|  |  |  |
| --- | --- | --- |
|  | WORK PLAN | # 2916 |

## I. Summary Project Information

### 1. Project Title and Taxonomy

|  |  |
| --- | --- |
| **Full title:** | Development of the model for nuclear fuel behavior during active phase of the Chernobyl accident (CHESS) |
| **Short title:** | State and behavior of fuel of the Ch NPP Unit 4  |
| **Technology area:** | ENV-SPC, FIR-MOD, FIR-MAT  |
| **Category of technology development:** | Applied Research |

### 2. Project Manager

|  |  |
| --- | --- |
| **Name:** | Borovoi Alexandr Alexandrovich |
| **Title:** | Doctor of Sciences, Honored Worker of Sciences and Technologies | **Position:** | Department head |
| **Street, address:** | 25 bld. 1, 8, General Glagolev st.  |
| **City:** | Moscow | **Region:** |  |
| **ZIP:** | 123103 | **Country:** | Russian Federation |
| **Tel.:** | (095) 197-56-59, (095) 196-90-92 | **Fax:** | (095) 196-61-08 |
| **E-mail:** | borovoi@online.ru |

### 3. Participating Institutions

#### 3.1. Leading Institution

|  |  |
| --- | --- |
| **Short reference:** | RRC “KI” |
| **Full name:** | Federal State Institution Russian Research Center "Kurchatov Institute" |
| **Street address:** |  Kurchatov sq. 1 |
| **City:** | Moscow | **Region:** |  |
| **ZIP:** | 123182 | **Country:** | Russian Federation |
| **Name of Signature Authority:** |  Polyakov Il'ya Nikolaevich |
| **Title:** |  | **Position:** | Director |
| **Tel.:** | (095) 196-96-45 | **Fax:** | (095) 192-81-94 |
| **E-mail:** |  pol@kiae.ru |
| **Governmental Agency:** | Government of the Russian Federation |

#### 3.2. Other Participating Institutions

#### Participant Institution 1

|  |  |
| --- | --- |
| **Short reference:** | IBRAE |
| **Full name:** | Nuclear Safety Institute |
| **Street address:** | B. Tulskaya, 52 |
| **City:** | Moscow | **Region:** |  |
| **ZIP:** | 113191 | **Country:** | Russian Federation |
| **Name of Signature Authority:** |  Bolshov Leonid Aleksandrovich |
| **Title:** | Doctor of Sciences, Corresponding member of RAS | **Position:** | Director |
| **Tel.:** | (095) 952-24-21 | **Fax:** | (095) 958-00-40 |
| **E-mail:** | bolshov@ibrae.ac.ru |
| **Governmental Agency:** | Russian Academy of Sciences |
| **Sub-manager:** |  Strizhov Valeri Fedorovich |
| **Title:** | Doctor of Sciences | **Position:** | Director of division |
| **Tel.:** | (095) 958-08-73 | **Fax:** | (095) 958-00-40 |
| **E-mail:** | vfs@ibrae.ac.ru |

### 4. Foreign Collaborators

#### 4.1. Collaborators

|  |  |
| --- | --- |
| **Institution:** | Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH |
| **Street address:** | Kurfurstendam 200 |
| **City:** | Berlin | **Region/State:** | Berlin |
| **ZIP:** | 10719 | **Country:** | Germany |
| **Person:** | Gunter Pretzsch |
| **Title:** | Doctor of Sciences | **Position:** | Chief of Department |
| **Tel.:** | 49-30-88-58-91-45 | **Fax:** | 49-30-88-23-655 |
| **E-mail:** | prg@grs.de |

|  |  |
| --- | --- |
| **Institution:** | Institut de Radioprotection et de Sûreté Nucléaire |
| **Street address:** | CE de CADARACHE, BP 3 IRSN/DRS/SEMAR Building 702 |
| **City:** | Saint-Paul-lez-Durance | **Region/State:** |  |
| **ZIP:** | 13115 | **Country:** | France |
| **Person:** | Bernard Adroguer |
| **Title:** | Senior Engineer | **Position:** | Deputy |
| **Tel.:** | 33 4 42 25 23 34 | **Fax:** | 33 4 42 25 29 29 |
| **E-mail:** | Bernard.adroguer@irsn.fr |
| **Institution:** | Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft |
| **Street address:** | Forschungszentrum Karlsruhe GmbH, Postfach 3640 |
| **City:** | Karlsruhe | **Region/State:** |  |
| **ZIP:** | 76344 | **Country:** | Germany |
| **Person:** | Alexsei Miassoedov |
| **Title:** |  | **Position:** |  |
| **Теl:** | 07247/82-2253 | **Fax:** | 07247/82-4837 |
| **E-mail:** | Alexei.miassoedov@iket.fzk.de |

|  |  |
| --- | --- |
| **Institution:** | European Commission, Directorate Geenral Joint Research Centre, Institute für Transurane |
| **Street address:** | Hermann-von-Helmholtz Pl. 1, Postfach 2340 |
| **City:** | Karlsruhe | **Region/State:** |  |
| **ZIP:** | 76125 | **Country:** | Germany |
| **Person:** | Paul David William Bottomley |
| **Title:** |  | **Position:** | Senior Scientific Officer |
| **Теl:** | 07247-951-364 | **Fax:** | 07247-951-593 |
| **E-mail:** | bottomley@itu.fzk.de |

### 5. Project Duration

30 months

### 6. Project Location and Equipment

|  |  |
| --- | --- |
| **Institution** | **Location, Facilities and Equipment** |
| **Leading Institution** | Moscow, Russian Research Center “Kurchatov Institute” premises: main building, building 5a, personal computers, spectral and radiochemical equipment for samples' analysis  |
| **Participant Institution 1** | Moscow, Nuclear Safety Institute (IBRAE) premises: rooms 305, 306,212, new building, personal computers. |

## II. Specific information

### 1. Introduction and Overview

**1.1**. **Aim of the work**

The aim of the present work consists in analyzing and modeling FCM activity during the active phase of the Chernobyl accident while bringing in a broad spectrum of the existing experimental data and computational models.

This model will make it possible to:

* explain current physical and chemical state as well as spatial location of fuel containing materials (FCM) and radioactive substances inside the damaged Unit;
* evaluate possibilities of modeling and find out “weak spots” within the existing computational programs while modeling Chernobyl type accidents;
* determine directions of future research on the problem.

**1.2. Topicality and Novelty of the Work**

The work topicality is determined by two principal factors:

**First, such a work is indispensable for solving specific practical problems that may arise in the future when mitigating the Chernobyl accident consequences.**

Among the works on Chernobyl accident mitigation activities, particular attention is paid to the Object “Shelter" safety problems. Built at the end of 1986, this encasement covered the damaged Unit 4 and still remains the only protective barrier against penetration of degraded nuclear fuel (amounting to about 180 ton in uranium equivalent within the object “Shelter") and radioactive substances into the environment. General opinion of the experts is that this encasement ‑ in its current state ‑ is not safe and it requires urgent transformation into an environmentally safe system.

So far an international program – the SIP (Shelter Implementation Plan) ‑ has been developed and it is financed (~ $ 750 million) by about 30 countries. Its principal goal consists of the development and construction of a new safe confinement enveloping the object “Shelter". The next step should be removal of nuclear fuel and radioactive substances followed by their ultimate disposal. It is just at this phase that the development of a model for the processes resulted in the current state of both FCM and building structures will help answering many important questions and will make an appreciable contribution to reducing financial and dose commitments.

Among such questions there are the following ones. Which processes resulted in the nuclear fuel stored in the reactor generating multiple FCM modifications? What building structures have participated in these processes? What was the corium behavior, and in what way did FCM spread out over the Unit compartments? What is the internal structure and distribution of the actual FCM? What unexpected events can we face when penetrating into large FCM accumulations during their dismantlement? And much more*.*

**The second factor contributing to the project topicality consists in that the model development will make it possible to use the results of an 'enormous in scale and practically impossible to repeat' “experiment” on nuclear fuel of the reactor Unit 4 in the solution of general nuclear industry safety-related problems.**

Within the Project, a unique data bank will be elaborated which can be used as basis for verification of computational models of corium behavior. The results of the project will find application in planning management during severe accidents in evaluation of the long-term corium behavior.

### Novelty of the work

### There are known some attempts to create a model (further- the Model) describing processes with nuclear fuel of Unit 4 during the active phase of the Chernobyl accident.

During early post-accident years it was supposed that processes which took place during its active phase (10 days after the explosion) were determined by the materials dropped down in reactor vault. This was a base for explanation of FCM formation and behavior. However, the subsequent studies within the Object “Shelter" indicated that only a small part of these materials had penetrated into the reactor shaft. These materials were unable to have effect on the processes in fuel.

There are investigations based on misguided or spurious ideas on the nature of the explosions which destroyed the reactor (see, e.g.2).

There are also studies that only outline solutions of individual ––issues but which are important for the model (see,e.g.3).

Unfortunately, there are many speculations pursuing, as a rule, far from technical objectives and contradicting experimental data (se, e.g. 4).

**The project novelty consists in the fact that huge amount of experimental data, obtained during studies within the Object “Shelter" (after its analysis and verification) shall be used in combination with the most modern computer codes describing corium behavior. To date only collaboration between RRC "Kurchatov Institute" and IBRAE will allow this work to be performed and to solve a wide range of tasks (from radiological to material studies) related to the Object “Shelter" safety and to the general problems of nuclear industry safety.**

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

1. Маслов В.П., Данилов В.П. «Математическое моделирование аварийного блока ЧАЭС», М.: Наука, 1978 г. 144 с.

2. Э. Пурвис «Сценарий чернобыльской аварии: по состоянию на апрель 1995 г.», Отчет МНТЦ, Чернобыль, 1995 г., 146 с.

3. Э.М. Пазухин «ЛТСМ 4-го блока ЧАЭС: топография, физико-химические свойства, сценарий образования». В сборнике «Обект «Укрытие»- 10 лет, основные результаты исследований»,Национальная Академия Наук Украины, Чернобыль, 1996, с. 78-79.

4. «Авария на ЧАЭС- результат диверсии?», интервью Чечерова К.П., «Труд», 26.04.95 г.

**1.3. Basic input data**

To develop the Model, the following basic input should be used:

* Investigations on determining radionuclide composition, activity and heat generation of fuel at Unit 4 of the Chernobyl Nuclear Power Plant (NPP), immediately before the accident, carried out by the RRC "Kurchatov Institute" in 1986 - 2001;
* Studies of the releases from damaged reactor of Unit 4 performed at the RRC "Kurchatov Institute", and IBRAE RAS in 1986 - 2001;
* Works on the dynamic behaviour model for corium formed during the Chernobyl accident performed at IBRAE RAS in 1986 -2001;
* Database on FCM of the Object “Shelter" developed in 1998 – 2002 at the RRC "Kurchatov Institute" in the frames of the French-German initiative which contains more than 6000 records and analyses of FCM samples;
* The total of works performed in 1986 – 2003 at the Chernobyl site by specialists of Russian and Ukrainian research institutions related to the state of structures and inner compartments of Unit 4 stored at archival depositories of both RRC "Kurchatov Institute" and IBRAE RAS.

### 2. Expected Results and Their Application

The proposed investigations are aimed at solving applied tasks.

The Principal tasks to be solved in the frame of this project can be subdivided into two categories:

* methodical tasks on the development and verification of the nuclear fuel behaviour model during the active phase of the Chernobyl accident on the basis of the experimental data.A Data bank will be created for verification of the existing and future computational models of the corium behaviour.
* Applications in connection with safety of the object "Shelter" and general nuclear industry safety-related issues in the sphere of evaluation of long-term corium behaviour during severe accidents.

**The results of the project can (and should) be used for the subsequent phases of the Object “Shelter"** **conversion into an environmentally safe system.** They will provide answers for the questions formulated in previous section «Topicality of the work”. Inter alia, to construct a comprehensive picture of generation and spreading of different FCM modifications within the damaged Unit. They will also make it possible to estimate the composition and status of materials in the depth of large FCM accumulations from which no sample has been taken yet. Based on these results, the FCM amount in places inaccessible for direct investigation can be estimated. Taken together with experimental investigations the model will answer the question about the amounts of zirconium and uranium in metal masses at the lowest levels of "Object Shelter".

The model application will make it possible to reduce significantly financial resources and dose commitments during further activities on the Object “ Shelter" conversion.

**The Project results will be important also for the prognosis of long-term corium behaviour in the melt localization systems (core-catchers) being developed for some PWR reactors.** The basic results and the results of modeling will assist in evaluating reliability of the existing modeling programs of severe accident corium behaviour .

### 3. Meeting ISTC Goals and Objectives

Implementation of the project will give a possibility:

* for Russian scientists and specialists involved in the weapons-related activities to re-orient to peaceful activities;
* to assist their integration into the international scientific society;
* to support applied research in the sphere of the environment protection and nuclear safety.

For the first time the Project will give an opportunity for the collaborators from the European Union to compare results of the computational modeling of corium behavior with Chernobyl data.

### 4. Scope of Activities

#### Task 1 Collection, verification and analysis of initial data on nuclear fuel behavior, formation and spread of corium at various stages of the active phase of the accident at the Chernobyl NPP 4th Unit, and the nuclear fuel status immediately before the accident

|  |  |
| --- | --- |
| **Description of the task and its main stages** | **Participating Institutions** |
| The task has a purpose of describing in general the problem and the obtainable initial data. Stages for the task implementation:1.1. Collection and analysis of the initial data for various stages of the accident active phase (data on geometry and composition of structural materials, radionuclides, fuel composition before the accident, damage seen as a result of the accident, quantity and composition of radionuclides ejected from the reactor, dynamics of the residual fuel heat emission, quantity and composition of materials thrown into the damaged reactor, etc.)1.2. Impact of graphite burning on the processes of corium formationDue dates (S+0) – (S+4)[[1]](#footnote-1)  | 1-RRC "Kurchatov Institute" 2-IBRAE RAN |
| **Description of deliverables** |
| 1 | Computational and analytical work with results summarized in the form of a report.  |

#### Task 2 Creation of the data base for modeling FCM formation and activity at Unit 4 of the Chernobyl NPP.

|  |  |
| --- | --- |
| **Description of the task and its main stages** | **Participating Institutions** |
| Based on the analysis of verified data on nuclear, chemical and mineralogical composition of larva-like FCM, on the geometry of intrareactor compartments etc. the FCM parameters (and their range) will be determined for the computational models. Scenarios of corium formation and spread will be created (of a high quality). Stages of the task implementation:2.1. Preparation of data on geometry of FCM location in the internal compartments of the Object “Shelter”.2.2. Preparation of the data on FCM composition.2.3. Detailled elaboration f the scenario versions for the activities during corium spread and its interaction with structural materials.Due dates: (S+0)- (S+6). | 1-RRC "Kurchatov Institute" 2-IBRAE RAN |
| **Description of deliverables** |
| 1 | Computational and analytical work with results in the form of a report |

#### Task 3 Determining uranium and zirconium concentrations in metallic melts in the compartments below the reactor.

|  |  |
| --- | --- |
| **Description of the task and its main stages** | **Participating Institutions** |
| Investigations on uranium and zirconium concentrations (& where possible carbon) in metallic melts formed during the accident will be performed for further comparison with the results of the model computations. All investigations will be performed using up-to-date and calibrated measuring instrumentation to yield quantitative results.Due dates (S+6)- (S+9)  | 1-RRC "Kurchatov Institute"  |
| **Description of deliverables** |
| 1 | Experimental work with results summarized in the form of a report. |

Task 4. Application of the existing computational models for evaluation of the FCM state at Unit 4 of the Chernobyl NPP.

|  |  |
| --- | --- |
| **Description of the task and its main stages** | **Participating Institutions** |
| Several parameters of FCM shall be selected and they will be modeled using the existing computational models. Stages of the task implementation:4.1. Determination of the key FCM parameters and preparation (adaptation) of the initial data for modeling within the selected computational programs.4.2. Conducting modeling by several computational methods and comparing the obtained results with experimental ones, and comparing them among themselves. Due dates (S+4)- (S+9). | 1-RRC "Kurchatov Institute" 2-IBRAE RAN |
| **Description of deliverables** |
| 1 | Computational and analytical work with results summarized in the form of a report |

#### Task 5 Preparation of the final report on the Project

|  |  |
| --- | --- |
| **Description of the task and its main stages** | **Participating Institutions** |
| The results obtained during modeling of the selected FCM parameters will be used for identification of the missing initial data and shortcomings of the existing computational models. Proposals for the second stage of the Project shall be prepared on the basis of this analysis for model improvement & further necessary data collection. Stages of the task to be fulfilled:5.1. Identification of the missing initial data and shortcomings of the models.5.2. Preparation of the proposals for the second stage.Due dates: (S+9)- (S+10). | 1-RRC "Kurchatov Institute" 2-IBRAE RAN |
| **Description of deliverables** |
| 1 | Computational and analytical work with results summarized in the form of a report |

### 5. Role of Foreign Collaborators/Partners

Participation of foreign collaborators is supposed to fulfill the following functions:

* holding consultations with executors on the most difficult issues during the work process.
* preliminary examinations of principal technical reports on the Project and preparation of the relevant recommendations.
* Organize joint meetings (seminars) to review the project progress and discuss plans of further activities.
* Carrying out of FCM modelling using the key parameters with the collaborator's own codes and offering this for comparison with the Project's codes results.
* Offering of any available experimental data that may be relevant to the project

### 6. Technical Approach and Methodology

An experimental-computational method will be applied for modeling nuclear fuel behaviour during the active stage of the accident. The method is based on comparison of particular results of modeling with the available experimental data. The unique feature of the situation is that there are many experimental results of Chernobyl lava investigations and there is a possibility to perform the necessary additional experiments. Re-developed and adapted mathematical models for melt behaviour will be examined in particular cases through comparing them with real experimental lava-sample examination data. The results of comparison will be used for model correction in order to achieve an acceptable level of concordance between the calculation results and experimental data. This approach will substantially increase the reliability and trustworthiness of the modeling results.

**Principal References**

1.Asmolov V.G., Borovoi A.A., Demin V.F. et al. “Accident at the Chernobyl NPP: one year after, Proc. Int. Conf. On Nuclear Power Performance and Safety, Vienna, 28 September – 2 October 1987, IAEA, Vienna, 1988, v. 3, hh. 103 – 147.

2. Abalin S.S., Belyaev S.T., Borovoi A.A. "Diagnostic investigations of the accident Chernobyl NPP reactor " //Atomic Energy, V.68, No. 5, 1990, pp.355-359 (In Russian).

3. Borovoi А.А., Analytical Report (Post- Accident Management of Destroyed Fuel from Chernobyl) //IAEA, Work Material, 1990, p. 1 - 99.

4. Borovoi, А.А., Galkin, B.Ja., Krinitsyn A.P., et al. "Neoformation products of fuel interaction with constructional materials of the Chernobyl NPP 4th Unit, Reports 1-2 // J. Radiochemia, v.32, n.6, 1990, pp. 103-113 (in Russian).

5. Aroutiounian, R.V., Bolshov, L.А., Vasiliev, А.D. and Strijov V.F. Physical models of severe accidents at nuclear power plants. Moscow, Nauka, 1992 (in Russian).

6. Vabischevich P.N., Popkov А.G., Strijov V.F. and Chudanov V.V. Fuel spreading modelling. In: "Problems of safe development of nuclear industry", Moscow, Nauka, 1993, pp.123-130 (in Russian).

7. A.A.Borovoi , A.R. Sich. "Chernobyl Accident Revisted, Part 2, The State of Nuclear Fuel Located Within the Chernobyl Sarcophagus", Nuclear Safety, Vol.36, No.1, January-June 1995, pp.1-32.

8. Aroutiounian, R.V., Bolshov, L.А., Dykhne А.М., *et al*. “Problem of confinement of the Chernobyl NPP 4th Unit melt during the active accident stage. Critical analysis”. In "Radioecological, medical and socio-economical consequences of the Chernobyl NPP accident" May 21-25, 1995, Extended abstracts, Moscow, 1995, p. 6 (in Russian).

9. Borovoi A.A. “Chernobyl Sarcophagus: Safety Problems”, IAEA International forum “One decade after Chernobyl: nuclear safety aspects”, Vienna, april 1-3, 1996, IAEA-J4-TC972, Working Material, p.265-286.

10. Bogatov, S.А. “Interaction of the damaged fuel of the 4th Chernobyl NPP Unit with constructional materials – qualitative estimates”. In collection of papers «Object Shelter ‑ 10 years on», principal investigation results», The Ukrainian National Academy of Sciences, Chernobyl, 1996, pp. 112-127 (in Russian).

11. Chudanov V.V., Popkov A.G.., Vabishchevich P.N., Latche J.C.,Veteau J.M.Validation of Hydrodynamic Models of the RASPLAV/SPREAD Code Against the CORINE Experiemnts. Heat and Mass Transfer in Severe Nuclear Reactor Accidents. Begell house, Inc. New York, Wallingford, 1996, PP.408-418.

12. Chudanov V.V., Popkov A.G.., Vabishchevich P.N., Latche J.C.,Veteau J.M.Validation of Hydrodynamic Models of the RASPLAV/SPREAD Code Against the CORINE Experiemnts. Heat and Mass Transfer in Severe Nuclear Reactor Accidents. Begell house, Inc. New York, Wallingford, 1996, PP.408-418.

13. Borovoi A., Bogatov S. “Consequences of Chernobyl; a view ten years on.” Advances in Nuclear Science and Technology, Vol.25, p.171 - 214, Plenum Press, New York and London, 1997.

14. Aksenova, А.Е., Vasiliev, А.D., Varenkov, V.V., Volchek, А.М., Krylov, S.F., Pakhomov, Е.P., Pervichko, V.А., Popkov, А.G., Strijov, V.F., Chudanov, V.V. Program complex for computational modeling of experiments on interactions of high-temperature metallic melts with dioxide-zirconium concrete, IBRAE's Preprint, **№ 97-19**, Moscow, 1997 (in Russian).

15. “The Shelter current safety analysis and situation development forecasts (update version)”, A. Borovoy et. all, TACIS, European Commission, 1998, 103 p.

16. Borovoi A., Gavrilov S. "Development of the database "Nuclear fuel and radioactive waste in the Shelter of Chernobyl NPP", Nuclear Safety Institute Russian Academy of Sciences, Preprint IBRAE - 2001-01, Moscow 2001, 28p.

17. Aroutiounian, R.V., Bolshov, L.А., Bogatov, S.А., Borovoi, A.A., Belikhov, E.P., Gavrilov, S.L., Gnedenko, V.G., Pazukhin, E.M. "Problems of the "Object Shelter"", IBRAE's Preprint: № IBRAE-2002-17, Moscow 2002, 22 p (in Russian).

1. S – start of the Project implementation [↑](#footnote-ref-1)