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|  | EUROPEAN COMMISSION  DIRECTORATE-GENERAL ‘RESEARCH’ | INTERNATIONAL  SCIENCE AND  TECHNOLOGY  CENTRE |  |

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## NON PROLIFERATION THROUGH SCIENCE AND CO-OPERATION

**CONTACT EXPERT GROUP**

**on**

**SEVERE ACCIDENT MANAGEMENT**

**(CEG-SAM)**

**MINUTES OF THE 15th MEETING**

**(shortened version)**

**Villigen, Switzerland**

**Paul Scherrer Institute (PSI), Laboratory for Thermo-Hydraulics**

**March 10-12, 2009**

Meeting Location: Conference room of the

“Paul Scherrer Institute”

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| Dissemination level: RE  PU: public  RE: restricted to EC and a group specified by the CEG-SAM members  CO: confidential, only for EC and CEG-SAM members |

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Final minutes (shortened version), September 8, 2009 CEG-SAM / M-15

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| Subject: 15th Meeting of the ISTC  “Contact Expert Group on Severe Accident Management” (CEG-SAM)  Place: Conference room of the “Paul Scherrer Institute”, Villigen, Switzerland  Date: March 10-12, 2009  Participants: 32 participants of 20 organizations from 8 countries:  Mr. J.Birchley PSI, Villigen  Mr. D.Bottomley EC, DG JRC / ITU, Karlsruhe  Mr. B.Clement IRSN, Cadarache  Mr. G.Ducros CEA, Cadarache  Mr. S.Güntay PSI, Villigen  Mr. M.Fischer AREVA NP, Erlangen  Mr. L.E.Herranz CIEMAT, Madrid  Mr. P.Hofmann Consultant, Karlsruhe (**secretary**)  Mr. M.Hugon EC, DG-RTD / J.2, Brussels (**chairman**)  Mr. Ch.Journeau CEA/DTN, Cadarache  Mr. M.Koch RUB, Bochum  Mr. M.Krause AECL, Chalk River, Canada  Mr. J.S.Lamy EdF, Clamart  Mr. A.Miassoedov FZK, Karlsruhe  Mr. A.Palagin FZK, Karlsruhe  Mr. G.Pretzsch GRS, Berlin  Mr. B.Schwinges GRS, Cologne  Mr. J.Stuckert FZK, Karlsruhe  Mr.K.Trambauer GRS, Munich  Mr. W.Tromm FZK, Karlsruhe  Mr. S.Bechta RIT-NITI, Sosnovy Bor  Mr. V.Chudanov IBRAE-RAS, Moscow  Mr. A.Kisselev IBRAE, DNS, Moscow  Mr. V.Krasnov ISP NPP, Kiev  Mr. V.Nalivaev NPO LUCH, Podolsk  Mr. V.Protsak UIAR of NAU, Kiev  Mr. V.Semishkin OKB “GIDROPRESS”  Mr. V.Stepanenko STCU, Kiev  Mr. L.Tocheny ISTC, Moscow  Mr. M.Veshchunov IBRAE-RAS, Moscow  Mr. S.Vorobiev ISTC, Moscow  Ms. T.Yudina IBRAE-RAS, Moscow  Distribution list: Ms. Z.Stancic DG-RTD  (Shortened version Ms. M.Minch DG-RTD / D  of the minutes) Mr R.Burmanjer DG-RTD / D.3  Mr. J.Sanders DG-RTD / D.3  Mr. O.Quintana Trias DG-RTD / J  Mr. A.Perez Sainz DG-RTD / J.1  Mr. S.Webster DG-RTD / J.2  Mr. P.Manolatos DG-RTD / J.2  Mr. G.Van Goethem DG-RTD / J.2  Mr. R.Schenkel DG-JRC  Mr. P.Frigola DG-JRC / 2  Mr. G.Sadler DG-JRC / 2  Intranet of Unit J.2  Mr. L.Tocheny ISTC, Moscow  Mr. S.Vorobiev ISTC, Moscow  Mr. W.Gudowski ISTC, Moscow  Mr. A.Gozal ISTC, Moscow  EU CEG-SAM members  Contact person: Mr. M. Hugon Tel.: +32 2 296 5719 – DG-RTD / J.2 |

Revised final agenda of the meeting see Annex 1, list of participants see Annex 2.

The Laboratory of Thermo-Hydraulics of the “Paul Scherrer Institute” (PSI) organized the 15th CEG-SAM meeting in Villigen, Switzerland, on March 10-12, 2009. The meeting location was the conference room “East” of the “Paul Scherrer Institute”.

The CEG-SAM meeting is divided into restricted and extended sessions. The restricted sessions are to discuss internal matters and the status of current ISTC/STCU projects. The extended sessions are dedicated to presentations of the progress of on-going ISTC/STCU projects and of new or revised ISTC/STCU proposals by scientists from the Russian Federation, the Republic of Kazakhstan and the Ukraine.

The chairmen M.Hugon (EC), L.Tocheny (ISTC), and V.Stepanenko (STCU) welcomed the CEG-SAM members

**Restricted session**

**Topic #1:** Welcome and opening remarks

The chairman M.Hugon opened the first part of the restricted session and welcomed the EU participants of the 15th meeting of the Contact Expert Group on Severe Accident Management (CEG-SAM) of the International Science and Technology Centre (ISTC) and of the Science & Technology Centre in the Ukraine (STCU).

He expressed his thanks to S.Guentay (PSI) who kindly offered to organize and host the 15th CEG-SAM meeting in Villigen, Switzerland. S.Guentay welcomed, for his part, the CEG-SAM group.

**Topic #2:** Adoption of the agenda of the 15th CEG-SAM meeting

The planned presentation of V.Loktionov (MPEI, Moscow) on the ISTC project #3635 on “Scale experimental investigation of the thermal and structural integrity of the VVER pressure vessel Lower Head in severe accidents” (Topic #24) will be given by V.Semishkin (OKB, Gidropress). With these changes, the appended agenda (see Annex 1) was accepted.

**Topic #3:** Approval of the minutes of the 14th CEG-SAM meeting in Kiev, Ukraine, September 9-11, 2008.

The secretary took into account the comments received on the draft minutes by the participants in the revised minutes dated November 14, 2008. The revised minutes were then approved by the CEG-SAM members without any additional changes at the 15th CEG-SAM meeting in Villigen, March 10, 2009.

**Topic #4:** Discussion of the “Specific action list” of the 14th CEG-SAM meeting in Kiev

**Action 14/1**: L.Tocheny (ISTC) will contact all managers of on-going ISTC projects to inform them that they should provide information (name and e-mail address) to A. Miassoedov (FZK) and K.Trambauer (GRS) to be included in the CEG-SAM website users list. After that they will have full access permissions for their projects web-pages and will be exclusively responsible for updating the project documentation/deliverables and the upload of presentations from project progress meetings. *Consecutive action. Up to now not all project managers fulfil the requested task*.

**Action 14/7:** L.Tocheny (ISTC) should provide invitations and visa support for the foreign participants at the 16th CEG-SAM meeting in Moscow in September 2009 (this request was expressed by IBRAE to CEG-SAM after the meeting). *L.Tocheny will provide the requested support.*

**Topic #5**: Reports by the secretariats

V.Stepanenko (STCU) expressed his thanks to the CEG-SAM, but especially to Canada, for the funding of the STCU project #4207. He reported on new structures between STCU and EU and the STCU and the Ukrainian Academy of Science as well as with other Ukrainian authorities. The STCU offices have moved to another location in Kiev (new address: 7a Metalistiv Street, Kyiv 03057 Ukraine).

M.Hugon (EC) mentioned that the financing of joint Ukrainian-Euratom projects will be as follows: Euratom will finance the European part and the Ukrainian part will be financed by Ukraine.

L.Tocheny (ISTC) introduced S.Vorobiev, the Russian Deputy Director of ISTC, who attended the meeting (the ISTC has altogether 5 deputy directors). S.Vorobiev manages several tasks such as export control and reports to ROSATOM on the status and on activities of CEG expert groups. There are about 400 projects which have to be controlled and managed. S.Vorobiev mentioned that export control activities are the main tasks of the organisations executing the projects. A detailed planning and careful preparation and presentation of the results are important. The whole system has changed into a bureaucratic one that complicates the co-operation.

**Topic #6**: Preliminary discussion of updated and/or new ISTC/STCU project proposals

The new and updated ISTC/STCU project proposals will be presented under topics #22 and #23.

# Extended session

**Topic #7**: S.Guentay from the “Laboratory for Thermal-Hydraulics” of the “Paul Scherrer Institute (PSI)”, who kindly organized and hosted the 15th CEG-SAM meeting in Villigen (CH), welcomed all the participants and gave a short overview on the planned course of the meeting.

**Topic #8**: Welcome of the Russian and Ukrainian colleagues; approval of the shortened minutes of the 14th CEG-SAM meeting in Kiev; adoption of the agenda of the 15th CEG-SAM meeting in Villigen.

M.Hugon opened the extended session of the meeting and welcomed the Russian and Ukrainian participants and expressed his thanks to S.Guentay (PSI) for organizing and hosting the 15th CEG-SAM meeting.

The shortened minutes of the 14th CEG-SAM meeting were distributed to the Russian, Kazakh and Ukrainian participants by the secretary. The obtained comments were then considered in the revised shortened minutes dated November 2008. This version of the minutes was accepted at the meeting without any additional changes.

The planned presentation of V.Loktionov (MPEI, Moscow) on the ISTC project #3635 on “Scale experimental investigation of the thermal and structural integrity of the VVER pressure vessel Lower Head in severe accidents” (Topic #24) will be given by V.Semishkin (OKB, Gidropress). With these changes the appended agenda (see Annex 1) was accepted.

**Topic #9**: Status of the official ISTC CEG-SAM webpage

The ISTC CEG-SAM webpage is hosted by GRS (Garching, Germany) and is now fully operational (http://cegsam.grs.de). In the new structure of the webpage all documents (project proposals, advice notes, work plans, progress reports) are collected under the ISTC project number. There will be a unique user name and password for each user and different read/write permissions for the different users. Russian, Kazakh and Ukrainian project managers should provide information (name and e-mail address) to A. Miassoedov/K.Trambauer to be included in the users list. After that they will have full access permissions for their project web-pages. They will be exclusively responsible for updating the project documentation/deliverables and the upload of presentations from project progress meetings.

The CEG-SAM members will have full access to the agendas, list of participants and minutes (restricted and open sessions) and all other stored documents (presentations). There will be special access rights for non-European members for the project in which they participate. It will be restricted to two names per institute per project.

A.Miassoedov reported that this is achieved for about 90% of the projects. He asked J.Stuckert (FZK) to contact V.Nalivaev (LUCH) to put his/their various project reports on PARAMETER test results into the CEG-SAM webpage (Action 15/2).

**Topic #10**: Future of the CEG-SAM

M.Hugon gave a presentation on the status of the ISTC contact expert group CEG-SAM. The objective is to provide a means of contact between various experts involved in project conception, recommendations and implementation and subsequent optimization of project results, to foster exchange of information between various ISTC/STCU projects, and to promote the possibilities of future or joint research through the ISTC/STCU. Results of SARNET activities are periodically presented to CEG-SAM members and ISTC/STCU proposals and project reports related to SAM are transmitted to the SARNET topical co-ordinators. The experimental results of ISTC/STCU projects are used for development of knowledge as part of SARNET Joint Programme of Activities (JPA).

The updated list of ISTC/STCU projects recommended by the CEG-SAM was presented and discussed. The CEG-SAM is successful since its launch in April 2002. Altogether 15 ISTC project proposals were selected for funding and 7 ISTC projects are in the meantime completed. In addition, several STCU project proposals are under discussion; one of them has now been funded by Canada (STCU #4207).

The current ISTC and STCU project proposals of potential interest for the CEG-SAM are: 1) ISTC #3919, VERONIKA; 2) ISTC #3702, CHESS-2, not supported by SAC; 3) STCU #4758, Hidden nuclear hazardous clusters of fuel in the Chernobyl NPP Unit 4; and 4) ISTC #3936 Fuel assembly tests with B4C, PARAMETER-SF5, -SF6 experiments. M.Hugon stressed once more that future ISTC/STCU project proposals should be in line with the SARNET priorities. The planned EC funding for ISTC/STCU projects amounts to about 8M€ for 2009.

M.Hugon then reported on the status of SARNET-2 (total cost about 38M€, EC funding 5.75M€, 41 partners including Canada, South Korea and USA), the results of the 2nd call of the Euratom FP7 and gave information on the 3rd call on Nuclear Fission for 2009. A direct participation of third country partners funding their own research work in Euratom projects is considered.

A co-operation with Russia on nuclear fission and radiation protection is planned. The future principle of co-operation will change from “assistance” to a “collaboration” approach, for example, in the field of containment thermo-hydraulics of current and future LWRs and for severe accident management measures. Both parties, Euratom and Russian partners, will develop jointly separate Euratom and Russian proposals, as well as a co-ordination mechanism. The European projects will be funded jointly by Euratom and the Member States and the Russian projects by Rosatom. The overall financial contribution of Euratom for these projects in the 3rd call will be about 3-5 M€. The funding level of the Russian projects by ROSATOM is not yet known.

M.Hugon then delineated the future of the CEG-SAM: 1) to continue its previous tasks with ISTC/STCU projects and interaction with SARNET-2; 2) to include in the CEG-SAM coordinated projects the projects funded by Euratom and Rosatom following the 3rd FP call on “Fission” in 2009; 3) to enlarge the scope of the “CEG-SAM” to a “CEG on Safety and Accident Management” as part of the Euratom-ROSATOM Working Group *(suspended until the results of the evaluations of the 3rd call of FP7 in July 2009)*; and 4) to investigate the possibility of establishing a structured dialogue between Euratom and the Ukraine.

Finally, M.Hugon mentioned that the FISA 2009 Conference will take place in Prague, June 22-24, 2009. Seven Post-FISA 2009 Workshops will take place on June 25, 2009. One of them will be “International collaboration with non-EU countries”; D.Bottomley (JRC-ITU) could give a presentation on the CEG-SAM experience and outcome, if required.

**Topic #11**: Update on SARNET-2

B.Clément (IRSN) presented the SARNET-2 (**S**evere **A**ccident **R**esearch **NET**work of excellence) update. SARNET-2 will start on April1, 2009, altogether 21 countries with 41 organizations will participate in the programme that will last 4 years. The main objectives of SARNET-2 are to tackle the fragmentation that exists between the different R&D organisations, notably in defining common research programmes and developing computer tools; in particular the continuation of ASTEC assessment and its extension to cover BWRs and CANDU reactors, and the continuation of storage of experimental data in the DATANET database.

B.Clement described briefly the work on Severe Accident Research Priorities within SARNET. Six issues remain open with high priority, four issues with medium priority, and five issues remain open with low priority and could be closed after finalizing the related research activities. The 6 issues with **high priority** are research on 1) core coolability during reflood and debris cooling in lower head. 2) ex-vessel melt pool configuration during MCCI and ex-vessel corium coolability by top flooding. 3) corium melt relocation into water and ex-vessel FCI. 4) hydrogen mixing and combustion in the containment. 5) oxidising impact on source term. 6) iodine chemistry in the RCS and in the containment. The tasks of SARNET-2 will be executed by 8 work-packages on management, excellence spreading, information systems, ASTEC, corium coolability, MCCI, containment and source term that were described.

Up to now the interaction between CEG-SAM and EC-SARNET works well and the EC-SARNET recommendations were considered in the final work programmes of the various ISTC/STCU project proposals. The results of ISTC projects are used by foreign collaborators in the framework of SARNET. The interaction between EC-SARNET and CEG-SAM brings mutual benefits and further assures a critical mass of expertise for ISTC/STCU proposals addressing specific issues in the SAM area. The objective of the interaction is the resolution of still-pending questions that are important for reactor safety, and the knowledge transfer for safety application.

**On-going project presentations**

**Topic #12:** Status of the ISTC project #3690 on the “Fuel assembly behaviour under severe accident top quenching conditions in the PARAMETER-SF test series (PARAMETER-SF3 and PARAMETER-SF4 experiments); Results of the PARAMETER-SF3 experiment

V.Nalivaev (FSUE SRI SIA, “LUCH”) presented the current status of the project PARAMETER that includes the conduct of VVER-1000 bundle experiments with UO2 pellets and Zr+1%Nb cladding tubes under severe reactor accident conditions (18 heated rods and 1 unheated rod). The PARAMETER-SF3 experiment was conducted under the following test conditions. Coolant flow rates: argon 2g/s (670K) and steam 3.5g/s (770K). The pre-oxidation of the bundle was carried out at cladding temperatures of about 1470K for 4000s. Then the bundle was heated up with 0.2 - 0.3 K/s to a maximum bundle temperature of 1870K. At this temperature top flooding of the bundle with water (40 g/s) was initiated. The test parameters for the bundle experiments (heat-up rate, steam flow rate, extent of pre-oxidation of the cladding, maximum cladding temperature before quenching, flooding rates) were fixed on the basis of SVECHA code predictions by IBRAE (see topic #13).

The cladding temperatures of the bundle were presented as function of time for different bundle elevations during the pre-oxidation and transient heat-up and quench stages. The total mass of hydrogen generated during the test was about 34g. Post-test destructive examinations of the fuel bundle have been performed to determine the extent of cladding and shroud oxidation; the obtained results were presented under topic #14.

**Topic #13:** ISTC project #3690. Results of PARAMETER-SF3 pre- and post-test numerical modelling

A.Kiselev (IBRAE-RAS) presented the results of PARAMETER-SF3 pre- and post-test calculations performed with different SA code systems: SOCRAT, ICARE/CATHARE, RELAP/SCDAPSIM, PARAM-TG and ATHLET-CD, respectively.

The PARAMETER-SF3 post- and pre-test calculations have been compared with the obtained experimental data. Beside the temperature evolution of the cladding and shroud also the oxide scale thicknesses at different bundle elevations as well as the generated hydrogen were determined. The comparison reveals that the applied experimental electric power at the pre-oxidation and the transient phase was higher than calculated. Post-test calculations were performed on the basis of the exact PARAMETER-SF3 experimental data of power history, mass flow rates, and inlet temperatures. In the course of the PARAMETER-SF3 post-test calculations, the heat loss in the external resistances (leads and electrodes) and the radial heat loss through the shroud, which were not exactly known, were improved.

All codes reproduce reasonably well the temperature evolution of the bundle. The calculated maximal temperatures before the onset of flooding correspond to the experimentally-measured ones (1870 K). At the flooding stage all codes predict practically no hydrogen release. Most code systems estimate the total amount of hydrogen well; the best coincidence between the experimentally-determined hydrogen mass (34 g) and calculated mass was achieved in calculations by the ICARE code system (about 33 g). The results of RELAP/SCDAPSIM calculations are always lower or different to the other code calculations.

**Topic #14:** ISTC project #3690. Post-test examination of the PARAMETER-SF2 and SF3 fuel assemblies

T.Yudina (IBRAE-RAS) presented the status of the PARAMETER-SF2 and –SF3 destructive post-test investigations.

Five bundle cross sections of the test bundle PARAMETER-SF2 were examined in detail. There was pronounced oxidation of the Zr+1%Nb cladding at bundle elevations between 1000 and 1300mm. Beside the formation of a compact ZrO2 layer on the outer cladding surfaces, a localized spalling of thin ZrO2 multi-layers took place. The cladding of the bundle elevations between 500 and 1300mm reveals pronounced breakaway oxidation. Quantitative data on the oxide layer thicknesses were given. The crack surfaces in the metallic part of the cladding (through-wall cracks) were not oxidized. The oxidation of the inner cladding surface is weak. Cladding fragmentation is not pronounced. No UO2 fuel relocation took place. The pickup of hydrogen by the shroud was measured at different elevations. The maximum hydrogen concentration was about 23 at% at 900mm elevation.

In addition first metallographic examination results of test bundle PARAMETER-SF3 at different cross sections were described and discussed in detail. The bundle showed pronounced breakaway oxidation of the cladding, shroud, and peripheral rods, especially at the higher and hotter bundle elevations. The oxide layer thickness on the outer cladding surface varied between about 250µm at the bundle elevation of 800mm and about 550µm at 1300mm. The maximum shroud oxidation was about 400µm. The circumferential cladding oxide layer thickness was inhomogeneous. Through-wall cracks in the cladding were not oxidized. The Ta heaters and Mo electrodes were partially oxidized in the upper bundle elevations. The calculated location of maximal oxide layer thickness on the cladding based on the measured thickness of the metallic layer corresponds to the hottest zone (1300mm) according to thermocouples readings.

**Topic #15**: Status of PARAMETER-SF4 planning analyses by EU partners

J.Birchley (PSI) presented the joint opinion of the EU partners on the key test objectives and proposed test parameters of the planned experiment PARAMETER SF-4. The test objectives are: 1) Achieve air oxidation, but limited to enable a significant period of oxygen starvation. 2) Achieve successful reflood without significant excursion and without melting/degradation. 3) Complete ZrO2/ZrN formation would be interesting but is less important than achieving oxygen starvation.

Following an action decided at the 13th CEG-SAM meeting held in Budapest, March 2008, PSI is coordinating the pre-test analytical support for PARAMETER-SF4. A task group was set up among collaborators and first scoping calculations were presented at the PARAMETER meeting held at Podolsk, in July 2008. A meeting was held at FZK on September 1, 2008, to clarify the most important test objectives, to identify a target transient and to define schedule of calculations. Among the goals are to achieve a transient analogous to QUENCH-10, including a period of complete oxygen consumption (in order to investigate nitriding), and to avoid an oxidation excursion during reflood (in order, as far as possible, to preserve the bundle in its post-air-ingress state). The outcome of the meeting was reported at the 14th CEG-SAM meeting in Kiev, shortly afterwards in September 2008.

In principle the proposed test parameters are as agreed at the Podolsk meeting in July 2008: 1) Pre-oxidation in air at a temperature of 1200°C, to achieve oxide layer thicknesses up to 300-400µm at the hottest bundle location. 2) Power reduction to decrease the maximum bundle temperature to about 900°C with an air flow of 0.8-0.9 g/s (similar to QUENCH-10). 3) Switch from steam flow (3.5 g/s) to air flow (0.8 – 0.9 g/s) to cause a temperature increase reaching about 1750°C, and then to initiate bottom reflood at an injection rate of about 40g/s water (same as in PARAMETER SF-3). A higher reflood rate may be needed to avoid reflood excursion.

Calculations are being performed by EDF, GRS, IRSN and PSI, using versions of MAAP4, ATHLET-CD, ICARE/CATHARE and SCDAP/RELAP5, respectively. The status of analyses was discussed among LUCH and collaborating organisations alongside the QUENCH Workshop in Karlsruhe, November 2008. Preliminary calculations suggest the desired objectives can be met. Final pre-test calculations will be performed after benchmarking of the models against PARAMETER-SF3 data, following the March 2009 meeting of CEG-SAM.

The coordination has been supported by the EU in the frame of the SARNET programme under work package WP14.1. It is hoped EU support will continue within SARNET-2, possibly under WP8.1.

**Topic #16:** PARAMETER-SF4 pre-test calculations with ATHLET-CD

K.Trambauer (GRS) presented the results of the PARAMETER-SF4 pre-test calculations with the new ATHLET-CD code system version 2.2a. The objectives have been to determine the temperature evolution of the cladding and shroud, the thickness of the oxide layers, the movement of the quench fronts and the generated hydrogen.

First of all a re-run of the PARAMETER-SF2 post-test calculation was performed as a validation basis for the –SF4 pre-test calculations due to the use of the new ATHLET-CD code system version 2.2a. Small changes in modelling were verified resulting in small differences compared to previous calculations. The calculations were performed on the basis of the jointly-decided test parameters by the EU partners (described by J.Birchley in topic #15). The various results of the pre-test calculations were presented using the cladding oxidation model of Leistikow/Prater-Courtright instead of the recommended Sokolov correlation.

The ATHLET-CD calculation result in maximal cladding temperatures during the pre-oxidation phase that are slightly higher than expected with the given time function for power (calculated about 1280°C, expected 1200°C). The temperature decrease to 900°C within 2000s before the start of the air injection is in agreement with the desired value; the maximal temperature within the air ingress phase of 1750°C as the start point for bottom water injection is reached earlier than expected (calculated: 14666 s, expected: 15060s). The air injection rate of 0.8g/s leads to an oxygen starvation at the elevations above 1000mm after about 600s. Thereafter the elevation of the maximum temperature moves to lower positions. The time needed for bottom quenching is 367s for a water injection rate of 40g/s. The total mass of hydrogen generated is 29.4g about 3g are formed during quenching. The calculated oxide layer thickness at the end of the pre-oxidation phase is higher than expected for the given power curve.

**Topic #17**: Progress report on the ISTC project #3592 "Corium Melt Interaction with Reactor Vessel Steel” (METCOR-P)

S.Bechta (RIT-NITI) described the objectives of METCOR-P project: Qualification and quantification of physico-chemical phenomena of corium melt interactions with reactor vessel steel with particular interest to interaction characteristics i) at vertically-positioned interfaces, ii) peculiarities of interaction with European vessel steel, and iii) corium melt oxidation transients.

Altogether three experiments were performed with C30 and C100 corium melts. The experimental results on the corrosion of vessel steel due to interaction with fully oxidized corium melt (C100) in oxidizing atmosphere were described and discussed. The essential results of the experiments are: A strong influence of melt composition, steel surface temperature and corium-steel heat flux on the corrosion rate; an Arrhenius character of the corrosion rate evolution versus steel surface temperature exists; an intensification of the corrosion after reaching a certain steel surface temperature as a result of liquefaction of phases in the corrosion layer (if corium melt contains iron oxides) was observed. Finally an insensitivity of the steel corrosion by replacement of the test atmosphere above the melt from air to steam was noted. A corrosion model and a semi-empirical correlation of the corrosion rate based on the experimental data and qualitative conclusions were presented.

In addition results of the vessel steel corrosion as a result of interaction with a sub-oxidized corium melt (C30) were reported. According to METCOR and METCOR-P experimental data the steel corrosion is, in this case, a result of corium and steel component partitioning through the oxidic crust, the formation and liquefaction of the surface Fe-U-Zr-(O) layer and the subsequent steel dissolution in the formed liquid. The final corrosion depth is determined by the position of the isotherm, which corresponds to a certain temperature. The relationship of this temperature with the surface layer composition and corium phase diagram was discussed.

A list of published and currently prepared papers was presented and finally organizational issues connected with Rosatom Export Control were discussed.

S.Bechta also mentioned some organizational problems such as restrictions imposed by the Rosatom Export Control measures, e.g., an export license is necessary. A partner should be found and the results confidentiality should be confirmed. JRC-ITU is ready to be a partner and has already sent a letter to that effect. JRC-ITU will then distribute the project results and deliverables to the other EU collaborators. An agreement on the conditions of providing project deliverables to the ISTC was negotiated between ROSATOM and ISTC and a revised letter from ITU to NITI was proposed.

**Topic #18**: Progress report on the ISTC project #3813 “Phase relations in corium systems” (PRECOS)”

S.Bechta (RIT-NITI) described the objectives of the project **PRECOS. The** subject of the project is the experimental investigation of phase diagrams of oxidic and metal-oxidic corium systems that form as the result of core meltdown and interactions of melt with construction and structural materials of the reactor core, concrete shaft, and core catcher. This project is not subject to export control, being considered as “fundamental research”.

The following systems will be studied in PRECOS: 1) Binary and ternary oxidic systems (CaO-UO2, CaO-FeO, SiO2-UO2, UO2-FeO-SiO2, UO2-FeO-CaO, ZrO2-FeO-SiO2, and ZrO2-FeO-CaO) that contain components of concretes and sacrificial materials, i.e., of importance for modeling the interaction of corium with materials of the concrete shaft and core catcher. The SiO2–containing systems should be specially mentioned, as their high viscosity and low conductivity make their experimental investigation problematic. 2) Metal-oxidic systems U-Zr-Fe-O with different concentrations of components, especially in the miscibility gap. 3) Multi-component mixtures representing prototypic ex-vessel corium.

Results of experiments in the SiO2-UO2 system (GPRS 1-3), to define the monotectic temperature and the shape of the miscibility gap, and in the systems U-Zr-O, CaO-UO2 and ZrO2-FeOy were presented. In the SiO2-UO2 system a large amount of new experimental data enables the phase diagram and crystallization peculiarities in the system to be defined. In the system CaO-UO2 the liquidus temperatures have been determined, in addition final solid solutions and eutectic nucleus have been synthesized. First results on the determination of the solidus temperature in the system ZrO2-FeOy were discussed.

**Topic #19:** Thermo-hydraulics of U-Zr-O molten pool under oxidising conditions in multi-scale approach (crucible- bundle -reactor scales); ISTC project #3876 (THOMAS)

M.Veshchunov (IBRAE-RAS) described the objectives and work plan of the project THOMAS and its current status. Non-destructive and destructive post-test examinations of bundles in various tests showed the formation of molten pools of different scales at various stages of core degradation. Small local pools were observed at different elevations in bundles in the early stage of core degradation in CORA and QUENCH tests. Results of the PHEBUS -FP tests confirmed that a significant part of the fuel bundle was liquefied and that the amount of fuel damage was close to TMI-2 with an extended molten pool located in a central zone of the bundle underneath a cavity. In the late stage of a severe accident, the formed melt can relocate into the lower head of the reactor pressure vessel and form a large molten pool interacting with cooled walls.

M.Veshchunov presented results of the Task 1 of the project “Development and Improvement of the Physico-Chemical Model for the U-Zr-O Melt Oxidation on the Base of New Crucible Tests”. The main stages of molten U-Zr-O corium interactions with stainless steel (SS) walls were analysed. During the initial transient stage a rapid ablation of SS takes place under formation of a solid or mushy (depending on oxygen content in the melt) crust forms controlled by (rapid) heat exchange processes accompanied with mixing of the melt. This stage can be generally described by thermo-hydraulic codes (i.e. to be realized in the CONV code). During the subsequent steady state stage the heat and mass exchange processes between melt, crust and walls should be considered self-consistently, taking into account steep temperature gradients and oxidizing conditions in the melt. During this stage, the following physico-chemical processes simultaneously take place: conversion of the crust from a mushy to solid one; accompanied with a growth of the formed crust, and a corrosion (oxidation) of the SS walls, which are strictly controlled by oxygen transport through the multilayered structure.

The growth of the solid crust due to oxygen transport through the melt to cold walls is described by the SVECHA Melt Oxidation (MO) model, developed within the previous ISTC Project #2936, which will be refined on the basis of new FZK crucible tests within the current project. The conversion (to solid) and growth of the mushy crust in steep temperature gradient is examined with the new analytical model based on the Flemings-Brody approach, which will be numerically realized in the subsequent stages of the project.

The corrosion of SS walls is analyzed using experimental data from the ISTC Project METCOR. The available SVECHA model for stainless steel oxidation in steam based on the parabolic correlation derived from the KI tests for 06Х18Н10Т steel is modified for 15 Kh2NMFA vessel steel (using METCOR data) and supplied with the “oxygen starvation” regime consideration, in which SS oxidation kinetics is controlled by external oxygen flux. The SS corrosion model will be numerically realized and implemented in the MO model in the subsequent stages of the Project.

V.Chudanov (IBRAE-RAS) presented results of Task 2 of the project “Development and Improvement of the Unified Thermal-Hydraulic Technique (CONV Code) for Simulation of Multiphase Processes in Complex Domains of Convectively Stirred Melts”. The code CONV was modernized by including a new procedure for solving elliptical equations for the correction of pressure and new developed numerical scheme of the highest order of accuracy for solving Navier-Stokes equations. The developed numerical scheme for solving the Navier-Stokes equations is based on the principle of splitting the physical processes. For the simulation of turbulence flows the quasi direct numerical simulation (QDNS) approach and developed algebraic turbulence model were implemented in the CONV code. The applicability of the developed turbulence approach was proved by an extensive validation against the 2D and 3D results of lid-driven flows, flow in a tube, the convection in a cavity with the walls supported under different temperatures, and convection of a heat-generating fluid. In all cases a good agreement of numerical predictions with experiments and benchmarks was obtained. The preliminary parallel version of CONV code was developed for multidimensional modelling of thermal-hydraulics processes. The outcomes demonstrate increased speedup of the parallel version CONV code in comparison with its PC analogues.

There will be no export control difficulties within this project proposal since Rosatom does not have to give its agreement but the Russian Academy of Sciences instead (to which IBRAE belongs). The developed code system will be available to CEG-SAM members (collaborators) on a bilateral basis.

**Topic #20**: Short overview on the main research activities at the “Paul Scherrer Institute”

On March 11, the CEG-SAM members were given a technical visit to 2 large-scale facilities PANDA and DRAGON. In this connection S.Guentay (PSI) presented a short overview on the main research activities in the “Department of Nuclear and Safety” (NES) and especially in the “Laboratory for Thermal-Hydraulics” (LTH) of the “Paul Scherrer Institut”.

The Nuclear Energy and Safety Research Department of the Paul Scherrer Institute has a long tradition in energy research. With respect to nuclear energy, PSI has a unique position in Switzerland. This is due to its heavy infrastructure, namely the Hot Laboratory with so-called ‘hot cells’, well equipped and shielded zones for work and research on radioactive material. Based on this infrastructure and the know-how of its collaborators the Department is involved in three main topics of research: Safety of currently operating light-water reactors, safety characteristics of future reactor concepts and related fuel cycles, and long-term safety of deep geological repositories for nuclear wastes of all kind.

The Laboratory for Thermal-Hydraulics (LTH) forms part of PSI's Nuclear Energy and Safety Research Department (NES) and is engaged in both analytical and experimental research and development (R&D) related to the design basis (DBA), beyond design basis (BDA) and severe accident (SA) conditions of current and future nuclear power plants. The rationale for the pursued activities is threefold: to offer R&D support to the Swiss utilities, nuclear safety authority and industry; to conduct research with national and international collaborations aimed at strengthening the reactor safety associated with the accidents, and to translate research results into services and new products for back-fitting to improve safety.

PANDA is a large-scale facility for the investigation of passive ALWR containment phenomena and simulation of system response. PANDA has a modular structure of cylindrical vessels interconnected by piping. The various mixing and natural circulation phenomena taking place in the containment are complex, depend on the particular geometry and dimensions of the containment building, and simple linear geometric scaling would have produced serious scaling distortions. The general philosophy adopted for PANDA was to allow multidimensional effects to take place by dividing the main containment compartments (DW and WW) in two. This allows spatial distribution effects to develop. A variety of controlled boundary conditions can be imposed during the experiments to study mixing phenomena under well-established conditions. Parametric or sensitivity experiments conducted under well-controlled boundary conditions can provide more valuable data for code qualification than experiments where the mixing phenomena are distorted by the scale of the facility or other reasons.

DRAGON is an aerosol production facility, which combines robustness and state of the art measurement techniques. Soluble and insoluble aerosol particles can be generated and mixed with a gas composed of steam and nitrogen in a given proportion. DRAGON 1 is the main facility used to generate aerosol particles with various techniques whereas DRAGON 2 is the facility, in which aerosol particles are generated only using the fluidized beds, used for mainly aerosol calibration purposes. Solid or liquid aerosol particles are generated using three different techniques: 1) evaporation and condensation technique, 2) fluidising powder using a fluidised bed, and finally 3) spraying liquid with a spray nozzle and generating droplets.

**New or updated project proposals**

## Topic #21: Status of the STCU project #4207 “Long-term prognosis of the behaviour of the fuel dust in the Chernobyl Shelter”

The Chernobyl shelter of the RBMK-1000 Chernobyl NPP unit 4 is a source of radioactive particles that formed during the accident (now present inside the construction in the form of dust) and in the subsequent period due to physical-chemical destruction of the fuel containing material (FCM). In view of the planned transformation of the “Shelter” into an ecologically safe system, the presence of the fuel dust in the shelter (about 30000kg) will become a serious problem. In spite of the numerous data on the characteristics, composition and localization of the fuel dust in the shelter, the mechanisms of its formation and, especially, the prognosis of its further physical/chemical transformation are still not clear

V.Protsak (ISP NPP) presented the current status of the STCU project #4207 (project funded by Canada).describing the physical-chemical characteristics of the Chernobyl fuel particles and mechanisms of their formation. The project studies will be focused on the fuel particles and main types of the fuel-containing materials (FCM) in the Shelter, as well as on the mechanisms governing their destruction. Experimental data show that the FCM destruction in the present time occurs due to internal and external influences. It results in the FCM transformation into the highly-mobile and highly-radioactive dust. The recent studies show also the increase of the airborne concentration of the fine aerosol particles (AMMD < 0.6 μm) in the Shelter rooms. For instance, the monthly increments in the rooms 207/4 and 318/2, according to the results of measurements in 2006-2008, were 5% and 10%, respectively. In the 318/2 room, the α-activity of the sub-micron aerosols was about 5·10-4 Bq/m3, and assuming that the α-activity of each fine particle (FP) was 5·10-8 Bq, the mentioned monthly 10% increase could be reached by formation of 1000 FPs per 1 m3 of the room’s volume. However, it is obvious that the actual rate of generation of the sub-micron fuel aerosol fraction can be determined only by means of periodical sampling of the aerosols directly in the rooms containing the fuel.

Therefore, it is very important to carry out experimental and theoretical studies within the framework of the project, which will enable the formulation of a model of the long-term behaviour of the fuel dust under the Shelter conditions. The model must describe both the transformation of the existing fuel particles and the processes of their formation from the main types of the FCM. The completion of the project tasks implies: i) the classification of the available information concerning the FP characteristics in the Shelter; ii) identification of the main mechanisms of the FP formation; iii) sampling of FP and fragments of the main FCM for their utilization in the model experiments aimed at determining the destruction and leaching rates of radio-nuclides under conditions that exist in the Shelter; iv) sampling the aerosols and waters from the Shelter for the determination of the FCM destruction parameters and identification of the origins of the sub-micron FPs.

The main objective of the project is to use these data and from the previous tasks to create a model predicting the long-term (50-100 years) behaviour of the radioactive dust in the Shelter. The model will describe both transformation of the existing fuel dust and the processes of the dust formation from the main types of FCM under the current and future shelter conditions.

**Topic #22**: Status of the STCU project proposal #4758 “Estimated experimental researches to characterize hidden nuclear hazardous clusters of fuel-containing materials in the destroyed Chernobyl NPP Unit 4”

V.Krasnov (ISP NPP) presented the status of the STCU project. Two fuel-containing material aggregations of about 50t were analyzed on the basis of dynamic temperature and neutron gradient measurements. The material aggregations are located in the concrete of the reactor foundation plate in cavities that have formed by the molten fuel-containing material during or immediately after the reactor accident. Currently these material aggregations are covered by water that penetrated to the foundation plate from atmospheric precipitation (rain) and condensate water. From the location of the material aggregation periodically a flow of heated water has been observed. Periodic temperature fluctuations have been noted in the eroded concrete foundation plate and related to the weather.

Based on the last researches (data on borehole core’s activities, temperature and neutron field dynamics), it was stated that the ChNPP accident in the year of 1986 had provoked a melting in foundation plate of reactor vault. As a result, two fusion penetration areas had been produced, which contain fuel-containing materials (FCM) with fuel concentration reaching 40% (by mass) and more. Currently, fusion penetration areas are covered with post-accident concrete and produce so-called «hidden» FCM clusters. A direct access to clusters is impossible. Data on temperature, neutron fluxes, as well as samples can be obtained solely from cluster peripheries via boreholes. Clusters have been produced as result of interaction of fuel melt with the concrete of the foundation plate, graphite, metal structures, and filling materials. The melt is assumed to consist of an upper layer of black (light) FCM with a uranium content of 3-4% (mass) and a bottom (heavy) layer with a uranium content of 40% (mass) and more. The upper (light) FCM layer, during its formation process, was flowing down via a breach into room 304/3 and formed a horizontal flow of FCM of more than 50m length along the wall. In 2008, examinations of the structure and chemical composition of the light layer of FCM were initiated in the formed horizontal LFCM flow. In 2009 it is planned to continue these works. The works are in progress for estimates of the mass and geometry parameters of the heavy layer in the fusion penetration areas.

In 2008 preliminary evaluations of mass- and geometry parameters of multiplying systems (homogenous and heterogeneous with U content from 40-65%) were performed. The estimations show that the systems, whose geometry determined by the fusion penetration area, may reach criticality under optimal wetting conditions, and under over-wetting they become subcritical ones with Kef>0,98.

The aggregation of fuel-containing material is nuclearly dangerous because it is immersed permanently in water and any change of the local physical and/or chemical conditions may result in the initiation of a nuclear incident. For this reason, a more detailed examination of the neutron/physical and physical/chemical characteristics of buried fuel-containing material aggregations as well as the development of methods for their safe removal, handling and containment under sub-critical conditions are the prior actions in transforming the object “Shelter” into an ecologically safe system.

**Topic #23**: ISTC project proposal #3936 on “Study of fuel assemblies with boron carbide absorber rods under severe accident quenching conditions in the PARAMETER-SF test series (PARAMETER-SF5 and PARAMETER-SF6 experiments)

V.Nalivaev (LUCH) presented the objectives of the project proposal. Two fuel assemblies with 18 heated fuel rods and 1 central B4C absorber rod will be tested under SA conditions with quenching from the top. The proposed test conditions are: coolant flow rates (argon/steam) 5/3.5g/s; rate of heating of the bundle 0.2-0.3К/s; temperature of pre-oxidation about 1470К; time of pre-oxidation 4000s. The maximal temperature of claddings should be for PARAMETER-SF5 about 1520К and for PARAMETER-SF6 about 1720К, respectively. Quenching from the top should be conducted with a water flow rate of about 40g/s.

The obtained results can be used for the verification of SA computer codes used (SOCRAT/B1, ATHLET, ICARE-CATHARE, etc.) for justification of critical limits of NPP design and operation.

**Topic #24**: Status of the ISTC project #3635 on “Scale experimental investigation of the thermal and structural integrity of the VVER pressure vessel Lower Head in severe accidents”

Unfortunately V.Loktionov (MPEI) could not attend the meeting, therefore V.Semishkin (OKB Gidropress) kindly presented the progress of the ISTC project. The objective of the project is the design and construction of the test facility for experimental examinations of VVER-440 vessel scale models under SA conditions in a VVER. The status of the different tasks was presented in detail as the manufacturing of the VVER LH reactor vessel scale models (1:5), the conduct of the scale experiments with VVER vessel models at high temperatures as well as separate-effects tests on the creep behaviour of the VVER vessel steel and numerical pre- and post-test analyses of the scale experiments.

The experimental and numerical studies of the behaviour of VVER-440 LH reactor vessel scale models during transient thermal and overpressure loading correspond to realistic SA scenarios. The expected results will be experimental data on the creep behaviour, heat-up and failure of the VVER-440 vessel material. The data will be used for verification of thermo-mechanical codes that are used in safety assessment in SA management strategy for NPPs.

For the calculations and analytical analysis the power Unit 1 of Kola NPP has been chosen as reference reactor plant. The goal of the calculations was to estimate the decay heat power level in the lower plenum. Parametric calculations were carried out using the code SOKRAT assuming different masses of debris relocating into the lower plenum after core disruption. Depending on the relocated mass (7-40t that corresponds to 1.2-12MW decay heat) the time of vessel failure varied between 4 and 25 h. At about 1MW decay heat the melt may be kept in the vessel without effective cooling.

For the construction of the vessel scale model the available financial means are not sufficient. About 80000€ are additionally needed; this finance is still being sought.

**Topic #25**: Next CEG-SAM meetings in September 2009 and March 2010

The 16th CEG-SAM meeting will be kindly organized by M.Veshchunov (IBRAE) in Moscow, September 8-10, 2009. The chairman M.Hugon thanked IBRAE for its co-operation and support in advance.

The 17th CEG-SAM meeting: L. Herranz kindly offered to host the meeting in Madrid in March 2010.

M.Hugon thanked once more S.Guentay (PSI) for the organization of the 15th CEG-SAM meeting in Villigen. He also expressed his thanks to all speakers and participants for their engagement at the meeting.

**Restricted session** (continued)

**Topic #26:** SARNET and CEG-SAM comments on ISTC & STCU proposals

The chairman M.Hugon suggested to look for ISTC/STCU projects that may be of interest for the CEG-SAM in other research areas, which are currently outside the scope of the group, as for example in the field of containment studies. In this connection it would be necessary to modify the present CEG-SAM guidelines and complement it regarding new activities. The new name for the group could then be “Contact Expert Group on Safety and Accident Management” (still CEG-SAM). The work of the group should be continued in the same manner as before.

**Topic #27:** Detailed discussion of presented ISTC and STCU project proposals and preparation of specific CEG-SAM advices

The following projects were discussed: ISTC #3919 VERONIKA; STCU #4758 (hidden fuel in the ChNPP) and ISTC #3936 PARAMETER-SF5/6.

**Topic #28:** Discussion of various actions

**Topic #29:** Other matters; Final remarks

M.Hugon stressed once more that the future of the CEG-SAM should be enlarged. No further comments.

The chairman M.Hugon thanked once more PSI for hosting the meeting and for all its related excellent efforts and he thanked also the participants for their efficient work and contributions and wished them a safe journey back home.

**M. Hugon** (chairman) **P.Hofmann** (secretary)

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**Annexes:**

1. Revised final agenda of the 15th CEG-SAM meeting
2. List of participants at the 15th CEG-SAM meeting