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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 20th MEETING**

Meeting organized by

**The International Science and Technology Centre (ISTC)**

**Moscow, Russian Federation**

**October11-12, 2011**

Meeting Location: ISTC Headquarter, Moscow

Krasnoproletarskaya ulitsa, 32-34

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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, November 25, 2011 CEG-SAM / M-20

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| Subject: 20th Meeting of the ISTC/STCU  “Contact Expert Group on Severe Accident Management” (CEG-SAM)  Place: Conference room of the ISTC Headquarter, Moscow  Date: October 11-12, 2011  Participants: 26 participants of 19 organizations from 9 countries:  Mr. D.Bottomley EC, JRC - ITU, Karlsruhe  Mr. B.Clement IRSN, Cadarache  Mr. S.Güntay PSI, Villigen  Mr. L.E.Herranz CIEMAT, Madrid  Mr. P.Hofmann Consultant, Karlsruhe (**secretary**)  Mr. Z.Hozer AEKI, Budapest  Mr. M.Hugon EC, DG-RTD / K.4, Brussels (**chairman**)  Mr. Ch.Journeau CEA, Cadarache  Mr. F.Oriolo University, Pisa  Mr. G.Pretzsch GRS, Berlin  Mr. A.Schumm EdF, Clamart  Mr. M.Sonnenkalb GRS, Cologne  Mr. J.Stuckert KIT, Karlsruhe  Mr. S.Weber GRS, Munich  Mr. P.Fomichenko NRC KI, Moscow  Mr. A.Goryachev RIAR, Dimitrovgrad  Mr. V.Khabensky NITI, Sosnovy Bor  Mr. A.Kolodeshnikov IAE-NNC KI, Kurchatov  Mr. E.Krushinov NITI, Sosnovy Bor  Mr. V.Loktionov MPEI, Moscow  Mr. M.Sheindlin IVTAN, Moscow  Mr. I.Slessarev NRC KI, Moscow  Mr. L.Tocheny ISTC, Moscow **(co-chairman**)  Mr. D.Tsurikov NRC KI, Moscow  Mr. M.Veshchunov IBRAE-RAS, Moscow  Mr. V.Zhdanov IBRAE-RAS, Novosibirsk  Distribution list:  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. H. Péro 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 K.4  Mr. L.Tocheny ISTC, Moscow  Mr. A. Van Der Meer ISTC, Moscow  Mr. V. Stepanenko STCU, Kharkiv  Mr. M. Zayet STCU, Kyiv  EU CEG-SAM members  Contact person: Mr. M. Hugon Tel.: +32 2 296 5719 – DG-RTD / K.4 |

# Restricted session

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

The International Science and Technology Centre (ISTC) organized the 20th CEG-SAM meeting in Moscow on October 11-12, 2011. The meeting location was the conference room of the ISTC Headquarters in Moscow, Russian Federation.

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/or the Ukraine.

**Topic #1:** Welcome of the CEG-SAM members and opening remarks

A. Van der Meer (Executive Director of ISTC) welcomed the participants. He described briefly activities of ISTC in the nuclear field. ISTC is providing high quality scientific collaboration to parties and partners that work together on a multilateral basis in order to contribute to the solution of common problems. The problems are so complicated that adequate results can only be achieved through combined effort. ISTC has great knowledge in the nuclear field. In this connection ISTC offered help for Japan concerning the Fukushima nuclear reactor accidents.

ISTC started an important discussion on the future transformation of the organization to address changed needs (the same is true for STCU). An important change is that the Russian Federation will withdraw from ISTC. Nevertheless, the organization will be maintained until the end of 2014 to continue ongoing projects until the current work in Russia is completed. There is a plan to transfer ISTC Secretariat to Kazakhstan. International exchanges and training activities will continue. But there will be no funding for new projects. What is important is to maintain the expertise at the ISTC Secretariat. Regarding the CEG-SAM, a new cooperation between Euratom and Rosatom has been established.

The chairman M. Hugon (EC) welcomed the CEG-SAM members. He expressed his thanks to L.Tocheny (ISTC) and his team who organized and hosted the meeting in Moscow. He described the usefulness of the partnership established between the Russian, Kazakh and Ukrainian teams with the European ones during the existence of the CEG-SAM. In the future, the Russian partners will have to pay for their own research activities as do the European partners.

The Russian co-chairman L.Tocheny (ISTC) welcomed the participants as well. 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) was not able to attend the meeting.

**Topic #2:** Adoption of the agenda of the 20th CEG-SAM meeting in Moscow

The agenda was accepted with the following changes: The planned presentations under Topic #16 will be dropped since the project manager (V.Krasnov, ISP NPP) was not present at the meeting. The presentation under Topic #18 will be given by S.Guentay (PSI) and that under Topic #20 by P. Fomichenko (NRC-KI).

**Topic #3:** Approval of the minutes of the previous 19th CEG-SAM meeting in Pisa, Italy, March 14-16, 2011

The secretary has taken into account the comments in the revised minutes 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 20th CEG-SAM meeting in Moscow.

**Topic #4:** Discussion of the “Action List” of the 19th CEG-SAM meeting in Pisa

**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 completed.*

**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 not yet completed 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. *Action under way.*

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

The remaining 4 ISTC and 1 STCU projects have been or will be finished by the end of this year except one, which will be completed in June 2012. No new projects will be considered, therefore, the work of the CEG-SAM may terminate soon.

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 international paper (see Action 19/3). A list of all published papers on ISTC/STCU projects should be made.

A final workshop at which the essential outcome of the international collaboration should be presented is planned for the autumn of 2012. The date and meeting location have not yet been decided (see Topic #25).

# Extended session

**Topic #6**: Welcome of the participants by the host of the meeting, general remarks

L.Tocheny (ISTC) welcomed the Russian participants of the 20th CEG-SAM meeting and wished them interesting discussions and exchanges of information. He mentioned once more that ISTC should finish its activities by the end of 2014. Any extension of project funding is not possible, but some money will be available for the organization of meetings.

**Topic #7**: Welcome of the Russian, Kazakh and Ukrainian colleagues; approval of the shortened minutes of the 19th CEG-SAM meeting in Pisa; adoption of the agenda of the 20th CEG-SAM meeting in Moscow

M.Hugon opened the extended session of the meeting and welcomed the Russian and Kazakh participants and expressed his thanks to L.Tocheny and his team for organizing and hosting the 20th CEG-SAM meeting in Moscow. He also expressed his thanks to P.Hofmann for his excellent management of the various activities in planning and executing the CEG-SAM meetings. He regretted that V.Stepanenko was not able to attend the meeting.

The shortened minutes of the 19th 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 20th CEG-SAM meeting without any additional changes.

**Topic #8**: Status of the official ISTC CEG-SAM webpage

J.Stuckert (KIT) explained once more the structure of the ISTC CEG-SAM webpage. The 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, 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.

The CEG-SAM members 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 #9**: Interaction between SARNET and CEG-SAM activities and future of the CEG-SAM

M.Hugon presented an overview on the status and future of the CEG-SAM. The group has been very successful since its launch in April 2002. In addition, there now exists an excellent interaction with SARNET2. The results of SARNET activities were periodically presented to CEG-SAM members. A transmission of ISTC/STCU proposals and project reports related to SAM to SARNET topical co-ordinators took place. The experimental results of ISTC/STCU projects have been used for development of knowledge as part of SARNET Joint Programme of Activities (JPA).

10 ISTC projects were funded and are completed. 4 ISTC projects and 1 STCU project are still ongoing. All ongoing projects will be finished by the end of 2011 except one, which will be completed in mid 2012. 7 project proposals were examined and supported by the CEG-SAM but not funded by the GBs. No new projects are under discussion. A joint paper that summarizes the main results of some of the 15 ISTC/STCU projects is being written and will be published in a peer-reviewed journal. A follow-up paper was also proposed.

The ISTC and STCU funding from EC has decreased from ~ 25 M€ in 2007, ~ 15 M€ in 2008 to ~ 8 M€ in 2009 and 6M€ in 2010. No more projects were funded since 2009. ISTC will be closed on 31/12/2014. However, collaboration with Russia will continue through the Euratom-ROSATOM Working Group on nuclear fission (under the cooperation agreement on nuclear safety between Euratom and Russia in 2002). 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).

Between Euratom and Ukraine exist two cooperation agreements: one on nuclear safety in 2002, and another one on peaceful uses of nuclear energy in 2006.

The status of the preparation of Euratom FP7+2 (2012-2013) and EU and Euratom next framework programmes, Horizon 2020 (2014-2020) was briefly presented. Following the Fukushima accidents, the FP7+2 text has been modified: it maintains research on Gen IV systems, but exclusively on safety aspects. The safety assessment tests (stress tests) proposed by the EC (DG ENER) were also briefly presented.

**Topic #10**: 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 of the 7th EC Framework Programme. SARNET2 started on April 1, 2009; with altogether 43 organizations from 22 countries 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. The WP5 to 8 cover the 6 high-priority issues defined by SARP in SARNET on corium coolability (core reflooding), MCCI, steam and/or hydrogen explosion and source term.

The interaction between CEG-SAM and SARNET2 worked 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 application of this knowledge to safety issues.

An evaluation of the Fukushima impact on R&D priorities has been considered: The SARP group will account for it when updating the priorities as defined in 2007, with the final deadline of early 2013, at SARNET2’s end: moreover an internal long-term process has been launched in some WPs by sharing the partners’ analyses of phenomenology and mitigation aspects.

B.Clement described in detail the progress achieved in the last 12 months and the future milestones. A few technical outcomes in the last year were: the continuous intensive storage of experimental data in DATANET database, in particular by KIT; the increase of synergy between the 3 different experimental programmes on debris reflooding; the progress of understanding the origin of the different cavity shapes in MCCI with (an)isotropy depending on the type of concrete (limestone, siliceous); success of 5 benchmarks between simulation codes (LP or CFD) on containment experiments; good progress on the Ruthenium transport in primary circuit (experiments, modelling) and synthesis of ASTEC V2.0 assessment by 27 partners.

**Topic #11:** R&D research priorities from SARNET2 project SARP (Severe Accident Research Priorities)

M.Sonnenkalb (GRS) presented the work program on “Severe Accident Research Priorities”. The proposal of the SARNET2 project is: to agree on updated assessment methodology; review issues resulting from SARNET-SARP not covered by SARNET2; analyse R&D progress and Level 2 PSA studies; reassess issue ranking and reorient priorities; identify experimental and theoretical programmes to address these (including estimated costs and duration); make recommendations for R&D updates and finally agree on issues to be closed.

SARP in SARNET identified 6 issues with high priorities which are still open. The Issues are dealt within SARNET2 and described under Topic #10 by B.Clement (IRSN). The result of SARP-2 should be an updated version of SARNET-SARP conclusions and proposals for future research in the severe accident domain. First steps are: summary of ongoing activities in SARNET2 and other related OECD projects with regard to the 21 ERI (Remaining Severe Accident Research Issues) issues. A discussion started on new/renewed topics based on Fukushima, like re-criticality in core by flooding with water, influence of sea water injection, pool scrubbing in wetwell water pool, spent fuel pool accidents, and others. The 3rd Meetingis planned at GRS, Cologne, November 29th, 2011.

**On-going and final project presentations**

**Topic #12**: Final report on the ISTC project #3592 "Corium Melt Interaction with Reactor Vessel Steel” (METCOR-P)

A short summary of the essential results of the METCOR-P project were presented by M.Sheindlin of the “Institute for high Temperatures of the Russian Academy of Sciences” (IVTAN). The head of the project has been V. Khabensky (NITI).

The objectives of METCOR-P project have been: The 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.

Based on the results of experiments on the interaction between molten corium and VVER Reactor Pressure Vessel (RPV) steel in an oxidizing atmosphere a model and correlations were developed to describe the experimental data on corrosion kinetics. A possibility of corrosion acceleration due to liquid-phase transfer (since there is diffusion & convection in a liquid) of Fe2+ ions through the corium crust on steel surface was established and the limitation of this phenomenon by the conditions of oxidizer access to corium melt was demonstrated.

On the basis of experimental results on the interaction between sub-oxidized molten corium and VVER RPV steel the effect of thermal gradient conditions on the composition of the oxide and metal phases of the U-Zr-Fe-O system in the miscibility gap was examined and recognized. A process model for the temperature boundary of corrosion was proposed. A correlation generalizing experimental data on corrosion kinetics was obtained.

Based on the results of experiments on the interaction between molten corium and European RPV steel a qualitative agreement and quantitative similarity between the results for European and Russian reactor vessel steels was demonstrated, Due to the lack of sufficient experimental data, a correlation to describe the corrosion kinetics for European Reactor steel only was not possible.

Based on the results of experiments on the interaction between molten corium and RP vessel steel samples with a vertically oriented interface it was found that the interface orientation had almost no effect on the interaction process which is of physico-chemical nature. A difference was revealed between the temperature boundary of corrosion for steel samples interacting with the metallic melt in a neutral atmosphere and those interacting with the sub-oxidized corium melt.

Based on the results of experiments on the oxidation of molten corium it was observed that under experimental conditions, the oxidation of melt followed the diffusion mechanism with oxidation starvation. It was found that the oxidation rate was essentially reduced by a crust on the melt surface. Because of cracks in the crust, the oxidation rate observed in the experiments remained constant and did not depend on the crust thickness.

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

8 thematic reports (МСР-1, МСР-2, МСР-3, МСР-4, МСР-5, МСР-6, МСР-7, and МСР-8) and 2 annual reports (for 1st and 2nd years) have been prepared. The final English project report is in progress and will be completed by the end of 2011 (the Russian version is already ready).

**Topic #13**: Progress report on the ISTC project #3813 “Phase relations in corium systems” (PRECOS)”

**The objective** of the project PRECOS 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 the melts with structural materials of the reactor core, concrete shaft, and core catcher.

M.Sheindlin of the “Institute for high Temperatures of the Russian Academy of Sciences” (IVTAN) presented the progress report of the project since S.Bechta (KTH), the long-time head of the project (formerly RIT-NITI) could not attend the meeting.

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).

A great number of laser-melting experiments were performed in the ZrO2 –FeO system. It was observed that the obtained liquidus values for both IVTAN and CORD samples are clearly lower than previously obtained by conventional methods (Galakhov micro-furnace, *etc*).

The project started on June 1, 2008. The studies of SiO2-UO2, UO2-CaO binary oxidic systems have been completed.  The study of other systems is in progress. The 4th project meeting was held on 8 June 2011 in St.Petersburg. Multi-component corium compositions for Task 4 implementation were discussed at the meeting. The progress report deals with experimental results on ternary oxidic systems: - UO2-FeO-CaO and UO2-FeO-SiO2.

With the agreement of the collaborators it is planned to prolong the project for 6 months without additional funding. Proposed tasks for the remaining extension period are: Measurements on sub-oxidized Zr-Fe-O systems to verify the existence and parameters of immiscibility cupola. Further experiments are planned with ZrO2-FeO systems on IVTAN samples and CORD samples. Possible use of the IVTAN high pressure setup can be considered. Study of possible immiscibility in Zr-U-O system on samples prepared at NPO “Lutch”.

**Topic #14:** 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 finished. Extension of the thermal hydraulic consideration of oxidised melt from small scale (crucible tests) up to a large scale (reactor pressure vessel) and its interaction with the vessel steel walls was launched.

The solution block of an advection-diffusion for oxygen in CONV2D was improved. The adaptation of turbulence model in CONV2D for solving the oxygen transport problem in the reactor case was carried out. Modification of the block of boundary conditions for oxygen transport in CONV2D code was completed.

The melt-steel oxidation 1-D module was modified, namely there are additional interlinkage variables, oxygen concentration in the melt bulk near melt-crust boundary was put in; steel corrosion mode under conditions of a thin crust layer was additionally implemented.

The interfaces of the melt-steel oxidation module and the corium melt 2-D thermo-hydraulic code were modified. Namely, the list of necessary parameters for operation of the modules was enlarged by oxygen concentration in the melt bulk near melt-crust boundary. Oxygen fluxes smoothing, necessary under high turbulence conditions for input to the wall corrosion module, was performed by time averaging procedure between corrosion module callings.

As a result, implementation of the physico-chemical melt oxidation 1-D module in the CONV2D code was completed, and verification of the advanced module and its application to simulation of real experiments has been continued. The preliminary results on convective mixing of oxidised corium in real geometry of the lower head and on corrosion of vessel steel walls were obtained.

The completion of the ISTC Project #3876 is foreseen within the next few months (without additional funding).

**Topic #15:** Final results 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”

V.Loktionov (MPEI) presented the current results 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 the manufacturing of the VVER LH reactor vessel scale models (scale 1:5); the conduct of these experiments with VVER vessel models at high temperatures as well as separate-effect tests on the creep behaviour of the VVER vessel steel and finally 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 were 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 model 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 will be the study of heating and deformation of the cylindrical part of the vessel model.

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

Results of Tasks 1 to 3: The final preparation of the scale experiment on the high-temperature heat-up and creep deformation of the vessel model was suspended for one year till September 2011. The first experiments 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. The loss of the integrity occurred because of an internal engineering flaw of the welded seam connecting the two parts of the electrical conductor made of copper and the stainless steel that failed.

Unfortunately, MPEI has not yet succeeded in performing the planned experiment on the vessel model in time. However, MPEI assured parties concerned in this project, and first of all to those from EU who collaborate with MPEI and provide financial support, that after the planned experiment will have taken place (November 2011) all the obtained results will be presented to the European participants in full accordance with the contract. Moreover, if we succeed in preparing an additional vessel model with elliptic bottom and conducting an experiment on breakdown of such a construction we will also provide all the information and the results of the testing to the project collaborators.

Results of Task 4: 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 25 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.

As a result of the creep tests in argon the following characteristics of the vessel steel have been determined: In the range of 750-800 °С, and in the range of 850-950 °С the time-to-failure of the real VVER vessel steel is two to three times longer than in case of the model vessel steel failure: particularly at higher loads; at low loads the difference of time to failure becomes insignificant. In the range of 800-850 °С the both steels (vessel steel of VVER and model vessel steel) have almost the same creep characteristics (eg. creep velocity) within the whole range of applied loads.

In the range of 900-950 °С the creep characteristics of the two types of steel are almost the same. In fact we have the same “bump” on the creep graphs with the same level of deformation; however, the “bump” appears at different time periods although the defined creep velocity is almost the same. We believe that the differences in the deformation of these 2 steels are connected with the differences in heat treatment of the VVER vessel steel and the model vessel steel. The model vessel material was treated with one temper drawing, whereas the VVER vessel material is treated with several similar temper drawings. The influence of such temper drawing(s) on the creep characteristics of VVER steel have not been taken into consideration before.

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 work 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 #16:** Progress of the STCU project #4207 “Long-term prognosis of the behaviour of the fuel dust in the Chernobyl Shelter”

V.Krasnov (ISP NPP) was not able to attend the CEG-SAM meeting, therefore, the obtained progress of the STCU project could not presented orally. The submitted results for the minutes are presented below.

The main objective of the project is the creation of 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 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 subsequent dust 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 dust formation and, especially, the prognosis of its further physical/chemical transformation are still not clear.

During the reported period the following works related to development and update of the data base (DB) were carried out: 1) Editing the fields of the main forms of the DB in accordance to the received remarks and desires of the staff; 2) Specification of the data for the Shelter rooms and their input into the DB. At this moment we possess comprehensive information for the rooms containing the main FCM. The work for description of the FCM themselves are in progress; 3) Taking into account the large volume of the additional data obtained within the frame of the project and that these data may be of interest, the main form of the DB was added with the new field “Additional information”. Activation of this field results in starting up the explorer showing the folders containing the text, photo and video information. The user can view the necessary files in any convenient form for viewing or editing . To enable that, all additional information on the FCM characteristics was formatted and links were established for each document to the corresponding record of the room in the DB,

**Topic #17**: Containment thermal-hydraulics of current and future LWRs for severe accident

Management; ERCOSAM

S.Guentay (PSI) described the hydrogen issues in the reactor containment in the frame of the ERCOSAM project funded by Euratom in cooperation with SAMARA funded by ROSATOM, which is aimed for a better understanding and improved margins for hydrogen management as well as 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 behaviour, assessment and design of SAM measures for hydrogen management).

Experiments are planned in the following facilities: “small scale” TOSQAN (IRSN, Saclay) and “SPOT” (JSC “Afrikantov OKBM” Nizhny Novgorod); "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.

Several management and project meetings as well as a steering committee meeting were organized in 2011. It is planned to conduct the first PANDA test late this year. The web base information/document/data exchange is fully functional and under continuous update.

**New project presentations and other matters**

**Topic #18:** Information on the planned ERCOSAM-SAMARA project

S.Guentay (PSI) presented the joint paper with A.Kisselev (IBRAE RAS) on the ERCOSAM-SAMARA project. The objectives of the projects is the generation of a high quality database on the physical phenomena occurring in the containment of light water reactors during postulated accident sequences involving SAM operation (spray, cooler, PAR) for CFD and lumped parameter codes and code verification and demonstration of predictive capability of state-of-the-art analytical tools (both LP and CFD codes).

The activities in framework of SAMARA Project are: 1) The analysis of VVER severe accidents; scaling down analysis from the plant to facilities; development of initial and boundary conditions for SAMARA tests (WP1, 2010-2011); 2) Planning, pre-and post-test calculations (WP2, 2011-2012); 3) Experimental and benchmarking tests (WP3, 2012-2013) and 4) Syntheses of experimental and analytical work: phenomenology and codes (3D, CFD and LP) capabilities (WP4, 2013-2014).

The current status of the SAMARA project that has been launched on January 15, 2010 can be summarized as follows: Signed Coordination Agreement between ERCOSAM Project and SAMARA Project constitutes a basis for cooperation between SAMARA and ERCOSAM partners; Current SAMARA activities are performing following a common ERCOSAM - SAMARA work programme on the basis of common approach to the investigations; Partner relationships established between the SAMARA and ERCOSAM organizations promotes successful project implementation.

In the frame of the SAMARA project the following tests are planned: Two tests with cooler at small-scale SPOT facility. Two code benchmarking tests with cooler and spray at “nearly full scale” concept HYMIX facility. Common approach (as in ERCOSAM Project) to develop initial and boundary conditions for the tests (common generic conditions, common scaling down consideration). The SAMARA test sequence is the same as in the ERCOSAM tests. The configuration (geometry, safety system) and boundary conditions are developed on the basis of GC calculations and WP1 scaling consideration.

**Topic #19:** Proposal for a new project called SAFER (Severe Accident Facilities in Europe and Russia) which would be in the EURATOM ROSATOM framework like ERCOSAM SAMARA

Ch.Journeau (CEA) presented the information on the proposal for the new project called SAFER. It should allow transnational access to large infrastructures. Community support will be provided to cover costs of Transnational Access to Large Infrastructures (TALI) for researchers from Member States and Associated States, other than the state where the infrastructure is established, in order to promote access for researchers to infrastructures that provide essential and unique services to the European research community. Access to researchers from 3rd countries could also be envisaged, where such access is part of the promotion of broader international cooperation with the countries concerned. The active participation of major infrastructure operators and potential users will be required to achieve the objectives.

Expected impact will be***:*** Optimised use of existing nuclear research infrastructures in Europe in all activities of the programme and facilitated access to these infrastructures by researchers throughout Europe and from 3rd countries. Access will be given to selected facilities for visiting scientists from EU and Associated 3rd countries to perform experiments. The EU will pay all facility costs and travel expenses; the 3rd country institution pays only the salaries of its scientists. Visitors may bring specific apparatus to install in the EU facility. Visitors must disseminate results in the open literature. Typically 3 to 10 accesses will be funded by the EU.

A short description of ALISA [EURATOM-China project] project was given. Enhanced transnational access to large research infrastructures in Europe and in China is offered to allow the optimal use of the resources in the extremely complex field of severe accident analysis for the existing power plants. This research involves very substantial human and financial resources and, in general, the research field is too wide to allow investigation of all phenomena by any national programme. To optimise the use of the resources, the collaboration between nuclear utilities, industry groups, research centres and safety authorities, at both European and Chinese levels is very important. This is precisely the main objective of the ALISA project, which aims to provide these resources and to facilitate this collaboration by providing large scale experimental platforms in Europe and in China for transnational access.

The ALISA project offers a unique opportunity for all parties to get involved in the networks and activities supporting safety of existing and advanced reactors and to get access to large scale experimental facilities in European and in Chinese research organisations to enhance understanding of material properties as well as reactor core behaviour under severe accident conditions. Activities within the ALISA project will focus on the large scale experiments under prototypical conditions addressing the remaining R&D issues on severe accident management in light water reactors.

Cooperation with Third Countries: A structured dialogue has already been established with Russia. If bodies from 3rd countries do not wish to, or cannot for legal reasons, sign the Euratom Grant Agreement, alternatively two administratively separate projects (so-called ‘coordinated’ or ‘parallel’ projects) could be established, each set up according to the respective rules and procedures, but strongly coupled via a Coordination Agreement (based on the format of a Consortium Agreement) to be signed by all partners engaged in the cooperative action. Transnational Access to Large Infrastructures is one of the items open for collaboration between EURATOM and Russia.

The financial constraints of the cooperation will be: No transfer of money over the border between EU and Russia. EURATOM pays for the tests in Europe and for the Russian visitors’ expenses. ROSATOM pays for the tests in Russia and for the European visitors’ expenses. EURATOM contribution is limited to 1 M€ for the whole project. ROSATOM contribution should be of same magnitude.

The current time schedule will be: Proposal to be submitted to EC in April 2012 (date not yet decided); Negotiation phase about 1 year, EU partners with EURATOM and RU partners with ROSATOM, thereafter Consortium and Cooperation Agreements. Start of projects in 2013. Preparation of rules for access of scientists and for the call for proposals. Experiments will start in 2014. Duration of the projects : 3-4 years.

**Topic #20**: Impact of Fukushima on future research on severe accident management/safety in Russia in application to advanced nuclear power systems

P. Fomichenko (NRC KI) presented some information on the threefold approach used in NRC KI in safety studies of advanced nuclear power systems. Such an approach proposes 1) further improvement of calculational models for severe accident studies by including in consideration additional phenomena that might have significant impact on accident consequences (e.g. physical-chemical processes like fuel hydrolysis); 2) development of a comprehensive computerized expert system for evaluation and improvement of safety level of existing and new reactor systems (such system is built on the concepts “Lines of Defense” and “Safety Potential”); 3) development of new reactor concepts that drastically minimize or even eliminate severe consequences of accidents (e.g. use of coated fuel micro-particles directly cooled by water). On the basis of this approach additional experimental and theoretical studies in Russia in the field of reactor safety and accident management as well as reactor off-site precautions can be proposed.

**Topic #21:** European approach on the NPP safety stress tests in the post-Fukushima situation. Examples of application to France and Germany

M. Sonnenkalb (GRS) and B. Clément (IRSN) presented comments on the Fukushima Accident and some views on French and German national Stress Tests. The “beyond design” Fukushima Dai-ichi accident consequences are extremely severe, but they could have been really much worse. Accident consequences have been minimised by the meteorological conditions (direction of the wind towards sea) for a large part of the radioactive releases. Melting of fuel in the storage pools would have induced more severe consequences (cliff edge effect).

A tsunami caused by the earthquake of 11 March 2011 of the northeast coast of Japan drowned the emergency diesel generators of three boiling-water reactors at Fukushima Dai-ichi, resulting in station blackout and the meltdown of the three reactor cores. Although emergency injection of seawater was improvised to remove the decay heat from the reactors, it was too late to avoid boiling off of much of the water in the reactor pressure vessels and the reaction with steam of the zirconium alloy cladding of the fuel rods in the reactor with the evolution of hydrogen, which in turn over-pressurized the massive concrete containment of the reactor and compelled venting of the hydrogen and some of the radioactive material from the reactor.

There are three levels of failure regarding the defence in depth concept. The accident initiating type of event (earthquake + tsunami) was included in the plant design but the amplitude of the event was “beyond the design” and has led to a cliff edge effect. The accident management procedures, the available equipment and maybe even the staff training were not sufficient to maintain the long term core cooling (despite all efforts made by the operator teams) during these extreme situations. Core melts after Station Black-Out (SBO) on Fukushima reactors 1, 2, 3 have lead systematically to hydrogen combustion in the reactor building and large releases (limited by retention in the suppression pool).

Lessons learned from the Fukushima Accident: The design is not appropriate for such external events as the quasi-simultaneous loss of the long-term core cooling and of the electrical power supply of all reactors on the same site.

As a result of national and international opinion European stress tests were requested to examine accidents initiated by events such as earthquake and flooding and the consequence of loss of safety functions for any conceivable initiating event at the plant site. These are: a) Loss of electrical power including station black-out; b) Loss of the ultimate heat sink and/or both. The corresponding Severe Accident Management (SAM) issues are means to protect from and to manage loss of function in: a) cooling the core b) cooling the fuel storage pool; c) containment integrity.

Three main aspects: a) The design and plant conformance to design requirements; b) Beyond design robustness of the plant; c) Protective measures to avoid extreme scenarios: ie. means to maintain fundamental safety functions; i) Mobile external means of support (mobile power station/fuel cells; ii) Procedures to link reactors & one reactor to help another; iii) Avoid Interdependence of reactor functions on the same site.

Other parameters that are crucial for severe accident management are: identification of when fuel damage becomes unavoidable (for PWR and BWR, time before water level reaches the core top and before fuel degradation). For storage ponds it is the time before pool boiling, time adequate radiation shielding is maintained, then as with the core, time before water level reaches assembly tops, time before fuel degradation.

Example of application to Germany - **Stress Test**: The German Ministry BMU asked the German Reactor Safety Commission (RSK), in agreement with the local German Authorities, to perform a plant specific Safety Check within a short time period *(End of March to Mid of May 2011).* The goal: check the NPP design robustness and the Accident Management measures against the extended challenges not considered so far. GRS was asked to manage the process with support from local TÜV and other German organizations. The final report was issued by RSK on May 16, 2011.

**Topic #22:** Impact of Fukushima on future research on severe accident management/safety in Europe

D. Bottomley (ITU Karlsruhe) and J. Stuckert, (KIT Campus Nord) outlined the major experiments and research themes carried out at ITU and KIT Campus Nord (ex-FZK Karlsruhe) during the last decades. These include their participation in the TMI-2 investigations, the Phebus-FP projects, and additionally the CORA and QUENCH experiments at KIT-Campus Nord. Further examples come from the current (SARNET) and past (COLOSS, & CIT) work programs of the European Commission in the severe fuel degradation domain.

Selected examples from these programmes were given to illustrate the broad scope of severe accident research carried out. These will include single effect tests (UO2- cladding interactions) to medium and large scale testing (single rod and fuel bundle tests) as well as modelling and plant simulations. Finally the main questions from the Fukushima accident were noted, then the objectives and the structure of a possible research programme were outlined.

I. Slessarev (NRC KI, Moscow) presented a short view on “WAYS to NUCLEAR POWER RENAISSANCE and VITAL RISK FREE NP”.

Several general issues (“painful points”) seem to cause the most significant doubts in society impeding the nuclear energy renaissance: 1. Non-eliminated threat of disastrous accidents (with high and hazardous risks for the society, uncertainties of their probabilities); 2. Weapons-grade material proliferation risks; 3. Indefinite risks related to long-lived toxic waste storage; 4. Threats of major investment loss in conditions of limited capital, economic crises and deep inflation processes; 5. “Progressive deadlock” effect in NP development scenario caused by the looming constraints in nuclear fuel resource.

All these issues, along with the respective risks/threats they involve, are substantial according to the definitions above and they are decisive (“vital”) ones for the fate of this technology. Development of an innovative nuclear technology capable of evoking the true nuclear energy production renaissance would necessarily require nuclear reactors and fuel cycles deliberately provided with counter-measures (with known ways of implementation) relative to all vital risks. The thermal nuclear reactors available now, as well as ordinary fast sodium-cooled reactors using oxide fuel (such as ancient BN and Super Phenix), do not definitely possess these qualities

The new Nuclear Power ideology leading to its accelerated revival should be able to exclude substantial threats and guarantee elimination of other vital risks attributable to the contemporary NP. It doesn’t mean that there are no more problems in the nuclear technology, however, these problems could be reduced to the category of “ordinary” issues imposing no constraints on the sustainable and long-term application of NP in the future.

As confirmed by recent analyses (Annals of Nuclear Energy, № 35 №4, (2008), Annals of Nuclear Energy, № 34 №11 (2007) ) the corresponding examples of reactor designs in the frame of existing nuclear technology have been advocated. The scope of main features (conformable to this ideology) of a power production unit is the following: application of self-protection principles respecting to all severe accident scenarios, multi-modular NPP with reactor-modules of about one hundred MWte each, dense reactor core composition with sufficiently hard neutron spectrum and small negative void reactivity feedback effects, application of the equilibrium close fuel cycle with non-enriched uranium feed, permanent and purposeful transmutation of both transuraniums and some of LLFP inside of the reactor radial blankets, etc. They are well coordinated with innovative trends in nuclear power development.

**Topic #23:** Discussion on the planned joint ISTC publication “An example of effective international collaboration in nuclear safety and other major technologies”

A joint paper is under preparation that should be published in an International Journal (Nuclear Engineering and Design). The paper should describe essential results of some selected ISTC projects. The objective of the paper is to highlight the structure behind the success of international collaboration achieved in the last 10 years through the “International Science and Technology Centre” (ISTC) in Moscow in the frame of the “Contact Expert Group on Severe Accident Management” (CEG-SAM). The latest corrections from L. Tocheny will be added and the next version sent round for comment by early November. In addition to submitting a paper it was also proposed to make a presentation at a coming meeting. This was also viewed positively.

**Topic #24:** Discussion of various actions

No further actions.

**Topic #25:** Next CEG-SAM meeting, March 2012; Other matters; Final remarks

The CEG-SAM members expressed their wish to organize a final meeting or workshop in 2012. A tentative date could be autumn 2012. Concerning the possible meeting location several places were mentioned respectively offered (Karlsruhe by J.Stuckert, Brussels by M.Hugon, Almaty by A.Kolodeshnikov). Regarding the ISTC project results that should be presented by Russian investigators a final meeting in Russia (or Kazakhstan) would be more appropriate/less costly. A general problem will be to engage the Russian scientists for this event since the projects will have mostly terminated. L.Tocheny (ISTC) will try to get some financial support for our Russian colleagues to attend the meeting.

M.Hugon thanked once more L.Tocheny (ISTC) for the organization and hosting of the 20th CEG-SAM meeting in Moscow. He also expressed his thanks to all speakers and participants for their engagement and efficient work and contributions at the meeting.

**Technical Tour to IVTAN**

Izhorskaya 13-2, 125412 Moscow, Russia

*http://www.jiht.ru*

On Wednesday October 12, 2011, a technical tour was organized by M.Sheindlin (IVTAN) to visit some laboratories of the “Joint Institute for High Temperature of Russian Academy of Sciences” (IVTAN).

## The Joint Institute for High Temperatures of the Russian Academy of Sciences is the leading research institute in the fields of high energy densities physics, shock wave physics, thermodynamics databases, numerical simulations and cluster computing, dusty plasma, applied electrodynamics, combustion, green power and many others. The history of the Institute begins in 1960, the year when the High Temperature Laboratory of the USSR Academy of Sciences was set up. During fifty years that passed since that time, the Institute grew up from a small research laboratory at the Moscow Institute of Power Engineering into a major institution of the Division of Energetics, Mechanical Engineering, Mechanics, and Control Systems of the Russian Academy of Sciences – the leading scientific centre of the country in the field of power generation and thermophysics (including the region of high energy densities). The Institute has 450 researchers, including 12 members of the Russian Academy of Sciences and about 300 researchers with PhD grade.

M.Sheindlin presented a few basic activities of the Institute: Development of effective, safe and reliable energy sources with low impact on the environment; Electro-physical, optical and mechanical properties of substances and low-temperature plasmas in a wide range of parameters up to extremely high temperatures and pressures; Heat and mass transfer, gas- and plasma-dynamics; thermo-physics and high-temperature materials science; development of new methods of generation of high energy density; energy-saving problems, renewable energy, development of electrochemical power generators, increased efficiency of natural fuel energy sources.

The following laboratories could be visited: AlumnoHydrogen (the new concept: use of Al as *energy carrier* – directly in Al-Air Fuel Cell, or for hydrogen production during Al oxidation in water); Technologies for Power Generation; The Giant Explosion Chamber (Internal diameter 12 m, able to take up to 1000 kg high explosive (trinitrotoluol)) and the equipment of the labs of Extreme States of Matter (use of femptosecond lasers for studies of matter at extremely high energy densities).

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

**Annexes:**

1. Updated final agenda of the 20th CEG-SAM meeting
2. List of participants at the 20th CEG-SAM meeting