Status of the ISTC project # K-1265 "Study of the processes of corium-melt retention in the reactor pressure vessel" (INVECOR)

(Presented by V. Zhdanov during 14th CEG-SAM meeting, Kiev, Ukraine, September 9-11, 2008)

Within the framework of 9 quarters following works on project INVECOR have been performed (results were published on CEG Web-site):

1) Technology of graphite details protection of experimental facility from interaction with corium components at a heating has been fulfilled. Reliability of protection has been checked up at melting of prototypic corium in small-scale facility and in large-scale experiments with heating of 12 kg of prototypic corium with application of coaxial plasmatrons. The design of crucible for melting of 60 kg of prototypic corium has been modified with the purpose of a possibility of uniform coating application on its internal surface.

2) Design of coaxial plasmatrons used for decay heat imitation in molten corium pool has been advanced. As a result of numerous experiments power of individual plasmatrons has been increased up to 18,5 kW at possible duration of operation till 2,5 hours.

3) Design of the device for decay heat imitation in molten corium pool has been developed, which included 5 coaxial plasmatrons by total power over 90 kW.

4) Experimental section representing RPV model of the semi-elliptic shape with internal diameter of 400 mm and the wall thickness of 50 mm has been developed and made. The experimental section was made from usual carbon steel. The samples of RPV steel equipped with thermocouples and gauges of moving/deformation are inserted into a RPV model wall. For heat maintenance in a interaction zone "corium/steel" the external surface of experimental section is covered by thermal insulating package. Experimental trial has shown, that application of thermal insulating package allows to increase temperature in the interaction zone "corium/steel" to more than 1000 degree C, that provides conditions of physical and chemical interaction between corium and a steel during experiment at continuous water cooling of an external surface of thermal insulating package.

5) 7 large-scale experiments with heating of of 12 kg initial prototypic corium components using individual plasmatrons (TOP experiments) have been executed. The experimental cell for TOP tests contained thermal insulating package on an external surface of a vessel for corium loading and was cooled by a continuous water flow. Duration of experiments made from 1 till 2,5 hours at plasmatrons power from 17 to 19 kW. Reliability of an external surface coating of an external graphite nozzle of plasmatrons has been checked up in experiments and erosion rate of an internal graphite nozzle of plasmatrons depending on test specifications and type of the graphite used for nozzle manufacture. Limiting parameters for plasmatrons and electric power supply equipments, and also ways of plasmatrons restart in case of not authorized interruption of an electric arch have been tested in experiments. Tests have shown that the plasmatrons resource can be considerably increased in case of application of graphite R4340 SGL Carbon Group.

6) Post-test researches have been executed after experiments allowed to estimate degree and character of corium heating, phase composition of solidified melt, a coating state on the graphite details which are in contact with corium during the tests.

7) Pre-test and the post-test calculations of experimental cells for TOP experiments and the pre-test calculations of experimental section for integral experiments with heating of 60 kg of prototypic corium have been executed.

8) Necessary equipment and materials for maintenance of tests and post-test researches except for the graphite materials necessary for manufacturing of details of the electro-melting furnace and electrode nozzles for integrated experiments has been bought. It should be noted that manufacturing of details of the electro-melting furnace is possible only using of graphite materials of SGL Carbon Group. In connection with a delay of the export license for delivery of necessary materials from Germany to Kazakhstan, and in connection with absence of such materials in the institute the work under the project will be suspended in 10th quarter.

RESEARCH OF SEVERE ACCIDENT PROCESSES IN CORE OF LIGHT WATER REACTORS

Vassiliev Yu., Zhdanov V., Zuyev V., Kolodeshnikov A.
(Presented by V.Zhdanov in the conference "Nuclear Power Engineering in Kazakhstan", Kurchatov-city, Kazakhstan, June 11-13, 2008)

Researches of the processes accompanying severe accidents in light water reactors (LWR) with core melting within the framework of the international program Japan - Kazakhstan have been carried out in IAE NNC RK within 10 years. In the course of realization of programs LHI, COTELS, IVR-AM large-scale experiments on modeling of various stages of LWR severe accidents have been executed, such as:

- Interaction of corium melt with coolant and RPV material in inter-case conditions (in-vessel FCI: LHI series);
- Interaction of corium melt with RPV steel at imitation of decay heat in fission products (IVR-AM series);
- Interaction of corium melt with water outside of RPV (ex-vessel FCI: A series);
- Interaction corium melt with concrete of the containment basemat at modeling of a decay heat and operation of systems of MCCI suppression (B/C, D series).

The general tests scheme consisted in melting of 60 kg of prototypic corium via induction heating in "hot crucible" and in subsequent discharging of the melt in experimental section. In experimental section the basic stage of modeling of the set phase of severe accident has been realized. Interaction parameters of corium with water and/or concrete were registered by data acquisition system.

Corresponding experimental facilities on the basis of electro-thermal stand "ANGARA" have been developed and made for realization of the above-stated scenarios. Designing and manufacturing of experimental installations for large-scale tests have been accompanied by corresponding calculations and supporting small-scale tests.

The experimental section has been equipped, depending on a kind of tests with device for imitation of decay heat, gauges of temperature, pressure, deformation, devices for modeling of reactor safety systems.

Developed data acquisition system has been created for realization of the set modes of tests and registration of parameters of experiments.

The post-test research included a technological sequent for primary dismantling and cutting of experimental sections; observation of character and depth of corium melt interaction with reactor materials, grain size analysis, studying of element and phase composition of products of interaction кориума with water, RPV material and concrete.

Results of tests have been put in a basis of the phenomenological and calculation models describing studied interactions which are published in reports at the international conferences.

EXPERIMENTAL STUDY OF THE PROCESSES AT THE CORIUM MELT RETENTION IN THE REACTOR PRESSURE VESSEL (INVECOR)

Zhdanov V., Baklanov V., Malysheva E.

(Presented by V.Zhdanov in the conference "Nuclear Power Engineering in Kazakhstan", Kurchatov-city, Kazakhstan, June 11-13, 2008)

Overall project objective of the project is an improvement of the safety assessment of LWR corium in-vessel retention (IVR) under severe accident conditions. This target is achieved by experimental modeling of the thermal and physicochemical processes at the retention of the prototypical corium molten pool on the water-cooled lower head of the reactor pressure vessel (RPV).

Thermal-hydraulic processes are rather completely investigated using melt simulators in R&D practice for IVR. Physicochemical processes in molten pool are investigated in RASPLAV and MASCA programs in small-scale experiments and in some large-scale experiences. Physicochemical processes of corium interaction with RPV steel are investigated in small-scale experiments only under ISTC METCOR project.

Complex of thermal and physicochemical processes at prototypic corium melt retention in large-scale RPV lower head model (LHM) is investigated in the Project.

LAVA-B facility is used for the tests performance. This facility is equipped with the induction furnace for melt production of the prototypical corium and with the discharged melt receiver (MR), which contained the water-cooled LHM, system of decay heat modeling in corium and the set of gauges for temperature, pressure and deformation measurement. Supporting experiments will be performed using the small-scale VCG-135 stand for preparation of large-scale tests and optimization of engineering and technological finding.

The main results of the Project will be new experimental data on the corium pool final structure with natural convection at the decay heat modeling and RPV lower head ablation at various melt composition and thermal loadings on the RPV wall in 2-D configuration with real RPV lower head curvature.

The obtained results will be used for the models development, which are describing behavior of the melt at in-vessel phase of accident, verification of computer codes for the IVR concept validation for present and future NPP designs. The technological concepts used at experiments performance can be used by researchers for the similar problems solution.

Performance of 4 tasks is provided in the Project:

1. Modernization of existing facilities and optimization of corium melting technology and modeling of decay heat in corium including 3 large-scale integral tests;
2. Calculation support of the experiments, including pre-test calculations of EMF operating modes and operating modes of device for decay heat modeling and the post-test calculations;
4. Post-test analysis of the experimental results, which includes investigation of corium – steel interaction, research of interaction products, INVECOR database formation.

Foreign collaborators of the Project:

Commissariat à l'Energie Atomique (CEA, Saklay and Cadarache)
Forschungszentrum Rossendorf (Dresden, Germany)
Forschungszentrum Karlsruhe GmbH (Germany)
Institute de Radioprotection et de Sureté Nucléaire (CEA, Cadarache)
Institute of trans-uranium materials research (ITU - JRC, Germany)
Pisa University (Italy)

SUPPORTING EXPERIMENTS IN A SUBSTANTIATION OF DESIGN OF DEVICE FOR IMITATION OF DECAY HEAT MODELING IN INVECOR PROJECT

Zhdanov V., Baklanov V., Malysheva E., Kukushkin I., Ignashev V., Mikisha A., Zverev V.

(Presented by V.Baklanov in the conference "Nuclear Power Engineering in Kazakhstan", Kurchatov-city, Kazakhstan, June 11-13, 2008)

Process of corium melt retention in reactor pressure vessel is accompanied both thermal influence on a steel wall from corium pool and physical and chemical interaction between corium components and steel. It is known by results of before executed experiments under programs CORA, RASPLAV, METCOR that physical and chemical interaction begins at temperature above 900 °C in a contact zone of corium with steel wall. For maintenance of such conditions in LAVA-B facility at existing possibilities on weight of discharged corium melt and power of the device for decay heat imitation would be required to increase a RPV model wall thickness to more than 200 mm. Placing of such model in the melt receiver is impossible because of the limited dimensions of the facility. It was offered for the decision of this problem to use a thermal-insulating layer between an external wall of RPV model and a flow of cooling water. As a thermal protection fiber glass cloth has been chosen.

Efficiency of thermal insulating package application has been checked primary in small-scale facility. Tests of a calorimetric cell have shown possibility of increase in temperature in a zone of prospective interaction "corium/steel" up to 850 … 900 °C.

The further tests of thermal insulating package have been carried out in calibrating experiments on LAVA-B facility using plasmatrons heating of prototypic corium in a steel vessel with thermally insulated wall. As a result of performance of 4 experiments with heating of 12 kg corium C-30 within 2 hours at power of plasmatrons up to 18 kW optimum parameters of thermal insulating package for maintenance of temperature of a steel wall up to 1100 °C at a thickness of a corium layer between plasmatrons and thermal insulated wall about 30 mm have been found. In a contact zone of corium with plasmatrons melting of zirconium and dissolution in received melt of urania has been reached.

Studying of graphite erosion rate of plasmatrons nozzles has shown possibility of performance of experiments within more than 2 hours in case of application of graphite ARV-1 and/or R4340.

The protective coating from zirconium carbide on an external surface of a graphite nozzles of plasmatrons has shown its high reliability against oxide corium components at temperature above 2500 °C.

Experiments have been accompanied with pre-test and the post-test calculations that allowed to correct modes of each subsequent test.

Results of executed calibration experiments have proved technical possibility of realization of demanded modes for research of processes at corium melt retention in reactor pressure vessel in experimental facility LAVA-B.

EXPERIMENTAL STUDY OF THE PROCESSES AT THE CORIUM MELT RETENTION IN THE REACTOR PRESSURE VESSEL (INVECOR)

Zhdanov V., Kolodeshnikov A., Baklanov V., Malysheva E.

(Presented by V.Zhdanov in the 5th Eurasian conference "Nuclear sciences and its application", Ankara, Turkey, October, 14-16, 2008)

Overall project objective – Improvement of the safety assessment of LWR corium in-vessel retention (IVR) under severe accident conditions. This target is achieved by experimental modeling of the thermal and physicochemical processes at the retention of the prototypical corium molten pool on the water-cooled lower head of the reactor pressure vessel (RPV).

Thermalhydraulic processes are rather completely investigated using melt simulators in R&D practice for IVR. Physicochemical processes in molten pool are investigated in RASPLAV and MASCA programs in small-scale experiments and in some large-scale experiences. Physicochemical processes of corium interaction with RPV steel are investigated in small-scale experiments only under ISTC METCOR project.

Complex of thermal and physicochemical processes at corium melt retention in large-scale RPV lower head model (LHM) is investigated in the Project.

LAVA-B facility of IAE NNC RK is used for the tests performance. This facility is equipped with the induction furnace for melt production (EMF) of the prototypical corium and with the discharged melt receiver (MR), which contained the water-cooled LHM, system of decay heat modeling in corium and the set of gauges for temperature, pressure and deformation measurement. Supporting experiments will be performed using the small-scale VCG-135 stand for preparation of large-scale tests and optimization of engineering and technological finding.

The main results of the Project will be new experimental data on the corium pool final structure with natural convection at the decay heat modeling and RPV lower head ablation at various melt composition and thermal loadings on the RPV wall in 2-D configuration with real RPV lower head curvature.

The received results will be used for the models development, which are describing behavior of the melt at in-vessel phase of accident, verification of computer codes for the IVR concept validation for present and future NPP designs. The technological concepts used at experiments performance can be used by researchers for the similar problems solution.

It is provided in the Project performance of 4 tasks:

1. Modernization of existing facilities and optimization of corium melting technology and modeling of decay heat in corium;
2. Calculation support of the experiments, including pre-test calculations of EMF operating modes and operating modes of device for decay heat modeling and the post-test calculations using of computer codes of the NITI (Sosnovy bor, Russia) and CEA (Cadarache, France);
3. Large-scale experiments (3 tests);
4. Post-test analysis of the experimental results, which includes investigation of corium – steel interaction, research of interaction products, INVECOR database formation.

Foreign collaborators of the Project:

Commissariat à l'Energie Atomique (CEA, Saklay)
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Pisa University

Several operations on experimental facility improvement and tests technique working off were performed during 2 years of project execution. Set of supporting tests included prototypic corium heating and melting using coaxial plasmatrons dipped into core components for imitation of decay heat in corium pool. Preparation of integral large scale tests is under way.

EXPERIMENTS ON CORIUM MELT RETENTION IN THE REACTOR PRESSURE VESSEL

Zhdanov V.

(Abstract of paper 9043 to ICAPP'9, Tokyo, Japan, May 10-14, 2009)

There has been proposed the Project for experimental modeling of the thermal and physicochemical processes at the retention of the prototypic corium molten pool on the water-cooled lower head of the reactor pressure vessel (RPV):

- for definition of effects of scale, shape of the interface surface and other 2-D effects on corrosion processes, which determine final thickness of the reactor pressure vessel (RPV) wall;
- for estimation of influences of the metal-oxidic stratified molten pool structure on the possibility of corium in-vessel retention;
- for obtaining of quantitative characteristics of processes at in-vessel retention (IVR), that are needed for the development and verification of the models used at IVR justification.

To achieve the Project objectives, LAVA-B Test Facility constructed in the Institute of Atomic Energy of NNC RK in the course of the International COTELS and IVR-AM Programmes run in cooperation with NUPEC company (Japan) is expected to use.

LAVA-B Test Facility allows the performance of the experiments with producing of 60 kg of prototypic corium melt (UO_2-based corium) and subsequent corium discharging from the height about 1,7 m into the experimental section that involves the RPV model equipped with thermocouples and gauges for measuring model walls deformation. Initial loading is melted in the LAVA-B electric melting furnace (EMF), installed above the experimental section, by means of induction heating in the “hot” crucible.

For simulating the decay heat in the corium located in the RPV model, the device consisting of 5 coaxial close-type plasmatrons with total power 90 kW is used. The plasmatrons nozzles design provides the stable combustion of the arc within the inter-electrode space in the specified plasmatrons area with sustained power for over 2 hours. Protective coating of the external surface of the graphite nozzles of plasmatrons avoids corium/carbon interaction in the course of the experiment.

Temperature conditions for physicochemical corium/steel wall interaction are ensured with thermal insulation at the external surface of the RPV model between its wall and cooling water flow. The experiments with a single plasmatrons immersed into the core components mixture of 12 kg mass, proved the possibility to maintain the temperature at the internal surface of the RPV model at 950…1000 C on cooling the external thermo-insulation surface with uninterrupted water flow. In addition the experiments have justified the reliability of the protective coating applied at the external surface of the graphite nozzles of the plasmatrons external electrodes and at the internal surface of melting crucibles. Preliminary calculations showed that the use of the profile thermal insulation at the external model surface allows to reaching the uniform temperature field at the internal model surface in the area of corium/steel interaction.

Based upon the supporting experiments and corresponding calculations there was developed the experimental section for LAVA-B integral tests.

EXPERIMENTS ON CORIUM MELT RETENTION IN THE REACTOR PRESSURE VESSEL

Zhdanov V.

(Abstract of presentation to ISAMM'9, Villigen, Switzerland, October 26 – 28, 2009)

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Based upon the supporting experiments and corresponding calculations there was developed the experimental section for LAVA-B integral tests.

EXPERIMENTAL STUDY OF THE PROCESSES AT THE CORIUM MELT RETENTION IN THE REACTOR PRESSURE VESSEL (INVECOR)

Zhdanov V., Baklanov V., Malysheva E.

(Annotation of paper to collection "Bulletin of NNC RK" (to be published))

ISTC Project devoted to an experimental research of processes in prototypic corium pool at core melt retention in reactor pressure vessel of RPW is described. Performance of large-scale experiments with reactor pressure vessel models in scale 1:12 and 60 kg of preliminary melted corium has been planned. "LAVA-B" facility with induction heating and the device for decay heat modeling on the basis of coaxial plasmatrons of total power up to 90 kg is applied for performance of experiments. Preliminary experiments have confirmed possibility of performance of experiments within more than 2 hours at cooling of an external surface of reactor pressure vessel model by a continuous water flow. Original technical decisions for protection of corium components against carbiding and for creation of conditions for physico-chemical interaction "corium/steel" by application of profile thermal insulating package on an external surface of model of the reactor pressure vessel have been found. The project of the experimental device has been developed; pre-test calculations have been executed; the supporting experiments in a substantiation of efficiency of separate units and systems of experimental facility have been conducted.

SUPPORTING EXPERIMENTS IN A SUBSTANTIATION OF DESIGN OF DEVICE FOR IMITATION OF DECAY HEAT MODELING IN INVECOR PROJECT

Zhdanov V., Baklanov V., Malysheva E., Kukushkin I., Ignashev V., Mikisha A., Zverev V.

(Annotation of paper to collection "Bulletin of NNC RK" (to be published))

Supporting experiments in a substantiation of efficiency of separate units of "LAVA-B" facility used at performance of experiments on research of processes in corium pool at core melt retention in the reactor pressure vessel of RPW are described. In the first group of experiments the choice of materials of thermal insulating package on an external surface of reactor pressure vessel model for creation of conditions for physical and chemical interaction "corium/steel" has been carried out. The second group of experiments has been devoted of the technology working off of application of a protective coating on an external surface of graphite nozzles of coaxial plasmatrons used in the device for imitation of decay heat in corium. In the third group of integral experiments check of efficiency of a protective coating on a graphite surface has been executed at long endurance of coaxial plasmatrons in a mix of core materials corresponding to corium C-32, and also an estimation of thermal insulating package efficiency on an external surface of a reactor pressure vessel model. The executed experiments have confirmed reliability of a protective coating at work of coaxial plasmatrons with a graphite nozzles with power over 18 kW during 2 hours. The chosen design of a thermal insulating package has allowed to reach thus temperatures more than 850 °C, that it is enough to start of physico-chemical interaction "corium/steel".