Liquid Wall Chamber Dynamics
ARIES Town Meeting
May 5-6, 2003, Livermore, CA
Summary

Introduction

A Town Meeting on IFE Liquid Wall Chamber Dynamics was held at the Hilton Garden Inn, Livermore on May 5-6, 2003. The meeting focused on liquid wall behavior under the IFE threat spectra and the ensuing clearing process dictating the chamber environment prior to the next shot. The major objective of the meeting was to bring together experts in these areas to identify the major issues, share the latest results, understand better the accuracy of (and any differences among) various modeling predictions and, through discussions, to help focus future analysis and experimental R&D efforts. These town meetings are intended to foster a productive and focused exchange of information and a solid block of discussion time was provided following presentations on each topic for discussion on the major issues and on what is missing between today's experimental and modeling efforts and information required to address these issues for designing future power plant systems.

The meeting was organized by Drs. Wayne Meier and Rene Raffray with the much appreciated administrative support of Ms. Judy Knecht. The agenda and list of participants are included in Appendices I and II, respectively. They are also available on the meeting web site (http://aries.ucsd.edu/ARIES/MEETINGS/) where additional details about the meeting can be found.

This meeting summary includes some major highlights of the presentations as summarized by the session chairs. In addition, following some fruitful discussions, tables were developed summarizing the different liquid wall chamber mechanisms occurring at different times following the IFE micro-explosion and the capabilities of present models and experiments to help in understanding and characterizing these mechanisms. It is hoped that these will help researchers working in this field to arrive at a better understanding and appreciation of the basic processes involved, of the range of modeling and experimental capabilities, and of the modeling and experimental areas requiring additional effort.

1. IFE Target Threats

Dr. Debbie Callahan (LLNL) noted that target design interfaces with target fabrication, target injection, driver, and chamber. She described a broad range of targets considered including distributed radiator, close-coupled distributed radiator, large-angle distributed radiator, fast ignition, and hybrid. The large angle distributed radiator target is the current baseline design, made necessary by the IFE robust point designs 24 degree half angle for the array of 60 beams (from each side). The required pulse shape (driver beam power vs time) is achieved by using blocks of beams each with roughly constant power output. The larger targets required for IFE (compared to Nova or NIF targets) allow greater surface finish and DT roughness tolerance. Low density high atomic number materials are needed to maintain pressure balance in the hohlraum. Laser Chemical Vapor Deposition (LCVD) may be used to fabricate this low density material.

Viewfactor calculations suggest a +/- 250 micron beam pointing error may be tolerable. Key issues involve focusing the ion beam to the required spot, manufacturing and hitting the target to the required tolerances, and choosing materials that will be acceptable to all parts of the power plant.

Dr. Don Haynes (UW) described the energy spectrum output from the NRL direct drive and close coupled HIF indirect drive targets. Ion energy dominates x-rays for the direct drive targets. The x-rays are also mostly highly penetrating >10 keV energy and cause relatively little surface heating and damage. HIF targets have a much larger x-ray fraction (25% x-ray and 7.5% ion) with x-ray energy mostly <0.5 keV. The first wall threat from HIF targets is therefore mostly from x-rays. The greatest issue for target threat is how large the chamber needs to be or what protection is needed for the first wall to avoid excessive damage.

2. <u>**Driver and Target Constraints**</u>

Recent liquid wall designs have been mostly associated with a heavy ion beam driver, whose transport imposes requirements on chamber clearing. Liquid wall designs have also been considered with a Z-pinch driver but with much more relaxed constraints on chamber clearing.

Dr. Simon Yu (LBNL) discussed the various options for accelerating heavy ion beams and amplified on the US-selected approach of the multiple beam induction linac driver. Several target approaches are available as noted by Dr. Callahan. The goal is to appropriately focus the beams onto the candidate targets. The chamber can be protected with dry wall, thin wetted-wall, and thick liquid-wall concepts that are being investigated. Each of these chamber approaches has unique challenges to transport the beams from the final focus beam elements to the target in the center of the chamber. The beams must be compressed both radially and longitudinally while controlling the nonlinear dynamics at final focus to have the proper conditions at the target. The mainline transport approach is neutralized ballistic transport for the current Robust Point Design (RPD-2002). This assumes a distributed radiator target. Assisted pinch, Z-pinch, and self-pinch transport are alternate transport schemes that have attractive features, but are less well developed. The requirements posed on the chamber gas depend on the mode of transport and focusing. Neutralized ballistic transport set the most stringent limit based on stripping with integrated line gas density equivalent to about 1 mtorr ($\sim 3.6 \times 10^{19}$ atroms/m^3). Channel transport set the least demanding limits based on scattering with integrated line density equivalent to about 1 torr. Self-pinched transport is somewhere in between setting limits based on self-pinch resulting with integrated line density equivalent to 100 mtorr.

Dr. Yu discussed a new approach that used a modular solenoid approach rather than the multi-beam linac accelerator. The beamlines are shorter, but different hardware subsystems are required, including a different type of chamber (perhaps an axisymmetric liquid vortex). He emphasized that the driver and transport options will be determined based on technical credibility and economics for an integrated design including the target and chamber .

Dr. Ron Petzoldt (GA) summarized the recommended materials for the current hohlraum targets, but he emphasized that the target must be simplified and alternate materials should be considered to achieve the desired unit material and fabrication cost and radioactive waste criteria. He noted the considerations to be evaluated in the material trades. He reviewed the material processes to separate the constituents in the waste stream. Recycling the materials has been eliminated due high cost and difficulty in handling the radioactive materials. The target materials were screened and ranked for energetics and material costs, then ranked for chemical toxicity and ease of separation from FLiBe. Finally, the material candidates were ranked for ease of fabrication and radiological toxicity. The remaining candidates were W, Yb, Nd, Pr, Ce, La, and Pb. The combination of Pb/W has a low energy loss, which is attractive for a target material, but it creates mixed waste. The final material choice will be made in conjunction with the target and beam performance. The hohlraum targets considered for use with thick liquid wall chambers are quite robust (thermally and mechanically) and are not expected to be significantly affected by chamber conditions. Beam propagation is a much more limiting constraint on pre-shot chamber conditions.

3. <u>**Chamber/Liquid Wall Dynamics Under Threats**</u>

This session consisted of two presentations. The first presentation by Dr. Haynes (U. of Wisconsin) described the use of the BUCKY code to model the energy deposition from target x-rays and ions into a wetted wall. These results indicate that the vapor cloud formed by the deposition of x-rays will absorb most of the debris ion energy, thereby reducing the total amount of evaporated liquid by nearly a factor of two. The second presentation by Drs. Raffray and Mofreh Zaghloul (UC San Diego) consisted of two parts; the first part delineated the physical processes involved in liquid layer ablation by x-ray energy deposition. The "explosive boiling" mechanism was outlined; estimates of the ablated layer thickness were presented. The mechanical response to the induced shock was outlined. Emphasis was placed on the fact that the "spallation strength" is strongly dependent on temperature. The second part of the presentation reported on recent results for the thermodynamic properties of Flibe. A correlation for the vapor pressure of Flibe over a wide temperature range was recommended.

Dr. Susana Reyes (LLNL) described ABLATOR, a 1-D finite difference code for the calculation of material response to x-rays. Four processes are included in the ablation model:

- energy deposition from the x-rays through the thin surface layers of material;

- transient thermal conduction model allows this energy to move between zones;
- thermal expansion, which raises pressures and causes hydrodynamic motion; and
- removal of material through surface vaporization and various spall processes

ABLATOR's main limitations are

- radiation model and no condensation model;
- only cold opacities are used; and
- numerical instability at small time steps.

Results for the initial vaporized mass from a flibe surface were given and shown to compare well with TSUNAMI estimates. ABLATOR, however, is not meant to be a chamber dynamics code for liquid walls. It was developed for and is being used for dry walls and laser final optics.

Mr. Christophe Debonnel (UC Berkeley/LBNL) gave a talk on modeling results using the 2D TSUNAMI (TranSient Upwind Numerical Analysis Method for Inertial confinement fusion) code. TSUNAMI was developed at UC Berkeley and is currently being updated and used to analyze thick liquid wall chamber dynamics. TSUNAMI:

- provides estimates of the gas dynamics behavior during the venting process in inertial fusion energy systems;
- solves Euler equations for compressible flows; and
- uses real gas equations (adapted from Chen's and including Zaghloul's correction).

Results from a simulation that included the beam access region of the chamber were shown. TSUNAMI predictions indicate that engineering devices in the beam tubes should be used to prevent debris contamination in the final-focus magnet region. Beam tubes coated with liquid vortex and use of moderate magnetic fields to divert debris are recommended. The material ablated from the inner surface of the pocket is vented through the jet array and is expected to condense on the cold droplets that are sprayed into the region between the first wall and central pocket.

Dr. Laila El-Guebaly (U. of Wisconsin) presented analysis on neutron isochoric heating. Results for volumetric energy deposition due to neutrons were given for HYLIFE-like chambers where the liquid is close to the target and for HIBALL where the liquid is contained in porous tubes at about 5 m. The rapid volumetric heating will cause pressurization and expansion of the fluid. If the rapid pressurization is high enough (depends on target yield and radius) the liquid will break apart (disassembly of jets). This is allowed for in free-jet systems like HYLIFE. In HIBALL the pressures are lower and the liquid is contained. Pulsed stresses in the 7 m radius steel first wall were estimated and found to be acceptable using unirradiated material properties. It was pointed out that the effect of radiation damage on fatigue life needs to be studied for the HYLIFE design where the 3 m radius FW is subject to a higher heat load compared to HIBALL.

Dr. Roman Samulyak (Brookhaven National Lab) described the FronTier MHD code. He reported that FontTier is based on front tracking without numerical diffusion across interfaces. It is ideal for problems with strong discontinuities. Away from interfaces, FontTier uses high-resolution (shock capturing) methods. It uses realistic EOS models, including SESAME and phase transition (cavitation) support. Application of the code for simulation of the Muon Collider target was discussed and the response of a free mercury jet to high-energy proton beam pulse in a magnetic field was shown. Comparison of experiments and simulation of mercury to proton beam in the Spallation Neutron Source (SNS) was also discussed. Planned future work includes studies of MHD processes in liquid lithium jets in magnetic filed related to APEX experiments.

Wall material ablated by x-ray loading from IFE indirect-drive targets behaves in a similar fashion as material eroded from a surface via laser ablation. The presentation by Dr. Mark Tillack (UC San Diego) brought to light several mechanisms expected to relax ablated material following intense energy loading. A series of laser ablation experiments was investigated with modeling tools developed to aide interpretation of ablation plume dynamics. General behavior of the plume is governed by the complex interaction of several physical mechanisms, namely photon absorption, energy transfer, rapidly-driven evaporative flux, development of charged species (plasma), collisional gas-dynamics, radiation transport, particulate nucleation and growth, and ultimately melt-layer ejection. The complexity required enhanced descriptions of general mechanisms, such as adding the effects of ions on particulate nucleation. While the modeling is used to estimate the interplay of various mechanisms, experimental measurements of several important parameters (specifically plasma temperature and electron density, particulate cluster size and density) gave very useful insight. First, the expansion plume behavior varies dramatically with the chamber backfill pressure. As indicated by a gated CCD camera (visible light??), plume transport into the background gas varied from ‘collisionless’ at low pressures of ~10 mtorr (i.e. very little energy and momentum exchanged between the expanding and background fluids) to confined behavior at atmospheric pressure. Electron densities and plasma temperatures were observed to rise to ~ 10^{19} cm^{-3} and 8 eV, respectively, and proceed to drop very rapidly (~200 ns) for tests performed at 150 mtorr. Particulate (or cluster) formation was observed with very clean, smooth Si witness plates located at the plume stagnation point. Size distributions of deposited particulate were obtained for three laser fluence values at 500 mtorr He backfill. An intriguing observation from these experiments is that average cluster size decreases with increasing laser fluence. This is likely due to the higher charge state and temperatures generated with greater laser fluence (for an equivalent collection location), thereby providing enhanced nucleation rates of stable clusters in the presence of ions. In summary, this work has shown experimentally that particles do nucleate in the expansion plume of ablated material, and models that assist in understanding the behavior of these plumes are inherently very complex. In relation to IFE chamber design, understanding the behavior of this material is very important due to its impact on intra-shot chamber dynamics and possible long-term accumulation. A sufficient description of these phenomena should be achieved so as to guide countermeasure (or chamber clearing) designs.

Condensation of hot vapors expanding from an ablation source is being studied at UCLA. Mr. Patrick Calderoni (UCLA) presented an update of the ongoing work to ultimately generate flibe vapor and study its condensation. Residual pressure in the expansion chamber is presently dominated by non-condensibles, and work is underway to install a clean chamber and an airlock system to prevent chamber contamination between tests. A significant effort is also underway to image the vaporized material expanding into the chamber. Measurements of the emission spectrum from the hot vapor/plasma plume will give component-dependent densities and temperatures. Observation of the time-evolution of line intensities during the test can indicate transient temperature and density behavior. Upcoming work includes extending spectroscopy to observe a condensing surface (i.e. a molten flibe surface to which the vapor is exposed) and performing tests with solid flibe sections in the source. This work will provide important insights on the molecular recombination and condensation behavior of flibe, as well as give experiment results for verifying model predictions and extending the understanding of these complex issues.

Prof. Riccardo Bonazza (U. of Wisconsin) described the experiments investigating shock impaction on a planar water surfaces which have been preformed at the U. of Wisconsin's shock tube facility. These tests demonstrate fluid behavior of IFE liquid wall concepts exposed to shocks associated with target microexplosions. Shadowgraphy and CCD imaging visualization techniques have been used to observe the behavior of the water layer. Shock compression and transmission in the fluid layer causes breakup and droplet generation at the back surface of the layer. Only single water layers have thus far been studied, however future work includes stacking layers to simulate thicker segmented liquid walls (i.e. made up of many jets) and momentum abatement.

4. <u>Chamber/Liquid Wall Dynamics</u>

4.1 <u>Chamber clearing mechanisms</u>

Mr. Calderoni described the UCLA modeling efforts for chamber clearing involving vapor condensation and droplet clearing in a pressure decay field. The approach chosen couples the UCB model for condensation at a liquid/vapor interface with the "enhanced" 2-D TSUNAMI code with FLiBe data. The intent is to compare the data on traces of condensable gases, vapor density into the transition regime, and accumulation of less volatile BeF_2 with related experimental data. Modeling equations, assumptions, and numerical domain geometry were explained.

He showed the liquid initial temperature, liquid layer thickness, and liquid initial temperature as a function of time up to 1.5 ms. Temperature and pressure distributions were provided as a function of time.

He also modeled the process of droplet clearing in a pressure decay field with the goal of determining if droplets produced by the blast would be cleared prior to the next blast. He would like to uncouple the TSUNAMI code from the developed incompressible free surface heat and mass transfer code for chamber clearing evaluation. He is adapting the LANL Truchas software program to simulation of solidification manufacturing processes, e.g., casting and welding. He feels the code can be modified to determine the mass evaporated from the droplet, set a time-dependent temperature boundary condition to a saturated temperature as a function of the known pressure decay. He is currently awaiting approval from LANL to modify the code.

Prof. Said Abdel-Khalik (Georgia Institute of Tech.). is addressing the chamber clearing issues for a HYLIFE-II chamber protection scheme using liquid cylindrical jets and sheets to protect the chamber structural elements from neutrons, x-rays, and charged particles. Specific objectives are to estimate the rate of droplet formation due to hydrodynamics (turbulent surface breakup) for the thick liquid protection concept and provide estimates of droplet formation. Prof. Abdel-Khalik described the process of turbulent breakup to form droplets along the free surface with both axial and lateral velocities. This approach is in agreement with published literature. He described the correlation parameters and processes as well as the surface breakup efficiency factor used to quantify the process.

Prof. Abdel-Khalik then described the specific geometry used, namely, the RPD-2002 configuration (a lattice of four quadrants of cylindrical jets (each quadrant has 12 rows of 3 to 6 jets per row)). For the case with fully developed flow at nozzle exit and no flow conditioning or boundary layer removal, the total droplet mass ejection rate is estimated to be around 1300 kg/s. He also provided radial velocity data to estimate the droplet ingress in the beam path.

Prof. Abdel-Khalik discussed the experimental setup and the nozzle and flow conditioning system. He described the time-averaged mass collection experiments, emphasizing that the collection must be accomplished for 0.5 to 1.0 hr at close proximity to the surface of the jet. Experimental data was presented for the mass flux and number density as a function of collected standoff distance. His conclusions are that flow straightening and use of a contracting nozzle would significantly reduce the droplet ejection by factors of 10^3 to 10^5. Even if the droplet emission were reduced by a factor of 10^4, this would still predict a mass flow rate of 0.13 kg/s. This estimate was disputed by UCB as they have conducted preliminary experiments and could not visually detect droplets from the smooth jets. The counter argument was that the ejected mass flow rate must be measured over a long time where significant droplet ejection were found for experiments with smooth jets performed at Georgia Institute of Tech.

Dr. Phil Sharpe (INL, previously INEEL) described a code that contains a gas dynamics model, a wall thermal response model, and an aerosol dynamic model. For each of these elements, he noted the present code condition and areas that must be improved to obtain a valid understanding of the aerosol production in a molten salt (flibe) protected IFE chamber. He modeled both a 3.0-m and a 6.5-m chamber with corrections for energy balance. The interior chamber volume was modeled in several different zones with differing conditions per the descriptions provided by Dr. Raffray. Dr. Sharpe presented data on vapor pressure profiles as a function of radial position and time for the two chambers at both 2-phase interfaces. He also showed the total chamber vapor and aerosol mass as a function of time. The Region 1 size distributions were provided for both chambers.

In conclusion, he noted the HYLIFE-II chamber has several enhancements that will improve condensation. The code can also be modified to include the effects of droplet seeding. He noted oblique and reflected shocks are excluded.

Dr. Zoran Dragojlovic (UCSD) explained the objectives of modeling the chamber physics to understand the chamber response to high energy (and high power) targets, understand critical chamber issues, develop a state-of-the-art computational model, develop benchmark physics model, and plan experiments. SPARTAN code uses 2-D Navier Stokes (NS) equations, empirical data on viscosity and thermal conductivity, is adaptable to an arbitrary geometry with adaptive mesh, is globally accurate to 2^{nd} order, and has between 1^{st} and 1.5^{th} accurate boundary conditions. The validation objectives are to verify:

- Shock propagation
- Diffusive terms in NS equations
- Arbitrary geometry
- Order of convergence

These objectives were verified with several known experimental and validated cases. The results of the code were shown for these experimental cases. SPARTAN in its present form does not include liquid condensation so its current use is limited to dry wall chambers.

Following the validation process, the IFE chamber dynamics were simulated. The objective was to determine the influence of viscosity, blast position in chamber, heat conduction from gas to the wall, and calculate the chamber density, pressure, temperature, and velocity distribution prior to the next target insertion. The target assumed is the DD NRL 160 MJ target with two laser beams. The initial conditions were zero particle and energy flux in the chamber. Time was initiated at the conclusion of the BUCKY data (500 μs). The conclusions were that viscosity has a strong dependence on temperature (kinematic viscosity law assumes a fully ionized gas). The blast position within the chamber (within normal tolerances) makes no significant difference. The difference between an insulative and conducting wall significantly affects both the pressure and temperature. It was assumed the gas is fully ionized, which might exaggerate the effect.

4.2 Liquid re-establishment

Two speakers in this session addressed issues of free surface liquid flow behavior in IFE chambers. Prof. Per Peterson (UC Berkeley) concentrated on the HYLIFE cylindrical jet behavior. He discussed shock attenuation in porous jet arrays. A simple snowplow model was developed, and scaled partial-pocket simulation experiments were performed in the Vacuum Hydraulics Experiment (VHEX) facility. Good agreement between modeling and experiments was obtained. Experiments using shotgun blasts to simulate the effect of target explosions on the jets were described. Some difficulties were observed with incomplete combustion; high energy explosives are being developed to replace the shotgun blasts.

A second topic discussed by Prof. Peterson was vortex flow. A design concept under consideration uses multiple inlet and exit tubes to control the rotation. Experiments were performed to demonstrate the ability to produce vortex flows.

The second speaker was Prof. Abdel Khalik (Georgia Institute of Tech.). He concentrated on the dynamics of thin films. The first part of his presentation explored droplet release from inverted porous walls. Both numerical simulations and experiments were performed over a wide range of dimensionless parameters, and good agreement was obtained.

A second topic discussed by Prof. Abdel-Khalik was detachment of injected films from inverted surfaces both with and without curvature. An extensive set of experiments was performed with both wetting and non-wetting surfaces over a wide range of parameters to quantify the detachment distance. Finally, experiments were described in which cylindrical dams were introduced to obstruct the flow. The results indicate that hydrodynamically tailored dam shapes will need to be developed to avoid massive disruption of the film flows.

Discussion

From the discussion, it seemed that it would be useful to summarize the different mechanisms occurring at different times in the liquid wall and chamber following the target micro-explosion for a thick liquid wall design such as HYLIFE-II. Understanding and characterization of these mechanisms are very important in designing the chamber and in being able to estimate key parameters such as the aerosol concentrations in beam lines prior to each shot (which must be compatible with the driver requirements). A compilation of current models and experiments including their capabilities to simulate (and in the case of experiments to measure also) these mechanisms was developed, as shown in the following tables:

Models:
ABLATOR, LLNL (Table 1a)
BUCKY, UW (Table 1b)
SPARTAN, UCSD (Table 1c)
TOPGUN, INL (Table 1d)
TSUNAMI, UCB (Table 1e)
TSUNAMI + condensation module, UCLA (Table 1f)

Experiments:
UCLA Plasma Gun Facility (Table 2a)
UCSD Laser Plasma and Laser-Matter Interactions Laboratory (Table 2b)
UW Shock Tube Facility (Table 2c)
XAPPER Facility, LLNL (Table 2d)
Z Facility, SNL (Table 2e)

Georgia Institute of Tech. Hydraulic Experimental Facility (Table 2f)
UCB Hydraulic Experimental Facility (Table 2g)

The information is summarized in an overall table (see Table 3) with a view to help better recognize where there are gaps in current understanding and capabilities and where future R&D effort should be directed. This represents just a starting point for a process which must be much more thorough (such as, for example, considering the possibility and cost of adding new capabilities to experiments and of running the experiments) to arrive at a clearer vision of a future R&D plan based on a given budget.

Appendix I

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Agenda

May 5

8:30-8:45	Welcome/logistics	W. Meier
8:45-9:10	Background and goals of the town meeting	R. Raffray
	Session 1 **IFE Target Threats**	
Chair: R. Petzoldt		
9:10-9:35	Indirect-drive targets	D. Callahan
9:35-10:00	Target output	D. Haynes
10:00-10:15	Break	
	Session 2 **Driver and Target Constraints**	
Chair: J. Latkowski		
10:15-10:40	Driver	S. Yu
10:40-11:05	Target materials selection and constraints on chamber conditions	R. Petzoldt
11:05-11:20	Discussion	
	Session 3 **Chamber/Liquid Wall Dynamics Under Threats** (short term, ~ microseconds-milliseconds) Liquid wall response to threats and early chamber dynamics	
Chair: S. Abdel-Khalik		
11:20-11:45	BUCKY simulation of source term for aerosolization studies	D. Haynes
11:45-12:25	(1) Liquid wall ablation under IFE photon energy deposition; & (2) Flibe properties from EoS	R. Raffray/ M. Zaghloul
12:25-1:30	Lunch	
Chair: W. Meier		
1:30-1:55	ABLATOR modeling of x-rays effects on liquid walls	S. Reyes
1:55-2:20	TSUNAMI modeling of early target and ablation debris venting	C. Debonnel
2:20-2:35	Isochoric nuclear heating and design implications	L. El-Guebaly
2:35-3:00	Numerical simulation of hydrodynamic processes in high power liquid mercury targets.	R. Samulyak

3:00-3:30	Discussion	
3:30-3:45	Break	

Chair: P. Sharpe

3:45-4:10	The effect of ionization on condensation in ablation plumes	M. Tillack
4:10-4:35	Plasma gun experiments	P. Calderoni
4:35-5:00	Shock tube experiments	R. Bonazza
5:00-5:30	Discussion	
5:30	Adjourn	

May 6

Session 4 **Chamber/Liquid Wall Dynamics** (long term, to ~0.1 s)

Session 4.1 Chamber clearing mechanisms

Chair: D. Haynes

8:00-8:25	Flibe condensation	P. Calderoni
8:25-8:50	Chamber clearing--The hydrodynamic source term	S. Abdel-Khalik
8:50-9:15	Aerosol modeling	P. Sharpe
9:15-9:40	Chamber dynamics code (2D)	Z. Dragojlovic
9:40-10:10	Discussion	
10:10-10:25	Break	

Session 4.2 Liquid re-establishment

Chair: M. Tillack

10:25-10:50	Jet disruption/recovery experiment	P. Peterson
10:50-11:15	Fluid dynamic aspects of thin liquid film Protection Concepts	S. Abdel-Khalik
11:15-11:45	Discussion	
11:45-12:30	Final discussion, wrap-up and summary	W. Meier/R.Raffray
12:30	Adjourn	

Appendix II
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List of Participants

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