Development of Integrated IFE System and its Industrial Application as Intense Neutron Source

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Abstract. We propose the development of integrated IFE system which enables the rep-rate operation of fusion reaction and neutron production. The industrial application of the laser driven neutron source will also be proceeded with the framework of an academia-industry collaboration.

1. Introduction
The increasing understanding on the implosion physics has enabled us the optimized design of the fuel pellet target and the corresponding laser pulse specification for a specific performance. The high temperature compression for a high fusion yield, and the high density compression up to 1000 times solid density have been experimentally achieved. The demonstration of the efficient coupling from the high intensity, short pulse laser to the compressed core shows the feasibility of the concept of the fast heating of high density target and ignition of the compressed fuel for efficient neutron production.

The remarkable progress on the solid state laser technology based on the power diode laser (DPSSL) gives us a feasible prospect toward the driver for a power plant, which requires rep-rate operation with high efficiency and robustness in operation and maintenance.

Now the laser driven implosion and fast heating of high density target with rep-rate operation is opening new fields of engineering which may have many important applications in science and technology, especially in the nuclear technology. The construction of an integrated IFE system is investigated aiming for the specific application of an intense neutron source and for the development of IFE power plant.

2. Intense neutron source by high power laser
Neutron production by lasers is the clearest evidence of the high temperature plasma production by lasers and it has been investigated since the beginning of the laser fusion research. Many experimental data have been accumulated together with the physical and numerical modelling. We can rely on the experimental results in designing the laser driven neutron source with a specific target and the corresponding laser specification.

Figure 1. Neutron production and its laser energy scaling.
The neutron production per shot and its laser energy scaling are shown in Fig. 1 for the different physical processes such as cluster/Coulomb explosion, transmutation by laser accelerated particle, target heating or implosion by laser. The average neutron yields depend on the possible repetition rate of the events.

3. Application of neutron source

The applications of the intense neutron source in science and industry are becoming increasingly important in developing new methodology in research and engineering. They are summarized in Table 1 being categorized in three fields of application such as neutron materials, neutron energetics, and medical and diagnostics.

| Neutron materials          | (1) Isotope production          |
|----------------------------|--------------------------------|
|                            | (2) annihilation of radioactive waste of fissile fuel |
|                            | (3) fusion material irradiation facility |

| Neutron energetics         | (4) neutron source for the blanket energetics of a fusion power plant, hydrogen production etc |
|----------------------------|---------------------------------------------|
|                            | (5) neutron source for a hybrid reactor where the primary fusion neutrons initiate the secondary fission reactions in the under critical blanket |

| Medical and diagnostics    | (6) medical application of neutrons such as Boron Capture Neutron Cancer Therapy (BCNT) |
|----------------------------|-----------------------------------------------|
|                            | (7) miscellaneous application for radiation diagnostics of structures and materials |

The application (3) in Table 1, fusion material irradiation facility in the category of neutron materials is essentially important in the process of the fusion power plant development. The application (6) for the Boron Capture Neutron Cancer Therapy (BCNT) is becoming effective in the Cancer Therapy due to the progress of the drug delivery technique which increases the density ratio of Boron in cancer and normal tissues of the organ in human body. A compact neutron source which can be used in a hospital is strongly expected to be facilitated.

The neutron imaging technique is progressing recently and the resolving power is greatly improved. The neutron imaging diagnostics gives us the completely different information than X-ray imaging diagnostics. An example of the neutron imaging diagnostics is the monitoring of the hydrogen behaviour in the fuel cell, which is very effective in the development of the hydrogen fuel cell.

4. Integrated IFE system

4.1. Integrated IFE system

The concept of a integrated IFE system is shown in Fig. 2. It consists of A: driver system, B: fuel target system, and C: reaction chamber system. Surrounding the reaction chamber, neutron diagnostics and application instruments are installed depending on the research program.

For the integrated system with a rep-rate operation, the required specification for the key elements of driver, target, and chamber are different from the research facility of a single shot operation. Specifically the interface issues between
the key elements must be considered and investigated. They are target tracking and shooting by lasers, influence of chamber environment to the target injection and laser beam propagation, final optics on the beam port etc.

The basic investigations and developments on these issues of elements and interface have been proceeded under the auspice of IAEA with several programs. They are IAEA Coordinated Research Project (CRP) on “Elements of Power Plant Design for IFE” from 2000 to 2005, and IAEA-CRP on “Pathway to Energy from Inertial Fusion – An Integrated Approach” which is now under operation since 2006.

These international collaborative programs have shown the feasibility of IFE system and also made clear the technical issues which have to be investigated toward the realization of IFE power plant. Within the key technical issues, the most critical issue is the driver development for which innovative technologies are essentially important.

4.2. Driver development

The progresses of the laser fusion driver are shown in Fig. 3 for the ICF research with single shot operation and for the IFE development. For the IFE power plant, high efficiency, rep-rate operation, long life, and low cost driver have to be developed.

![Figure 3. Glass laser system for implosion experiment and DPSSL development for power plant in the world](image)

![Figure 4. Comparison of the processing of VCSEL and Edge-emitter LD](image)

We can see remarkable progress in high power laser technologies which can improve the design and performance of the power plant driver. The recent innovative achievements of them are as follows;

1) The high conversion efficiency of 73% at high power CW operation has been achieved, and further improvement is expected. For the cost reduction of high power LD stuck, VCSEL (Vertical-Cavity Surface-Emitting Laser) is preferable as shown in Fig. 4, where the monolistic process on wafer base could make the high power emitter array [1]. It has been reported that the enough high power output of 3.7 kW/cm² at 100 μs and 0.3% duty cycle for the laser pumping has been achieved with VCSEL.

2) New laser materials are under development including crystal, glass, and ceramic materials. The Yb ceramic YAG demonstrated very high potentiality for IFE driver with temperature control for optimizing the emission cross section and thermal shock parameter as shown in Fig. 5. New laser material based on silica glass has been successfully developed as shown in Fig. 6 which shows high peak power operation [2].
The future prospect of the high average power driver with high efficiency, and low cost for the IFE will open new industrial applications such as intense neutron source and particle accelerator by a high peak intensity laser.

Figure 5. Laser materials for a high-power laser amplifier.

Figure 6. High-peak-power laser material based on silica glass.

5. Summary
The physical process of neutron production by laser is well understood and the yield scaling of neutron production is well established experimentally and with the numerical simulation. The technical investigations and developments for the construction of an integrated IFE system are proceeding all over the world, intensively conducted under the auspice of IAEA.

It is expected that the fusion ignition and energy gain by laser implosion would be demonstrated around the year 2010-2015 with the MJ lasers which are under construction in the USA and France. If the fast ignition works well, it is very attractive in the design of an IFE power plant because of the higher pellet gain with smaller driver energy.

A possible road map toward the IFE power plant is shown in Fig. 7. The integrated IFE system for an intense neutron source which is proposed here has the role of integrated system engineering in the road map.

The separability of the element blocks of the driver, chamber and pellet enables us the independent development keeping the close connection and collaboration of the independent groups of the world. The IAEA Coordinated Research Project (CRP) being titled as “Pathways to Energy from Inertial Fusion – An Integrated Approach” could be the core for the world wide collaboration in IFE developments.

6. References
[1] Seurin J F, D’Asoro L A and Ghosh C 2007 Photonics Spectra July 66
[2] Sato T, Fujimoto Y, Okada H, Yoshida H, Nakatsuka M, Ueda T and Fujinoki A 2007 Appl. Phys. Lett. 90 221108