4.9 | Participation in experimental investigations performance | 20 | 80 | 1600 |
| **Total:** | | | | | | **2600** | **78000** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Feldberg Lev | 1941 | Ph.D | Investigation of structural and kinematical characteristics of aerosol particles | 30 | 500 | 15000 |
| Blinov Mikhail | 1972 |  | Engineer, experimental investigations | 25 | 500 | 12500 |
| Mukhin Vjacheslav | 1966 |  | Computer processing of experimental data | 25 | 400 | 10000 |
| Semidetnov Nikolay | 1946 | Ph.D., (Reader) | Investigation of structural and kinematical characteristics of aerosol particles | 30 | 400 | 12000 |
| Alexandrov Sergey | 1955 | Doctor of science (chem.)., professor. | Generator of aerosol particles adjustment (SPbSPI) | 30 | 120 | 3600 |
| Grekov Fedor | 1941 | Doctor of science (chem.)., professor. | Generator of aerosol particles adjustment (SPbSPI) | 30 | 120 | 3600 |
| Gorbachev Yuri | 1955 | Doctor of science (phys.-math.., professor.. | Generator of aerosol particles adjustment (SPbSPI) | 30 | 120 | 3600 |
| Salnikov Vjacheslav | 1959 |  | Adjustment of measurement systems and test facility automatic control (ZAO «Mars – technology») | 25 | 90 | 2250 |
| **Total:** | | | | | **2250** | **62550** |

#### Supporting Personnel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| 2 | Translator of documentation,  Welding and installation | 20 | 925 | 18500 |
| **Total:** | | | **925** | **18500** |

### Participant Institution 4: VNIPIET

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Weapon**  **Expertise Ref.** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Kritsky Vladimir | 1943 | Professor, Dr.Sc. | 4.8 | Sub manager leader theme 4 – theoretical results analysis | 35 | 150 | 5250 |
| Ampelogova Natalie | 1929 | Professor, Dr.Sc. | 4.9 | Manager, deputy leader theme 4 – program sand methods development, experimental researches, results analysis, coordination of activity | 35 | 350 | 12250 |
| Bobrov Yuri | 1933 | Cand., Scientist | 4.9 | Models, codes, constants analysis and development | 28 | 300 | 8400 |
| Vasiliev Vladimir | 1947 | - | 4.9 | Tests performance, models and codes development, results analysis | 28 | 310 | 8680 |
| Krupennikova Vera | 1947 | Cand., Scientist | 4.9 | Preparation and performance of tests; physico-chemical analyze | 28 | 310 | 8680 |
| Chetverikov Viktor | 1953 | Cand., Scientist | 4.9 | Manager, deputy leader theme 4 for NITI. Development of tests methodic, results analysis | 35 | 260 | 9100 |
| Epimakhov Vitali | 1950 | Cand. | 4.9 | Preparation and performance of tests, results analysis | 30 | 170 | 5100 |
| Leontiev Gennadi | 1946 | Cand. | 4.9 | Analysis of results | 28 | 80 | 2240 |
| Matsaev Vladimir | 1954 | - | 4.9 | Analytical providing | 25 | 200 | 5000 |
| Pankina Elena | 1956 | Cand. | 4.9 | Test performance, physico-chemical analyze | 25 | 200 | 5000 |
| Korablev Nicolai | 1961 | - | 4.9 | Preparation and performance of tests, measuring | 25 | 200 | 5000 |
| **Total:** | | | | | | **2530** | **74700** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Name** | **Birth**  **Year** | **Scientific Title** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| Alemaskina Elena | 1959 | - | Data analysis, computer calculations, office work | 25 | 140 | 3500 |
| Bachilov Sergei | 1938 | - | Tests preparation and performance, putting of equipments into operation | 25 | 260 | 6500 |
| **Total:** | | | | | **400** | **10000** |

#### Supporting Personnel

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Number of persons** | **Function in project** | **Daily rate**  **(US$)** | **Total days** | **Total grants**  **(US$)** |
| 2 | Measuring, supply, office-work, participation in tests | 20 | 315 | 6300 |
| **Total:** | | | **315** | **6300** |

#### 8.2. Managerial responsibilities

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  | | **SPAEP**  Leading Institution  Project Manager  Bezlepkin Vladimir | |  | |  | |
|  |  |  | |  |  |  | |  |  |
|  |  |  |  |  |  |  |  |  |  |
| **SPAEP**  (Tasks 1, 5, 7)  Project sub-manager  Leontiev Yuri | | **IBRAE**  (Tasks 1, 3, 5)  Project sub-manager  Kisselev Arkadi | | **NITI**  (Task 2)  Project sub-manager  Bechta Sevostyan | | **CKTI**  (Task 4)  Project sub-manager  Krektunov Oleg | | **VNIPIET**  (Tasks 6, 7)  Project sub-manager  Kritsky Vladimir | |

### 9. Financial Information

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

|  |  |
| --- | --- |
| **Estimated total cost of the project** | 1040000 |
| **Leading Institution - SPAEP** | 150000 |
| **Participant Institution 1 - IBRAE** | 100000 |
| **Participant Institution 2 - NITI** | 370000 |
| **Participant Institution 3 - CKTI** | 280000 |
| **Participant Institution 4 - VNIPIET** | 140000 |

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Institution** | **Category I** | **Category II** | **Supporting personnel** | **Total** |
| **Leading Institution - SPAEP** | 21300 | 85800 | 8800 | 115900 |
| **Participant Institution 1 - IBRAE** | 42250 | 38150 | 3750 | 84150 |
| **Participant Institution 2 - NITI** | 163520 | 51820 | 6660 | 222000 |
| **Participant Institution 3 - CKTI** | 78000 | 62550 | 18500 | 159050 |
| **Participant Institution 4 - VNIPIET** | 74700 | 10000 | 6300 | 91000 |
| ***Subtotal:*** | | | | 672100 |

#### 9.1.2. Equipment

|  |  |  |
| --- | --- | --- |
| **Institution** | **Equipment description** | **Cost (US $)** |
| **Leading Institution - SPAEP** | computers and office equipment | 5100 |
| **Participant Institution 1 - IBRAE** | none | - |
| **Participant Institution 2 - NITI** | Instruments, computers and office equipment | 77700 |
| **Participant Institution 3 - CKTI** | Instruments, computers and office equipment | 60950 |
| **Participant Institution 4 - VNIPIET** | Instruments (ionomer, detectors, scales), computers and office equipment | 14000 |
| ***Subtotal:*** | | 157750 |

#### 9.1.3. Materials

|  |  |  |
| --- | --- | --- |
| **Institution** | **Materials description** | **Cost (US $)** |
| **Leading Institution - SPAEP** | - | - |
| **Participant Institution 1 - IBRAE** | - | - |
| **Participant Institution 2 - NITI** | oxidic powder, chemical reactants, thermocouples, meters, office consumables | 18500 |
| **Participant Institution 3 - CKTI** | thermocouple cable, stainless steel sheets 08KH18N10T, stainless steel tubes 08KH18N10T, valves, regulator orifices, heat insulation, lab materials and chemicals, office consumables | 19000 |
| **Participant Institution 4 - VNIPIET** | office consumables, reagents, electrodes | 5000 |
| ***Subtotal:*** | | 42500 |

#### 9.1.4. Other Direct Costs

|  |  |  |
| --- | --- | --- |
| **Institution** | **Direct costs description** | **Cost (US $)** |
| **Leading Institution - SPAEP** | Communication | 3000 |
| **Participant Institution 1 - IBRAE** | Communication | 2350 |
| **Participant Institution 2 - NITI** | Communication, subcontracts, publications, logistics, other | 7400 |
| **Participant Institution 3 - CKTI** | Communication, energy, security, calibration, publications | 10000 |
| **Participant Institution 4 - VNIPIET** | Communication, energy, security, calibration, publications | 11000 |
| ***Subtotal:*** | | 33750 |

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Institution** | **CIS travel** | **International travel** | **Total** |
| **Leading Institution - SPAEP** | 0 | 15000 | 15000 |
| **Participant Institution 1 - IBRAE** | 0 | 6700 | 6700 |
| **Participant Institution 2 - NITI** | 0 | 25900 | 25900 |
| **Participant Institution 3 - CKTI** | 0 | 15000 | 15000 |
| **Participant Institution 4 - VNIPIET** | 2000 | 8000 | 10000 |
| ***Subtotals:*** | *2000* | *70600* | 72600 |

#### 9.1.6. Overhead (US $)

|  |  |  |
| --- | --- | --- |
| **Institution** |  | **Amount** |
| **Leading Institution - SPAEP** |  | 11000 |
| **Participant Institution 1 - IBRAE** |  | 6800 |
| **Participant Institution 2 - NITI** |  | 18500 |
| **Participant Institution 3 - CKTI** |  | 16000 |
| **Participant Institution 4 - VNIPIET** |  | 9000 |
| ***Subtotal:*** | | 61300 |

### 9.2. Funding Sources

|  |  |
| --- | --- |
| **Estimated total cost of the project (US $)** | 1040000 |

#### 9.2.1. Financial Sources

|  |  |  |
| --- | --- | --- |
| **Financial Source** | **Written confirmation (Y/N)** | **Amount**  **(US $)** |
| **Requested from the ISTC** |  | 1040000 |
| Other financial source 1 | - | - |
| Other financial source 2 | - | - |

#### 9.2.2. Non-Financial Sources

|  |  |  |  |
| --- | --- | --- | --- |
| **Source** | **Short description of contribution** | **Written confirmation (Y/N)** | **Estimated**  **amount**  **(US $)** |
| - | - | - | - |
| - | - | - | - |

#### 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

Support letters for the EVAN project are already provided by collaborators from VTT, GRS, and ITU; additionally the support letters are expected from PSI, CEA and IRSN.