Summary Report of the
1st Research Coordination Meeting on

The Element of Inertial Fusion Energy Power Plants

Vienna, Austria, IAEA Headquarters, 20-24 May 2001

Prepared by
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Abstract

This report contains a summary of the 1st Research Coordination Meeting for the Coordinated Research Project entitled, "The Elements of Inertial Fusion Energy (IFE) Power Plants," held at the IAEA Headquarters, Vienna, Austria, from 20 to 24 May 2001. The goal of the project is to promote and support international collaboration on various aspects of IFE power plants with a focus on addressing interface issues for drivers, targets and chambers. This report includes abstracts of the activities that the participants described in oral presentations at the meeting. The full reports submitted by the participants are also attached. A list of worldwide organizations conducting research relevant to IFE and key contracts at those organizations was developed at the meeting and is included in this report. Preliminary cataloging of a wide range of interface issues was developed and reported here. Finally, suggestions for continued and new international collaborations are presented.

Table of Contents

1) Introduction

2) Summary of Activities of the Participants

3) Overview of Worldwide IFE Activities

4) Identification of Interface Issues

5) Opportunities for International Collaboration

6) Recommendation

Appendix A
Information on the CRP

Appendix B
Agenda for Research Coordination Meeting

Appendix C
List of CRP Participants

Appendix D
Contributed Papers Describing IFE Research Activities

Appendix E
Preliminary List of Interface Issues and Considerations

1. Introduction

Fusion research is proceeding effectively to develop a new energy source that is abundant, safe, environmentally acceptable, and economical. There are two major approaches, Magnetic Fusion Energy (MFE) and Inertial Fusion Energy (IFE). The basic physics of IFE (compression and ignition of small fuel capsules containing deuterium and tritium) is becoming increasingly well understood. New megajoule-class laser facilities under construction in the USA and in France are expected to demonstrate ignition and energy gain in this decade. Conceptual design studies have developed credible IFE power plants that have attractive cost, safety and environmental features.

Based on recent advances by individual countries, IFE is now at the stage where large benefits can be obtained from a coordinated approach in the form of a CRP. This CRP will help Member States to promote the development of plasma/fusion technology transfer and to emphasize safety and environmental advantages of fusion energy. The CRP will document the state of art and conduct research to help resolve key issues. While there are many issues to be resolved and significant technology development needed, this CRP will focus on interface issues including those related to 1) the driver/target interface (e.g., focusing and beam uniformity required by the target), 2) the driver/chamber interface (e.g., final optics and magnets protection and shielding), 3) the target/chamber interface (e.g., target survival during injection, target positioning and tracking in chamber). This CRP will also include an assessment of the state of the art of the technologies required for an IFE power plant (drivers, chambers, targets) and systems integration and assessments of environmental, safety and economic (ESE) aspects.

Fusion research is proceeding effectively to develop a new energy source that is abundant, safe, environmentally acceptable, and economical. There are two major approaches, Magnetic Fusion Energy (MFE) and Inertial Fusion Energy (IFE). The basic physics of IFE (compression and ignition of small fuel pellets containing deuterium and tritium) is becoming increasingly well understood. New megajoule-class laser facilities under construction in the USA and in France are expected to demonstrate ignition and energy gain in this decade. Fusion reactor design studies indicate that IFE power plant are feasible and have attractive cost, safety and environmental features.

In December of 2000, the IAEA approved the start of a Coordinated Research Project on the Elements of IFE power Plants (see Appendix A). The overall objective of this CRP is to stimulate and promote the Inertial Fusion Energy development by improving international cooperation. The CRP will 1) assess the status of IFE, 2) identify and contribute to the resolution of issues particularly related to the interfaces between the drivers, targets and chambers, and 3) to identify and promote areas of possible collaborations between the countries and institutions participating in the CRP.

The first Research Coordination Meeting (RCM) for the CRP on the Elements of IFE Power Plants was held 21-24 May 2001 at the IAEA Headquarters in Vienna, Austria. The preliminary meeting agenda is attached as Appendix B. This meeting was attended by 18 scientists and engineers representing 10 countries including: Czech Republic, Hungary, India, Japan, Rep. of Korea, Poland, Russia, Spain, USA, and Uzbekistan (see Appendix C). A representative from Germany, also a participant in this project, was not able to attend. The purpose of the meeting was to begin work on this CRP.

The meeting began with short presentations by each participant to introduce their current and proposed research related to the development of IFE. Abstracts of the reported work are given is Section 2. Short, written summaries (up to 8 pages) were also contributed by each attendee and distributed at the meeting (see Appendix D). This helped set the stage for the following interactions and began the process of identifying areas of mutual interest and possible collaborations.

As an initial group activity, attendees developed a list of worldwide institutions that are conducting activities that will contribute to the development of IFE, including the activities of organizations outside those represented at this meeting. Organizations and activities were identified in each of the following areas: Target Design and Modeling; Target Experiments; Laser, Heavy-Ion, and Z-pinch Drivers; Chamber and Power Plant Studies; and Target Fabrication and Injection. For each area, key contacts and a synopsis of activities were listed. This list is given in Section 3 of this report.

A second activity at the meeting was to develop an extensive list of issues and top-level requirements for IFE organized along the lines of the major interfaces: driver/target, target/chamber, and chamber/target. In many cases, broad goals for IFE power plants were identified. This list, while much too broad for the undertaking of this CRP, will help highlight areas requiring R&D in the worldwide IFE programs. The complete list is given in Appendix E.

Each attending member also identified areas of current ongoing collaborations and, more importantly, possible areas for further collaborations. A summary of this is presented in Section 5 of this report

Recommendations for future activities are presented in Section 6. Over the coming year, individuals will be responsible for making the contacts that have been suggested and perusing coordinated research activities. These may include things such as sharing of information on research activities, possible exchange of personnel, joint experiments, etc. The group also agreed, that over the course of this four year CRP, they would work to identify a possible joint international IFE project (or projects) for the next step. The RCM attendees proposed holding the next RCM jointly with a Technical Committee Meeting (TCM) that has been proposed for July 2002 in San Diego, California, USA.

2. Summary of Activities of the Participants

1. Thermal Smoothing of Laser Imprint in Double Pulse Plasma

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In the *direct drive fusion experiments* severe constraints on the laser wavefront uniformity are imposed to achieve an efficient compression of the target. Non-uniformities exceeding certain level may destroy the symmetry of the target implosion. Numerous *optical* smoothing techniques recently proposed and implemented are, however, *unable* to eliminate the *laser imprint* problem arising from the early-time stage of the laser target interaction, when the plasma corona has not yet formed, the critical and ablation surfaces are practically coincident and the *thermal smoothing* due to *the transverse thermal conduction* is not active. The residual structure of the intensity non-uniformities imprinted on the still cold target surface cannot be smoothed away in this transient stage and persists throughout the rest of laser-target interaction. A promising method, how to overcome this difficulty, is the use of *foam buffered targets*. The presence of the foam plasma separates the critical and ablation surfaces on the target and enhances the effect of the plasma smoothing by the transverse thermal conduction. *In our research* we are going to investigate the alternative so called *double pulse* method which assumes that the smoothing plasma buffer layer is generated by an *auxiliary prepulse* preceding the main high power laser pulse. The critical surface position and the size of the absorption zone of the main pulse are controlled by a relative time delay of both laser pulses and by ratio of their intensities. The aim is to assess the conditions under which an optimal smoothing effect takes place. An influence of the prepulse plasma on the effectiveness of the laser-target coupling will be explored. The high power iodine laser system PALS operating at 1.315 μm and 0.438 μm with 400 ps pulse (energies up to 1 kJ and 0.5 kJ respectively) will be exploited. The density structures in the expanding corona will be identified by the X ray side-on laser shadowgraphy as well as interferometry. Two-dimensional hydrodynamic simulations of the proposed experiments will be performed. The results obtained from simulations will be post-processed to allow for direct comparison with the results provided by diagnostics from experiments.
Expected collaborations can fit in three major categories:

- Direct collaboration on our topic of *laser imprint* (e.g. Prof. Rudraiah Nanjundappa, National Research Institute of Applied Mathematics, Bangalore, India: IND-29824).
- Making the laser system PALS available for other research groups from abroad willing to perform experiments relevant to the IFE program.

Broadening our interest to include investigation of the *fast ignitor* scheme (after a successful conversion of the PALS into the fs region).

Fast Electrons for the Fast Ignitor Scheme of Inertial Confinement Fusion

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ICF-related researches in Hungary are presently limited to the activity of a group on the field of laser-plasma interactions. The group is based on a collaboration between the Department of Experimental Physics of the Szeged University and the Department of Plasma Physics of the KFKI-Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences.

The group carries out researches with a subps KrF laser system. One of the main fields of interest is the investigation of fast electrons for the fast ignitor scheme of ICF, especially as concerns the wavelength of the laser, i.e. the present aim is to clear whether a laser of 248 nm short wavelength can be applied for fast ignition. Main directions of investigations:

1. Mechanisms for generation of fast electrons, dependence on laser wavelength (in a planned collaboration with the Technical University of Wien)
2. Transport of fast electrons toward ignition (in an existing collaboration with MPQ, Garching).

Laser Driven Ablative Surface Instability in IFE

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A simple analytical model for ablative stabilisation of Rayleigh Taylor Instabilities is presented considering a porous shell instead of a solid or hallow shell used in the study of IFE. The advantage of using porous shells over solid or hallow shells are: it will be easy to locate the segregation of inner skin shells, it will overcome hydrodynamical unstability in the ablation region where the gradients in pressure and density are of opposite signs and also prevents the indefinite growth rate of RI instability at an ablating surface at a rate n^2 which is smaller from the classical rate $g\alpha$ made by Taylor. Here g is the gravity and α is the wave number of perturbations.

Instabilities that exist in this porous shell can be divided into two types: those that occur in the body of plasma saturated porous shell and those that occur at the ablative surface. To start with we investigate the instability at the ablative surface. Our findings are: (I) Momentum method to obtain dispersion relation is more effective than using the usual energy method used in the literature. (ii) We have used the following density profiles: exponentially blowoff plasma with a density gradient β followed by a constant density porous shell of thickness δh. For perturbations of arbitrary wave number α, we obtained an explicit expression for the growth rate n as a function of δ, β, δh, σ and the modified Reynolds number R where σ is the porous parameter and R involves σ and hence called modified Reynolds number. For R=10 the system is always stable for both thin (*i.e.*, $\beta\delta h \leq 1$) and thick ($\beta\delta h > 1$) shells for arbitrary α. Therefore, the effect of porosity is to stabilize the system which is in contrast to a situation in the absence of porous

material where the system was always unstable for $\beta\delta h \geq 1$. For R=100, we found that all the three modes (namely stable, neutral and unstable) of instability exist depending on the thickness of the shells. For thin profiles (*i.e.*, $\beta\delta h<0.5$) the system is stable for arbitrary α and $\beta\delta h>2$ neutral instablity exist for different values of α and then become stable. We conclude that increase in R (*i.e.*, the effect of porosity) decreases the growth rate and hence permeability is more suitable for control of instability which is more suitable to increase the efficiency of IFE power plant.

The future work is:

(a) Extend the present Darcy results to Brinkman model. Study both linear and stability.

(b) Study the effect of the external constraints of magnetic field and electric field to control instability.

Design Study and Technology Assessment on IFE Power Plant

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Based on the conceptual design of Laser Driven IFE Power Plant, technical and physical issues have been examined. R&D on key issues that affect the feasibility of power plant have been proceeded taking into account the collaboration in the field of laser driver, fuel pellet, reaction chamber and system design. Together with the development of individual element, investigations of interface issues between driver/chamber, chamber/target, and target/driver are also performed. We are concentrating our effort on several concepts of power plant design as follows:

Target:	Direct (with/without fast ignition)
Driver:	DPSSL
Chamber:	(1) Magnetically guided thick liquid flow (SENRI)
	(2) Wetted wall (KOYO)
	(3) Dry wall (KOKI)

Integrated Reactor Engineering experiment is planed to investigate the interface issues with rep-rate operation of target irradiation and implosion. Along with the design of rep-rate integrated system, high intensity neutron source by laser has been proposed to initiate under the worldwide collaboration scheme.

Peripheral Elements and Technology Associated with Pulsed Power Inertial Fusion

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The fast pinch discharge can now transform the stored electrical energy into X ray with very high efficiency. The pulsed ion beam with medium-weight is also interesting from the point of view

of a candidate energy driver for IFE and the industrial application. These belong to the group of pulsed power inertial fusion. If the problem of the rep-rate operation of the pinch source will be solved, and if the tight focus of the beam will be obtained, the power plant designs with both energy drivers will become more realistic in the near future. So that, we will try to investigate the peripheral elements and technology associated with these drivers. Common subjects for the laser IFE are included in our program.

The ablation of various materials with intense X ray is calculated. We consider X ray which is produced under model target implosions with the fast pinch and the laser light. The object materials are the IFE reactor wall materials and the viewing port materials for the laser. Experiments to measure the ablated thickness of the materials with intense X ray will be tried, and the value will be compared with the calculated value. The production of medium-weight pulsed ion beam is revisited, and the beam micro-divergence angle at the anode surface will be measured in more detail. The ablation processes of various materials (under solid and liquid conditions) with pulsed lasers and ion beams will be also investigated to enrich the data-base for the ablation of various materials under the IFE implosions. Collaboration with Sandia National Laboratories (USA), ILE-Osaka University (Japan) and Institute of Opto-electronics (Poland) etc. are scheduled during our courses.

Feasibility study of the high power laser system with beam combination method using phase conjugation mirrors of stimulated Brillouin scattering for generating an ultra high power output with high repetition rate over 10 Hz

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The feasibility of a new high power laser system for producing an ultra high power output with high repetition rate over 10 Hz will be studied in this work. Phase conjugation mirrors using a stimulated Brillouin scattering will be used to accomplish it and the main goal of this work will be focused in how to get the phase locking of many beams (>10) in the beam combination using the stimulated Brillouin scattering phase conjugation mirrors. The author suggests three new methods to phase lock. If one of them is proved practically useful to lock many beams over 10 up to millions, the high power laser with unlimited output energy with high repetition rate over 10 Hz will be possible to realize and it will enhance the commercial IFE in near future.

Investigation of the High-Z Laser-Produced Plasma with the Use of Ion Diagnostics for Optimization of the Laser Interaction with the Hohlraum Targets

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The main goal of this project related to the IFE issues is to investigate the physical properties of laser-produced high-Z plasma with the use of ion diagnostic methods supplemented by X ray diagnostics. Combined measurements using several diagnostic methods are essential for quantitative analysis of hohlraum-like high-Z plasma. The precise ion diagnostics offer the alternative methods of studying such plasma. We would like to determine the plasma

characteristics in dependence on laser plasma parameters, illumination geometry as well as target material and a shape. The experimental results will be used to analysis of the thermal and non-thermal processes in the plasma influencing the energy distributions of electrons and ions as well as X ray generation in the hot Z-plasma. Preliminary experiments were performed at the IPPLM with the use of Nd:glass lasers (=10^{17} W/cm^2 in the 1.2-ps pulse and =10^{14} W/cm^2 in the 0.5 ÷ 5 ns pulse) and the measuring equipment available in the institute (ion energy analyzers, ion collectors as well as X ray detectors and spectrometers). The first results of measurements show the importance of non-linear processes influencing the ion stream parameters. The additional measurements will be accomplished within the collaboration with the PALS Research Centre in Prague (Czech Rep.) with the use of the high energy iodine PALS laser operating at 1.315 μm and at 0.438 μm in the 0.4-ns pulse (energy up to 1 kJ or 0.5 kJ respectively). We also presume applications of our ion diagnostic methods for studies of other IFE-related issues, particularly: laser, X rays, ions and debris interaction with targets correlated to projects No. 11537 (R. Khaidarov) and No. 11635 (K. Kasuya). Our 1-ps 1-TW laser and X ray diagnostics can be used for experiments related to the fast ignition that is the subject of the project No. 11633 (I. Foldes).

Investigation of Beam-Plasma Interaction as Specific Problem of the Heavy Ion Driver-Target Interface

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Investigation of heavy ion beam interaction physics with dense plasma is one of key issues for Inertial Confinement Fusion (ICF) driven by powerful heavy ion beams. Both for direct and indirect drive scenarios of Heavy Ion Fusion the target design is determined by the processes of beam-plasma interaction. For any type of targets temporal profile of the energy deposition of intense ion beam strongly depends on experimental data on ion stopping in dense, strongly coupled plasmas and related hydrodynamic response of absorbing layers. Therefore, beam-plasma interaction process becomes a key issue in the design study of the interrelated ensemble Heavy Ion Driver – ICF target. In fact it determines the requirements to the output parameters of powerful ion beams, final focusing system, number of beamlets in reactor chamber, beam transport through the reactor chamber, target positioning and the design of the target geometry itself.

The Detailed Research Objectives recearch objectives of the ITEP group in frame of the collaborative project can be specified as follows:

- to investigate the energy losses and charge state distribution of 110 keV/u Cu and U ion beams in plasma target by using the ITEP RFQ linac.
- to investigate the energy loss and the charge state distribution of heavy ion beams of different atomic mass in dense, explosively driven plasma in collaboration with GSI-Darmstadt and ICP RAS in Chernogolovka by using the UNILAC facility.
- to analyze the influence of the data obtained on the requirements to the parameters of the heavy ion accelerator-driver and on the design of the HIF targets.

Extension of Free-Standing Target Technologies on IFE Requirements

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Fusion reactor studies indicate that energy generation by means of cryogenic target compression requires that targets are injected into a reactor chamber with a high repetition rate. In this regard, one of the challenges for inertial fusion energy (IFE) reactor is building the cryotarget factory. which works with moving free-standing targets. The free-standing layering technologies (FST) are the research area, which has been intensively explored at the Lebedev Physical Institute (LPI). It has been well documented (theoretically and experimentally) that using FST-layering technology one can provide for (a) the work with a batch of free-standing targets, and (b) a rep-rate cryogenic target fabrication and their rep-rate injection into the test chamber. Based on these advances, the FST is now at the stage of extension on a reactor-scaled target design for IFE power plant. This work is performed under IAEA Research Contract #11536/RBF. The research objectives of our current and near-term program are aimed at (a) obtaining new information and its subsequent analyses to confirm the FST feasibility for IFE, and (b) giving a practical guide for design of IFE target factory based on FST.

Elements of Inertial Fusion Energy Power Plant Design (numerical simulations, computational models)

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A new 2D-radiation transport code has been coupled with an existing multi-material fluid dynamics code using Adaptive Mesh Refinement (AMR). A campaign of *ad hoc* experiments is presently running for comparison in very demanding conditions. New target simulations considering the effect of inverse Compton scattering in Tritium-less targets working in a catalytic regime, show the reducing effect of performance but still largely feasible. Important advances in atomic physics, opacity calculations and NLTE calculations, participating in significant experiments (LULI/France), have been obtained, including well tested analytical formulation. Neutron activation of all natural elements in IFE reactors for waste management and that of target debris in NIF-type facilities have been completed. Pulse activation in structural walls is computed with a new accurate methodology and the role of uncertainties remarked. The role of HT and HTO for different conservative conditions is being assessed. We recognize recombination barriers (metastable defects), amorphization by damage accumulation and compute first systematic high-energy displacement cascade analysis in SiC, and radiation damage pulses by atomistic models in metals. A full time-space multi-scale modelling for irradiation damage is being developed for lifetime evaluations.

Work in three main areas is performed relevant for this IAEA CRP: Target design, Safety & Environment, and Materials. Our methodology is being the numerical simulation modelling with consistent pre-comparison with *ad hoc or* existing experiments. Our present work (and potential identified co-ordination) is answering to: which is the optimal target design for high gain?, how are the different hydro instabilities modifying the performance of the implosion?, which are the atomic physics (EOS; opacities) data and methods to successfully reproduce the implosion, and

how to run it in fast / accurate modelling?, which are the more stringent conditions needed for ignite and burn tritium-less / neutron-less targets?, how the tritium chemical forms influence the dose from conservative releases conditions?, how to reproduce with feasibility the extreme neutron pulsed activation?, which is the role of debris activation, primary and secondary activation?, how the uncertainties in activation data modify the consequences in operation, accident, and wastes disposition?, which are the potential accident situations and their consequences in safety & environment ?; which is the sequential physics in neutron irradiation damage of materials?, how to predict the degradation of properties (optical, structural, others) of materials due to irradiation that influence performances and lifetime?

Target Injection and Tracking in Inertial Fusion Energy Power Plants

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Fueling of a commercial Inertial Fusion Energy (IFE) power plant consists of supplying about 500,000 fusion targets each day. The most challenging type of target in this regard is for laser-driven, direct drive IFE. Spherical capsules with cryogenic DT fuel must be injected into the center of a reaction chamber operating at temperatures as high as 1500°C and possibly containing as much as 0.5 torr of xenon fill gas. The DT layer must remain highly symmetric, have a smooth inner ice surface finish, and reach the chamber center at a temperature of about 18.5 K. This target must be positioned at the center of the chamber with a placement accuracy of ±5 mm. The accuracy of alignment of the laser driver beams and the target in its final position must be within ±20 μm. All this must be repeated six times per second. The method proposed to meet these requirements is injecting the targets into the reaction chamber at high speed (~400 m/s), tracking them, and hitting them on the fly with steerable driver beams. The challenging scientific and technological issues associated with this task are being addressed through a combination of analyses, modeling, materials property measurements, and demonstration tests with representative injection equipment. Measurements of relevant DT properties are planned at Los Alamos National Laboratory. An experimental target injection and tracking system is now being designed to support the development of survivable targets and demonstrate successful injection scenarios. Analyses of target heating are underway. Calculations have shown that the direct drive target must have a highly reflective outer surface to prevent excess heating by thermal radiation. In addition, heating by hot chamber fill gas during injection far outweighs the thermal radiation. It is concluded that the dry-wall, gas-filled reaction chambers must have gas pressures less than previously assumed in order to prevent excessive heating in the current direct drive target designs. An integrated power plant systems study to address this issue has been initiated.

Summary of IFE Activities at LLNL

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Lawrence Livermore National Laboratory (LLNL) is engaged in a broad range of activities that support the development of Inertial Fusion Energy (IFE). The National Ignition Facility (NIF) is being constructed at LLNL and is expected to be complete in 2008. The demonstration of ignition and gain on NIF will be an important milestone for IFE. LLNL's IFE target design work includes target concept development and detailed computer simulations to determine the performance and emissions from various types of targets (heavy-ion, laser, fast-ignition). This work provides important information for chamber design studies. LLNL has significant activities in both heavy-ion and laser driver development. LLNL is a major participant in the Heavy Ion Fusion (HIF) Virtual National Laboratory (VNL) that is responsible for developing the science and technology base for using a heavy ion accelerator as a driver for IFE. LLNL's Diode Pumped Solid State Laser (DPSSL) program is developing an efficient, high-repetition-rate laser as a candidate driver. LLNL is also involved in chamber and power plant design studies and conducts environmental, safety, economics assessments for both heavy-ion and laser-driven IFE. Currently we have national and international collaborations in all of theses areas and plan to seek expanded opportunities through this IAEA Coordinated Research Project. The range of IFE activities at LLNL are summarized in attached report.

Z-Pinch Power Plant Design and IFE Materials Program on Z and RHEPP at SNL

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There are presently four driver technologies that are being developed for IFE Power Plants: these are HIF (Heavy Ion Fusion), KrF (Krypton Fluoride laser), DPSSL (Diode-Pumped Solid-State Laser), and Z-Pinches. This project will (1) develop the Z-Pinch Power Plant concept, and (2) investigate IFE chamber materials response to X rays (from Z at SNL), and to ions (from RHEPP at SNL). For (1), the overall problem is to develop a z-pinch power plant that is robust, efficient, and economically attractive. The long-range objective is to perform the necessary research and development to systematically develop the Recyclable Transmission Line (RTL) Z-pinch power plant concept into a viable energy source. For (2), the overall problem is to test IFE chamber first wall materials to exposure to X rays at power plant level fluences (from the Z facility at SNL), and to ions at power plant level fluences (from the RHEPP facility at SNL). The long-range objective is to perform IFE materials testing for X rays and ions for candidate materials for all IFE power plant concepts (HIF, KrF, DPSSL, Z-Pinch), and to determine the optimum materials for each case. This project fits naturally into the CRP on "Elements of Power Plant Design for IFE." Under this CRP, and for (1), collaborations with Russia are envisioned, and other countries are also invited to join in the development of the z-pinch power plant concept. Also under this CRP, and for (2), collaborations with Japan, Russia, and Uzbekistan are envisioned, and other countries are also invited to join in this IFE chamber materials program.

Clearing Phenomena and Driver Interface Design for Thick-Liquid IFE Chambers

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The use of thick liquid pockets around IFE targets to protect chamber structures can greatly simplify the selection of structural materials and allow almost all plant components to last the life of the plant. Waste minimization and tritium breeding are likewise greatly simplified. For heavy ion drivers, the additional neutron shielding from thick liquids allow final focus magnets to be located closer to targets, improving focusing and increasing target gain.

The research at UC Berkeley will refine current scaling methods for IFE chamber phenomena, in particular scaling for reproducing liquid pocket hydraulic response using scaled water experiments. This work will include pocket disruption experiments and analysis, and address driver interface issues.

Proper scaling methods contribute to the design of experiments to study microsecond, millisecond, and quasi-steady IFE chamber phenomena, and provides a framework for interfacing the major chamber technology areas. UC Berkeley also performs multi-dimensional gas dynamics modeling of microsecond venting processes for ablation and target debris, to provide information on impulse loads delivered to liquids and structures and to provide data on mass fluxes up beam lines and into chamber condensing regions.

In upcoming work UCB will perform experimental investigations of millisecond liquid hydraulics response phenomena, including experimental studies of shock propagation through oscillating jet arrays, using sequential chemical detonations to disrupt partial pockets formed by multiple oscillating jets. UCB will also contribute to analysis and experiments for chamber interface design for heavy-ion drivers, including analysis and experiments for phenomena controlling mass fluxes up beam lines.

Vapor Clearing Rate and Condensation Study for IFE Liquid Chambers

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The proposed vapor clearing and condensation study addresses issues associated with the IFE target/chamber interface and deals with the provision of a correct chamber environment prior to the target explosion at an economically competitive repetition rate. Experimentally, it involves rapidly generating an IFE prototypical post-shot vapor density in a control volume using characteristic liquid chamber material (FliBe, Li_2BeF_4), and investigates the condensation rates for the proposed schemes. This experimental goal is achieved by: 1) a pulsed electrothermal plasma source that simulates the pellet explosion for rapid vapor generation and 2) an expansion chamber that represents the IFE liquid chamber. The study consists of two phases. Phase I is aimed at characterizing plasma source capability in terms of maximum quantity of material that can be ablated, and to setting guidelines for the design of the next phase. The first phase experimental results confirm the possibility of simulating IFE processes with this facility.

The research effort during phase II is oriented at studying the vapor condensation process. A condensation chamber incorporates droplet sprays at the chamber entrance, and a film flow around the wall is under construction. The objectives are to study the effect of liquid/vapor interaction on the vapor clearing and condensation rate. In parallel with the construction and testing of the phase II chamber, vapor condensation modeling will be developed. The experimental data will be analyzed and compared to the numerical simulation results. At the final stage of phase II activity, an assessment on the achievable repetition rates for an IFE HYLIFE-II like liquid chamber protection scheme will be performed and documented. Phase II activities are considered as part of IAEA research collaboration.

Chamber Dynamic Response, Laser Driver-Chamber Interface and System Integration for Inertial Fusion Energy

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The University of California at San Diego performs research in several key areas of IFE power plant technology including chamber physics, driver-chamber interface and system integration.

(1) The ARIES Team, which historically has focused its efforts on developing integrated power plant visions for magnetic fusion concepts, is performing a broad assessment of IFE chamber technologies including dry walls, walls protected with sacrificial layers and thick liquid schemes. The motivation for this work is to understand trade-offs and to identify design windows for promising concepts.

(2) A key uncertainty for IFE power plants is whether or not the chamber environment will return to a sufficiently quiescent and clean low-pressure state following a target explosion to allow a second shot to be initiated within 100–200 ms. Initial steps have been taken toward developing a predictive capability in this area. This includes a combination of computer simulation together with experiments to ensure that all relevant phenomena are taken into account, as well as to benchmark the calculations.

(3) The interface between a laser driver and the chamber environment poses particularly challenging problems. Three types of studies are underway at UC San Diego in order to address this problem:

a. Experimental studies of laser-induced damage to grazing-incidence metal mirrors,
b Modeling and measurements of the wavefront distortion from imperfect surfaces to establish requirements which guarantee adequate beam characteristics on target, and
c. Studies of laser beam propagation in simulated chamber media, including determination of breakdown threshold of low-pressure impure gases and the wavefront distortions which occur near or beyond breakdown.

Investigation of Secondary Processes by Interaction of Plasma Streams with Various Materials

Ragab T. Khaydarov
University of Uzbekistan, Tashkent

Damage of the first wall by expanding products of micro-explosion (fast ions, debris) is one of most significant problems for the design of the reactor chamber, experimental modeling of the interaction processes and for choice of materials of the first wall in different IFE scenarios.

The goal of the project is to study a charge and an energy spectra of multiply charged ions generated by interaction of multiply charged laser-produced plasma with the surface of secondary targets. Experiments were carried out by using as diagnostic tool the laser mass-spectrometer with mass resolution of $m/\Delta m=100$ and with time of flight distance 100 cm. Neodymium glass laser providing power density $q=5\cdot10^{10}$ W/cm^2 was used. Characteristics of ion plasma bunch were measured in two cases: at presence of secondary target and without one. The secondary target intended for removing the ions to the laser mass-spectrometer is a disk for diameter 8 mm with a slot in the medium of size 0,4 mm and it was installed as parallel to target surface.

In course of the project execution an interaction chamber for experiments with accelerated ions and with different materials, simulating the internal wall of the reactor chamber, will be developed.

3) Overview of Worldwide IFE Activities

There are a large number of activities worldwide that contribute, either directly or indirectly, to the scientific and technological development of IFE. The RCM attendees compiled the lists given in the following tables. The work has been divided into several major areas: 1) Target Design, Laser Plasma Theory and Modeling, 2) Target and Laser Plasma Experiments, 3) Drivers, 4) Chambers and Power Plants, and 5) Target Fabrication and Injection. In each area, the participating institution, key contacts and key aspects of the research are listed.

Table 3.1 Target Design, Laser Plasma Theory and Modeling

Institution	Key Contact	Activities
USA	Wayne Meier meier5@llnl.gov	IAEA CRP Representative
LLNL www.llnl.govhttp://www.llnl.gov/	Max Tabak tabak1@llnl.gov	Burn calculations and emissions Target concept development Fast ignition
NRL www.nrl.navy.mil	Denis Colombant colombant@ppd.nrl.navy.mil	Direct drive target concepts and emissions
SNL www.sandia.govhttp://www.snl.gov/	Steve Slutz saslutz@sandia.gov)	High yield Z-pinch targets Fast ignition
Univ. of Wisconsin - Madison www.engr.wisc.edu/ep/neep	Bob Peterson rrpeters@facstaff.wisc.edu	1D burn calculations with BUCKY
Russia	Boris Sharkov boris.sharkov@itep.u	IAEA CRP Representative
ITEP	M. Basko basko@vitep5.itep.ru M. Chruazov churazov@vitep5.itep.ru	Implosion physics Target design (HIB)
VNIEEF-Sarov	V. Vatulin vatulin@vniief.ru	3-D integrated simulation, target design (HIB)
Lebedev Inst.	S. Gus'kov guskov@sci.lebedev.ru	Target design (Laser)
VNIITF- Snezhinsk	V. Lykov	Computer simulations (Laser)
IAM (Keldysh) Inst. RAS	V. Zabrodin zabrodin@iam.ru	Implosion simulations
Japan	S. Nakai	IAEA CRP Representative
ILE	T. Yamanaka	Director
Kynsyu U.	Y. Nakao	DT/DD fuels

Europe	M. Perlado	IAEA CRP Representative
Instituto Fusión Nuclear (DENIM) www.denim.upm.es Univ. Politécnica Madrid Univ. Nacional Educación Distancia Univ. Las Palmas de Gran Canaria	J.M. Perlado mperlado@denim.upm.es	Modeling Radiation Hydro Advanced Targets Hydro Instabilities Atomic Physics Target Design Fast Ignitor
Max-Planck-Institut für Quantenoptik www.mpq.mpg.de Hans-Kopfermann-Str. 1 D-85748 Garching (GERMANY) Phone: 49-89-32905137 Fax: 49-89-32905200	J. Meyer-ter-Vehn meyer-ter-vehn@mpq.mpg.de	Target Design / Indirect Drive Fast Ignitor (see also Particle acceleration by High Intense Lasers)
CEA /DAM-ILE de France www.cea.fr BP12-91680 Bruyeres le Chatel (FRANCE) Phone: 33-1-69267549 Fax: 33-1-69267015	P. Holstein holstein@bruyeres.cea.fr (also S. Jacquemot, sylvie.jacquemot@cea.fr)	Target Design Numerical Modelling
Universita degli Studi di Roma "La Sapienza" www.uniroma1.it/energ/ Dipartimento di Energetica Via Antonio Scarpa, 14 00161 Rome (ITALY) Phone: 39-0649766532 /39-0649766800	S. Atzeni atzeni@uniroma1.it	Radiation-Hydrodynamics Hydro Instabilities Fast Ignitot
Johann Wolfgang Goethe-Universität Frankfurt am Main www.witrans.uni-frankfurt.de Institut für Theoretische Physik (GERMANY) Phone: 49-69-798-23459 Fax: 49-69-798-28350	J.A. Maruhun maruhn@th.physik.uni-frankfurt.de	2D-3D Modelling of Hydrodynamics for Target Design
Max-Born-Institut www.physik.tu-darmstadt.de/tqe/hartmut www.mbi-berlin.de Max-Born-Strasse 2 A 12489 Berlin (GERMANY) Phone: 49-30-63921368 Fax: 49-30-6392 1309	Hartmut Ruhl ruhl@mbi-berlin.de hartmut.ruhl@physik.tu-darmstadt.de	Target Modelling Simulation Fast Ignitor

Rutherford Appleton Laboratory www.clf.rl.ac.uk Council for the Central laboratory of the Research Councils (CLRC) Central Laser Facility Chilton, Didcot Oxfordshire OX11 0QX (UNITED KINGDOM) Phone: 44-1235-445582 Fax: 44-1235-445888	M.H.R. Hutchinson h.hutchinson@rl.ac.uk	Atomic Physics for Target Design Opacities Fast Ignitor

Table 3.2 Target and Laser Plasma Experiments

Institution	Key Contact	Activities
USA	Craig Olson clolson@sandia.gov	IAEA CRP Representative
LLNL	Bruce Hammel Hammel1@llnl.gov Mike Key Key1@llnl.gov	ICF experiments Fast Ignition
LLE www.lle.rochester.edu	Bob McCrory rmcc@lle.rochester.edu	ICF experiments
NRL	Steve Obenschain	Planar, beam smoothness, instabilities
SNL	Keith Matzen mkmatze@sandia.gov	Z-experiments
Russia	Boris Sharkov boris.sharkov@itep.ru	IAEA CRP Representative
VNIIEF-Sarov	Nikolai Jidkov, Jidkov@iskra5.vniief.ru S. Garanin (garanin@vniief.ru)	Target experiments ISKRA-5 laser
TRINITI-Troitsk	M. Pergament S. Nedoseev	Hydrodynamics, ablation (lasers) Angava-5 Z-pinch power plant
ITEP- Moscow	A. Golubev alexander.golubev@itep.ru	Heavy ion beam-plasma interaction
ICP-Chernogolovka	V. Fortov (fortov@ras.ru) V. Mintsev	Shock wave physics
HEDRIC IHT RAS	N. Ardreev	Fast ignition simulations
Japan	S. Nakai	IAEA CRP Representative
ILE	H. Azechi	Experiment group leader Stability of Implosion
ETL	Y. Owadano	KrF laser-plasma interaction

TITech	M. Ogawa	HI plasma interaction
Europe	J. Wolowski wolowski@ifpilm.waw.pl	IAEA CRP Representative
Laboratoire pour l´Utilisation des Lasers Intenses (LULI) www.luli.polytechnique.fr Ecole Polytechnique Route de Saclay 91128 Palaiseau, Cedex (FRANCE) Phone: 33-1-69333850 Fax: 33-1-69333009	A.Migus migus@greco2.polytechnique.fr	EOS Opacities Hydro Instabilities Diagnostic Fast Ignitor Particle Acceleration by High Intensity Lasers
Institute of Plasma Physics and Laser Microfusion www.ifpilm.waw.pl LPP Department 23 Hery St. 00-908 Warsaw (POLAND) Phone: 48-22-6859605 Fax: 48-22-6668372	J. Wolowski wolowski@ifpilm.waw.pl	Plasma-Focus and Z-pinches (discharge stability, particle and X ray generation, neutron activation, plasma target interaction)
Technical University Darmstadt* // Gesellschaft für Schwerionenforschung mbH-Plasmaphysik♠ http://www.tu-darmstadt.de/ http://www-aix.gsi.de/ Planckstr. 1 D-64291 Darmstadt (GERMANY) Phone: 49-6151-162923*//49-6159-712664♠ Fax: 49-6159-712785♠	D.H.H. Hoffmann*♠ Dieter.hoffmann@physik.tu-darmstadt.de M. Roth mroth@gsi.de	Beam Plasma Interaction Fast Ignitor Particle Acceleration by High Intensity Lasers
Rutherford Appleton Laboratory Council for the Central laboratory of the Research Councils (CLRC) Central Laser Facility www.clf.rl.ac.uk Chilton, Didcot Oxfordshire OX11 0QX (UNITED KINGDOM) Phone: 44-1235-445582 Fax: 44-1235-445888	M.H.R. Hutchinson h.hutchinson@rl.ac.uk	Laser-Plasma Interactions EOS Fast Ignitor

Plasma Physics Group Blackett Laboratory Imperial College of Science, Technology and Medicine http://www.ph.ic.ac.uk/ Prince Consort Road London SW7 2BW (UNITED KINGDOM) Phone: +44 (0)207 594 7653 Fax: +44 (0)207 594 7658	O. Willi o.willi@ic.ac.uk	Laser-Plasma Interactions Fast Ignitors
Universitá degli Studi di Milano-Bicoca Dipartimento di Fisica http://fisica.bicocca.mi.infn.it/en/ricerca/index.html Via Emanueli 15 20126 Milano (ITALY) Phone: Fax:	D. Batani batani@mib.infn.it	EOS Laser-Plasma Fast Ignitor
Czech Technical University in Prague Faculty of Nuclear Sciences and Physical Engineering http://www.fjfi.cvut.cz/ Brehová 7 115 19 Prague 1 (CZECH REPUBLIC) Phone: 420-2 21912274 Fax: 420-2 6884818	M. Kálal kalal@troja.fjfi.cvut.cz	Laser-Plasma Interaction Diagnostic Thermal
KFKI Res. Inst. Part. Nucl. Phys. Plasma Physics http://www.rmki.kfki.hu/ P.O. Box 49 H 1525 Budapest (HUNGARY) Phone: 36-1-3959220/2464 Fax: 36-1-3959151	Istán B. Földes foldes@rmki.kfki.hu	Laser-Plasma Interaction Fast Ignitor
Laser Plasma Interaction Group Istituto di Fisica Atomica e Moleculare Area della Ricerca del CNR http://www.ifam.pi.cnr.it/ Via Alfieri, 1 56010 Ghezzano Pisa (Italu Phone: +39 050 315 2219 / 2257 Fax: +39 050 3152230	Antonio and Danilo (also Univ. Pisa) Giulietti tonino@ifam.pi.cnr.it	Laser-Plasma Interaction Hydro instabilities

MPI für Quantenoptik www.mpq.mpg.de Laser-Plasma-Group Hans-Kopfermann Strasse 1 D-85748 Garching (GERMANY) Phone: 49-89-32905727 / 739 Fax: 49-89-32905200	Klaus Jürgen Witte klw@mpq.mpg.de klaus.witte@mpq.mpg.de	Laser Plasma Fast Ignitor EOS
Associazione Euratom/ ENEA SULLA Fusione, CRE Frascati ENEA http://www.frascati.enea.it/ Via E. Fermi 45 CP65 00044 Frascati (RM) (ITALY) Phone: 39-6-94005603 Fax: 39-6-94005603	Angelo Caruso caruso@frascati.enea.it	Laser-Plasma Interaction Target Design Fast Ignitor
Instituto Superior Técnico http://www.ist.utl.pt/ Departamento de Física Av. Rovisco Pais 1049-001 Lisboa (PORTUGAL) Phone. 351-218419324 (Ext. 3324) Fax: 351-218419013	T. Mendonça titomend@beta.ist.utl.pt	Laser-Plasma Interaction

Table 3.3 Drivers

Institution	Contact	Activities
Heavy Ion Drivers		
USA	Craig Olson clolson@snl.gov	IAEA CRP Representative
LBNL	Grant Logan bglogan@lbl.gov	HI drivers for IFE all aspects
LLNL	Alex Friedman friedman1@llnl.gov	Computational modeling for source to target
PPPL www.pppl.gov	Ron Davidson rdavidson@pppl.gov	Plasma neutralization for transport
SNL	Craig Olson	Final transport
Mission Research Corp. (MRC)	Dale Welch	2D, 3D simulations of final transport
Russia		
ITEP- Moscow	D. Koshkarev koshkarev@vitep5.itep.ru	Heavy ion driver designs
Japan		
Riken	T. Katayama	Accelerator Development
Europe	D.H.H. Hoffmann	
Gesellschaft für Schwerionenforschung mbH-Plasmaphysik http://www-aix.gsi.de/ Hochstrom-Strahlphysik Depatment Planckstr. 1 D-64291 Darmstadt (GERMANY) Phone: 49-6159-712409 Fax: 49-6159-712785	I.Hofmann I.Hofmann@gsi.de	
Laser Drivers		
USA	Wayne Meier (meier5@llnl.gov)	IAEA CRP Representative
LLNL	Steve Payne (payne3@llnl.gov)	DPSSL development – all aspects
NRL	John Sethian (Sethian@this.nrl.navy.mil)	KrF Laser development – all aspects

UCSD http://aries.ucsd.edu	Mark Tillack (mtillack@ucsd.edu)	Final optics, beam propagation
Russia		
VNIIEF-Sarov	S. Garanin (Garanin@vniief.ru)	Laser driver designs
TRINITI- Troitsk	M. Pergament	Laser driver designs
Japan		
ILE	M. Yamanaka	DPSSL
HAMAMATU	H. Kan	LD development
JAERI	Y. Kato	Ultra-short pulse laser development
UEC	K. Ueda	SS laser material development
Europe	M. Kalal	IAEA CRP Representative
Commissariat a l´Energie Atomique www.cea.fr DAM/ILE – de France PB 12 91680 Bruyeres le Chatel (FRANCE) Phone: Fax:	M. André	Laser Megajoule
Rutherford Appleton Laboratory Council for the Central laboratory of the Research Councils (CLRC) Central Laser Facility www.clf.rl.ac.uk Chilton, Didcot Oxfordshire OX11 0QX (UNITED KINGDOM) Phone: 44-1235-445582 Fax: 44-1235-445888	M.H.R. Hutchinson h.hutchinson@rl.ac.uk	Solid State (VULCAN) Short Pulses / High Intensity
Laboratoire pour l´Utilisation des Lasers Intenses (LULI) Ecole Polytechnique www.luli.polytechnique.fr Route de Saclay 91128 Palaiseau, Cedex (FRANCE) Phone: 33-1-69333850 Fax: 33-1-69333009	A.Migus migus@greco2.polytechnique.fr	Solid State Short Pulses / High Intensity

Associazione Euratom/ ENEA SULLA Fusione, CRE Frascati ENEA Via E. Fermi 45 CP65 00044 Frascati (RM) (ITALY) Phone: 39-6-94005603 Fax: 39-6-94005603	A. Caruso caruso@frascati.enea.it	Solid State
Z-Pinch Driver		
USA	Craig Olson	IAEA CRP Representative
SNL	Dillon McDaniel dhmcdan@sandia.gov	Z-pinch driver – all aspects
Univ. of Nevada, Reno www.unr.edu	Bruno Bauer bbauer@physics.unr.edu	Small scale z-pinch development
Cornell University www.cornell.edu	Dave Hammer dah5@cornell.edu	Z-pinch physics
Russia		
TRINITI- Troitsk	S. Nedoseev	Z-pinch drivers
Kurchatov Inst.	V. Smirnov (vsmirnov@inf.kiae.ru)	Z-pinch drivers
Europe	J. Wolowski wolowski@ifpilm.waw.pl	
Institute of Plasma Physics and Laser Microfusion LPP Department 23 Hery St. 00-908 Warsaw (POLAND) Phone: 48-22-6859605 Fax: 48-22-6668372	J. Wolowski wolowski@ifpilm.waw.pl	Laser-Target Interaction Laser Ion and X ray Sources Plasma Diagnostics (ion, X ray and interferometry)
Plasma Physics Group Blackett Laboratory Imperial College of Science, Technology and Medicine http://www.ph.ic.ac.uk/ Prince Consort Road London SW7 2BW (UNITED KINGDOM) Phone: 44-207-5947656/7 Fax: 44-207-5947658	Malcolm G.. Haines m.haines@ic.ac.uk	Z-Pinch concept

Table 3.4 Chamber and Power Plants (Design, Modeling, Experiments)

Institution	Contact	Activities
USA	Wayne Meier	IAEA CRP Representative
LLNL	Wayne Meier	Chamber Design, Activation, Nuclear Shielding Analysis
SNL	Gary Rochau	Z-pinch power plant design
ORNL www.ornl.gov	Lance Snead sneadll@ornl.gov	Material, Lifetime, Neutron Damage
UC-Berkeley www.nuc.berkeley.edu	Per Peterson peterson@nuc.berkeley.edu	Chamber dynamics modeling, design and technology
UCSD	Mark Tillack	Power plant design studies, Chamber dynamics modeling and experiments, Chamber wall Materials Responses
UCLA www.fusion.ucla.edu/ife	Alice Ying (ying@fusion.ucla.edu)	Chamber Technology (Vapor condensation experiments and modeling, Free surface flow, SiC/SiC breeding blanket design, and Volumetric neutron source)
Georgia Tech.	Minami Yoda minami.yoda@me.gatech.edu	Thick liquid chambers jet fluid mechanics
U. Wisconsin	Bob Peterson	Chamber Dynamics Modeling and Experiments (Dry wall concepts)
INEEL www.inel.gov	Dave Petti pti@inel.gov	Tritium, Safety and Environment
Boeing	Les Waganer lester.waganer@mw.boeing.com	Plant System Design and Optimization
UC-Davis www.ucdavis.edu	J. Degroot jsdegroot@ucdavis.edu	Plant System Design and Optimization
RPI www.rpi.edu	Don Steiner steind@rpi.edu	Reliability and Operational Analysis
LANL www.lanl.gov	Scott Willms willms@lanl.gov	Tritium

Russia		
IHT RAS	S. Medin	Power plant thermal cycle, chamber design
Kurchatov Inst.	A. Shelaev	Tritium cycle, safety, materials
Inst. Scientific Research of Applied Physics	R. Khaydarov ragab@iaph.silk.org	Chambers, Streams interaction with various materials
Japan		
ILE	Y. Kozaki	Chamber design and system design
Kyoto U.	A. Kooyama	Chamber materials – Sic
Tohoku U.	T. Abe	Chamber materials – metal
TITech	K. Kasuya	Dry-wal chamber
Tokyo U.	T. Tanaka	Tritium
Kyushu U.	M. Nishikawa	Tritium
Mitsubishi Heavy Industry Co	Y. Soman	Mechanical design of chamber
Osaka	T. Iida	Neutronics
Europe	J.M. Perlado	IAEA CRP Representative
Instituto Fusión Nuclear (DENIM)	J.M. Perlado mperlado@denim.upm.es	Target Emissions X-Raus Debris Interaction FW Activation Radiation Damage Particle Transport Safety & Environment
CEA/Cadarache http://www-cad.cea.fr/ Association EURATOM-CEA sur la Fusion, Contrôlée Départment de Recherches sur la Fusion 13108 St Paul Lez Durance cedex (FRANCE) Phone: 33-1-42257000 Fax:	Jean Johner	Materials Activation Safety & Environment

Politecnico di Torino Dipartimento di Enregetica (Italy) Corso Duca degli Abruzzi, 24 http://www.polito.it/dipartim/energeti/ Tel. +39 011/564.4464 Fax +39 011/564.4499	M. Zuchetti zucchetti@polito.it	Safety & Environment
EURATOM/UKAEA Fusion Association Culham Science Centre Abingdon Oxfordshire OX14 3DB U.K. http://www.fusion.org.uk/	N.P. Taylor	Safety & Environment Radiation Damage Materials
FZK Karlsruhe (Germany) Forschungszentrum Karlsruhe GmbH http://www.fzk.de/FZK2/english/forschung/index.html Stabsabteilung Öffentlichkeitsarbeit Postfach 3640, D-76021 Karlsruhe Phone +49-7247/82 2860 or 82 2861 Fax +49-7247/82 5080.	A. Möslang	Materials Safety & Environment

Table 3.5 Target Fabrication and Injection (Technology Development and Analyses)

Institution	Contact	Activities
USA	D. Goodin	
General Atomics	D. Goodin	Fabrication technology Materials development Injector and tracking Mass production methods/cost
Los Alamos	A. Nobile	Target fabrication technology Materials development
Schafer Corporation	D. Carey	Foams development
Russia		
Lebedev Physical Inst. (LPI) of RAS	Merkuliev Yu. A merkuli@sci.lebedev.ru	Shell fabrication and analysis (including shell form behavior)
LPI of RAS	Koreshova, E. R. koresh@sci.lebedev.ru	Cryo-target technology, characterization, injection Theoretical analyses and computer calculations all above issues Design and engineering (fill facility, injector, cryogenic experiments)
VNIIEF (Sarov)	Nikolai Jidkov jidkov@iskia5.vniief.ru	Target fabrication
Technical Univ. of St. Petersburg, TUAP Ltd.	Boris Kuteev	Pellet injectors
Europe		
CEA France		
AWE Aldermaston, U.K.		

List of Institutional Abbreviations used in Tables 3.1-3.5

Abbreviation	Institution	Web site if applicable
USA		
Boeing	Boeing Aerospace - High Energy Systems	http://www.boeing.com/assocproducts/hienergy/home.htm
Cornell U.	Cornell University	www.cornell.edu
GA	General Atomics	http://fusion.gat.com/icf/
GaTech	Georgia Institute of Technology	www.gatech.edu
INEEL	Idaho National Engineering and Environmental Lab	www.inel.gov
LANL	Los Alamos National Laboratories	http://fusionenergy.lanl.gov/
LBNL	Lawrence Berkeley National Lab	http://www-hifar.lbl.gov/
LLNLhttp://www.llnl.gov/	Lawrence Livermore National Lab	www-lasers.llnl.gov
NRL	U.S. Naval Research Laboratory	http://other.nrl.navy.mil/
ORNL	Oak Ridge National Laboratory	www.ornl.gov/fed
RPI	Rennselaer Polytechnic Institute	www.rpi.edu
SNLhttp://www.snl.gov/	Sandia National Laboratories	www.sandia.gov/pulspowr
UCB	University of California, Berkeley	www.nuc.berkeley.edu
UCD	University of California, Davis	www.ucdavis.edu
UCLA	University of California, Los Angeles	www.fusion.ucla.edu/ife
UCSD	University of California, San Diego	www-ferp.ucsd.edu
UNR	University of Nevada, Reno	www.unr.edu
UWis	University of Wisconsin, Madison	http://fti.neep.wisc.edu
Russia		
ITEP	Institute for Theoretical and Experimental Physics	
VNIEEF-Sarov		
Lebedev Inst.		
VNIITF-Snezhinsk		
IAM (Keldysh) Inst. RAS		
TRINITI-Troitsk		
ICP-Chernogolovka		
HEDRIC IHT RAS		

IHT RAS		
Kurchatov	Kurchatov Inst.	
Inst. Scientific Research of Applied Physics	Inst. Scientific Research of Applied Physics	
Uzbekistan	University of Uzbekistan	
Japan		
ILE	Institute for Laser Engineering	
Kynsyu U.		
TI Tech	Tokyo Inst. of Technology	
Poland	Institute of Plasmaphysics and Laser Microfusion	
Korea		
KAIST	Korea Advanced Institute of Science and Technology	
EU		
Czech Republic	Laser Plasma Research Centre	
Spain DENIM	Instituto de Fusion Nuclear, Madrid Spain	
Germany GSI	GSI Darmstadt, Germany	
Hungary	Hungary (Central Research Institute for Physics, Hungary	
	Institute of Plasmaphysics and Laser Microfusion, Poland	
India	National Research Institute of Applied Mathematics	

4) Identification of Interface Issues

An IFE power plant will require successful integration of the driver, chamber and target. One of the important activities at the RCM was identification of interface issues and considerations for IFE power plants. These are given in Appendix E organized by Driver/Chamber, Driver/Target, and Target/Chamber. In addition to highlighting areas were design integration is needed, the lists also serve as a guide to topics of possible international collaboration.

5) Opportunities for International Collaboration

Another activity that was completed at the RCM was the preliminary identification of opportunities for international collaboration on elements of IFE power plants. As indicated below, each RCM participant identified specific areas of interest where they thought collaboration would be possible. It was recommended that the RCM participant try to develop some of these collaborative efforts and report at the next RCM.

Milan Kalal (Laser Plasma Research Center, Czech Republic)
- Laser facility in Prague is available for international collaboration
- The topic of thermal smoothing is of particular interest
- Instability work in India (Tara Desai/N. Rudraiah) may be of interest
- Other related collaborations (*e.g.*, Wolowski) already exist
- Short-pulse capabilities expected in several years, opening new opportunities

Istvan Foldes (Central Research Institute of Physics, Hungary)
- Short-pulse and FI physics research interests
- Interest from Poland (Wolowski) in FI physics
- Possible interest in Hungary on surface diagnostics and ion irradiation testing

Jerzy Wolowski (Institute of Plasma Physics and Laser Microfusion, Poland)
- General interest in Z-pinch and plasma focus applications (magnetized plasma)
- Existing collaboration with Prague on high-Z plasmas
- Collaboration possible with Uzbekistan (ion interactions with wall materials)
- Collaboration with Hungary (ps laser material interactions)
- Opportunity to collaborate with US/SNLA on z-pinch and plasma focus

Nanjundappa Rudraiah (NRIAM, India)
- Instability research: general ablation, target instabilities, convective instabilities, magnetofluid instabilities
- Interest in dispersion of dust and toxic materials
- Studies of surface and bulk instabilities with Prague (Kalal)
- Fibrous dendrite formation in targets with Japan (Nakai)

Ragab Khaidarov (U. Uzbekistan)
- Existing collaboration ITEP Moskow, GSI Darmstadt (Ingo Hoffman)
- Ion and laser interactions with materials
- Diagnostic systems
- Interaction of charged particles with FW (Woloski)

Koichi Kasuya (TITech, Japan)
- Mroz (Military Univ. of Technology, Poland) and Wolowski interested in particle beam diagnostic methods
- Negotiating collaboration with RIKEN
- Interested to expand activities in chamber and target technology
- Possible collaboration with SNLA on wall ablation by X rays (z-pinch) and ion beams
- Also interested in modeling wall ablation together with US (UW, UCB, *etc.*)

- Opportunities also exist in using ablation plume diagnostics (*e.g.* from laser-ablation)

Sadao Nakai (ILE, Japan)
- Main topics of interest, available for collaboration are stability of implosion, FI experiments (Gekko-12)
- Collaboration with GA and Lebedev on targets, can be expanded
- Uzbekistan: laser-plasma and laser-wall interaction for chamber R&D
- Spain: laser-plasma and laser-wall interaction for chamber R&D
- India: analysis of plasma stability in chamber with magnetic protection and pellet design robust against instabilities
- Korea: beam combining with SBS
- Interested in developing intense neutron source using lasers
- Possible collaboration on wetted wall behavior with US

Elena Koresheva (Lebedev, Russia)
- Collaboration on target characterization with Japan (ILE, Univ.Osaka) already in place (ISTC project #1557)
- Formation of reactor-scaled targets using Fall and Strike Technique (FST) in collaboration with Japan (ILE, Univ.Osaka) in the frame of the current ISTC project #1557
- Repetitive target injection from the layering module (created at Lebedev Inst., Russia) with US gas gun at room temperature (1st step) and cryogenic temperature (2nd step)
- BeD and BeH foam and shell production (Yuri Merculiev, Lebedev Inst., Russia) in collaboration with US
- Optics to monitor spherical shells (prof.Kong, Korea) is interested for future collaboration

Boris Sharkov (ITEP, Russia)
ITEP already has a heavy-ion program that involves Acad. of Science & defense labs, EU labs
- Target design and modeling
  - Collaborate with MPQ Garching, GSI, Frankfurt, Frascati Italy (ENEA)
  - Exploring opportunities with ILE and VNL
- Target experiments
  - Existing collaboration with GSI, Orsay France, RIKEN/TITech on HI beam-plasma interaction
  - Shock wave physics, diagnostics (ISKRA-5)
  - ANGARA-5 Z-pinch (could add SNLA collaboration)
  - FI: ILE
- Drivers
  - HI work with GSI-Darmstadt
  - TRINITI could be used with Z-pinch (SNLA)
- Chambers and power plant design
  - HI work is being "dressed" into integrated power plant study
  - Good opportunity to collaborate with US/VLT, incl. Berkeley
  - Interested in collaboration with Uzbekistan and SNLA on wall interactions

Manuel Perlado (DENIM, Spain)
- Existing collaborations
  - LULI: experiments and modeling on rad. hydro, atomic physics
  - LLNL: neutronics, S&E, radiation damage

Lebedev: target physics modeling
U. Cagliari Italy- radiation damage modeling for SiC

- Past collaboration with ILE : KOYO, system integration, radiation damage, would like to continue
- Working on collaboration with US (UCB, UCLA) simulating hydrodynamic chamber phenomena
- Explore FW response and neutronics with ITEP
- Interested in intense neutron source using lasers

Craig Olson (SNLA, USA)

- Z-pinches: Russia (Sharkov), possibly Poland (Wolowski)
- Z-pinch power plant with RTL: Sharkov, Smirnov
  everyone is invited to collaborate on this
- IFE material response on Z and RHEPP - can accept samples to test
- Koichi Kasuya, Uzbekistan
- HI fusion/VLT with Russia
  existing with ITEP and with GSI (e.g., channel transport)
  possible with Koichi Kasuya cryogenic high-brightness ion source

Wayne Meier (LLNL, USA)

- Target modeling/ARIES output emission spectra are available, more possibly available in the future
- Target materials selection and design concepts
- DPSSL drivers: S. Payne already interacts with Osaka, annual workshops
- HI VNL collaborations with GSI, ITEP
- Possible collaboration on GILMM with Rudraiah
- Chambers: neutronics, safety and radiation damage with DENIM, thick-liquid-wall chamber R&D with US universities and possibly others
- Can collaborate with Japan on thin liquid walls
- Interest in Flibe, Jupiter-II
- Fast ignition work at LLNL

Wayne Meier (LLNL) for John Sethian (NRL, USA)

- Kong: pulse compression and pointing accuracy could collaborate with NRL
- ETL Japan has close collaboration with NRL
- Short pulse KrF laser work at Prague may be interested

Mark Tillack (UCSD, USA)

- ARIES - existing collaboration with Japan and EU historically on MFE
  Could do more with IFE: Nakai, Perlado, Sharkov
- Driver-chamber interface: optics damage (Kong), beam propagation
- Chamber physics modeling and experiments
- Materials responses

Dan Goodin (General Atomics, USA)

- Topics of interest
  Target fabrication: micro-encapsulation, layering, cryogenics, foam shells
  Target injection: DD and ID targets

- New opportunities
    - FI (Rich Stephens), short pulse laser-plasma interactions
    - Short pulse lasers, laser drivers (Mike Perry, GA)
    - Target design (Jill Dahlburg, GA)
- ARIES work
- Possible collaboration with Kong on optical characterization methods
- Collaboration opportunities with Russia
    - Collaboration with Lebedev looks fruitful including mass fabrication, mass production layering
    - BeD shell with Yuri Merculiev looks promising
- Bilateral US/J-IFE collaboration exists (workshop on Nov.) on target fab. and injection

Per Peterson (UC Berkeley, USA)

- Target-chamber interface and coupling, especially systems with high power density
- Integrated system modeling, optimization and response:
    - target emissions
    - impulse loads and wall interactions
    - venting phenomena
    - thermophysical properties
    - response of liquid systems to impulse loading
- Design of experiments to reproduce phenomena (simulation experiments) and ability of models to compensate for lack of simulation quality, energy sources for simulation experiments (z-pinches, chemical explosions, electrical discharges)
- Collaboration opportunities:
    - Russia (Sharkov) on chamber-related phenomena
    - Japan (Kasuya) on X ray ablation
    - India on fluid mechanics and heat transfer in poorly-conducting materials

Alice Ying (UCLA, USA)

- Interested in chamber technologies, part of VNL
- Modeling - 2D codes on hydrodynamics
- Have existing collaborations with U. Kyoto, JAERI (Jupiter-II) on SiC and SB materials
- Interested in vapor clearing and condensation work with Kozaki
- Plasma MHD and liquid metal MHD coupling
- Interested in laser neutron source activity

Hong Kong (KAIST, Korea)

- Has TW laser system (130 J, 40 ps, 15 min, 90 mm, SHG@50%)
- Has target chamber (w/spectrometer) available for simulation experiments
- Previous collaborations with ILE (Nakai, Nakatsuka), Triniti, RAL
- New shearing interferometer for fringe analysis of transparent target:
    - aberration-free, fast alignment, vibration insensitive
    - interest at Lebedev
- New collaboration opportunities on SBS-PCM
    - Beam smoothing with UCSD
    - Beam pointing with NRL
    - Target tracking system

6) Recommendations

Over the coming year, individuals will be responsible for making the contacts that have been suggested and perusing coordinated research activities. These may include things such as sharing of information on research activities, possible exchange of personnel, joint experiments, etc. The group also agreed, that over the course of this four year CRP, they would work to identify a possible joint international IFE project (or projects) for the next step.