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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 19th MEETING**

Meeting organized by

**University of Pisa, Italy**

**Department of Mechanical and Nuclear Engineering**

**March 14-16, 2011**

Meeting Location: Conference room of the “Gran Hotel Duomo”

Pisa, Via S.Maria, 94

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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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Reviewed minutes, May 28, 2011 CEG-SAM / M-19

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| Subject: 19th Meeting of the ISTC/STCU  “Contact Expert Group on Severe Accident Management” (CEG-SAM)  Place: Conference room of the “Gran Hotel Duomo”, Pisa, Italy  Date: March 14-16, 2011  Participants: 26 participants of 18 organizations from 7 countries:  Mr. D.Aquaro University, Pisa  Mr. G.Azarian AREVA NP 8AS, Paris  Mr. D.Bottomley EC, JRC - ITU, Karlsruhe  Mr. B.Clement IRSN, Cadarache  Mr. G.Ducros CEA, Cadarache  Mr. G.Forasassi University, Pisa  Mr. S.Güntay PSI, Villigen  Mr. P.Hofmann Consultant, Karlsruhe (**secretary**)  Mr. M.Hugon EC, DG-RTD / K.4, Brussels (**chairman**)  Ms. R.Lo Frano University, Pisa  Mr. W.Luther GRS, Munich  Mr. F.Oriolo University, Pisa  Mr. A.Palagin KIT, Karlsruhe  Mr. G.Pretzsch GRS, Berlin  Mr. A.Schumm EdF, Clamart  Mr. J.Stuckert KIT, Karlsruhe  Mr. S.Bechta RIT-NITI, Sosnovy Bor  Mr. A.Gozal ISTC, Moscow  Mr. O.Kliuchnikov ISP NPP, Kiev  Mr. V.Krasnov ISP NPP, Kiev  Mr. V.Loktionov MPEI, Moscow  Ms. I.Poldiaeva RIT-NITI, Sosnovy Bor  Mr. M.Sheindlin IVTAN, Moscow  Mr. V.Stepanenko STCU, Kharkov **(co-chairman**)  Mr. L.Tocheny ISTC, Moscow **(co-chairman**)  Mr. M.Veshchunov IBRAE-RAS, Moscow  Distribution list: (Shortened version of the minutes)  Mr. J.Sanders DG-RTD / D3  Mr. R.Liberali DG-RTD / K  Mr. G.Evans DG-RTD / K.1  Mr. A. Zurita DG-RTD / K.1  Mr. S.Webster DG-RTD / K.4  Mr. P.Manolatos DG-RTD / K.4  Mr. G.Van Goethem DG-RTD / K.4  Mr. D. Haas DG-JRC / 2  Mr. J. P. Joulia DG-AIDCO/A.4  Mr. P. Servais DG-AIDCO/A.4  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  Mr. V. Stepanenko STCU, Kyiv  EU CEG-SAM members  Contact person: Mr. M. Hugon Tel.: +32 2 296 5719 – DG-RTD / K.4 |

# Extended session

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

The “Inter-University Consortium for Nuclear Technological Research” (CIRTEN) and the “Department of Mechanical and Nuclear Engineering” of the University of Pisa organized the 19th CEG-SAM meeting in Pisa on March 14-16, 2011. The meeting location was the conference room of the “Gran Hotel Duomo” in Pisa, Italy.

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.

**Topic #1:** Welcome of the participants by the hosts of the meeting, general remarks

F.Oriolo, G.Forasassi and D.Aquaro (University of Pisa) welcomed all the participants. They described briefly the research activities in the nuclear field performed at the University of Pisa at the Department of Mechanical and Nuclear Engineering in the frame of the “Inter-University Consortium for Nuclear Technological Research” (CIRTEN). The CIRTEN Consortium was constituted with the purpose of promoting the scientific and technological research and co-ordinate the Universities’ participation with national and international Research Institutions and Industries in the study of problems such as energy production, nuclear energy power and fuel cycle plants as well as physical and environmental protection problems.

**Topic #2:** Welcome of the CEG-SAM members and opening remarks

The chairman M. Hugon (EC) welcomed the CEG-SAM members as well as the Russian, and Ukrainian participants of the meeting. He expressed his thanks to F.Oriolo (University Pisa) and his team who organized and hosted the meeting in Pisa. He mentioned that Italian Institutions always have been involved in European research programs.

The Russian co-chairman L.Tocheny (ISTC) as well welcomed the participants and expressed his thanks to the Italian colleagues. He described the successful work of the CEG-SAM in various fields which resulted in many international publications on nuclear safety and material behaviour of NPPs.

The Ukrainian co-chairman V. Stepanenko (STCU) expressed his thanks to the University of Pisa to host the CEG-SAM meeting. Future activities by STCU will be in the frame of Euratom-Ukrainian Academy of Science cooperation.

*In view of the different catastrophic and tragic events which happened in Japan (earthquake, tsunami, reactor accidents at Fukushima), the participants of the meeting observed one minute of silence for the victims.*

**Restricted session**

**Topic #3:** Report on the actual and future situation in ISTC

A.Gozal (ISTC) described the role and achievements of ISTC. Creation of a civilian research community working on the basis of international standards; new career for CIS scientists and engineers; integration of CIS scientists into the global scientific community – network; and adequate IPR protection for CIS institutes.

The impact of ISTC has been on 1) Economic Diversification: new technologies and jobs; 2) Dual-use: promotion of culture of responsibility and awareness; 3) Physical security: lock down of dangerous pathogen collections at research installations; 4) Non-proliferation: substantial reduction in proliferation threat; 5) Most importantly: building of trust and confidence among stakeholders.

The strength of ISTC is to bring together best expertise worldwide via its extensive network; Capacity to handle effectively multilateral funds for research projects and support programs; Capacity to carry out commercialization and innovation projects; and Capacity to adapt to changing circumstances.

The future of ISTC activities in Russia has to follow the Decree of the Russian President announced on 11 August 2010. The main decisions are: 1) The ISTC agreement has to stay in force until the current work in Russia is completed; 2) Projects in pipeline have to be completed; 3) International exchanges and training activities will continue. For Non-Russian States a transition plan has been proposed.

What is important to maintain is sufficient expertise at the ISTC Secretariat, i.e. to stop further staff reductions. To develop a set of contingency measures: ISTC Agreement must continue until a new organization is in place. For a successor organization 6 Options are possible: 1) Total closure of ISTC (within 6 months to 4 years). 2) Operations only in Non-Russian States. 3) Transfer to STCU (Armenia/Azerbaijan). 4) Formation of a successor multilateral Science and Technology Organization. 5) Formation of a worldwide Scientists Engagement Centre.

**Topic #4:** Adoption of the agenda of the 19th CEG-SAM meeting in Pisa

The agenda was accepted with the following changes: The planned presentations under Topic #14 and #22 will be dropped since the project managers were not present at the meeting.

**Topic #5:** Approval of the minutes of the previous 18th CEG-SAM meeting in St.Petersburg, Russia, September 28-30, 2010

The secretary has already taken into account in the revised minutes the comments that he received from the participants of the meeting. The revised minutes were then approved by the CEG-SAM members without any additional changes at the 19th CEG-SAM meeting in Pisa.

The title of Topic #23 of the minutes of the 18th CEG-SAM meeting has to be changed into STCU #5243 “Interaction studies of improved VVER structural materials at severe accident conditions”.

**Topic #6:** Discussion of the “Action List” of the 18th CEG-SAM meeting in St.Petersburg

**Action 18/1**: P.Hofmann (Secretary) will distribute all available information on the STCU project #5243 on “Interaction studies of improved VVER structural materials at severe accident conditions”. *Action completed: A detailed description of the project STCU #5243 was distributed to the CEG-SAM members on October 5, 2010.*

**Action 18/2**: M.Hugon (EC) will contact M. Zayet (STCU) and J.Sanders (EC) in order to recommend them to postpone the examination of the STCU project proposal #5243 until the GB meeting in April 2011. *Action completed on 14 October 2010.*

**Action 18/3**: D.Bottomley (JRC-ITU), Ch.Journeau (CEA), J.Stuckert (KIT), and Z.Hozer (AEKI) will prepare an advice for the STCU project proposal #5243. The new advice (A-22; A-21 corresponds to STCU #5244) should be sent to M.Hugon (EC) and to the Secretary. *Action completed by CEG-SAM. However, the STCU GB rejected the project proposal.*

**Action 18/4**: A.Miassoedov (KIT) should make a link from the ACT (SARNET) webpage to the CEG-SAM webpage and vice-versa. *Action completed.*

**Action 17/5**: M. Hugon (EC), D.Bottomley (JRC-ITU), B.Clement (IRSN), Ch.Journeau (CEA), S. Güntay (PSI) and W.Tromm (KIT) should prepare a paper on the future of the CEG-SAM and how to improve the collaboration with the Russian Federation and the Ukraine. The paper should be distributed to the CEG-SAM members before the next meeting and discussed at 18th CEG-SAM meeting in St.Petersburg. *Pending action.* *As a result of the unknown future of ISTC the action has been postponed.*

**Topic #7**: Reports by the secretariats

V.Stepanenko (STCU) assured that STCU has no intention to close the STCU activities. There exists many research and development programs between the countries issuing from the former Soviet Union. The Ukraine would like to continue the co-operation between STCU and ISTC. Some of the ISTC projects may be shifted to STCU. The co-operation could also be extended to other organizations.

A.Gozal (ISTC) mentioned the demand of Non-Russian States that the ISTC agreement should continue until a new organization is in place. There is a request to continue funding new project proposals in Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan and Tajikistan.

**Topic #8**: Preliminary discussion of updated and/or new ISTC/STCU project proposals

There were no new ISTC/STCU project proposals to discuss. The two STCU project proposals, which are of potential interest to the CEG-SAM: STCU project proposal #5244 on “Nuclear fuel interaction products with structural materials under heavy nuclear – radiation accidents” and STCU project proposal #5243 on “Interaction studies of improved VVER structural materials at severe accident conditions” were not approved by the STCU GB. Some discussion took place on how to reactivate the STCU project proposal #5243. V.Stepanenko (STCU) will discuss once more this matter with the responsible Ukrainian authorities.

Action 19/1: M.Hugon (EC) will contact M. Zayet (STCU) again regarding the STCU project proposal #5243 (Kharkov) that was recommended by the CEG-SAM but rejected by the STCU/GB.

# Extended session

**Topic #9**: Welcome of the participants by the host of the meeting, general remarks

F.Oriolo (University Pisa) welcomed the participants of the 19th CEG-SAM meeting and wished them interesting discussions and information exchanges. Information on the planned technical tour to the Geothermal Power Stations in Larderello was given.

**Topic #10**: Welcome of the Russian, and Ukrainian colleagues; approval of the shortened minutes of the 18th CEG-SAM meeting in St.Petersburg; adoption of the agenda of the 19th CEG-SAM meeting in Pisa

M.Hugon opened the extended session of the meeting and welcomed the Russian, and Ukrainian participants and expressed his thanks to F.Oriolo and his team for organizing and hosting the 19th CEG-SAM meeting in Pisa.

The shortened minutes of the 18th CEG-SAM meeting were distributed to the Russian, Kazakh and Ukrainian participants by the secretary. The obtained comments had been considered in the revised shortened minutes. This version of the minutes was accepted at the 19th CEG-SAM meeting without any additional changes.

L.Tocheny (ISTC) and V.Stepanenko (STCU) expressed their greetings and thanks to the University of Pisa for hosting the meeting. L.Tocheny mentioned that in the frame of the CEG-SAM many interesting projects have been performed which resulted in great benefits for all involved international organisations. The outcome of the various projects should be summarized in a joint paper. A list of all published papers on ISTC/STCU projects should be made.

Action 19/2: L.Tocheny (ISTC), D.Bottomley (JRC-ITU), J.Stuckert (KIT), and V.Stepanenko (STCU) will collect all reports concerning the activities/projects performed and resulting publications in the frame of the CEG-SAM. L.Tocheny prepared a paper in 2009 (“Short review of the ISTC activity and list of relevant projects”) which may be used as a basis and updated. The STCU activities and publications should be provided by V.Stepanenko.

Action 19/3: L. Tocheny (ISTC) proposed to write a paper gathering all CEG-SAM activities (see Action 19/2) to be published in an international journal.

**Topic #11**: Status of the official ISTC CEG-SAM webpage

J.Stuckert (KIT) explained once more the structure of the ISTC CEG-SAM webpage. It 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, and joint publications) are collected under the ISTC/STCU project number. There will be a unique user name and password for each user and different read/write permissions for the different users. The Russian, Kazakh and Ukrainian project managers will be exclusively responsible for updating the project documentation/deliverables and the upload of presentations from project progress meetings. S.Bechta (RIT-NITI) complained that the implementation of reports sent to KIT sometimes works extremely slowly.

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(s) in which they participate.

The requested link between the CEG-SAM and SARNET web pages has been established.

**Topic #12**: Interaction between SARNET and CEG-SAM activities and future of the CEG-SAM

M.Hugon presented a short overview on the status and future of the CEG-SAM. The group has been very successful since its launch in April 2002. There exists an excellent interaction with SARNET2. 11 ISTC projects were funded and are completed. 3 ISTC projects and 1 STCU project are funded and ongoing. All ongoing projects will be finished by the end of 2011. 7 project proposals were examined and supported but not funded by the GBs. No new projects are under discussion.

The ISTC/STCU funding from EC in 2011 is not yet known.

The CEG-SAM could help in the definition and preparation of future coordinated research proposals on severe accident management to be jointly executed by Russian scientists (funded by ROSATOM) and European scientists (funded by Euratom). Some of them could participate in the meetings of the Euratom-ROSATOM Working Group, which monitors the progress of these coordinated research projects.

The status of the preparation of Euratom FP7+2 (2012-2013) and EU and Euratom next framework programmes (2014-2020) was briefly presented.

**Topic #13**: Update on SARNET2

B.Clément (IRSN) presented the SARNET2 (**S**evere **A**ccident **R**esearch **NET**work of excellence) update. The SARNET2 Project is part in 7th EC Framework Programme (follow-up of SARNET FP6 project 2004-2008). SARNET2 started on April 1, 2009; altogether 21 countries with 42 organizations are participating in the programme that will last 4 years. The total effort is about 8.5M€ per year with about 1.5M€ per year of EC funding. The main objectives of SARNET2 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.

B.Clement described briefly the work on Severe Accident Research Priorities within SARNET2. 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 the 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 fuel coolant interaction; 4) hydrogen mixing and combustion in the containment; flame acceleration; 5) the impact of oxidising conditions on source term (Ru oxidising conditions or air ingress for HBU and MOX fuel elements); 6) iodine chemistry in the RCS and in the containment.

The tasks of SARNET2 is executed by 8 work-packages on management, spreading of excellence (courses, conferences), information systems, ASTEC, corium and debris coolability, MCCI, steam explosion and hydrogen combustion in containment and oxidising impact on source term.

Up to now the interaction between CEG-SAM and SARNET2 works well and the SARNET2 recommendations were considered in the final work programmes of the various ISTC/STCU project proposals. The results of ISTC/STCU projects are used by foreign collaborators in the framework of SARNET2. The interaction between SARNET2 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.

B.Clement described in detail the progress achieved in the last 6 months: October 2010 until March 2011 and the future milestones as WP8 meetings on Source Term; SARNET2 newsletter N°4; paper on a general presentation of SARNET2 at ICAPP’11 conference in Nice (France); 2nd meeting of the Severe Accident Priorities Group; 5th ERMSAR conference in March 2012, hosted by GRS in Cologne.

**Topic #14:** Progress on SARNET2 activity “Severe Accident Research Priorities”; SARP

Since M.Sonnenkalb (GRS) was not able to attend the meeting, B.Clement (IRSN) mentioned that the work program on “Severe Accident Research Priorities” has started. The 1st meeting of the Severe Accident Research Priorities Group took place in Cologne on November 17, 2010, organized by GRS. Other SARNET2 activities had been: the WP6 meeting on MCCI; WP8 Source Term meetings (including THAI benchmark); Course in Pisa (Italy) on Severe accident phenomenology including GEN.III NPPs; 1st meeting of SARNET2 Advisory Committee (12 experts from end-users organizations, only 2 SARNET2 members); Kick-off meeting of OECD/WGAMA – SARNET2 benchmark on alternative TMI2 scenario; and SARNET2 participation to ASAMPSA2 Workshop.

**On-going project presentations**

**Topic #15**: 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 effects.

The purpose of the last test of the ISTC project, the МСР-8 test, is to investigate the vessel steel corrosion during the interaction with a (U-Zr-Fe) metallic melt at the vertical position of the steel/melt interaction interface. Current status is: Pre-tests have been performed aimed at fine tuning of the vertical specimen cooling system and of the corrosion rate ultrasonic measuring system. The test facility has been completely prepared for conducting the test. The melt composition was U-41, Zr-17, SS-15Kh2NMFA(wt. %), which was the same as the metal melt of the МА-3 experiment of the OECD MASCA program. The experiment was performed under inert gas conditions using high purity argon. The maximum initial temperature at the surface of the steel specimen was about 1400°C. The duration of steel/melt interaction under steady-state conditions was 10 hours.

The preliminary results show that the corrosion kinetics in this test indicated the tendency to reach saturation. The maximum corrosion depth was 9 mm and the temperature at the final corrosion boundary was 1050 to 1150ºС. The physicochemical analyses of the test specimen are in progress.

The experimental part of the project METCOR-P has been completed. 5 thematic reports (МСР-1, МСР-2, МСР-3, МСР-4, and МСР-5) and 2 annual reports (for 1st and 2nd years) have been prepared. 3 other thematic reports (МСР-6, МСР-7 and МСР-8) are in progress and will be completed in May, 2011. The final project report is in progress and will be completed in May, 2011.

Due to a delay in Project implementation a 6-month project time extension without additional funding has been approved by the ISTC.

**Topic #16**: Progress report on the ISTC project #3813 “Phase relations in corium systems” (PRECOS)”

S.Bechta (RIT-NITI) described the objectives of the PRECOS project**. The objective** of the project is the experimental investigation of phase diagrams of oxidic and metallic-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.

The following chemical systems were studied in the frame of the PRECOS project: 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 concrete and sacrificial materials, which are of importance for modeling the interaction of corium with materials of the concrete shaft and core catcher at the ex-vessel stage of a severe accident. The SiO2–containing systems should be specially mentioned, as their high viscosity and low thermal conductivity make their experimental investigation problematic. Nevertheless, they are very important for modeling the ex-vessel corium behaviour for a series of power reactors, including such modern ones as EPR. 2) Metallic-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.

The main results of the project provided the following experimentally determined data: Tliq and Tsol concentration dependencies; coordinates of characteristic points, such as eutectic, dystectic, etc.; Limits of components solubility in the solid phase; Compositions of the liquids coexisting in the miscibility gap. The experimental methods applied to the phase diagram studies were: visual polythermal analysis in the cold crucible (VPA IMCC); differential thermal analysis (DTA) and differential scanning calorimetry (DSC); visual polythermal analysis in the Galakhov micro furnace (GM); high-temperature microscopy (HTM); and laser pulse heating (LP).

The project started on June 1, 2008; the study of SiO2-UO2, UO2-CaO binary oxidic system has been completed and thestudy of the remaining systems is in progress.

At the third project meeting in St.Petersburg on June 2, 2010, a decision was made to abandon the investigation of eutectic points in the systems ZrO2–FeO–SiO2 and ZrO2–FeO–CaO in favour of more detailed investigations of higher priority systems such as: UO2-FeO-CaO and UO2-FeO-SiO2. The obtained extensive experimental results were presented in detail.

The Project has been prolonged for 6 months without additional funding. The work scope for the next quarters will be the study of the systems: ZrO2-FeOy; UO2-SiO2-FeO; CaO-UO2-FeO and U-Zr-O. Measurements of the eutectic composition of a realistic complex corium mixture will be started. In this connection the collaborators of the project are kindly requested to provide the compositions of typical German and French corium mixtures.

**Topic #17:** Laser heating experiments with different corium compositions. Recent results and perspectives

M.Sheindlin of the “Institute for high Temperatures of the Russian Academy of Sciences” (IVTAN) presented a short introduction to show the place and method of laser-heating experiments in the frame of the PRECOS project. The main objective is to elaborate a possible immiscibility of liquids in the U-Zr-O system. The major problem encountered in examining the U-containing system concerns the licence that is required for experiments with natural uranium. The set of U-containing samples have been prepared at NPO “LUCH”, however, the transfer of the samples to IVTAN is delayed. The current status of the licensing procedure has been presented as well as the extended planning for the next few months. Further development of this relatively new technique is mostly focused on the progress in optical diagnostics and optimization of the heating regimes.

Hundreds of experiments have been performed with different systems namely Zr-ZrO2, CaO and FeO-ZrO2 to verify the adopted experimental procedure and gain some experience with different kinds of materials. The examined materials range from metallic to non-metallic semitransparent materials covering melting temperatures from a low temperature eutectic in the FeO-ZrO2 system to CaO, one of the most refractory oxides. One should especially stress that for the first time most of the experiments with laser melting are conducted with specimens made by mechanical blending followed just by cold pressing of the required components without subsequent sintering, a procedure that makes the composition of the samples more stable and predictable.

Some details on the further development of the laboratory equipment and techniques were discussed in view of remaining issues on corium phase diagrams.

Due to the delay in the transfer of the U-containing specimens from NPO “LUCH” to IVTAN it has been mutually agreed that in the mean time the experimental work is focused on systems that do not contain uranium. The first one is the Zr-ZrO2 system, which can be considered as a good model for validation of the experimental technique to be used for the U- ZrO2 system.

**Topic #18:** Progress report on the ISTC project #3876 on “Thermo-hydraulics of U-Zr-O molten pool under oxidising conditions in a multi-scale approach (THOMAS)”

M.Veshchunov (IBRAE-RAS) described the objectives and work plan of the project THOMAS and its 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 at an early stage of core degradation in the 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 conditions 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 vessel walls.

The work on implementation of the physico-chemical model for U-Zr-O melt oxidation and steel corrosion (as a stand-alone module) into the code CONV2D was continued. The coordination between boundary conditions (fluxes of oxygen and heat) of the melt oxidation module and of the code CONV was achieved. Since in the melt oxidation model there is a lower limit for the melt temperature of 2250 К (melting temperature of the oxygen saturated α-Zr(O)), the debugging of the implemented melt oxidation model in the code CONV was carried out for the melt temperatures above 2250 К.

The interfaces of the melt-steel oxidation 1-D module and the corium melt 2-D thermo-hydraulic code were coordinated. Namely, the list of necessary parameters for operation of the modules was chosen. The interchanging of variables (i.e. a lack of the common blocks and interior allocation of memory) were reduced to uniform standard form. The adaptation of CONV2D in a part of the coordination of the grid data with the melt oxidation 1-D module was carried out. An auxiliary calculated grid *r - φ* was entered. The subprogram for conversion of data with a rectangular grid to a *r - φ* grid and the reverse was developed.

The basic computing cycle of CONV2D was supplemented with a call to the melt oxidation 1-D module. CONV2D transfers into the melt oxidation 1-D module the necessary data on an auxiliary *r - φ* grid, i.e. value of temperature at the crust boundary and heat flux. In response CONV2D receives data for the crust coordinates and oxygen flux. A simulation of combined work of the melt-steel oxidation 1-D module with the corium melt 2-D thermo-hydraulic code was carried out: data from CONV2D were manually transferred to the input of the 1-D module and an adequate comparison of ‘manual’ with ‘automatic’ results was obtained.

As a result, implementation of the melt oxidation 1-D module in the CONV2D code has been carried out, in accordance with the Working Plan of the Project. The next step will be verification of the advanced module and its application to simulation of real experiments.

**Topic #19:** 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”

Loktionov (MPEI) presented the status of the project. The overall objective of this project is the experimental and numerical study of VVER-440 lower head (LH) reactor vessel models under thermal and overpressure loadings corresponding to realistic SA scenarios. The different tasks are 1) the manufacturing of the VVER LH reactor vessel scale models (scale 1:5), 2) the conduct of these experiments with VVER vessel models at high temperatures as well as 3) separate-effect tests on the creep behaviour of the VVER vessel steel and finally 4) numerical pre- and post-test analyses of the experiments.

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 and in SA management strategies for NPPs.

The project efforts are focused on the following tasks:

Task 1: Pre-test simulations that will be carried out by means of the numerical codes to determine the behaviour of the vessel models during the scale experiments for the chosen SA scenarios.

Task 2: Development and manufacturing of the experimental test facility and supporting systems for the VVER-440 scale vessel models testing (a geometrical scale ~1:5). The material and thermal treatment of the vessel steel have to correspond to the same conditions as for a regular VVER vessel.

Task 3: Examination of the VVER-440 vessel behaviour under SA conditions by experimental and numerical investigations (thermal and structural analyses). The mathematical treatment and analysis of scale experiments will be done with the domestic code ATM-VVR and with commercial codes MSC-Marc, MELCOR, RELAP/SCDAP for validation of the physical models implemented in these codes. The experimental investigation to study heating and deformation of the cylindrical part of the vessel resulted in a failure of the electrical conductor at a pressure of 2.5MPa. The failed conductor has to be repaired or will be replaced.

Task 4: Determination of the creep characteristics and mechanical properties of the vessel steel 15Kh2NMFA.

The short-term tensile and material creep tests with samples from the VVER vessel steel have been conducted. The creep experiments in vacuum and argon from 650 to 1050°C up to 50 hours at constant load have been carried out and are finished. The obtained results are shown in dependence of time-to-failure and the applied stress. The elongation of the specimens considerably exceeds 100%. In some cases there were two or three necks in the deformed part of the specimen. At present, the analysis and mathematical treatment of test results are in progress which will be presented in the final report. The tests in the air atmosphere were, as a rule, short-time, with temperatures up to 600 ºС.

The use of argon as protective medium leads to a considerable reduction (about 2 times and more) of the time-to-failure of the specimen. It probably depends on oxidation of the surface of the specimens due to partial ingress of air into the test section. The formation of an oxide film on the outer surface of the test specimens and its destruction under deformation leads to earlier failure of the specimens in comparison to tests conducted under vacuum. In the examined temperature range from 700 to 1200 °C the stress versus time-to-failure behaviour of the specimens is similar. It was decided to make a control batch of samples from the vessel steel to study the creep behaviour of this steel.

A prolongation of the project without additional funding has been requested and was confirmed for up to one year. There is a hope that the works in the frame of this project may be financed by the concerned Russian organizations (The Ministry of Science and Education and RosEnergoAtom). Talks with the concerned parties in Russia were held, and the technical parameters of the scaled model were preliminarily approved.

**Topic #20**: Containment thermal-hydraulics of current and future LWRs for severe accident

Management; ERCOSAM

S.Guentay (PSI) described the containment hydrogen issues in the frame of the ERCOSAM project, which is aimed at a better understanding and improved margins for hydrogen management, the project partners and current status.

The presence of a stratification of hydrogen in a NPP containment is a source of concern, as pockets of hydrogen in high concentration could lead to a deflagration or detonation risk and damage equipment necessary for safety and even the containment’s integrity. The objectives of ERCOSAM are: 1) to establish whether in a test sequence, representative of a severe accident in a LWR, chosen from existing plant calculations, a hydrogen (helium) stratification can be established during part of the transient starting from the loss-of-coolant accident (LOCA) blowdown until the end of bulk hydrogen release from the reactor vessel into the containment, and 2) how this stratification can be broken down by the operation of severe accident management systems (SAMs); sprays, coolers and passive auto-catalytic recombiners (PARs).

A two tier approach is planned: 1) Experiments in four containment simulators with very small to very large scales at conditions scaled down from prototypical accident conditions in real plants. 2) Planning, pre- and post test calculations using 3D, CFD and lumped parameter codes to improve confidence in the codes for future plant safety analyses (PSA L2, plant behavior, assessment and design of SAM measures for hydrogen management).

Experiments are planned in the following facilities: “small scale” TOSQAN (IRSN, Saclay); "medium scale" MISTRA (CEA, Saclay); “large scale” PANDA (PSI, Villigen) and "nearly prototypical scale" KMS-like facility (only for code benchmarking).

The current status is as follows: IRSN prepared a scaling study which considers plant studies provided by IRSN, PSI and IBRAE about the steam and H2 loads of certain PWR designs. This information is transposed to a generic 1000 MWth plant containment size. Studies to determine H2 distribution for several conditions for this reference size have been conducted. IRSN is currently determining the ranges of initial and boundary conditions of the tests to be conducted in TOSQAN, MISTRA, PANDA and KMS-like facility.

**Topic #21:** Technical tour to the geothermal power stations of ENEL Green Power in Larderello, Italy

R.Parri (ENEL Green Power) welcomed the participants of the CEG-SAM meeting at the INEL Headquarter in Larderello (about 80km from Pisa) and described the energy production by the various geothermal power stations. After the visit of the “Geothermal History Museum” (from 1777 to nowadays) a visit of the geothermal well head and geothermal electric power plant in “Valle Secolo” took place.

Electricity from geothermal energy had a modest start in 1904 at Larderello in the Tuscany region of north-western Italy with an experimental 10 kW-generator. These “earth-heat” units operate with an average capacity factor of 71%; though, many are “on-line” over 95% of the time, providing almost continuous base-load power. Electric power from geothermal energy, originally using steam from resources above 150oC, is now produced from resources down to 100oC using the organic Rankine cycle process in binary power units in combination with a district heating project.

Geothermal energy was not new to the Larderello area in 1904, as sulphur, vitriol, alum and boric acid was extracted from the hot spring areas, and marketed at least since the 11th century. In the late 18th century, boric acid was recognized as an important industry in Europe, as most was imported from Persia. Thus, by the early-1800s, it was extracted commercially from the local borate compound using geothermal heat to evaporate the borate waters in *lagoni* or *lagone coperto*--a brick covered dome. *Renewable Energy World, Vol. 7, No. 4 (July-August, 2004).*

**Topic #22:** Progress of the STCU project #4207 “Long-term prognosis of the behaviour of the fuel dust in the Chernobyl Shelter”

V.Krasnov (ISP NPP) described the main objective of the project that is to create a prognosis of the long-term (50-100 years) behaviour of radioactive dust in the Shelter. Knowledge of the transformation of existing fuel dust and processes of dust formation from the main fuel-containing material (FCM) types under the current and future Shelter’s conditions is of prime importance. 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 subsequently due to physical-chemical destruction of the FCM. In view of the planned transformation of the “Shelter” into an ecologically safe system, the presence of the fuel dust in the shelter 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.Krasnov described the physical-chemical characteristics of the Chernobyl fuel particles and mechanisms of their formation in detail. 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 both internal and external influences. It results in the FCM transformation into the highly mobile and highly radioactive dust. 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 (50-100 years) 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.

According to diverse estimates, around 500 to 2000 kg of irradiated nuclear fuel in shape of fuel dust are located in the Shelter. The analysis of existing technologies points to the fact that the time needed to retrieve and to rebury the Shelter fuel-containing materials can take 50-100 years. The dust rise and radioactive dust spread in the Shelter occurs not only during any emergency situations associated with building structures’ demolition, but as well as under any personnel’s activities. In spite of a huge amount of data collected on characteristics, content and spread of fuel dust in the Shelter, the issues of its origins and mechanism of formation, and most importantly, forecasting estimates of radioactive dust transformation in the future still remain open.

The obtained results are as follows: Accessible information pertaining to Project topics was analyzed and classified. Pilot database (DB) version for project was created (room number → FCM availability and parameters → water availability → FCM destruction model). Currently, filling out of DB with information is underway. A procedure to evaluate effective areas of FCM clusters was developed and the assessment of areas of main FCM clusters is being performed. Regular sampling and analysis of water and aerosol samples in Shelter rooms is made and is linked to FCM clusters in the evaluation.

A model structure describing fuel particle destruction within the Shelter conditions is adopted. The estimates of the velocity of main FCM types produced in the model environments has been made and the generation of radioactive aerosol by LFСМ surface is carried out.

**Topic #23:** 25th Anniversary of the Chernobyl NPP Accident; Yesterday-Today- Tomorrow

V.Krasnov (ISP NPP) presented a video produced by National Geographic on the Chernobyl accident and the Shelter condition.

**Topic #24**: PARAMETER-SF4 post-test calculation with ATHLET-CD

W.Luther (GRS Munich) presented the results of the air ingress test PARAMETER-SF4 which was performed in July 2009 at the LUCH Research Centre in Podolsk, Russia, with the aim to investigate the bundle behaviour during reflooding after air ingress. For this purpose a VVER bundle of 19 rods (18 heated and 1 unheated) was heated up electrically to about 1200 °C before an inlet flow of 0.5 g/s air was injected. Due to the electrical power and steam oxidation followed by the chemical reactions during the air ingress, the temperatures in the bundle rose up to 1740 °C before the quench phase was initiated and the air injection was stopped. The bundle was flooded by a water mass flow in the range between 30 and 80 g/s. At first, the quench water injection led to a temperature increase above 2000 °C and a hydrogen generation of 86 g at the beginning of the quench phase (107 g during the whole test). Afterwards the bundle could be cooled down by the water injection. Due to the high temperatures shortly before and at the beginning of the quench phase strong bundle degradation was observed.

The simulation of PARAMETER-SF4 was performed with the current released version ATHLET-CD 2.2A1 using two separate fills for O2 and N2 to simulate air ingress. For steam oxidation the correlation of Cathcart/Prater-Courtright and for air oxidation a correlation on the basis of AEKI data for Ar-O2-mixture are used. Nitride formation during air ingress is not considered in the current released version of ATHLET-CD.

The results of the simulation show a good agreement in comparison to the experimental data during the pre-oxidation phase with only a slight underestimation of the maximum temperature. During the air ingress phase the higher temperature excursion moves to lower elevations because of oxygen starvation in the upper bundle region (above 600 mm) in the simulation as well as in the experiment. In comparison with the test data a slight delay of the oxygen consumption can be detected. The calculated temperatures are in good agreement with the experiment in the lower and upper bundle regions, but are overpredicted in the middle bundle heights during the air ingress phase. Up to the beginning of quenching, the hydrogen generation is very close to the experimental data (approx. 21 g), afterwards the total amount of H2 is underpredicted and results in ca. 76.6 g only, because melt oxidation is still underestimated. Parameter studies show that the temperature behaviour as well as H2 generation during quenching can be improved by reduction of the melt velocity from 5 to 2 mm/s leading to a total H2 generation of 91 g.

The results of the simulation could be improved by using more realistic input values (depending on O2 content and Zr phase) for Zr melt temperatures compared to previous calculations. A further improvement was possible by implementing a new model to consider nitride formation during air ingress. First results with this new option show that the oxygen consumption during air ingress is simulated correctly now and higher temperatures – especially in the lower bundle region – are calculated. Due to the higher temperatures before quenching the hydrogen generation increases leading to approx. 99.6 g hydrogen in total. The model and its input parameters will be further developed and validated.

**Topic #25**: PARAMETER-SF4 post-test calculation with MAAP 4.07; update

A.Schumm (EdF) carried out a simulation calculation of the test PARAMETER-SF4 with a customized version of MAAP 4.07, including specific extensions for Zr oxidation in air and material properties of the heater element materials. In a nuclear power plant, a severe accident is an unlikely event that may lead to core damage and fission products release in the environment. In the situation of a reactor pressure vessel (RPV) failure, a potential danger is an ingression of air. Air is a highly oxidizing environment that can potentially lead to an enhanced fission product release, that is why it is important to model correctly the kinetics of cladding oxidation by air. PARAMETER-SF4 test is designed to study the air ingress issue in severe accidents And it has been used to validate air oxidation models available in MAAP4.07 that have been implemented using correlations available in the literature.

The Zircaloy steam oxidation law used for PARAMETER-SF4 modelling is Cathcart and Urbanic. The Zircaloy air oxidation law is called NUREG, taken from the “*Review of the technical issues of air ingression during severe reactor accidents*”. For this third simulation, the bundle is divided in four channels: the unheated central rod for the first channel, 6 heated rods for the second one, 12 heated rods for the third one and 12 peripheral rods for the last channel that are also considered as special little rods in the global geometry.

For the validation of MAAP4.07 against PARAMETER-SF4, the pre-oxidation phase under steam atmosphere is considered to check approximately rod temperature and hydrogen production. The initial conditions before air ingress are thus well estimated. During air ingress, the hottest point seems to have moved to a lower part of the bundle, in comparison with the steam phase. This ‘hot spot’ moving is partially reproduced with MAAP4.07, which is at about 800 mm height during this phase. Oxygen starvation is predicted with a quite good agreement compared to the experiment: only about 60s later.

The reflood calculated with MAAP occurs too soon. There are multiple explanations, such as the non-simulation of molten metallic oxidation and the establishment of an instantaneous water flow rate. In consequence no real hydrogen production during reflood is calculated. This new simulation has underlined the need to take into account the overall characteristics of the 12 peripheral rods: the simulation has thus been improved.

**Topic #26:** Post test analysis of PARAMETER-SF4 with SCDAP/RELAP; update

Due to the current catastrophic situations in Japan (earthquake, tsunami, and reactor accident) the initially planned paper described below was not presented as initially planned. Instead by S.Guentay (PSI) gave a brief status of the accident situation of the Fukushima nuclear power plants in Japan.

The PARAMETER-SF4 experiment included an air ingress phase and was a counterpart of the QUENCH-10 experiment, except for a more limited pre-oxidation in steam during SF4. Pre-test planning and preliminary post-test calculations were performed using local interim versions of SCDAP/RELAP5 and SCDAP/Sim, modified to include models for the tantalum heater elements and to simulate the heat generation from air oxidation. The kinetics was modelled by a simple adaptation of the standard MELCOR correlation that attempts to capture the more rapid oxidation in air. The results using the MELCOR correlation overestimated the rate of oxygen consumption, suggesting a need for an improved treatment of the kinetics.

A new model developed at PSI is based on analysis of separate effects data on oxidation in air and seeks to capture the transition to breakaway oxidation that can occur in some conditions. The model has been implemented in a developmental version of SCDAP/Sim which has been used in recent calculations of SF4. The new model gives results in good agreement with the SF4 data for oxygen consumption and similar to results using the correlation for steam oxidation kinetics. In particular breakaway was not calculated, again in agreement with indications from post test examination of the SF4 bundle.

The strong reflood excursion, observed in the experiment and due to oxidation of molten metallic cladding exposed to the flowing steam after failure of the oxide scale, was also calculated by SCDAP/Sim following failure of the oxide scale. To capture this excursion the oxide scale failure criterion was reduced to 2200 K. It is conjectured that the comparatively thin oxide scale and the extended period of exposure to nitrogen under conditions of oxygen starvation made it less robust to withstand the conditions during reflood.

**Topic #27:** Next CEG-SAM meeting; other matters

The 20th CEG-SAM meeting will take place in Moscow in the 41st week starting October 10, 2011. L.Tocheny (ISTC) kindly offered to host the meeting.

M.Hugon thanked once more F.Oriolo (University Pisa) for the organization of the 19th CEG-SAM meeting in Pisa. He also expressed his thanks to all speakers and participants for their engagement at the meeting.

Remarks on a special workshop on "Severe Accident Management" and the future of the CEG-SAM:

1.) At the CEG-SAM meeting in Pisa, F.Oriolo and G. Forasassi (University of Pisa) made a proposal that ISTC/STCU should organize a special workshop on the “Fukushima nuclear accidents” in Kiev. The expertise of the group should be used for recommendations concerning nuclear power plant safety. What will be the impact of the nuclear accidents in Japan on the international community? A. Gozal (ISTC) proposed to use the supplementary budget of ISTC to finance the workshop.

According to L.Tocheny ISTC/STCU will provide logistical support to organize and host a special workshop on “Current problems of severe nuclear accidents”. IBRAE (L.Bolshov) agreed to lead the meeting. The members of the CEG are confident that this decision will promote further cooperation with IBRAE laboratories in different directions and forms.

2.) Several members of the CEG-SAM proposed to keep the group alive after the end of the on-going ISTC/STCU projects as an international expert group to analyze severe accidents worldwide (to be further discussed).

The CEG-SAM believes that it is useful to establish an international organization of experts, specialized in providing expert emergency assistance in place of a nuclear accident. There is no doubt that the relevant interest in Russia, CIS and abroad Secretariat ISTC/STCU can provide effective assistance in organizing this matter, especially at its initial stage.

**Restricted session** (continued)

**Topic #28:** SARNET and CEG-SAM comments on ISTC & STCU proposals

There were no new project proposals to discuss.

**Topic #29:** Detailed discussion of presented ISTC and STCU project proposals and preparations of specific CEG-SAM advices

See Topic #28.

**Topic #30:** Discussion of various actions

See specific action list (Annex #3).

**Topic #31:** Other matters; Final remarks

The chairman M.Hugon thanked once more the University of Pisa 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. Updated final agenda of the 19th CEG-SAM meeting
2. List of participants at the 19th CEG-SAM meeting
3. Specific action list (appended below)

**Annex #3:**

**Action List**

19th CEG-SAM meeting; Pisa, Italy, March 14-16, 2011

**Action 19/1**: M.Hugon (EC) will contact M. Zayet (STCU) again regarding the STCU project proposal #5243 (Kharkov) that was recommended by the CEG-SAM but rejected by the STCU/GB.

**Action 19/2**: L.Tocheny (ISTC), D.Bottomley (JRC-ITU), J.Stuckert (KIT), and V.Stepanenko (STCU) will collect all reports concerning the activities/projects performed and resulting publications in the frame of the CEG-SAM. L.Tocheny prepared a paper in 2009 (“Short review of the ISTC activity and list of relevant projects”) which may be used as a basis and updated. The STCU activities and publications should be provided by V.Stepanenko.

**Action 19/3**: L. Tocheny (ISTC) proposed to write a paper gathering all CEG-SAM activities (see Action 19/2) to be published in an international journal.