The International Atomic Energy Agency’s Programme on Inertial Fusion Energy

G. Mank
Physics Section, IAEA, Wagramer Str. 5, 1400 Vienna, Austria
g.mank@iaea.org

Abstract. The International Atomic Energy Agency has been promoting international activity and collaboration related to the use of inertial fusion confinement schemes for energy production for many years. Thorough review of inertial fusion research and a detailed analysis of future prospects has been conducted. Inertial Fusion Energy is now approaching the turning point in the long history from physics oriented research to fusion energy oriented development. The programme of the International Atomic Energy Agency reflects, to some extent, this development.

1. Introduction

The International Atomic Energy Agency (IAEA) has long promoted international activity and collaboration related to the use of inertial fusion confinement schemes for energy production. “Energy from Inertial Fusion” [1] is one of many comprehensive expert reviews of the main aspects of use of inertial fusion confinement schemes for energy production. The key premise of the IAEA’s strategic approach is that fusion (magnetic as well as inertial) can provide society with safe, clean, economic, abundant and widely available electric power. The IAEA supports the route to a power plant through projects which optimise existing knowledge. A series of Technical Meetings is related to the environmental impact of fusion and fusion power plant safety [2]. Results of IFE related work presented at the Technical Meeting in Daejon have been published as an IAEA TEC-DOC [3].

In 2000 the IAEA started a Coordinated Research Project (CRP) on “Elements of power plant design for inertial fusion energy”. This CRP supported IAEA Member States in the development of plasma/fusion technology transfer and emphasized safety and environmental advantages of fusion energy. The intent was to focus research on interface issues such as the driver/target interface, the driver/chamber interface, and the target/chamber interface. The final report [4] includes an assessment of technologies required for an IFE power plant (drivers, chambers, targets) and systems integration presented and evaluated by members of the CRP. The overall objective of this CRP was to foster inertial fusion energy development through improved international cooperation [5].

Research indicates that the Diode Pumped Solid State Laser (DPSSL) is currently the most feasible candidate as an IFE power plant driver. Multi-beam combined with stimulated Brillouin scattering (SBS) phase conjugation is a proposed technique for formation of a large laser IFE driver with well-configured elemental modules. Excellent results reported for this technique indicate potential practical applications of this technology. Reports and discussion of the progress of the Z-pinch IFE as well as a new power plant concept involving fast ignition heavy ion fusion attracted much interest. Further IFE modeling towards safety and environmental issues of IFE as well as target

© 2008 IOP Publishing Ltd
and chamber dynamics have been discussed. This presents new challenges for real evaluation of IFE power plants. Interaction physics remains an important issue for improving target design. The aim is more efficient, robust implosion with higher gain, and development of an advanced concept such as fast ignition. Work on target fabrication focused mainly on technical aspects of the repetitive operation essential for a power plant. Fast ignition concepts were also discussed. Chamber studies mainly emphasized plasma wall and particle wall interaction.

2. An integrated approach towards fusion energy
IAEA’s first CRP on Elements of Inertial Fusion Energy Power Plants, which ended in 2005, served to enhance international communication and collaboration in this field. With strong and growing interest in IFE, the IAEA’s continued support of research relevant to IFE is timely and important and facilitating significant progress in inertial fusion and high repetition-rate technologies. This is vital to advance towards inertial fusion energy (IFE).

The recommendations made by the participants of the final Research Co-ordination Meeting (RCM) on Elements of Power Plant Design for Inertial Fusion Energy, the TM on Physics and Technology of Inertial Fusion Energy Targets, Chambers and Drivers and the Consultancy on Integrated Approach to Dense Plasma Applications in Nuclear Fusion Technology concluded that a new CRP addressing research relevant to further development of IFE is warranted. Of key importance is the need to translate the results of specific research into specifications for the facility itself.

2.1. IFE needs
The Coordinated Research Project will cover four main areas of need for the development of Fusion Energy and research.

**Beam target coupling and capsule dynamics.** Common research on beam uniformity imprint, production of energetic particles and conversion efficiency can particularly influence beam target coupling. Research topics include shock-propagation and target compressibility, implosion efficiency, hydrodynamic instabilities, non-spherical perturbation and effects of importance for the fast ignition scheme as charged particle propagation and hot spot formation. Research on these topics is also relevant for heavy ion induced fusion and laser fusion.

**Interface issues related to building blocks of a fusion power plant and driver-target-chamber.** New and developing techniques such as the use of Stimulated Brillouin Scattering Phase Conjugation Mirror (SBS-PCM), can positively influence future development despite high risk in terms of development. The CRP signifies commencement of novel research. Areas of importance include laser ignition schemes, heavy ion fusion and related experiments. Facilities such as FAIR at GSI Darmstadt, Germany, provide laser facilities for analysis as well as the opportunity to investigate heavy ions and their interaction with matter. Collaboration between ITEP (heavy ions) and the laser facility PALS Prague, is foreseen with experiments supported by simulations from DENIM, Madrid. New concepts or extensions of existing ideas such as using KrF lasers will be a central aspect of this work.

**Direct Drive** is the preferred heating mechanism for a power plant. Central ignition, or fast ignition schemes may also be applied for power plants with dry or liquid walls as well as for laser and heavy ion fusion.

**International cooperative research** projects provide unique opportunities for young researchers and students. Schools, such as the one held at ITEP, help generate the interest of new students in work on fusion power. The IAEA’s approach fosters this educational aspect.

2.2. International collaboration on IFE power plants
Nineteen international institutions have thus far participated in the newly commenced CRP. A summary of the working proposals of these institutions follows in alphabetical order of countries.

- The Czech Technical University Prague ASTERIX laser (PALS) has a keen interest in high power laser based IFE research with many existing collaborations. Main research topics include laser
imprint related studies, investigation of energy transfer mechanisms and impact ignition related experiments.

- A joint proposal coordinated by the Institute Lasers and Plasmas (ILP) on direct drive ignition studies for the laser megajoule facility, involves the University of Bordeaux 1 (CELIA), École Polytechnique (LULI and CPhT), and CEA (DPTA, DCRE and DLP). The ILP is coordinating the PETAL project, the results of which will be used in the study of critical issues of the fast ignitor scheme.

- The interaction of heavy ion beams with dense plasmas and ordinary cold matter within the topic of "Transverse diagnostics of intense, focused heavy ion beams" is currently being studied at the Gesellschaft fuer Schwerionenforschung (GSI) in Germany.

- The concept of using "Short-pulse KrF lasers for inertial fusion" has gained further interest with the development of new lasers. The KFKI Research Institute for Particle and Nuclear Physics in Hungary is contributing research in the field of "Laser non-uniformity mitigation" which is of principal impact for future development.

- An Indian group at the National Research Institute for Applied Mathematics (NRIAM), Bangalore, are analysing theoretical aspects as well as participating in joint experiments. These will be conducted both at PALS and at the Universita degli Studi in Milan in conjunction with Italian researchers.

- Two Japanese groups are integrating their studies on IFE approach and on applications of laser fusion and are supported by the Graduate School for the Creation of New Photonics Industries and the Institute for Laser Engineering (ILE) Osaka. More detailed studies on the "Analysis of liquid wall responses against the high flux fusion products" are underway at Tokyo Tech. The Japanese groups, and a Polish group from the Institute of Plasma Physics and Laser Microfusion (IPP-LM), are working on "Studies of phenomena related to fast ignition of a fusion target by laser driven photon beams". Novel and high risk research can foster new technological developments for the inertial fusion community.

- Work on Stimulated Brillouin Scattering Phase Conjugated Mirrors (SBS-PCM) was started during the first CRP on inertial fusion and has shown encouraging results. The work at the Korea Advanced Institute of Science and Technology (KAIST), Daejon, shows a possible route to laser systems with high power/energy and high repetition rate.

- A Russian group from Lebedev Physical Institute (LPI) in Moscow is working on optimized cryogenic layering for IFE targets. Success in recent years means the group are ready to study targets under experimental conditions. The interlinked activities between heavy ion inertial fusion and laser driven fusion are handled by the Institute for Theoretical and Experimental Physics (ITEP), Moscow. Many power plant related aspects are of importance for both areas of fusion research. ITEP is also conducting schools on inertial fusion, enabling lecturers in several topics to discuss their results with young students and experts. A third Russian group at the Ioffe Physical Technical Institute (PTI), St. Petersburg, is contributing to the CRP by investigating ignition of microimplosions in IFE power plants.

- The Instituto Fusion Nuclear (DENIM) in Madrid, Spain provides input on target design, safety and environment and materials for targets and blankets in future experimental facilities and reactors. Hydrodynamic instabilities in inertial fusion systems come under a collaboration headed by the University of Castilla-La Mancha (UCLM) in Spain.

- The Rutherford Appleton Laboratory (RAL), U.K., is researching the new HiPER project. Aspects of this project are open to participants of the CRP involved in fast ignition research.

- Two American groups, General Atomics (GA) and the University of California, San Diego (UCSD) are supporting the CRP. Researchers at GA are investigating technologies needed for a target factory and injection and tracking of the target into the IFE power plant chamber. UCSD activities relate to target engagement, chamber armour thermomechanics and chamber design studies.
• The National University of Uzbekistan; Institute of Applied Physics; Laboratory of Laser Analysis of Materials (IAPh) is investigating interaction of laser radiation and plasma beams with materials of reactor chambers for IFE.

2.3. Matrix of activities
The proposals cover nearly all aspects of IFE research for a fusion power plant and represent just one of the many interests and objectives of these institutions. This CRP facilitates interaction and exchange between scientists within a matrix which can be modified according to results. Many of these results have already been published during this conference [6]. An outline of the matrix is represented below:

1 Beam plasma/matter interaction: PALS (chair), DENIM, GSI, PTI, ILE, IPL, ITEP
   Beam target coupling: ITEP, IPPLM, NRIAM, PTI, IAPh, KFKI
   Capsule dynamics: ITEP, UCLM
   Thermonuclear performance (incl. thermonuclear gain scaling, simpler target) : ITEP
   High risk/high return: GA, IPPLM, KFKI, PTI
2 Building blocks: GSI (chair), ILE
   Driver: ITEP, KAIST, PALS, GSI
   Target: DENIM, GA, NRIAM, LPI, GSI
   Chamber: Tokyo Tech., KAIST, UCSD, PTI, IAPh
   Interface issues, target-chamber: GA, KAIST, PALS, UCSD, LPI, PTI, IAPh, KFKI
3 Integrated approach: DENIM (chair), DENIM, PTI
   Direct Drive: UCSD,
   Central Ignition: dry wall: GA and liquid wall: ITEP
   Fast Ignition (dry and liquid wall): Tokyo Tech., ILE, ITEP, IPPLM
   Heavy Ion Fusion, Liquid wall: ITEP
4 Education: IPL, ITEP, PALS, Tokyo Tech., NRIAM, GSI, DENIM (Erasmus Mundus school)

3. Conclusions
The IAEA’s first CRP on Elements of Inertial Fusion Energy Power Plants provided encouraging results and strengthened international cooperation. The IFE community actively conducts research and the IAEA is still receiving requests to join the latest IFE project. This paper outlines the IAEA’s IFE project, which currently includes contributions from 16 countries. The matrix activities are determined in direct response to fusion needs of the IAEA’s Member States.

4. Acknowledgement
Acknowledgement go to the members of the CRP and the preparation consultancies: N. Alexander, T. Desai, M. Dunne, A. Fertman, I. Foldes, D.D. Hoffmann, M. Kalal, K. Kasuya, R. Khaydarov, Hong Jin Kong, E.R. Koresheva, W. Martin, W.R. Meier, S. Nakai, T. Norimitsu, J.M. Perlado, A.R. Piriz, R. Raffray, N. Rudraiah, B.Y. Sharkov, M. Shmatov, V. Tikhonchuk, M.S. Tillack, J. Wolowski, A. Ying, and their co-workers.

References
[1] IAEA, Energy from inertial fusion, ed. W.J. Hogan, ISBN 92-0-100794-9, Vienna (2005).
[2] IAEA, Fusion Power Plant Safety, Proceedings of a Technical Meeting, Vienna, 10–13 July 2006, IAEA-Proceedings, ISBN 92–0–102007–4, Vienna (2006).
[3] IAEA-TECDOC-1466, ISBN 92-0108405-6 (2005).
[4] IAEA-TECDOC-1460, ISBN 92-0-107005-5 (2005).
[5] Mank, G., Proc. of XXIX ECLIM, 11-16 June 2006, ISBN 84-690-2624-0, Madrid (2006).
[6] Multiple papers at IFSA 2007.