**УКРАЇНСЬКИЙ НАУКОВО-ТЕХНОЛОГІЧНИЙ ЦЕНТР**

**PROPOSITION FOR PROJECT**

**4758**

**Ukraine**

**1. PROPOSITIONS FOR PROJECT**

**1.1 Title of Project:**

Natural and calculation-experimental research of processes of fuel melt interaction with

construction materials for severe radiation accidents on nuclear power plants.

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**1.3 Participating Institutions:**

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**1.5 Project Duration:** 30 months

**1.6 Participants:**

Number Person-days of efforts

Weapon Scientists 15 6800

Total Participants 21 9500

**1.7 Project Summary:**

On April 26, 1986, a most global technological catastrophe occurred at Chornobyl nuclear power plant Unit 4 (hereinafter «Shelter» object or SO) with a RBMK-1000 reactor. As result of the following reactor core destruction, around (25-50) ∙ 106 Ci activity was thrown out into atmosphere as gases, aerosols and fuel particles.

Inside ruined Unit 4, approximately 180 t of spent nuclear fuel (SNF) had remained, which is contained as reactor core fragments and lava-like fuel-containing materials (LFCM).

LFCM was produced at the active stage of the nuclear accident. The main fused mass of lava and fuel produced was located in SO room 305/2 and spread along adjacent rooms and created clusters of different configurations and diverse uranium content. Expert estimates show that they contain from 90 to 120 t SNF. Some of these clusters are in open condition and have been well studied.

Significant part of the LFCM (according to experts – estimated as more than 50 t SNF) is now buried under the ruined Unit's concrete that was poured during the construction of the Shelter in 1986. Such clusters are practically inaccessible and only a few have been studied, and our concepts of them were formed on the basis of information - either samples or measurements - obtained from the boundaries of these clusters.

According to this preliminary data, such hidden LFCM clusters are located in south-east part of sub-reactor room 305/2 SO. They are located in cavities produced as result of melting of sub-reactor plate concrete by lava with a high content of fuel that relocated down to the sub-reactor plate concrete after core seal failure (Fig. 1).

Presence of such clusters is confirmed by:

* results of core analyses in boreholes drilled in expected areas of hidden clusters of fuel;
* local peaks or gradients of temperature and neutron fluxes in these areas;
* unstable neutron activity over many years;
* the critical neutron incident in the summer of 1990.

Sub-reactor solid fields, where FCM presence with high uranium content is expected

Fig. 1 – Layout of areas with high uranium content in FCM

According to preliminary estimates, the fuel nuclear concentration in such clusters can reach 40 % and more.

The FCM clusters near sub-reactor plate of SO room 305/2 are constantly covered with water penetrating down to the room due to atmospheric precipitation (from outside the Shelter) and condensation (from inside the Shelter). From above (see Fig. 2), clusters are sealed with concrete layer poured over these areas during «Shelter» construction.

From 2008 onwards, the temperature at the periphery of the cluster, located in southern part of south-east quadrant of room 305/2, exceeds the temperature of sub-reactor plate at more than 20 °С.

From this cluster area, the heated water leakage is periodically observed.

«Concrete site» over hidden FCM cluster in room 305/2

Fig. 2 – Location of FCM cluster in room 305/2, covered with «fresh» concrete layer

It is thought that the approach to criticality in the 1990 incident occurred as a result of water inundating the clusters (temperature of the cluster dropped below 100 °С initially), and then self-quenching of the chain reaction occurred as a consequence of strong moisteningof the cluster.

Changes in the extent water penetration or its form in the cluster can then return to optimal wetting and as a consequence - to a recurrence of such neutron 'incidents'.

Therefore, a combined modelled and experimental research of hidden nuclearly-hazardous clusters, as well as definition of methods to suppress neutron-moderating conditions is today a priority task, and one which must be solved before NSC construction commences.

**1.8 Project Facilities:**

1. Information - research systems (IRS) for monitoring neutron flux, temperature, γ-radiation rate;
2. Computer net containing the database of the «Shelter» object and ChNPP;
3. Laboratory for physicochemical analysis methods (LPAM), secondly , laboratory for nuclear and physical analysis methods (LNPAM) and finally – Certificate of qualification ВРМ № 07А062/482;
4. Experimental mechanical laboratory and site with vehicle department for design of remotely-controlled sampling vehicles.

One will acquire in the frame of this project:

1. Software for conducting neutron-physical estimates;
2. Software for conducting temperature field estimates;
3. Computers and communication devices;
4. Measuring sensors: neutron fluxes, γ-radiation, temperature, moisture;
5. Spectrometer for gamma radiation with detector GMX-30 and analyzer of DISPEC type of Ortec (USA) company;
6. Alpha spectrometric complex Alpha Analyst, of Canberra,USA;
7. Spectrometer for beta radiation energies СЕБ-01;
8. Expendables: paper, printer and xerox cartridges, paints, solvents;
9. Expendables for radiochemical and nuclear-physical research.

**1.9 Scientific and technical sphere:**

Main: Nuclear Energy & Safety

Secondary: Physics

**1.11 Introduction**

**What’s the problem?**

Our knowledge about the volume below the sub-reactor plate, where the presence of high uranium content FCMs is expected is based on indirect data obtained only from the boundaries of such zones. The actual interior of the above clusters was inaccessible from boreholes drilled in subreactor slab concrete (due to the lack of an agreed procedure for extraction of highly-active cores). Thus, the analysis is limited to the collection of data pertaining to neutron-physical and physicochemical characterization of the edges of these clusters without direct access.

**1.12 Problem state**

**What have other people done?**

In period 1990 – 1996, research of nuclear and physical characteristics of the FCM open clusters was carried out. Assessment of SO nuclear safety was made by several research groups from Ukraine, Russia, Belorussia and Germany. They prepared many models of FCM structure and content, and estimates of subcriticality with variation of cluster geometry and at medium wetting rates were made. It was demonstrated that open clusters in no way represent any nuclear danger.

First estimates of Kourchatov Institute, which were based on experimental data of the Complex Expedition (later – ISTC «Shelter» - ISP NPP), had shown that in homogenous medium (the relevant condition for the sub-reactor room FCM), SCR (Self-sustaining Chain Reaction) is only possible, if the fuel content in the FCM does not exceed 40%. Since the samples with such fuel concentration were not detected at that time, the conclusion of SO total nuclear safety was reached.

From 1996 until 1998, GRS carried out a data programme on behalf of the BMU & BfS (Project SR 207518-1). This assessed the criticality conditions of hypothetical assemblies of fuel-containing masses inside the object 'Shelter', including the influence of rain water on the neutron field (and so explain the enhanced neutron rates in September 1996). This would support the regulatory authority in their surveillance & evaluation of future monitoring for the object 'Shelter'. This document outlined the conditions under which criticality could occur but concluded that this was very unlikely given a fuel concentration not exceeding 10-12%.

In 1998-99, IPSN (now IRSN) & GRS jointly instructed the Kurchatov Institute to carry out a Project (N°1) on Safety State of the Shelter of Chernobyl Nuclear Power Plant. In this project the data was collected and a Data Base was created on the ChNPP accident, the samples and boreholes, their location, the sample radiochemical analyses (fp's and actinides), the references to previous investigations and the accumulations of material in the main reactor room 305/2 and the adjacent investigated rooms. In sub-project No3 on “Nuclear Fuel and Radioactive Waste” the working report from Oct '99 (deliverable No.8) summarized and gave the data format for imput into the Data Bank. Annexe 2 of this working report gives the locations of the accumulations, their FCM volume and U mass estimates of the accumulations as well as the overall/average compositions and estimates along with references. Annexe 3 gives a detailed description of 305/2, quadrant by quadrant, of features and accumulations. Neutron dose monitoring is also given. Then it gives similar information but broken into individual samples analyses (description, chemical, radiochemical, -spectroscopic analyses) for each of the 7 main accumulations of FCM in 305/2 and the adjacent rooms.

**What application have their results?**

It was concluded that all open FCM clusters can be exposed and studied, and can not be nuclearly hazardous in any way, since their fuel concentration did not exceed 10 – 12 %. However, the probability of the existence of FCM with higher fuel contents (i.e. 40 – 50 %) was not considered. This, however has not been confirmed.

**1.13 Objective and tasks**

**What are we going to do?**

To assess the available Data Bank from the previous GRS/IPSN project (named above) and other major investigations and check for consistency. The Data Bank should be used as a starting point for modelling or assessing the risk of hazardous clusters in the reactor rooms and their location. Significant gaps in the data should be identified. If possible, new experimental data to fill these gaps should be obtained, from existing access routes to FCM clusters in room 305/2. For example:

* take and analyze further samples (FCM, aerosols, water);
* measure neutron and temperature field dynamics;
* analyze the core samples .

The assessed data will be used (together with collaborators) to further develop a) material thermophysical and neutron physical models, b) the material reactions occurring in the cluster medium, c) dynamics of neutron and temperature field changes. Next the improved models should be used to make predictions on a) the possible flow of the FCM corium and the clusters location, b) the possibility of higher U content clusters, c) the conditions and possibility of criticality during particular weather conditions.

**What is project’s objective ?**

To improve existing data and to obtain further data on the structure and content of FCM produced as result of fuel melt interaction with subreactor plate concrete and melting of reactor materials: graphite, fuel channels, metal and materials of the sand/gravel filling.

**1.14 Expected value**

**What is new?**

The exisiting data, for example the data mentioned in section 1.12 above from the GRS-IPSN –KI studies and annexes or any other relevant reports, will be improved. In particular:

* refinement of nuclear fuel balance in subreactor room 305/2;
* more accurate information assembled on the structure, composition of the FCM mass as well as the corium's neutron physical and physicochemical characteristics;
* a more realistic scenario of cluster production with high fuel content at accident active stage will be proposed.

**1.15 Organization, qualification and personnel content**

**Who are we?**

Personnel involved in project will include the employees of Institute for Safety Problems of Nuclear Power Plants (ISP NPP) of National Academy of Sciences (NAS) of Ukraine.

During the work realization at ChNPP (from 1986 onwards), the institute has conducted a huge volume of research, which resulted in building up a unique experience in the execution safely within complicated conditions of the “Shelter” object:

ISP NPP has got the following licenses to perform work:

License series АБ № 112842 for the right to carry out the transport of radioactive materials.

Date of issuance - September 27, 2006. Expiry date - September 27, 2011.

License series АБ № 112855 for the right to use ionizing radiation sources. Date of re-draw up - October 04, 2006. Expiry date - October 04, 2011.

License series ОВ № 000221 for right to design nuclear facilities or repositories for the burial of radioactive waste according to i.2.1 of Chapter 2. Date of issuance - September 29, 2004. Expiry date - October 24, 2007 р.

Certificate for Quality Management System (UkrCEPRO № UA 2.051.1248). Registered – September 20, 2004. Valid until September 19, 2009.

International certificate for Quality Management System (Bureau “VERITAS” ISO 9001:2000). Registered – February 03, 2005. Valid until January 30, 2007.

ISP NPP has the following facilities & experience: Labs for physicochemical analysis methods (LPAM), secondly, work with IRS, and laboratory for nuclear physical analysis methods (LNPAM), and thirdly work with IRS. They also have a certificate of attestation to perform measurements in metrological monitoring field № 07А062/482. Issued – 26.06.2006. Valid until – 26.06.2009.

The majority of the project's participants have already taken part in research and development and design work to provide SO nuclear and radiation safety at all stages of its construction. These include studies of: FCM physicochemical properties, FCM clusters, nuclear and physical parameters, sampling and its research, estimates of FCM amount and their layout geography in the SO, radioactive aerosol research in SO, development of remote procedures to work in SO, SO radiation monitoring, supporting studies for the dust suppression system for the ruined ChNPP Unit 4, etc. Currently, the staff are involved in carrying out research work associated with the SO scheduled work and the construction of the confinement over the ChNPP building. Project personnel includes: 1 Corresponding Member of Academy of Sciences, 2 Science Doctors, 7 Science Candidates and 10 high-professional research engineers.

We deem that our experience and scientific level is high enough to fulfill tasks of project being offered.

Most of our project participants took part in research and development and design works to provide SO nuclear and radiation safety**.**

**How this project is associated with other projects at our institute?**

During the work (from 1986 onwards), ISP NPP employees were involved in this project and have acquired and have unique experience in conducting research and development in Chornobyl projects performed directly at SO, such as:

* Investigation of rooms where FCM clusters are located;
* FCM sampling;
* development and execution of methods for accessing FCM clusters at SO;
* estimate of geometry and mass parameters of FCM clusters;
* research of FCM physicochemical properties and nuclear-physical parameters of FCM clusters;
* development and operation of a system for monitoring the «Shelter» object's FCM conditions.

Currently, ISP NPP workers are performing related research work such as:

* safe and effective operation of SO and NPP;
* research of «Shelter» object and scientific support for its conversion into an ecologically safe system;
* Scientific Support Work in support of the NSC (Arch) Project.

**1.16 Expected results**

**What will be done in this project?**

In this project, the following will be analyzed:

- visual observation data;

- information obtained when drilling research boreholes;

- results of sampled FCM analysis ;

- instrumental measurements;

- mechanisms of FCM cluster production with uranium high content.

The above data drawn from the previous reports (such as is given section 1.12) will be analysed , along with the latest neutron and heat estimates, new instrumental measurements and results of physicochemical properties research. Any information requirements will be defined. In the light of these requirements and in the frame of Shelter's instrumental possibilities, newly taken measurements from a cluster area will be proposed in two 'critical mass' risk areas, in south-west quadrant of room 305/2.

These measurements will be executed and then be analysed for the neutron physical and thermal physical processes, which occurred during accident active stage, and the impact of external factors in the longer term.

 This data will then be used both to help verify the models for corium flow and to give improved estimates of the FCM clusters size and composition. Here it is expected that Collaborators and partner institutes working in this field may be able to contribute with modelling with their own corium flow or neutronic codes.

With an improved estimation of nuclearly-hazardous clusters (NHC) and their condition the best options for future work in the Shelter object can be proposed.

**What are next steps?**

One should note that existence of NHC in SO is a priority problem in order that the SO can be converted into an ecologically safe system. An obligatory condition of SO operation and conversion into an ecologically safe system is provision of nuclear and radiation safety.

The results from this project are vital to assess risks of SCR occurrence and their aftermath, but, more importantly, will allow precautions to be taken to minimize SCR risk and improve radiation safety for SO staff.

To provide the needed radiation safety level during SO works one should optimize in all aspects the project actions pertaining to nuclear safety. Results obtained from this project are necessary for such optimization and can be used in other estimates, such as:

* work execution costs (including costs for antirad protection and radioactive waste management);
* collective effective dose;
* collective radiological risk of personnel;
* collective radiological risk of the public;
* financial risk;
* risk value for aggravated conditions of scheduled work execution , NSC construction, FCM retrieval.

**1.17 Scope of works**

**What tasks will be performed?**

1. Experimental data from 1988-1992 to be verified.
2. Preliminary modelling of data, or modellers review data to assess lacking data.
3. Experimental data over project construction period to be obtained.
4. Material model of clusters to be completed by all Collaborators/Contributors and comparisons made.
5. Optimised Neutron physics estimates of clusters to be conducted.
6. Optimised Thermal physics estimates of clusters to be conducted.
7. Assessment from models of the most likely distribution of NHC, their composition and their physical condition.
8. Assessment of the clusters' future degradation processes & associated risks.
9. Finally outline the best options for their removal or rendering them safe.

Additionally, the following will be performed:

- information-patent search of technical decisions;

- coordination of joint works and technical issues;

- patenting of original decisions;

- preparation of technical and financial reports.

**1.18 Technical approach methodology**

**How it will be done?**

Over ISP 20-year period, NPP has been accumulated unique experimental data (see section 1.12 for examples) on change dynamics of different physical parameters measured at NHC periphery, such as neutron flux density, effective dose rate, temperature, as well as results of sample analyses from sub-reactor room boreholes. There also exists the possibility to sample and analyze water, aerosols and smears from sub-reactor room boreholes.. All that data will be a basis for new versions of NHC (nuclearly-hazardous clusters) material models, which will be developed in this project. Material models will be built on the basis of experts proposed processes of NHC medium creation as result of interaction of a melt with high fuel content with concrete. The developed model will simulate the current conditions of a NHC medium, and the version will be refined and/or validated by comparison the experimental data until a satisfactory coincidence is reached, while using NHC model parameters which correspond to the real cluster behaviour.

The data will also be made available to collaborators (such as CEA, Cadarache) or other Russian (e.g. Kurchatov Institute, Moscow) or Ukrainian Institutes that have models of corium flow and neutronics and that wish to participate. They can apply this data to their codes for corium flow. There is information available for the conditions during the active part of the accident hence they can model the corium flows and therefore estimate the final probable material distributions upon corium solidification. Preliminary modelling or evaluations on the basis of existing information can reveal the lacking data. This can be used to define the additional measurements necessary. The additional information can be used to refine the modelling by all collaborators/contributors to optimise the model. The report from the optimised model should assess the distribution of unknown clusters as well as the known clusters and their neutronic and physical condition. The report should also evaluate the current risks and propose options for the removal of hazardous clusters (i.e. by accessibility or by its SCR risk). This report can then be presented to the ChNPP and SIP project authorities.

**1.19 Planning self-sufficiency**

***What „market” shall we study?***

Most probable fields for implementing the results of this project are:

1. Mitigation of technological accidents’ aftermath at NPPs for other enterprises linked with nuclearly-hazardous production.

2. Mitigation of aftermath or preventive maintenance when operating repositories with nuclearly-hazardous materials.

3. Works for NSC (Arch) construction and operation.

***What is our specific objective of marketing research?***

As result of this project's realization, the most valuable information will be that concerning NHC production mechanisms during severe accidents at NPPs and facilities linked to nuclearly hazardous production. It will enable: the prevention of technological accidents at NPP and other such facilities, mitigation of accident aftermaths, and development of preventive actions during operation of repositories and finally to optimally execute the NSC (Arch) construction, as well as to provide for its safe operation.

This project managers, after its completion, will use this valuable experience in the above fields.

For this, it is necessary to organize a wide publication of this project results, to acquaint foreign managers of the SIP project and Project Management Unit (PMU) in Ukraine with potential value of the proposed STCU project.

Another field of further activity of collaboration could be co-operation with foreign nuclear safety organizations for NPPs and other enterprises linked with nuclearly-hazardous production.

***What are we going to do?***

Talks on co-operation with foreign managers of SIP Project PMU shall be held by means of personal contacts in the town of Slavutych (Ukraine). Talks shall be expediently initiated after obtaining the first reliable results. Organization of co-operation with foreign companies shall be initiated already during project start by publishing announcements and information about the project on the coordinating organization and STCU web sites.

To assist in a positive decision for this project, it is proposed to draw this to the attention of Ukraine government by sending a request for the project funding from the State budget to the Ministry for extraordinary situations.

In addition to the above steps, the project executors will deliver information at conferences and will set up information stands at relevant exhibitions. After obtaining specific propositions on co-operation, agreements for protection of intellectual property will be made by way of patenting technical decisions in appropriate countries – for investors and potential consumers.

Planning and coordination of actions related to project continuation will be made by Project Manager.

***What will be the results?***

The final result of the marketing study for the project end will be the signing of a contract or protocol of intention with a company-partner (in conformity with the business-plan), or with a State structure (Ministry) in accordance with the request for funding. In this case, all further steps of the team will be defined by the contract or protocol conditions. A positive result will be talks with a potential partner to agree the plan for implementation of the procedure for SO nuclear safety provision.

If our propositions are not accepted and steps made are insufficient, positive results of project will also be:

1. Information confirming NHC's existence and the correctness of NHC material model in SO rooms 305/2, based on the assessment of the existing information and the analysis of the newly-acquired data of the NHC medium. Estimates and program documentation, containing economic design proposals , for execution of countermeasures to avoid SCR occurrence in NHC of SO rooms 305/2 will also be proposed.

2. Financial report on the costs for project realization.

Project materials can be published on the website of the coordinating organization in the form of articles in scientific journals and professional literature.

Based on the above results, the search of potential partners can be continued after the project's completion, since after the project duration (2.5 years) and its restricted funding, all previous problems related to this issue will be solved.

During the project's execution, project materials will be produced as regards:

* technical reports with substantiation of principal decisions and test results.
* slides in Powerpoint.
* Website presentation with description of main achievements.
* reports on actions for self-sufficiency, participation in conferences and exhibitions.
* feasibility report on financial profit of proposed option of available robots usage.

The information mentioned above allows the project managers to assure the execution of the proposed project and to extend the project after its completion.