1. Preface

In the last decade, a big progress has been seen in laser technologies. The CPA (Chirped Pulse Amplification) technique has made it possible to generate relativistic electron plasmas even with table top lasers [1]. Livingston chart of laser power from the invention of laser at 1960 indicates that the laser power has increased by an order of magnitude every three years [2]. This is owed to innovation and invention of technology such as mode-locking, Q-switching, CPA and so on.

Lawrence Livermore National Laboratory has constructed the world-first PW (peta-watt: $10^{15}$ W) laser system in 1996 [1,3] and has carried out a variety of interesting experiments in relation to nuclear physics [4]. In the experiment, the PW laser was focused on a gold foil with the intensity over $10^{20}$ W/cm². Then, laser energy is efficiently converted to that of relativistic electrons, triggering nuclear reactions directly or via $\gamma$-photons generated through the bremsstrahlung process in the target. With the increase of energy of particles to be measured in laser experiments, scientists whose academic background is not plasma physics but nuclear physics have joined such laser experiments. In a good meaning, PW laser has triggered interdisciplinary activities in laser-plasma physics.

Even in such ultra-high intense laser interaction experiment, laser photons do not directly interact with nuclei. Since the size of a nucleus is 1 fm (= $10^{-13}$ cm) and the electric potential by laser field over the nucleus is only 0.1 V at the laser intensity of $10^{20}$ W/cm², it is hopeless to directly excite the nucleus with the laser electric filed. It is, however, noted that such value of the electric field is very high enough to excite or rather directly ionize the bound electrons in atoms. This is because the electric potential is 10 kV over the size of atoms (~ Å) and the electron of a hydrogen atom would be violently stripped from the nucleus by such laser field. Atomic physics under super-strong filed is an attractive subject. I recommend readers interested in such field to refer, for example, to Ref. [5].

The nuclear reactions are induced by the relativistic electrons produced with lasers as mentioned previously. In the experiments by T. Cowan et al. [4], electrons with energy up to 100 MeV have been observed [see Fig. 3 in Chap. 3]. Such relativistic electron can directly interact with nuclei or in-directly interact through $\gamma$-photons produced by the bremsstrahlung process. Under some controlled condition, we can study nuclear physics with the electron scattering due to the electromagnetic force of nucleus. By calculating the electron orbit under the laser field quantum mechanically, we can know the wave function of the relativistic electron(s) oscillating around the nucleus. Since the oscillation energy is in the range of 10 MeV at laser intensity $10^{20}$ W/cm², we would be able to induce nuclear transmutation of nuclear wastes. In order to study such scenario quantitatively, we started to solve time-dependent Dirac equation for an electron around a nucleus under super-strong laser field [6].

It is better to explain the direct motivation of our start of studying laser nuclear physics. In Japan, the joint project between KEK (http://www.kek.jp/) and JAERI (http://www.jaeri.go.jp/english/research/re06.html) has been in progress, where their final goal is to realize the high-intensity proton beam of 50 GeV with 1 MW output power [7]. This high intensity proton accelerator will be constructed for fundamental science
in relation to high-energy physics as the name of Large Hadron Collider from KEK side and for nuclear transmutation of nuclear wastes and material science as the name of Neutron Science from JAERI side [details in Chap. 6]. In the nuclear transmutation, neutrons produced by the fragmentation of heavy nuclei driven by the irradiation of the proton beam are designed to be irradiated on long-life nuclear wastes. We would like to know how different in case of lasers compared to the case with such neutrons from the viewpoints of cost, efficiency, processes and so on.

The direct motivation for the present subject is given to the author after listening to the talk by Prof. Yukawa at the meeting organized by Prof. Nakajima, held at Souken-dai, Hayama, February 2000 [8]. As briefly described in Chap. 7 by Prof. Yukawa, he studied, almost ten years ago, a possible scenario of nuclear transmutation of wastes with rare collisions of electrons with nuclei by considering chaotic motions of outer-bound electrons in laser field. In this meeting I pointed out the outstanding progress of laser technology over the last decade. This was the start of planning of this special topic article.

I was at the same time a member of the program committee of the Japan Physical Society, as the representative of the field of plasma physics, fusion, and discharge. I was required to organize a symposium at the annual meeting of 2001 (March 29) at Chyuo University in Tokyo and decided to pick up this subject. I was also driven by another strong motivation to have such symposium; that is, I was always frustrated with the shortage of interdisciplinary symposiums in the Japan Physical Society meetings at least around my field. I started to talk to people in nuclear physics.

I wanted to know if ultra-intense lasers can be a new tool to understand the physics of nuclei. I talked to Prof. Otsubo, Department of Physics, Osaka University. With his understanding and interest, he kindly recommended Prof. Sato for reviewing the present status of theory of nuclear physics and Prof. Tamae for reviewing the experiment with electron beam. Of course, the present topics and knowledge of nuclear physics must be very wide, and I asked them to pick up the topics seemed to relate to laser nuclear physics situation.

On the other hand, I also wished to pick up the topics relating to engineering viewpoint. So, I contacted Dr. Ohyama at JAERI to ask him to recommend somebody who can review the neutron science project. Thoroughout such process, I came to the following program of the symposium.

1. Introduction (H. Takabe)
2. Theory of Nuclear Physics (T. Sato)
3. Experiment of Nuclear Physics with Electron Beams (T. Tamae)
4. Application of Neutron Beams to Nuclear Transmutation (Y. Ikeda)
5. Nuclear Physics with Ultra-intense Lasers (H. Yoneda)
6. Discussion

Honestly speaking, I do not think that I can summarize all the talks together in some coherent manner. This is partly, of course, because of the shortage of my knowledge on modern nuclear physics. We have tried to discuss in the symposium to clarify what only laser can do in nuclear physics and if laser is acceptably efficient in nuclear transmutation compared to neutrons. It was, however, difficult within a limited time to come to some conclusion.

Around the end of April after the symposium, I had a chance to visit Bruyers-le-Chatel, CEA near Paris to give a talk. After my talk, I visited Dr. C. Guet and talked to him on the laser nuclear physics. He showed much interest in what we talked in the symposium and asked me if some written material have I. In the Global Science Forum organized by OECD at Kansai JAERI (May 28 – 30, organized by Prof. Y. Kato, Document will appear on web-site; http://www.oecd.org/sti/gsf), in addition, I was asked by many participants about what we talked and discussed at the symposium. These are the motivation to publish this Special Topic Article (STA) in English. I initially asked the authors of the STA to write their manuscripts in Japanese. But, after knowing that many scientists over the world are very much interested in laser nuclear physics, I asked them to write their manuscripts in English just after the OECD meeting.

Since we are publishing the STA in the Journal of Plasmas and Fusion Research, we assumed that most of the readers are not specialist of nuclear physics. In order for plasma physicists and engineers to easily get into the present topics, we re-arranged the order of the articles in the following order.

Chapter 1. Preface (this one; H. Takabe)
Chapter 2. Introduction to LNP (H. Takabe)
Chapter 3. Nuclear Physics with Lasers (H. Yoneda)
Chapter 4. Experiment of Nuclear Physics (T. Tamae)
Chapter 5. Theory of Nuclear Physics (T. Sato)
Chapter 6. Application of Nuclear Physics
(Y. Ikeda)

Chapter 7. Comments on Nucleus under Strong Laser Field (T. Yukawa)

We, all the authors, wish many people will be interested in the Laser Nuclear Physics (LNP) and we hope the readers welcome the activity of our interdisciplinary trial.

Finally, I would like to thank Prof. H. Otsubo and Dr. Y. Ohyama for their interest and kind help in nominating the speakers in the symposium. I also thank Prof. K. Nakajima for providing me with the trigger to finally come to this bunch of the special topic article. I thank the Japan Physical Society and the members of the editorial board of the Journal of Plasma and Fusion Research.

References