Implementing Agreement on Nuclear Technology of Fusion Reactor
Annual Report 2011

Annual Report of Subtasks for Annexes I and II
Annual Report for Annex I of IA on NTFR
Annex I

2011 Activity Summary Report and 2012 Work Plan of Subtask 1: Solid Breeding Blanket
Author: M. Enoeda

Summary

1. Activities in 2011

As part of the activities of Annex 1 Subtask 1, the 17th subtask review meeting was held in Portland, USA on 10th of September 2011. Total 15 person of subtask group members and experts, from China, EU, Japan, Korea, Russia and US participated in the review meeting. During the subtask review meeting, working group (WG) coordinators reported the progresses on the four active research topics, while the work plans for 2012 were discussed and agreed. In 2011, six Working Groups have been performed. A detailed report of research activities in 2011 is attached as Attachment 1. Major topics are as follows.

1) WG-G: The goal of irradiation experiment (HICU) has been achieved, as planned, DEMO relevant Li burn up and dpa with DEMO relevant dpa – Li burnup (dpa/%BU > 1.1). Thus, this Working Group was closed successfully. The planning of the post irradiation examination (PIE) and its tools has been performed. A new Working Group on the PIE has been discussed.

2) WG-N: As the activities of “Development and validation of computational tools for describing the Hydrogen isotopes transport in the breeding zones of the pebble bed blankets”, progress was made on the purge gas flow visualization experiment using a pebble bed test setup, for the purpose of validation of the computer simulation.

3) WG-O: As the activities of “Evaluation of tritium permeation rate and permeation reduction factor in the real operation conditions of the working fluids”, new contributions of experiments have been started by Korea and RF.

4) WG-P: As the activities of “Characterization of newly developed ceramic breeder pebbles”, measurement apparatus list which includes all available measurement apparatus of all members, were generated. Also, additional expected evaluation items, such as the evaluation of equilibrium vapor pressure of Li containing compounds, are discussed and added to the list of measurement apparatus list. Also, efforts of new measurement apparatuses of pebble bed thermo-mechanics have been performed by China, India and Korea. It was proposed to discuss the possibility of starting the measurement of pebble bed thermo-mechanics of newly developed breeder pebbles as a new Working Group, separately from WG-P.

5) WG-J: The activity of “Design Database for Solid Breeder Blankets and Test Modules” is decided to be terminated.

As one of most important activities in this Subtask group, the International Workshop of Ceramic Breeder Blanket Interactions (CBBI) is performed once in every 2 years. The 16th International Workshop of Ceramic Breeder Blanket Interactions (CBBI-16) was held in Portland, USA, on Sept. 8-10, 2011, hosted by UCLA. Twenty four papers were presented. Three topical panel discussions were performed. Major essential achievements of solid breeder blanket development were covered.

2. Summary of Work Plan in 2012

Work plan in 2012 was discussed in the 17th subtask group review meeting. It was agreed to continue the on-going working groups of L, M, N, O and P in 2012. The detailed report of the work plan in 2012 is attached as Attachment 2. Major topical plans are as
follows.

1) WG-N: Comparison between analysis and experimental observations on tritium release behavior of breeder pebble bed will be performed to confirm the consistency of the developed codes. Also, new efforts on development of analysis models will be started.

2) WG-O: Experimental evaluation will be performed with the same configuration of test specimen by gas-gas system and gas-water system. Also, newly started two experimental works will be worked.

Regarding the meetings, the 18th review meeting is planned during the SOFT 2012 in Belgium, before the Ex-Co meeting. Regarding the CBBI-17 in 2013, the date and place of will be discussed in a year, after the locations and time schedules of ISFNT-12 and ICFRM-12 are decided.

3. New Task Proposal
(1) The PIE to follow WG-G
The discussion of new Working Group on the PIE of irradiated pebble beds by WG-G (HICU) will be continued.

(2) Possible new Working Group of pebble bed thermo-mechanics measurement for newly developed pebbles
It was proposed to discuss the possibility of starting the measurement of pebble bed thermo-mechanics of newly developed breeder pebbles as a new Working Group, separate from WG-P.

4. Coordination of Working Groups
The Contact Person List was updated for the on-going Working Groups as shown in Table 1.

5. List of Attachments
Attachment 1: 2011 Activity review report
Attachment 2: 2012 Work Plan of Activities

Table 1 List of Contact Person of Working Groups in Annex 1 Subtask 1, Solid Breeder Blanket (Nov. 2011)
(under lined person is the WG Leader)

<table>
<thead>
<tr>
<th>WG</th>
<th>China</th>
<th>EU</th>
<th>India</th>
<th>Japan</th>
<th>Korea</th>
<th>RF</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>WG-L</td>
<td>Long Zhang/Yongjin Feng(SWIP)</td>
<td>A.J. Magleisen /A. V. Fedorov (NRG)</td>
<td>P. Chaudhuri /A. Sircar (IPR)</td>
<td>M. Enoeda (JAEA)</td>
<td>Mu-Yong Ahn (NFRI) (temporary)</td>
<td>A. Ying (UCLA)</td>
<td></td>
</tr>
<tr>
<td>WG-M</td>
<td>Yongjin Feng(SWIP)</td>
<td>Ratna Annabattala (KIT)</td>
<td>P. Chaudhuri (IPR)</td>
<td>M. Enoeda (JAEA)</td>
<td>Mu-Yong Ahn (NFRI) (temporary)</td>
<td>A. Ying (UCLA)</td>
<td></td>
</tr>
<tr>
<td>WG-N</td>
<td>Kaiming Feng(SWIP)</td>
<td>L. A. Sedano (CIEMAT)</td>
<td>P. Chaudhuri (IPR)</td>
<td>Y. Seki / M. Enoeda (JAEA)</td>
<td>Mu-Yong Ahn (NFRI) (temporary)</td>
<td>A. Ying (UCLA)</td>
<td></td>
</tr>
<tr>
<td>WG-O</td>
<td>Kaiming Feng(SWIP)</td>
<td>David Demange (KIT)</td>
<td>P. Chaudhuri /A. Sircar (IPR)</td>
<td>H. Tanigawa (JAEA)</td>
<td>Mu-Yong Ahn (NFRI) (temporary)</td>
<td>B. Merrill (INL)</td>
<td></td>
</tr>
<tr>
<td>WG-P</td>
<td>Yongjin Feng (SWIP)</td>
<td>R. Knitter (KIT)</td>
<td>P. Chaudhuri (IPR)</td>
<td>T. Hoshino (JAEA)</td>
<td>Mu-Yong Ahn (NFRI) (temporary)</td>
<td>V. Kapyshev /V. Kovalenko (NIKIE)</td>
<td>R. Kurtz (ORNL)</td>
</tr>
</tbody>
</table>
2011 Activity review report:
Subtask 1 Solid Breeding Blanket

1. Meetings
One subtask review meeting was held on Sept. 10, 2011, in Portland, USA, the details are described in 1.1.
Also, the International Workshop of Ceramic Breeder Blanket Interactions (CBBI) was held from 8th to 10th, Sept. 2011 in Portland, USA, hosted by UCLA. 24 papers were presented. 3 topical panel discussions were performed. Major essential achievements of solid breeder blanket development were covered. Details of CBBI-16 is described in 1.2.

1.1 17th review meeting of the Subtask Group on Solid Breeding Blanket
Date: 10th of September, 2011
Place: Portland, USA
Participants: 15
STG members: M. Enoeda(Japan), L. V. Boccaccini(EU), A. Ying(US), P. Chaudhuri (India), V. Kapyschev for V. Kovalenko (RF), K. Feng (China), Mu-Young Ahn (Korea)
Experts: S. van Til (NRG), T. Hoshino (JAEA), Y-H Park (NFRI), D. Demange (KIT), M. Kolb (KIT), R. Annabattula (KIT), X. Chen (CAIP), Y. Feng (SWIP)
The activities are summarized in section 2.

1.2 CBBI-16
Date: 8th - 10th of September, 2011
Place: Portland, USA
Host: UCLA
Participants: about 25

Twenty four papers were presented summarizing the latest achievements of the world’s blanket research activities. The topics presented covered the following areas, including a lecture on the Overview of the Pebble Bed Assembly Experiment:
- Progress in Ceramic Breeder Material Development, Properties and Characterizations
- Irradiation Testing, Tritium, and Recent Results
- Modeling and Experiments of Pebble Bed Thermo-mechanics and Properties
- Modeling and Laboratory Experiments
- Evolutions in Solid Breeder Blanket Design, Including ITER TBM
Also, 3 topical panel discussions were performed:
- Tritium Breeding Material R&D Outlook
- Current status and outlook of thermo-mechanics research and development for blanket pebble beds
- Modeling Development Direction and Plan

As the general observation, research and development efforts are being guided more and more to achieve a complete integration of solid breeder blanket technology with higher degrees of reliability, performance and universality. It was noted that new breeder pebble material developments are now active. Also, new pebble bed thermo-mechanics experiments and hydrogen permeation experiments were now started. It was expected that these new activity will show important progress.
2. Major outputs
Two papers on the achievement review were presented as the invited papers in the ISFNT-10 and ICFRM-12.
The results of the review meeting can be summarized as follows.

2.1 Review of on going activities

**Working Group G; High fluence irradiation of ceramic breeder pebble beds**
The goal of irradiation experiment (HICU) has been achieved, as planned, DEMO relevant Li burn up and dpa with DEMO relevant dpa – Li burnup (dpa/%BU > 1.1).
Thus, this Working Group was closed successfully. The planning of the post irradiation examination (PIE) and its tools has been performed. A new Working Group on the PIE has been discussed.

**Working Group J; Design Database for Solid Breeder Blankets and Test Modules**
This working group has been decided to be stopped, because intellectual property rights of the data cannot be preserved when compiled data from the literatures are made accessible.

**Working Group L; Tritium control in solid breeder blankets including purge gas conditions**
Since almost all data from EXOTIC experiments were already analyzed, this Working Group will be finalized after confirmation.

**Working Group M; Assessment of ceramic breeder pebble bed/coolant structural wall interface integrity**
Literature review was performed for clarification of the current status of evaluations of thermo-mechanics of breeder and multiplier pebble bed structure. It was clarified that benchmarking effort is important further.

**Working Group N; Development and validation of computational tools for describing the H isotopes transport in the breeding zones of the pebble bed blankets**
Previously, calculation codes were previously developed for the simulation of tritium behavior inside breeder pebble bed. This year, progress was made on the purge gas flow visualization experiment using a pebble bed test setup, for the purpose of validation of flow near the wall of the breeder pebble bed. It was shown that flow visualization of the purge gas flow in the pebble bed can be done by water as the working fluid, using pebbles made by MEXFLON, whose optical properties are the same as the water.
In EU, Literature review was performed to get the state of the art on tritium transport computational tool, and benchmarking / performances analysed. Two models were learned, one developed by UCLA, benchmarked by in pile T release, and another by Kyushu University, benchmarked by out of pile T release from irradiated breeder pebbles. By the review, it was recognized that coupled phenomena, such as, ageing effect (burn up, defects, chemical change…) and the effect of magnetic field and other external environments, needs to be considered. Also, development of tritium transport computational tool to support the design of tritium processes was performed, based on TMAP (especially developed for permeation), including processes / components, and chemistry (isotopic equilibria, oxidation potential). Presently, the code is being refined to predict “parasitic effects” for TBM experiments (tritium lost along TBM and processes, not available for accountancy).

**Working Group O; Evaluation of tritium permeation rate and permeation reduction factor**
In the real operation conditions of the working fluids
In this Working Group, new experimental setups were started in Korea and RF. In Korea, HYPER (HYdrogen PERmeation) facility was installed. HYPER is an experimental setup for measurement of hydrogen isotopes permeation through a disk specimen and tube-type specimen. In RF, a laboratory facility for investigation of hydrogen permeation through structural materials (T=100-500 °C, P(H₂/D₂~0.1 MPa)) was installed. Also, development of reactor experimental facility for investigation of tritium release through structural materials under reactor irradiation (T=100-500 °C, neutron flux ~ 10¹⁴ n/s/m²) is going on.

Working Group P; Characterization of newly developed ceramic breeder pebbles
As the activities of “Characterization of newly developed ceramic breeder pebbles”, measurement apparatus list which includes all available measurement apparatus of all members, were generated. Also, additional expected evaluation items, such as the evaluation of equilibrium vapor pressure of Li containing compounds, are discussed and added to the list of measurement apparatus list. Also, efforts of new measurement apparatuses of pebble bed thermo-mechanics have been performed by China, India and Korea. It was proposed to discuss the possibility of starting the measurement of pebble bed thermo-mechanics of newly developed breeder pebbles as a new Working Group, separately from WG-P.

3. Collaboration with other IEA activities
3.1 Collaboration with IEA-IA Fusion Materials
Information exchange on design of the blanket was performed with the IEA-IA Fusion Materials, Reduced Activity Ferritic / Martensitic Steels (RAFMS) Group.
2012 Work Plan of Activities: 
the Subtask Group on Solid Breeding Blanket

1. Meetings
A review meeting and a workshop are scheduled in 2012.

1.1 the 17th Review meeting of the Subtask Group on Solid Breeding Blanket
Date: During 24th - 28th Sept. 2012
Place: as an SOFT 2012 satellite meeting in Liege, Belgium.

1.2 the 17th International Workshop on Ceramic Breeder Blanket Interactions (CBBI-17)
The place and schedule will be discussed and proposed in a year.

2. Work Plan in 2012

2.1 Work Plans of the ongoing activities

Working Group L; Tritium control in solid breeder blankets including purge gas conditions
This Working Group will be concluded in 2012, after confirmation of analysis progress.

Working Group M; Assessment of ceramic breeder pebble bed/coolant structural wall interface integrity
This Working Group will be continued. Experimental apparatus development will be continued.

Working Group N; Development and validation of computational tools for describing the H isotopes transport in the breeding zones of the pebble bed blankets
This Working Group will be continued. The efforts on comparison between analysis by developed codes and experimental observations on tritium release behavior of breeder pebble bed will be worked to confirm the consistency of the developed codes. Also, new efforts on development of analysis models will be started.

Working Group O; Evaluation of tritium permeation rate and permeation reduction factor in the real operation conditions of the working fluids
This Working Group will be continued. Experimental evaluation and comparison will be performed with the same configuration of test specimen by gas-gas system and gas-water system. Also, newly started two experimental works will be worked.

Working Group P; Characterization of newly developed ceramic breeder pebbles
This Working Group will be continued.

2.2 Proposal of New Working Group
Possible new WG will be discussed. If possible, the new WG will be proposed on “Thermal conductivity measurement of Newly Developed Ceramic Breeder Pebble bed with Compressive Loads”.

3. Collaboration with other IEA activities
3.1 Collaboration with IEA-IA Fusion Materials
Information exchange will be planned with the IEA-IA Fusion Materials, Reduced
Activity Ferritic / Martensitic Steels (RAFMS) Group. Adaptation of RAFM materials in French regulation of pressure vessel will be discussed.
Annex I

2011 Activity Summary Report and 2012 Work Plan of
Subtask 2: Liquid Breeder Blanket
Author: Neil Morley, Dai-Kai Sze

2011 Activity Summary Report of
Subtask 2: Liquid Breeder Blanket

1. Activities in 2011
The Chair of this subtask, Dai-Kai Sze, resigned from the Chairmanship due to his physical condition. Prof. Neil Morley was named as the US representative and the chair of this subtask at the end of 2011. This report is summarized by Dr. Dai-Kai Sze outline the direction and the achievement of this task during the past few years, and the possible future direction of this subtask.

The R/D program of the liquid breeder task is a complicated one. The issues depend on the selection of the breeding material, the structural material, the neutron multiplier (if any), the coolant, the flow velocity, and the blanket concept itself. Therefore, it is important to select a common issue which will be of interest to all the parties.

The important liquid breeders include liquid lithium, LiPb and molten salt. Aligned with the proposed ITER Test Blanket Module (TBM) concepts being developed, it was clear that LiPb is the only liquid breeder to be selected by all the liquid TBM concepts, with RAFS as the structural material. There are many TBM concepts proposed based on LiPb. After much discussion, it was agreed that tritium issues on LiPb are of interest to all LiPb based blankets. Also, there are large uncertainties on the database on tritium interaction with LiPb, such as tritium solubility, tritium recovery, tritium control and insulating coating development and its effectiveness.

The most significant research on tritium interaction with LiPb were carried out by EU. To support this collaboration, R/D programs were set up at US (INL) and many Japanese universities. Many good results have been obtained and will be discussed later.

There are many important technical areas within the liquid breeder area that need to be investigated and can be a part of the IEA collaboration. Some important areas are corrosion and corrosion product transport, and MHD and its impact on heat and mass transfer. Those technical areas, and maybe other, can be included in the future to be a part of the IEA collaboration.

The elements of the tritium interaction with LiPb are discussed here:

1. Breeding material definition: The Li atomic fraction (15.8% Li), and the allowable impurities level were agreed. Different parties have produced LiPb based on this definition. The Li atomic fraction may impact the chemical activity of Li which will cause tritium solubility much larger than just the atomic fraction. The impurity level will have impact on corrosion, as well as tritium solubility.

There was discussion that a strong effort should be made to produce common source of LiPb. By using the same material, the results obtained should be more consistent. This is important to compare the results from different party.
However, we could not find any party willing to supply the required material. Future effort should be made to make a large heat of LiPb and experimental program can use the same material.

2. Tritium solubility measurement: The tritium solubility defines the relationship between tritium concentration in LiPb, and the tritium partial pressure over LiPb. All the tritium related work, including the tritium recovery, tritium control, depends on the tritium solubility. Most work of tritium solubility measurements were done in EU, US and Japan. However, the divergence of the results covered four orders of magnitude. There are many reasons that the results have such large uncertainties. They include the different LiPb materials, the different ways of measurement, the uncertainties of instrumentation, and the different Q (H+D+T) concentration, and other reasons.

It was clear that much better data on tritium solubility will be needed develop the blanket tritium system. New R/D programs were set up to measure the tritium solubility. The new results obtained during the past two years show the uncertainty of the results were reduced to one order of magnitude.

Future work will be required to reduce this uncertainty from a factor of 10, to maybe a factor of two. Dr. Calderoni suggested to do a broad review of the experimental programs to understand the reason of the divergence of the results. This effort was delayed due to his change of position. The effort to review the experimental programs identify the impact of the experimental processes to the solubility results will be very important. It should be on the list for the future activities.

3. Tritium recovery: Most of the work on the tritium recovery from LiPb was done in EU. The process was based on gas/LiPb contact. The identified recovery efficiency was less than 30%. However, the recovery efficiency used on some TBM design was as high as 95%.

US suggested a tritium recovery process based on permeation process. In this process, LiPb can flow in a high turbulence regime thus minimize mass transfer resistance in the liquid phase. INL proposed to set up an experimental program to develop this process. However, proper funding of this project was not available.

High tritium recovery efficiency can reduce both the tritium inventory and tritium partial pressure. It is a starting point to solve the tritium control issues. (Tritium partial pressure is the driving force for tritium permeation.) Therefore, highly efficient tritium recover process needs to be developed.

For the gas-liquid contact process, it is important to identify which step is the rate limiting process. Only if the rate limiting step is identified and eliminated, the recovery efficiency can be improved.
For the permeation process, the key problem is the contamination of the permeation window material. The allowable impurity level, and the process to keep to the level, has to be identified.

4. Tritium control: For a commercial power plant, an allowable tritium loss rate is thought to be ~10 Ci/d. The loss rate of CANDU is much higher than that, with much lower tritium production rate and circulation rate. A process to limit tritium loss rate to below 10 Ci/d, and the required steps to reach that limit need to be developed. Those steps include, but not limit to:

- Proper tritium solubility
- High efficiency tritium recovery process
- Reliable tritium permeation barrier
- Efficient tritium recovery from He
- He loop design with low He loss rate
- Highly efficient RADS (Room Air Detrition System)

Much work will be required on the development of this process. Collaboration with other task areas such as solid breeder, material, safety and tritium, will be necessary. Collaboration with ITER

Over the past year, there has also been an increase in PbLi Blanket research and research facilities including several new or upgraded PbLi flow loops studying MHD interactions and corrosion in the US (see fig.1), RF, CN, KO. These new facilities will augment existing facilities in the EU and JA and can provide an additional focus for future collaborations on PbLi based blankets.
Fig. 1. Newly constructed MHD PbLi loop at UCLA: maximum pumping capacity – 50 l/min, maximum pressure head – 0.15 MPa, maximum magnetic field – 1.8 T. (courtesy of S. Smolentsev, UCLA)

1 – PbLi melting tank with heaters, 2 – glove box, 3 – EM pump, 4 – EM flow-meter, 5 – piping, 6 – electromagnet, 7 – data acquisition system.
2012 Work Plan of
Subtask 2: Liquid Breeder Blanket

The collaboration in 2012 can be summarized as follows.

- The focus of tritium interactions with PbLi will be continued. The concept to prepare a large heat of PbLi in order to perform tritium solubility and diffusivity measurements on a consistent sample will again be pursued.
- Possible new foci:
  1. PbLi flowloop and instrumentation technology
     - With the addition of several new PbLi flowloops in different parties, it may be useful to add a theme on flowloop and instrumentation technology for high temperature PbLi.
  2. Benchmark problems for MHD code development
     - Several years ago, a benchmark LM-MHD problem was proposed based upon experiments performed in the USA. This exercise continues to be successful as new researchers developing sophisticated MHD code capabilities still use it for code validation.
     - Continue this practice to catalog additional high quality experimental data from current experimental programs such that they can be used for code validation by interested parties now and in the future.
- The new Subtask Leader will look for an opportunity for a workshop in 2012, likely attached to an existing meeting.
1. Meeting
The IEA Meeting on Fusion Neutronics was held in Portland (Oregon, USA) on 13th September 2011, during the 10th International Symposium on Nuclear Fusion Technology (ISFNT-10). It was attended by 23 participants from China, EU, Korea, Japan, USA, and by observers from ITER IO and F4E. Unfortunately, no representatives from the Russian Federation and from India could attend the Meeting. No report of Russian Federation activities has been received.

2. Activities in 2010

2.1 TBM and shielding neutronics experiments (EU, JA)
The east Japan great earthquake on 11th, March, 2011, gave JAEA/FNS to a serious damage for the high voltage part. The recovery from the damage is delayed and FNS is still off-line. Hopefully FNS will re-start next year. Nevertheless, the following experiments and analyses from October, 2010 to September, 2011 were carried out.
In order to study the tritium recovery ratio in Li$_2$TiO$_3$ breeding blanket, a tritium recovery experiment has been performed at FNS facility in JAEA. In this study, an online experiment during DT neutron irradiation was conducted. The Li$_2$TiO$_3$ pebble of 70g was put into a container which was set up into a Be assembly. The Li$_2$TiO$_3$ pebble was heated up to a constant temperature (573 K). He sweep gas including H$_2$ (1%) was flowed and extracted tritium was collected to water bubblers during DT neutron irradiation. The tritium recovery system was arranged to measure tritiated water vapor (HTO) and tritium gas (HT), separately, and to investigate the time dependency of the tritium recovery ratio. The tritium recovery ratio was 0.95 ± 0.08 and it was expected that the tritium recovery of Japanese TBM had a good prospective. The collected HTO recovery fraction was larger than the collected HT one, and the time response of the collected HT was slower than that of the collected HTO.
A new integral experiment with a DT fusion neutron beam started in order to validate scattering cross section data. First the DT neutron beam was constructed with a collimator. The performance of the collimator system and the characteristics of the DT neutron beam were measured. Then the experiment for type-316 stainless steel was carried out with this DT neutron beam. Reaction rates of the $^{93}$Nb(n,2n)$^{92m}$Nb reaction in the assembly were measured with the activation foil method and were calculated with the Monte Carlo transport calculation code MCNP. The ratio of calculation to experiment of the $^{93}$Nb(n,2n)$^{92m}$Nb reaction rate became smaller than 1 with the distance from the beam axis. It was indicated that larger angle scattering cross section data has problem. Finally, JAEA succeeded in producing a large tritium target for FNS. It was produced by absorbing tritium in an evaporated thin Ti layer on disk-shaped copper-alloy substrate. It is essential to remove residual gas, particularly humidity, from the Ti layer and substrate because residual gas blocks the tritium absorption. An adsorption chamber was developed and it was found out a condition for the tritium adsorption through many deuterium adsorption
tests to the titanium. The amount of the adsorbed tritium of the large target was about 26 TBq, and the initial DT neutron generation rate was $1.7 \times 10^{11}$ n/sec/mA. This performance was very good compared with commercial ones.

In the EU, the experiment on a LiPb mock-up of the EU TBM - HCLL concept has been completed. The objective was to validate the capability of nuclear data to predict nuclear responses, such as the tritium production rate (TPR), with qualified uncertainties. The experiment has been conducted at FNG in collaboration between ENEA, Technical University of Dresden (TUD), KIT, University of Science and Technology Krakow (AGH) and the Josef Stefan Institute of Ljubljana, with the participation of JAEA. In the experiment, the TPR has been measured by independent measurements, using Li$_2$CO$_3$ pellets, TLD-LiF detectors and diamond detectors by ENEA, TUD, AGH and JAEA. Direct tritium measurement in LiPb material has been obtained for the first time by EU (AGH) by direct measurement of $^3$H activity generated by neutrons in LiPb material. The analysis of the experimental data, including also the measurement of the neutron flux spectra at TUD neutron generator, has demonstrated that the Li content in PbLi has a non natural isotopic composition. In particular, it has been demonstrated using various techniques that the Li-6 content is significantly reduced at 3.48% level (to be compared to 7.5% natural value). Having defined the material composition, the analysis of the experiment has been completed. Both FENDL-2.1 and JEFF-3.1 nuclear data libraries can accurately predict the TPR in HCLL blankets. The C/E ratios for the TBR are close to unity within the total uncertainty (±5.7%).

Preparation for experiments for Neutronics TBM has continued in EU (KIT, ENEA) with detector development and testing. In particular, diamond detectors have been tested at FNG at high temperature, up to 200 °C. Other detectors investigated were Li glass scintillator, self-powered neutron detectors, Li glass detector, SiC schottky diode, for their possible use in TBM.

EU (ENEA, KIT) completed the analysis of the shutdown dose rate experiment performed at JET in 2010 with the purpose to validate shut down dose rate calculation methods. The experiment was carried out taking advantage of JET shutdown for the installation of the ITER-like Be wall, and consisted in the measurements of dose rates in front of Octant 1 port (with closed and open flange), and inside the port at different distances up to the centre of the vacuum vessel, up to more than 7 months after shutdown. The analysis was carried out using both D1S and R2S methods. In both cases, a good agreement has been found with experimental results within experimental uncertainty (±30%).

Finally, in the UK a neutron generator primary standard for 14 MeV neutrons (ASP) will be used by CCFE in the frame of a collaboration for fusion neutronics studies, mainly for radiation hardness testing for electronic equipment, and for nuclear data validation. Recent work included 54 activation experiments to assess measurement feasibility and facility capability (fluence $\sim 10^{12}$-$10^{13}$ n/cm$^2$). Irradiated samples were extracted quickly via a ‘rabbit’ transfer system (4-6 s) and the short-lived reaction products were measured via gamma spectrometry. A new experimental campaign, scheduled for December 2011, will focus on improve estimate of neutron spectrum and fluence.

An experiment for the characterization of deuterium ion beam for Intense 14-MeV Neutron Generator was carried out at IPR in India. In this experiment an ECR ion source is used to produce deuterium plasma and deuterium ions are extracted up to 20 KeV. The ion beam is accelerated up to 300 KeV and then it strikes a Tritium target to produce 14 MeV neutrons. The neutron flux is strongly dependent on the stability, shape, energy and intensity of the beam. For diagnostic of beam parameters, a beam profile monitor (BPM) and Faraday Cup
have been installed in the beam line. In BPM, a single grounded wire formed into a 45° segment of a helix is rotated by a motor about the axis of the helix. During each full revolution, the wire sweeps the beam to give x and y profiles. By using of BPM, we have measured the position, shape, size and intensity distribution of the deuterium ion beam.

A moderator for BF$_3$ long counter (107 cm active length and 5cm diameter from CENTRONIC) has been designed. The counter is used to monitor neutrons in the energy range of 10keV to 5MeV. It is filled with a mixture of BF$_3$(Boron Trifluoride) gas and Ar gas at a pressure of 70 cm Hg. Boron in BF$_3$ is enriched up to 96% in $^{10}$B. The proportional counter was placed inside a moderator assembly block of high-density polypropylene (HDPE) and other materials optimized for efficient neutron moderation. A 16Ci Am-Be neutron source is employed to carry out the experiments to calibrate the energy and efficiency of BF$_3$ counter with the moderator assembly. MCNP code was used to optimize the moderator design for dimensions and for choice of materials. The detector signals were simulated and compared with the experimentally measured values.

An experiment to measure the absolute neutron yield of the 14 MeV neutron generator using water activation techniques was undertaken. A stainless steel loop was designed and fabricated to flow the water around neutron generator and γ-ray spectrometer. The induced γ-ray activity of $^{16}$N was measured with NaI(Tl) detector system. From this activity neutron flux was measured.

Finally, the effect of foil thickness on fissile fuel breeding has been measured using Neutron Activation Analysis. The 14-MeV neutrons produced in (d,t) fusion reactions have the potential of breeding Uranium-233 fissile fuel from fertile material Thorium-232. In order to estimate the amount of U-233 produced, experiment was carried out by irradiating thorium foils of different thickness with neutrons produced from 14-MeV neutron generator. Induced gamma rays activity was measured with High Purity Germanium (HPGe) detector. From this activity reaction rates of Th-232(n,γ)U-233 in different foil thickness were calculated and the correction factor as a function of thickness was found. To estimate the amount of fissile fuel (Uranium-233) produced, the 312 keV (1γ 38.6%) gammas emitted by Protactinium-233 ($T_{1/2}$ = 27 days) was measured using the High Purity Germanium (HPGe) detector. The amount of Th-233 produced by the (n,γ) was calculated using the Monte Carlo code MCNP. The self-shielding effect is determined by calculating the reaction rates for different foil thicknesses. The neutron transport calculation results are compared with the experimental values and suitable correction factors for self-shielding of neutrons and absorption of gamma rays for various thicknesses of foils are estimated.

In China, the design of the Accelerator-Based Fusion Neutron Source (HINEG, D-T neutron production rate in the range $10^{10}$~$10^{13}$ n/sec) has started. It is designed for neutronics experiments (validation of codes and data, nuclear data measurement, materials activation and irradiation), radiation protection studies (neutron shielding, neutron detection, neutron effects on biological tissues) and other nuclear technique applications.

### 2.2 Neutronics Research & Development

In EU, CCFE continued the development of the MCR2S code (MCNP transport and the FISPACT activation codes to perform shut down dose rate calculations with Rigorous 2 Steps (R2S) approach with very high spatial and energy resolution via mesh tallies) and the automated MCNP global variance reduction (GVR) methods required for “global” problems such as shielding and activation dose analyses.

KIT continued the development of the CAD - Interface McCad for MCNP, latest work being dedicated to improvement of stability and to extension of the read capabilities for MCNP geometry.

McCad has been applied to TBM system and IFMIF analyses. The R2S technique has been further extended to calculation of shutdown dose rate distributions on superimposed mesh tallies (R2Smesh technique). The technique has been verified in ITER shutdown dose rate
benchmark, benchmarked against FNG shutdown dose rate experiment, and finally applied to ITER shutdown dose rate analyses (NBI, EPP, TBM).

At University of Wisconsin – Madison, substantial improvements have been made to the DAGMC software library that is used to create DAG-MCNP5. In order to approach a guarantee of no lost particles during Monte Carlo simulation of complex geometries, a series of related improvements were implemented in the core infrastructure: an implicit complement to avoid defining the void regions explicitly, watertight repair of all surfaces and curves, a numerically robust tracking algorithm, and modifications to accommodate small overlaps. At the same time, the capability to perform mesh tallies on unstructured tetrahedral mesh has been demonstrated. In general, this provides the benefit of tallying results in single materials, even if those materials have complex boundaries. In practice, this simplifies the process of providing nuclear heating to thermal analysis tools during a multi-physics analysis and permits the visualization of results on complex regions.

For China, ASIPP-USTC reported the further development of an integrated multi-functional neutronics analysis system, named VisualBUS, including codes for coupled calculations, automatic modeling of Monte Carlo geometries (MCAM) to support MCNP/TRIPOLI and now also FLUKA/GIANT4, discrete ordinates geometries (SNAM), MC-SN coupled geometries (RCAM), and visualized analysis. It can be used for neutron transport calculations, fuel burn-up, material activation & radiation damage, radiation dose, fuel cycle management etc. It employs CAD-based modeling, time-dependent physics processes coupling, 4D visualized analysis and web-shared and user-friendly GUI.

A new super Monte Carlo simulation program SuperMC has been started. It adopts parallel computing, cloud computing and intelligent computing technologies. It is easy extended and maintained due to networked open architecture. It is developed from learning from advantages of main state-of-the-art codes MCNP / TRIPOLI / Geant4 / FLUKA / EGS etc..

Supporting components include Hybrid Evaluated Nuclear Data Library for fusion/fission/hybrid systems, and interfaces for other physics process simulations such as thermal-hydraulics, mechanics, safety, environmental impact and economics. Visualized analysis codes include SVIP (Integrated Scientific Visualization Platform for Neutronics) for mixed rendering of static / dynamic physical data fields and model geometry, RVIS (Radiation VIrtual Simulation System for Dosimetry) for virtual roaming of human and dosimetry assessment in radiation environment, FVAS (Fusion Virtual Assembly System for Assembly Planning) for virtual assembling of component models. SVIP has been designed to directly support many state-of-the-art neutronics codes and, recently, the visualization capabilities to MCNP mesh tally results have been implemented to supports various styles of visualization, such as iso-surface, color map and volume rendering. It supports mixed visualization with data and geometries and provides also four-dimensional visualization of time-varying data.

2.3 Nuclear data
JENDL-4 was released in May, 2010. Its official multigroup library MATXSLIB-4.0 of 199 neutron groups and 42 gamma groups with up-scattering data and thermal scattering law data was also released in September, 2010. We examined a validation of MATXSLIB-J40 through analyses of benchmark experiments at JAEA/FNS with Sn codes and the Monte Carlo code MCNP. As a result, the following results are obtained. 1) The calculated results with Sn codes and MATXSLIB-J40 agree well with the measured data and the calculated ones with MCNP. The self-shielding correction in MATXSLIB-J40 has no problem. 2) It is notable that thermal
neutron peaks, which were hard to represent, are adequately calculated. It is strongly recommended that a multigroup library of the next Fusion Evaluated Nuclear Data Library (FENDL), FENDL-3, should also have 199 neutron groups, up-scattering data and thermal scattering law data.

In the EU, data validation for the European Activation file (EAF) progressed in 2011 with measurements and analysis of activation of Co and Cr at FNG, of Pb at AGH-UST and Co, Nb at NPI-Rez/KIT. The neutron induced decay heat on samples of Co and Cr irradiated at Frascati Neutron Generator (FNG) in an First wall-like neutron spectrum has been measured and compared with EAF-2007 predictions. Concerning the Co gamma decay heat, a slight overestimation of the calculated heat at about 20 hours of decay time was found but within the uncertainties. For longer times a slight underestimation is found. As for the beta decay heat, a 10% overestimation of the calculated heat up to 20 hours of decay time was found within the uncertainties. For longer decay times there is an underestimation. The EAF2007 data for the reactions $^{59}\text{Co}(n,2n)^{58}\text{Co}$ and $^{59}\text{Co}(n,p)^{59}\text{Fe}$ could be responsible for the observed discrepancy. The Cr gamma decay heat is strongly underestimated at short times by EAF2007 while an overestimation for short decay time and an underestimation for longer times is found for the beta decay heat.

$^{203}\text{Hg}$ isotope produced in LiPb and Pb material irradiated at FNG by $^{206}\text{Pb}(n,a)$ and $^{207}\text{Pb}(n,n')a$ reactions was measured and compared with calculation using MCNP with JEFF3.1.1, FENDL2.1, JENDL4.0 libraries and EAF2010 calculation results are presented as well. Very good agreement was found for JEFF, EAF2010 and JENDL calculations. Calculated results with the use of FENDL library are strongly overestimated. Measurements of $^{59}\text{Co}$ and $^{93}\text{Nb}$ activation cross sections in a quasi-mono energetic neutron spectrum (<35 MeV) was needed for IFMIF application. Samples were irradiated with quasi-monoenergetic neutrons from p+Li/C, gamma activity and reaction rates were measured and cross sections were derived up to E = 40 MeV using Modified SAND-II code.

### 2.4 Nuclear Design Analyses

Korea has been developing a solid-type Test Blanket Module, named Helium Cooled Solid Breeder Test Blanket Module (HCSB TBM), to be tested in the ITER. This device uses the pebble type material in the tritium breeder, neutron multiplier and neutron reflector region. The neutronics analysis should be performed iteratively to search for optimal design values for the HCSB TBM. In this process, the complexity and randomness of the pebble type geometry make a straightforward neutronics calculation inefficient. For this reason, it is necessary to apply a simplified model for the pebble regions in the design process. Sensitivity study of the pebble geometry and the simplified model was preceded in the neutronics analysis as the initial step of HCSB TBM design.

The nuclear data evaluation team in Korea Atomic Energy Research Institute (KAERI) has been involved in the Korea TBM design project as a neutronics analysis group since April, 2011. MonteBurns ver. 1.0 code system consisting of MCNP5 ver. 1.30, a modified ORIGEN ver. 2.1 and FENDL 2.1 was used in the neutronics analysis for the Korea TBM design until 2010. In 2011, the code system was replaced by MonteBurns ver. 2.0 which has MCNP5 ver. 1.40, CINDER 1.50 and FENDL 2.1. Benchmark calculation of the two code systems was performed.

In the USA, in support of the ITER blanket design detailed profiles of nuclear heating were determined using 2-D models. Tabulated results were provided over a fine mesh to use for engineering analyses. These profiles are significantly impacted by the variation in water
content with larger SS heating in zones with larger water content due to enhanced gamma generation. The SS helium production values in regions with large water content are enhanced due to production by low energy neutrons in B and Ni. While these 2-D profiles are useful for quick evaluation of the different blanket module design options, detailed 3-D analysis using the CAD-based Monte Carlo code (DAG-MCNP) is underway for three blanket modules. The detailed CAD models for each individual module are inserted in the most recent global ITER model with the accurate source profile to determine a high-resolution map of nuclear heating. In addition, detailed DAG-MCNP 3-D analysis was performed for the ITER in-vessel ELM control coils. Nuclear heating and damage parameters were determined for the CuCrZr conductor and MgO insulator. In addition, the peak heating, dpa, and helium production in the vacuum vessel behind the ELM coil and multi-pipe manifold were determined. Another application to ITER was utilizing the ORNL Monte Carlo/deterministic hybrid methods (CADIS and FW-CADIS) to generate a detailed map of the prompt dose in and around ITER during operation using the A-lite03 MCNP model. With more than 16 orders of magnitude attenuation, this technique proved to speed up the MCNP calculation significantly with accurate results behind the bio-shield.

DAG-MCNP was also utilized for nuclear analysis of several conceptual designs for fusion power plants as part of the US project ARIES. DAG-MCNP 3-D neutronics analysis was performed for FDF which is proposed in the US as a next step fusion nuclear science facility. Two blanket concepts were considered; Dual Coolant Lead Lithium (DCLL), and Helium Cooled Ceramic Breeder (HCCB). The results indicated that the PF coil in the divertor region must be moved vertically farther away from the mid-plane to allow adding ~15 cm of shield which will be implemented in the new baseline design.

The adaptation of the 3-D FEM Discrete Ordinates code, ATTILA in ITER design has also made a progress. Both the serial version and the distributed memory parallel version of ATTILA-7.0 have been used to assess the global dose rates in ITER diagnostics ports. This includes the mapping of these dose rates in the interspace extension areas of the upper VIS/IR port, the equatorial port 3 (EQ3), and the lower divertor port 8 (LP8) which houses the components of the interferometer diagnostics. A dose rate of a 100 µSv/hr has been set as an upper target value inside ports interspace areas such that routine maintenance can be performed ~12 days following shutdown. This recent work explores the impact of some design-oriented variations on the assessment of these dose rates such as considering the impact of activating some components of the model (vs. activating all components) and/or installing (or removing) relatively massive shield block from the large openings of LP8. Also examined is the impact of variations in the calculation-oriented parameters used in the Discrete Ordinates method such as the number of the energy groups and/or the number of angular directions used to describe the decay gamma transport. The A-lite04 ITER CAD model was used in this analysis along with the FENDL2.1/FORNAX data bases.

JAEA studied the lithium burn-up effects on TBR for DEMO. Lithium in a breeding blanket is burned up through neutron nuclear reactions in fusion DEMO reactors. For the SlimCS blanket design, TBR is calculated taking into account the lithium burn-ups by one dimensional Sn radiation transport calculation code ANISN in this study. The $^6$Li burn-ups are 8 - 79 % after 10-year operation. TBR due to $^6$Li decreases to 40 % of the initial one in some layer, while it increases in some layers. The total TBR integrated over all the blankets decreases to around 96 % of the initial one. It is found out that the reduction of the TBR due to the lithium burn-up is not so large.

In China, shielding design and analysis has been performed for EAST tokamak based on CAD models and the shutdown dose distribution has been evaluated. Personal and
environmental dose has being monitored by many kinds of detectors, such as ionization detectors, BF3 detectors, Bonner neutron spectrometers and Thermoluminescence detectors. Moreover, the Neutronics analysis of EAST-TBM has been performed. EAST-TBM is planned to test the blanket technologies in EAST prior to ITER.

The FDS team worked on a series of reactor designs, such as fusion-driven subcritical system FDS I, fusion power reactor FDS II, high temperature fusion reactor FDS III, spherical tokamak reactor FDS ST, fusion-fission hybrid reactor for spent fuel burning FDS SFB, and accelerator-driven subcritical system for nuclear waste transmutation ADS-CLEAR. ADS-CLEAR is a China Lead Bismuth cooled accelerator-driven reactor for nuclear waste transmutation. It’s based on spallation reaction and fission reaction. Its main functions include: energy production, fuel breeding and waste transmutation. It’s characterized by high safety margin, efficient transmutation and thorium fuel utilization instead of uranium.

Furthermore, many activities for supporting other’s reactor designs have also been performed, such as the compact reversed shear tokamak reactor CREST in Japan in collaboration with University of Tokyo, the force-free helical reactor FFHR in Japan in collaboration with NIFS.

In EU, all fusion neutronics groups actively participated in the ITER neutronics analysis. KIT performed nuclear performance & shielding analysis of the HCPB/HCLL Test Blanket Module System, and the nuclear design of the Neutral Beam Upper Port Shielding Block (shielding & shutdown doserate analyses), and of the In-vessel Viewing (IVV) System & Glow Discharge Cleaning (GDC) system (activation and shutdown dose rate analyses). Extensive parametric shielding and doserate analyses of the Equatorial Port plug (EPP) design options were performed. The EPP model was extracted from the full model and modified according to STEP files of CATIA drawings. Parametric studies were performed on the effect of straight/bent gaps dimensions on neutron fluxes nad doserates as function of distance from the first wall.

At ENEA, a new concept for the design of the ITER EPP1 is under investigation: it is based on a modular structure with three independent vertical drawers in which the diagnostic systems have to be re-arranged and integrated. Nuclear heating radial profiles for different toroidal and poloidal positions and the total heat load on the drawers were calculated and coupled to thermal and thermo-mechanical analyses. 3-D Neutron flux maps have been calculated to assess the effect of radiation streaming through all gaps and to verify the effectiveness of the new Port Plug concept in terms of shielding capability.

CCFE analysed the Test Blanket System (TBS) nuclear shielding and calculated the activation dose mapping in ITER in-vessel, port cell and galleries.

CCFE also performed the preliminary evaluation of decay heat and assessment of tritium self-sufficiency times including time varying neutron spectra in HCPB DEMO reactor, using HERCULES code.
Proposed activities in 2012 within Subtask Neutronics are as follows.

- Continue exchange of experimental data of recent experiments for nuclear data and code validation (in particular of HCLL mock up experiment)
- Continue uploading new benchmark experiments and data on SINBAD database of NEA Data Bank as soon as well established results are available
- Development of new database/methodology for cross-section sensitivity/uncertainty analysis: sensitivity to energy/angular distribution (SED, SAD)
- Collaboration on selection of most suitable plasma neutron source routines (mesh representation)
- Benchmark of routines used for 14 MeV neutron source calculations at different facilities
- IEA Neutronics Workshop dedicated to future Fusion Neutronics experiments to be organised in 2012
1. Co-ordination
In 2011, activities for ITER tritium technologies have been focused on the design and review of the tritium plant and a series of related R&D studies. In accordance with the discussions through workshops between EU and JA, Basic studies for tritium technology for a fusion DEMO reactor has been carried out under the BA (Broader Approach) program. A series of the discussions on the fundamental tritium technology under the IEA program becomes vital for the above BA and ITER activities.

Coordinators of this subtask are B. Bornschein (FZK/EU), R.S. Willms (LANL/US), V. Kapyshev (RF), S. Mohan (India), T. Wan (ABC/CN), K. M. Song (KEPRI/KO), and T. Yamanishi (TPL (Tritium Process Laboratory) of JAEC/JA). A new coordinator of Korea has been joined into our group from this year. The members of this subtask group convened at some ITER meetings and at ISFNT10. Some detailed discussions were also made through e-mails. These discussions were focused on understanding the mission of the subtask group, current activities of each institute, and priorities for R&D subjects in view of ITER and DEMO.

2. Collaborative Activities
  a) Tritium Accountancy Technology
  The Beta ray induced X-ray spectrometry (BIXS) method has been studied as a monitoring of tritium in the blanket system. It can measure tritium by counting the X-ray that is induced by interaction between the beta ray of tritium and the materials. To reduce the memory effect of tritium water, an advanced sensor of BIXS, which could be used at 150 °C, has been developed. The advanced BIXS monitor has showed the good performance at high temperature. A modified calorimeter instrument measuring decay heat of tritium with larger cells has been designed and been tested at TPL. The minimum detective heat (20nW: 22 MBq) of the instrument have been demonstrated by a series of preliminary runs. The Imaging plate (IP) method has also been studied to measure the amount of tritium in the solid. The IP consists of a storage film coated with photo-stimulated phosphor (BaFBr:doped Eu2+). The phosphor captures the X-rays induced by b-rays from tritium, and emits the light by irradiating the laser light.

  b) Basic Tritium Data Base
  The following collaborative works have been carried out as one of the active topics in this field from 2008 by changing some samples and discussions between JA and IPP Garching.
The deuterium (D) concentrations in the tungsten (W) samples exposed to low-energy and high flux D plasma at various temperatures has been measured by using the accelerators of IPP Garching. This work is important to discuss on the tritium behavior in a vacuum chamber of a fusion reactor. In this year, our attention has been focused on the effect of displacement on deuterium retention in W exposed to exposure both to the pure D and D-He plasmas. As the result, several joint papers of JA and IPP Garching have been reported in 2011. The hydrogen transfer behavior from water to metal has been studied as a function of temperature. It was expected that the surface of iron piping was oxidized to magnetite; and then deuterium generated by the oxidation reaction permeated though the iron piping. The tritium behaviors in concrete materials and in the epoxy paint have been studied to evaluate the function of the tritium confinement.

c) Tritium Processing Technology
A large amount of tritium water is expected to be produced in a DEMO plant. It is essential to develop an effective system processing the tritium water. A series of basic studies on the chemical exchange column has been carried out in JA: performance of catalyst, liquid flow conditions in the column; and an analysis model. A basic study on the R&D of a hydrophobic catalyst which converts tritium to water at room temperature has been started in JAEA. This study has still been early stage; a set of good data has been produced. As the blanket tritium processing system, the ceramic proton conductor has been studied as a tritium processing method for the blanket system. These R&D subjects would be good collaborative activities.
2012 Work Plan of
Subtask 4: Tritium Technology

The members of the tritium subtask group are responsible for the construction of ITER tritium plant as one of the most important duties. The R&D subjects on tritium technology in the BA program are also carried out by the subtask group of JA and EU. It is further desired to carry out the activity for the data on the basic tritium behavior under this IEA agreement. The R&D subjects in 2011 for the tritium accountancy and for the tritium processing should be continued. For the basic tritium data, there are many subjects on the tritium-material behaviors. These data are essential for the R&D on the blanket tritium technology. As described above, a new coordinator of Korea has been joined into our group from this year, and the personal exchanges among the subtask group should be discussed. A possible subject to be studied with the personal exchange is the tritium retention in metal (W and F82H) and ceramic (SiC and concrete); or the tritium behaviors in the blanket materials (Li and Be); or tritium storage materials. Recently, in TPL, the tritium durability test for the organic materials has been carried out in TPL by using tritiated water. These R&D subjects would be good collaborative activities for the personal exchanges.

A meeting of the subtask leaders occurred on September 14, 2011 in Portland, Oregon, USA at the ISFNT-10 conference. The agenda included presentations summarizing the 2011 activities by each leader followed by an open discussion on 2012 work plans. Participants present included the EU, IN, JA, RF, and US.

Joint Activities:

Most of the 2011 effort focused on continuing development of helium-cooled refractory plasma facing components, developing NDE techniques for PFCs and making arrangements for high heat flux testing in 2012.

As mentioned above, the largest meeting occurred the day prior to the Executive Committee meeting in Portland to review progress and make adjustments to the 2011 workplan. We worked to strengthen and broaden collaborations in helium-cooled refractory PFCs already underway, by bringing together the design and testing efforts of the EU/RF and the US programs and including new participation by JA, CN and IN. We also discussed adding water-cooled tungsten components to the testing matrix. A summary of activities in each party appears in the following sections.

The 2011 Japan/US Workshop on PMI, was entitled the “Workshop on Critical Issues, Components and Technology Gaps in Progress toward a Fusion Nuclear Facility” was held in Kyoto, Japan on October 29-31, 2011. The workshop focused on critical issues, components and corresponding FNST R&Ds for the next fusion machines. There were 32 attendees, 7 from the US and 25 from Japan. Discussion centered on identifying technology gaps in the development of fusion nuclear facilities, MHD modeling, magnets, engineering diagnostics, the TITAN collaboration and recent modeling regarding helium and water cooling in swirl and screw tubes.

CN activity:
Development of Ductile Refractory Materials.

EAST has entered into its up-grade phase that aims to operate under high power and long pulse conditions. Auxiliary heating systems, inner components as well as other diagnostic systems are being upgraded. A full W-coated wall is the final objective. The structural design of W PFCs for EAST continued throughout 2011. Due to extensive collaboration between domestic companies and universities, China successfully developed the ITER-like mono-block type W/Cu mock-up using hot isostatic pressing (HIP) method. In the meantime, the primary first wall, except the divertor areas, has been fitted with Mo tiles for a transition period to perform the preliminary physics experiments to gain experience and understanding of plasma operation under high Z metal wall conditions envisioned for a fusion power reactor.

EU activity:

Tungsten Limiter Experiments in TEXTOR. EU, JA

Transient heat load tests on recrystallized tungsten limiters exposed in TEXTOR. Surface modification due to melting and grain growth was characterized. Melt layer mechanisms determined to be plasma pressure and JXB forces due to thermoelectric emission. The EU also continued with transient thermal loads (ELMS) on ultra-fine grained tungsten with Prof. Kurishita from Tohoku University. Thermal shock tests were performed on various W-TiC alloys with 100 1-ms-pulses with an energy density of 1.1 MJ/m² at 100 °C bulk temperature.

Post-irradiation testing of neutron irradiated first wall modules. EU, RF

HHF testing was performed in the Judith1 electron beam consisting of screening tests (0.5 to 1.5 MW/m²), 1000 cycles of fatigue testing at 1.5 MW/m² and thermal response tests from 2.0 to 3.0 MW/m²

Set-up and Evaluation of Electron Beam HHF Test Facilities

An information exchange occurred with IN, CN, and RF regarding electron beam high heat flux testing equipment and procedures used on Judith2. This was done to aid IN and CN in developing their national HHF testing capabilities.
**<II-1 3a> HHF testing of EU helium jet cooled mockups in TSEFEY and EB-1200**
A nine-finger HEMJ module is in manufacturing with HHF testing scheduled for Efremov and Sandia and NDT testing at CEA. Further improvements were made to the high temperature brazing process. New brazing filler materials PdNi and PdCu produced very good results for the W-WL10 and WL10-steel joints, respectively. The EU also initiated an investigation on mass production of divertor parts using powder injection molding of W tiles and deep drawing of the W-alloy thimble.

**<II-1 T7a> International Workshops**
PFMC-13, Intl workshop on Plasma Facing Materials and Components was held in Rosenheim, Germany May 09-13, 2011. The 20th PSI Intl. Conference on Plasma Surface Interactions in Controlled Fusion Devices will be held in Aachen, Germany May 21-25 in 2012. And, the 27th Symposium on Fusion Technology will be held in Liege, Belgium September 24-28, 2012.

**IN activity:**

**<II-1 T1d> Set-up and Evaluation of Electron Beam HHF Test Facilities: IN, RF, US**
IN completed work on conceptual design of an Electron Beam HHF test facility. Engineering design and fabrication of vacuum chamber as well as procurement of relevant equipment and utilities are in progress. Quotations were received for the 200 kW electron gun. Procurement of high power electron beam system has been initiated. Meeting with vendors occurred in October.

**<II-1 T2c> Simulation of transient thermal loads on Be and W in JUDITH/JUDITH-II : EU, IN, RF**
IN Tungsten materials development is in progress. Characterization of Indian W materials developed using microwave an electrical heater furnace sintering process is in progress. IN signed an agreement with Kharkov Institute, Ukraine for use of QSPA facility for ELM-like heating tests.

**<II-1 T2e> HHF Tests of IN First Wall and Divertor test mock-ups in EB60facility : IN, US**
Graphite and tungsten brazed test mock-ups with a macro-brush geometry provided by IN
were HHF tested in the US. An aggregate of 66 shots were taken. The C-based mock-up received 15 shots, while the W-based mock-up received 51 shots at various incident heat loads. Both the C and W mock-ups could withstand 10 MW/m$^2$. Two rounds of testing occurred. The first was in May 2010 and the second in March 2011.

**<II-1 T5a> Development of NDE Techniques for PFC applications: IN, US**

Procurement of UT module of CIVA software for computer simulation of Ultrasonic testing has been initiated. Infrared thermography and ultrasonic testing on small-sized macro-brush test mock-ups is underway in India. Improved facilities for both ultrasonic and infrared NDE are planned for 2012.

**JA activity:**

**<II-1 T7a> PFC/HPD Workshop**

JA hosted the Japan/US PMI Workshop in Kyoto, Japan on October 29-31, 2011. The workshop was hosted by Prof. Ueda of Kyoto University. The workshop addressed critical issues, components and technology gaps in our progress toward a fusion nuclear facility.

US and Japanese representatives attended a satellite meeting for this IEA subtask which was arranged in conjunction with the workshop. JA gave a detailed presentation on the critical heat flux and pressure drop of swirl tubes and screw tubes as candidate cooling tubes for DEMO. The US gave presentations on numerical simulation of helium jet-cooled tungsten divertor components and simulations of helium gas cooling in porous media.

**KO activity:**

**<II-1 T1d> Set-up and Evaluation of Electron Beam HHF Test Facilities. IN, KO, RF, US**
KO has two radiative heating facilities (KoHLT-1 and KoHLT-2) and is installing a new 300 kW electron beam high heat flux facility. KoHLT-1 was used to test beryllium FW qualification mock-ups for ITER. It can provide a max. 1.5 MW/m² heat flux and provide 0.1 MPa 25 °C cooling water. KoHLT-2 is a larger facility with 2x the power and 3 MPa, 120 °C water. A beryllium compatible e-beam facility is under construction that will replace the KoHLT-2 chamber. It consists of a 300 kW, 60 kV gun and can scan 70x50 cm² samples. A helium loop will also be connected to the e-beam system.

KoHLT-2 Radiative Heat Flux Facility

<II-1 T2f> KoHLT facility HHF testing
W/FMS HIPped samples were created for HHF testing with Ti and Cr interlayers. Testing in KoHLT-1 and further development will occur in 2012.

<II-1 T5a> Development of NDE Techniques for PFC applications
KO obtained a flat Panametrics probe and instrumentation for ultrasonic evaluation of pfc joints. 3d images can be created showing the integrity of bond joints.

RF activity:

<II-1 T1d> Set-up and Evaluation of Electron Beam HHF Test Facilities. IN, KO, RF, US
Assembly of the new testing facility IDTF was completed at Efremov Institute. Maximum power of 800 kW was achieved. The facility will be used for the HHF testing of ITER vertical target and dome/liner components during their serial production. The facility uses a
von Ardenne electron gun with power supply and beam control. It is capable of operating with the following parameters:

- \( P_{\text{max}} = 800 \text{ kW} \)
- Chamber: \( D=2.2\text{m}; \ L=3\text{m} \)
- Water loop: \( P=4.5\text{ MPa}, \ Q=30 \text{ m}^3/\text{h}, \ T_{\text{in}} \sim 130^\circ\text{C} \)

**<II-1 T1d> Evaluation of test results of PFC in electron beam and ion beam facilities**

FZJ specialists visited Efremov Institute to discuss HHF testing methods and procedures used at Tsefey

**<II-1 T2c> Simulation of transient thermal loads on Be and W in JUDITH/JUDITH-II**

Qualification tests of Russian Be-grade TGP-56FW were performed at Judith1 on sample coupons and water-cooled mock-ups. These tests helped prove acceptance of Russian beryllium grade for ITER first wall applications.

**US activity:**

**<II-1T2e> HHF Tests of First Wall and Divertor test mock-ups in EB1200 facility**

Second round of HHF testing on Indian C and W-based first wall mock-ups completed in March 2011. This effort was further detailed under IN activities above.

**<II-1T3a,b,c> Evaluation of gas-cooled PFC designs**

Testing of the ARIES Tee tube concept was delayed until early 2012 due to fabrication delays and availability of the EB-1200 system. Planning has started for testing of the nine-finger
HEMJ module. A target mask is under preparation and design drawings were obtained from Dr. Norajitra to accommodate the assist in the mounting of the module.

The ARIES design studies at UCSD have investigated several advanced divertor designs including finger, plate and tee tubes and combination jet and pin concepts. Fluid flow and 3d elastic-plastic analyses were completed and published. Comprehensive “birth-to-death” modeling in progress that includes fabrication, operating scenarios and off-normal events. Meanwhile, work continues on fluid flow simulations of helium through porous media for design of advanced refractory pfc's and heat exchangers..

<II-1T7a> PFC/HPD Workshop

Seven US researchers attended the Japan/US Workshop in Kyoto, Japan on October 29-31, 2011. Further details are presented under JA activity.
**2012 Work Plan of**

**Subtask 1: Solid Surface Plasma Facing Components**

D. Youchison, J. Chen, I. Mazul, S. Khirwadkar, J. Linke, S. Suzuki

An updated list of NTFR Annex II Subtask 1 activities appears at the end.

**T1. Evaluation of Test Facility Characteristics** – The RF has installed new high heat flux testing capabilities to support the ITER divertor. India is procuring hardware for a new HHF test system. The EU will also assist IN and CN through further information exchanges regarding electron beam technology and high heat flux test procedures. Korea will install a new electron beam facility for high heat flux testing in Korea as well as a new helium loop. Most likely, Korea will obtain an e-beam system from von Ardenne in Germany. US will use Sandia’s helium flow loop and the EB-1200 to support high heat flux testing of Tee-tube and HEMJ refractory heatsinks and compare to the EU/RF HEMJ effort at Efremov.

**T2. Evaluation of Joining Technologies for PFCs** – Some further work will continue on W coatings on CFCs. The EU and CN will evaluate W-coated tiles in 2012. Korea will complete Be mock-up testing in KO graphite heater facility, KoHLT-1 (Korea Heat Load Test facility #1), and W/FMS mock-up tests. A task may be added on water-cooled tungsten mock-up testing in various high heat flux facilities once a sponsor is identified.

**T3. Evaluation of Gas-cooled PFC Designs** – The EU and RF will continue collaboration on design, fabrication and testing of He-cooled tungsten PFC mockup with 9-unit cells (thimbles). They will fabricate improved 1-finger mock-ups and a 9-finger module. HHF testing and a study on mass production techniques in the EU will continue. It was agreed to use the EB-1200 to test the EU/RF HEMJ modules as well as the US ARIES tee-tube concept. IN will procure CFD software and hardware to perform modeling of helium-cooled porous media. IN is working with RF on the design of a helium low loop for the IN facility. Korea will perform the conceptual design to allow performance testing of the KO FMS FW in KoHLT-2 (Korea Heat Load Test facility #2) with helium gas cooling system.

T5. Development and testing of non-destructive evaluation (NDE) techniques for application to plasma facing components during fabrication will continue in 2012. For example, this collaboration may include the development and related testing of ultrasonic and IR thermal wave imaging on complex 3-d geometries involving multiple materials and joints. Collaborations now exist between JA IN and the US to explore thermography as well as ultrasonics for NDE of plasma facing components. Improved facilities for IR-Thermography and Ultrasonic Flaw Detection will be completed in IN. KO will perform preliminary testing of large ultra-sonic test stand for ITER FW semi-prototype in Korea.

T6. Task 6 on W-alloy development will continue. China and Japan have performed work on nano-TiC-doped W, W/Cu FGM joints using Spark Plasma sintering and VPS W-coatings. In 2012, China will perform the technology optimization of PFCs and mock-up testing (i.e. high heat loading testing). They plan to use the hot radial pressing (HRP) method for the development of W/Cu mono-block components. They also plan a plasma discharge experiment in EAST under high Z metal conditions and test the W/Cu mono-block type mock-up by means of the Materials and Plasma Evaluation System (MAPES). The EU is working with JA on HHF testing of ultra-fine grain tungsten under transient thermal loads such as ELMS and in transient HHF testing of re-crystallized tungsten limiters exposed at TEXTOR. The US is also pursuing advanced manufacturing techniques to synthesize dispersion strengthened W alloys.

T7. International Workshops/Meetings – The IEA Workshop on Solid Surface Plasma Facing Components will be held in the US during the summer of 2012 in conjunction with the Japan/US HPD workshop. It will focus on materials and high heat flux components. The venue is still being planned. The 20th PSI Intl. Conference on Plasma Surface Interactions in Controlled Fusion Devices will be held in Aachen, Germany May 21-25 in 2012. And, the 27th Symposium on Fusion Technology will be held in Liege, Belgium September 24-28, 2012.

T8. ANNEX II Subtask 1 Meetings – The next meeting of Subtask II leaders has not yet been set but will likely adopt the venue of a fusion meeting in the fall of 2012. Most likely, it will be at the 27th SOFT meeting in Liege, Belgium.
Task T6 now addresses an initiative on the development of more ductile refractory alloys for use in plasma facing components. This is essential if solid PFCs are to be used in high power density fusion reactors. This task will move forward more vigorously in 2012. No progress was made on a proposal to include collaborations on integrated self-powered diagnostics for real-time performance and lifetime monitoring of plasma facing components regarding erosion, temperature distribution, stress, and tritium uptake.

A new proposal was made to include water-cooled tungsten armored pfcs in the international test matrix. We have yet to identify the sponsor who will fabricate the mock-ups. However, the EU, RF and US have shown interest in a new round-robin test campaign. Testing of the new mock-ups would fall under subtask 1a.
Below are the updated NTFR Annex II-Subtask 1 activities for 2012.

<table>
<thead>
<tr>
<th>IEA ANNEX II Subtask 1 Activity</th>
<th>partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Eval. of Test Facility Characteristics Round robin tests in EU, US, JA All</td>
<td></td>
</tr>
<tr>
<td>1a Round robin tests, EU, RF &amp; US heating facilities</td>
<td>EU, RF, US</td>
</tr>
<tr>
<td>1b Round robin tests, Japanese heating facilities</td>
<td>EU, JA</td>
</tr>
<tr>
<td>1c Evaluation of test results of PFC in electron beam and ion beam facilities</td>
<td>EU, RF</td>
</tr>
<tr>
<td>1d Set-up and Evaluation of Electron Beam HHF Test Facilities</td>
<td>CN, IN, KO, RF, US</td>
</tr>
<tr>
<td>2 Eval. of Joining Technologies for PFCs Evaluate samples prepared by each All party in HHF test facilities in EU, JA, US, KO</td>
<td></td>
</tr>
<tr>
<td>2a HHF tests of JA middle-scale first wall mock-up, with Be tiles, in EU, JA JUDITH/JUDITH-II</td>
<td></td>
</tr>
<tr>
<td>2b HHF tests of EU samples in JEBIS or PBEF and evaluation of thick W-coatings EU, JA including HHF-tests</td>
<td></td>
</tr>
<tr>
<td>2c Simulation of transient thermal loads on Be and W in JUDITH/JUDITH-II</td>
<td>EU, IN, RF</td>
</tr>
<tr>
<td>2d HHF tests of W7-X divertor tiles</td>
<td>EU</td>
</tr>
<tr>
<td>2e HHF Tests of First Wall and Divertor test mock-ups in EB1200 facility</td>
<td>EU, IN, RF, JA</td>
</tr>
<tr>
<td>2f HHF tests of Be and W/FMS mock-ups in KoHLT-1</td>
<td>KO</td>
</tr>
<tr>
<td>3 Evaluation of gas cooled PFC designs</td>
<td>CN</td>
</tr>
<tr>
<td>3a HHF testing of EU helium jet cooled mockups in TSEFEY and EB-1200</td>
<td>EU, RF, US</td>
</tr>
<tr>
<td>3b HHF testing of US multi-channel foam mock-ups in EB-1200</td>
<td>IN, JA, US</td>
</tr>
<tr>
<td>3c HHF testing of US ARIES tee-tube mock-up in EB-1200 and TSEFEY</td>
<td>CN, KO, RF, US</td>
</tr>
<tr>
<td>3d Conceptual design of KoHLT-2 with helium cooling system</td>
<td>KO</td>
</tr>
<tr>
<td>4 Simulation of ELM Heat Loads and EM Loads</td>
<td>CN</td>
</tr>
<tr>
<td>4a Tests of EU W samples in RF plasma guns</td>
<td>EU, RF</td>
</tr>
<tr>
<td>4b Modelling and pulsed HHF experiments</td>
<td>EU, RF</td>
</tr>
<tr>
<td>4c Tests of US W rod mockups in RF plasma guns</td>
<td>RF, US</td>
</tr>
<tr>
<td>4d Tests of US W rod mockups in EB1200</td>
<td>US</td>
</tr>
<tr>
<td>4e Tests of W-based materials in EB1200 facility</td>
<td>CN, IN, US</td>
</tr>
<tr>
<td>5 Development of NDE Techniques for PFC applications</td>
<td>CN</td>
</tr>
<tr>
<td>5a Ultrasonic evaluations</td>
<td>CN, IN, KO, US</td>
</tr>
<tr>
<td>5b Thermal wave or Lock-in IR thermography</td>
<td>EU, US</td>
</tr>
<tr>
<td>6 Development of Ductile Refractory Materials</td>
<td>CN</td>
</tr>
<tr>
<td>6a Nano TiC doped W</td>
<td>CN, JA, US</td>
</tr>
<tr>
<td>6b W/Cu FGM interfaces</td>
<td>CN, JA, US</td>
</tr>
<tr>
<td>6c VPS W coatings</td>
<td>CN, EU, US</td>
</tr>
<tr>
<td>7 International Workshops/Meetings</td>
<td>CN</td>
</tr>
<tr>
<td>7a PFC/HPD Workshop - co-sponsor</td>
<td>CN, EU, US</td>
</tr>
<tr>
<td>8 Annex II Subtask 1 Meetings</td>
<td>CN</td>
</tr>
<tr>
<td>8a Annex II Subtask 1 Planning Meeting</td>
<td>CN, EU, US</td>
</tr>
<tr>
<td>8b Annex II Subtask 1 Review Meeting</td>
<td>CN</td>
</tr>
</tbody>
</table>
Plasma Surface Interactions (Tritium Retention and Tritium Removal) Subtask:

Long-term tritium inventory is one of the main concerns for the ITER operation. It is especially pronounced in devices with carbon plasma-facing components (PFC) because of the co-deposition of hydrogen isotopes with all species originally eroded from the wall. As long as carbon targets in ITER are under consideration, the study of carbon-related effects is to be performed. The outstanding issues are related to monitoring and curtailing of inventory. Two main options are being explored:

(i) development and testing of methods for fuel removal, where one has to assess:
    efficiency of removal, the surface state of PFC following the treatment and the type of products generated (e.g. gaseous products and/or dust) by that treatment;

(ii) machine operation with metallic PFC; this requires major investments related to the wall (re)construction.

In all cases detailed information on material migration is needed, i.e. mapping and quantification of fuel on plasma-facing surfaces and in remote areas such as pumping ducts and grooves of castellation;

Comprehensive studies of fuel retention are done in several fusion devices by gas balance measurements and ex-situ analyses of PFC and using specially designed instrumented marker tiles and other deposition monitors. Thermal, chemical and photonic methods for fuel removal are tested. The largest effort was directed towards completion of the ITER-Like Wall Project at JET (JET-ILW). The refurbishment of the JET wall was completed in May 2011 and since August 2011 JET is operated with beryllium in the main chamber and tungsten in the divertor. Studies of material erosion, its migration, fuel inventory and dust formation belong to the most important in the research programme. These issues have been studied by all partners including new member, Korea, represented by Prof. Suk-Ho Hong.

An overview of the ongoing projects and achievements (Progress Report) was presented at the Executive Committee Meeting held in Portland, Oregon, USA during the 10th Int. Symposium on Fusion Nuclear Technology (ISFNT-10), September 2011. Earlier exchange of
information and planning of future work with partner institutions took place in connection with:

- 13th Int. Workshop on Plasma-Facing Materials and Components, Rosenheim, Germany, May 2011,
- ITPA and Annual Meeting of EU Task Force on Plasma-Wall Interactions (PWI) when the exchange of information and decisions on further cooperation were taken in discussion of EU, US, JP, China and Korea;

The list of 2011 activities carried out by China, EU, India, JP, Korea and the USA comprises:

- Delivery and installation of Be marker tiles for JET-ILW. The markers were manufactured, shipped to JET and installed: EU–US. Now they are exposed during the JET-ILW operation.
- Assessment of fuel inventory in High-Z metals in tokamaks: FZJ, VR, IPP-Garching from EU and Kyushu and Osaka Universities.
- Assessment of fuel retention and co-deposition in castellated structures and gaps between tiles of plasma facing components: FZJ, JET, VR from EU, JAEA and Kyushu University and Korea. (Continuation of work initiated in 2003.)
- Development of tracer techniques for material migration. Co-operation of institutions from EU (FZJ, VR, JET) and JAEA, Kyushu and Osaka Universities.
- Further studies of influence of small He plasma concentration on the retention of D in tungsten in order to determine nano-bubbles formation and morphology of nano-scopic tungsten fuzz: US, JP, EU.
- Examination of tungsten fuzz on surfaces exposed to intense plasma gun pulses: JP, US.
- Investigation of surface loss from Be deposited on W (mixed material effects) during simultaneous laser and plasma exposures: US, JP.
- Detailed studies of dust collected in tokamaks and dust mobilization: EU, JP, Korea, US.
- Comparison of multi-layer and single-layer Be co-deposits impact on fuel retention and release: US and EU co-operating in the PISCES Program.
- Studies of tungsten under divertor relevant conditions: crack formation, brittle fracture due to recrystallisation: JP, US.
- Completed design of MAPES experimental system in EAST for PWI studies: China.
○ Development of a linear PWI simulator: MFCAP: China.
○ Fuel and co-deposit removal by laser-induced desorption and laser induced ablation, EU, China.

• Activities with Russian partner institutions
  ○ No contact has been established (no reply since 2006) and no information has been provided on activities in the field of this Subtask.
Plasma Surface Interactions (Tritium Retention and Tritium Removal) Subtask

Fuel retention in plasma-facing components (PFC) and material behaviour under plasma exposure will remain the main scope of the Subtask. Already initiated activities will be continued and several new topics will be added. Very strong emphasis will be given to studies of wall materials and special erosion-deposition probes exposed during the ITER-Like Wall Project at JET (JET-ILW). Retrieal of some components is expected in the second half 2012. Important activities in studies of co-deposition and dust are expected within the newly started cooperation with Korea. Equally important will work related to the MAPES system at the EAST tokamak. Proposed and planned activities will be concentrated on fuel retention in metals and mixed materials and, on further assessment of fuel removal methods. The general strategy in the IEA cooperation will be focused on integration and coordination of research efforts with IEA Subtasks of PSI and In-vessel Tritium, ITPA Group on Divertor and SOL and Task Forces on PWI (EU) and at JET. Mutual cooperation on multi-machine comparison of PWI effects will be continued. The list of particular activities encompasses:

• Characterisation of surface morphology and fuel retention after various treatments of plasma-facing components: laser, flash-light detrination, torch, oxidation-based and nitrogen-based methods: All partners
• Composition of dust generated by cleaning methods. Primary target: determination of remaining fuel content in dust.
• Fuel inventory in beryllium and mixed-material layers
• Erosion and fuel retention studies of Be marker films for the assessment of Be wall erosion: (in support of the ITER-Like Wall Project at JET)
• Transmission electron microscopy studies of tungsten surfaces exposed first to ion irradiation (to produce damage) and then to deuterium plasma.
• Assessment of the impact of material microstructure on fuel retention in tungsten and its alloys (different grades): all partners. Experience of China in tungsten studies will be of great importance.
• Examination of nitrogen puffing in D plasma on change in Be surfaces and fuel retention: EU-US
• Development and application of high pressure Argon-Oxygen torch for localised heating (India).
• Application of SLEIS for irradiating samples received from IEA partners: JA
Several joint projects for 2012 have been defined. Discussion about the progress and plans for new activities may take place on the occasion of international symposia such as: PSI-20, Aachen, Germany, May 2012, SOFT in Liege in September and ITPA on SOL and Divertor in January (Juelich) and in October (San Diego).