A Microcapsule, *Hohlraum*, Confined Inertial Nuclear Fusion Analysis Using Ion Beams: US DOE's Triumph by Non-Magnetic Confinement in LLNL for Commercialization

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1. Introduction

Nuclear fusion was achieved by the National Ignition Facility (NIF) that produced 3.15 megajoules (MJ) of fusion energy output using 2.05 MJ of laser energy delivered to the target, demonstrating the basic scientific consequences for inertial fusion energy [1]. In addition, this is just a new step for next 10-years' challenge of 'Commercialization' supported as the 50 million dollars to the design of a pilot inertial fusion plant. The facility fired 192 powerful lasers onto a BB-sized target of deuterium and tritium (DT) which produced the record-breaking excess energy. Fig. 1 shows the Configuration of Hohlraum [1,2,5,6]. DT fusion is described as [3],

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{1}_{0}n + {}^{4}_{2}He + 17.6MeV \qquad (1) $$

Table 1 shows the history of energy productions [4-10] which makes Fig. 2 of the list of energy output by equal energy of input and output. During the injections of laser that was lasting less than 100 trillionths of a second, 2.05 MJ of energy, the equivalent of 1 pound of TNT, bombarded the hydrogen pellet. A flood of neutron particles as the fusion reactions carried about 3 MJ of energy in which a factor of 1.5 in energy gain was achieved [11].

The beam line starts as a weak laser pulse of about 1 billionth of a joule, which is going to optical fibers to 48 preamplifiers that produce the pulse's energy by a factor of 10 billion, to a few joules [12]. The 48 beams are then split into four beams that are injected to the 192 main laser amplifier beamlines. The NIF of Lawrence Livermore National Laboratory (LLNL) operates guided by laser mirrors in which each beam zooms through two large glass amplifiers of the power amplifier and the main amplifier. The main amplifier has a special optical switch called a plasma electrode Pockels cell (PEPC) traps the light [13]. The beams are composed of 192 units proceed to two 10-story switchyards on either side of the Target Chamber. Just before entering the Target Chamber, each quad passes through a final optics assembly, where the laser pulses are converted from 4 million joules infrared to 2 million joules ultraviolet energy, and focused onto the target. Laser beams run about 1,500 meters until the target at the center of the spherical Target Chamber in which the journey takes only about 5 microseconds.

Historically, although USA was a founding member of the International Thermonuclear Experimental Reactor (ITER), it withdrew around the late time of the 20th century in Table 2 [14] where the rejoining was done after 5 years.

2. Methods

The theoretical analysis of Coulomb's barrier and the ionic simulations are performed in this study. In order to complete the nuclear fusions, it is needed to overcome the energy potentials, the Coulomb barrier. The electrostatic potential energy is shown as [15],

$$ E_{Coubm\ b} = c\frac{Q_1 \cdot Q_2}{R} = \frac{1}{4\pi\epsilon_o}\frac{Q_1 \cdot Q_2}{R} \qquad (2) $$

where c: Coulomb constant (8.9876×10^9 N m^2 C^{-2})
ϵ_o: Permittivity
Q_1, Q_2 : Electrical charge
R: Distance between two particles

Therefore, it is needed for the kinetic energy of two particles to be higher than the energy of Coulomb barrier in Fig. 3. By the way, considering the quantum tunneling, the Camow factor shows the probability to overcome the electrostatic barrier as [16],

$$ B_G(E) = e^{-\sqrt{\frac{E_G}{E}}} \qquad (3) $$

where E_G is the Gamow energy which is combined of reduced mass, the fine structure constant, the light speed, and the respective atomic numbers.

The Stopping and Range of Ions in Matter (SRIM) is used for the simulations for the interactions of the hydrogen ion (proton) beams, which is known as the Transport of Ions in Matter (TRIM). For the application in this study, it is modeled as 10.677 kJ in 192 laser beams where the isotropic beam makes the 2.05 MJ in Fig. 4. The laser's photons induce the proton collisions into the proton layers where the hydrogen ions are modeled as the ion beams are bombarded. The multiplied energies are imagined where the simplified configuration by two times calculations is simulated in an initial modeling. TRIM in SRIM-2008 code system will accept any values from 10 eV to 10 GeV/amu [17]. So, the maximum energy of injected proton is 10 GeV in Fig. 5(a) which shows simulations of Trim calculations with 10 GeV injected protons.

Overcoming Coulomb's barrier by non-conventional ways, Low energy nuclear reactions (LENRs) have tried to achieve the nuclear fusion in last 35 years since 1989. As non-conventional way to achieve the high energy using non-magnetic forces such as electricity, catalyzer, vacuum and so on that produce the plasma conditions. In the first announcement of the locally-induced fusion-like reactions called Cold Fusion in 1989, the catalyzed solutions are incorporated with the electricity to make the strange heat productions by the late Martine Fleischmann and Stanley Pons [18]. In addition, Dr. Iwamura in Japan used the ion penetrations through the material layers of the nuclear transmutations [19].

3. Results

The maximum energy of injected proton is 10 GeV in Fig. 6 which shows simulations of Trim as Collision event, Ionization, Phonons, and Energy to recoils where just the Ionization decreases within 100m target length. Although 10.677 kJ is converted as 6.664×10^{13} GeV, the maximum energy of the code is just 10 GeV. So, the incoming particle has very tremendous energy, which is not seen in the conventional ion-beam interation simulations. That is, the fusion could be done in the very higer enerngy of laser. Therefore, it is reasonable to seek the fusion method usign less energy with the cheaper cost, which could be the mass productions as the most imporatant condifion of the commercialization. Consideing the Coulomb's barrier jumping-over by non-conventional ways, the tiny region intensive energy could be used to achieve the LENR of caltalyzer, electricity, vacuum, and so on.

4. Conclusions

The study gives the characteristics of energy productions as fusion energy such as the laser of intensive strengthen energy, the catalyzed energy productions by electricity, vacuum, and so on in Table 3. Comparing to the electromagnetic confinement, the locally-intensive energy reactions could give the new trends of fusion energy industrializations. There are some important points in the study.

- The laser fusion in LLNL is investigated.
- Non-electromagnetic confinement analysis is performed in locally-intensive space.
- The catalyzed energy productions by electricity, vacuum, and more are shown.
- Future nuclear energy is proposed.

New kind of nuclear energy could by imagined for the commercialization associated with some variations. It is expedited for the industrialized nuclear fusion when the applied and versatile ideas are to be utilized in the excess energy generations. Fig. 7 shows the comparisons of fusion methods where the confinement transitions are shown from magnetic confinement to lattice confinement which is the cheapest one to make the fusion reactions.

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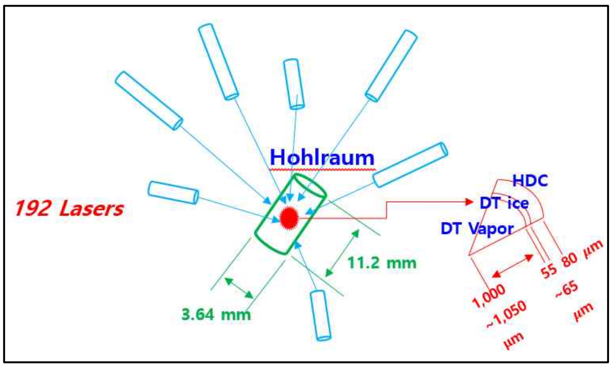


Fig. 1. Configuration of Hohlraum [1,2,5,6].

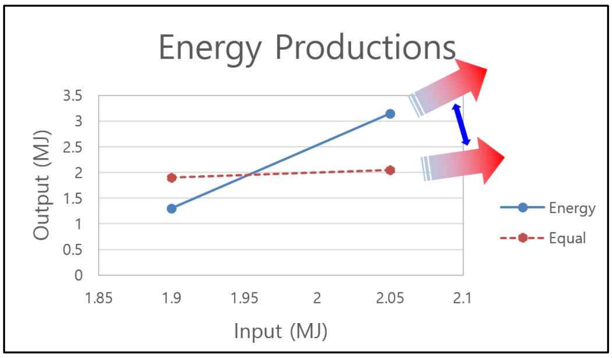


Fig. 2. List of energy output [1].

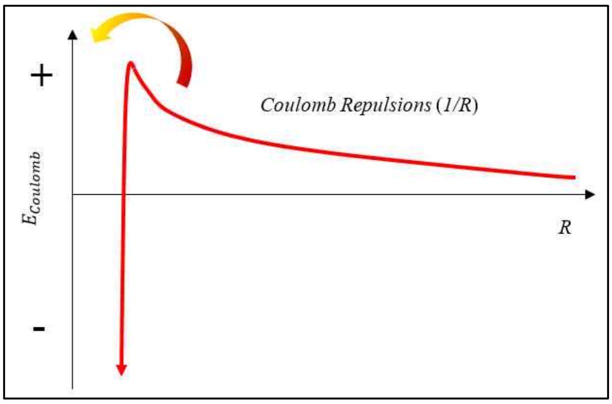


Fig. 3. Configuration of Coulomb barrier.

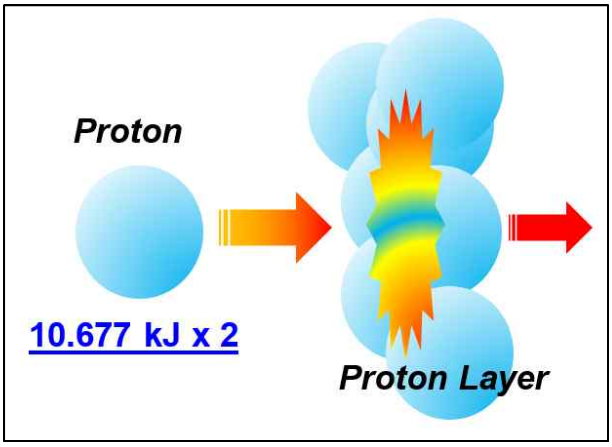
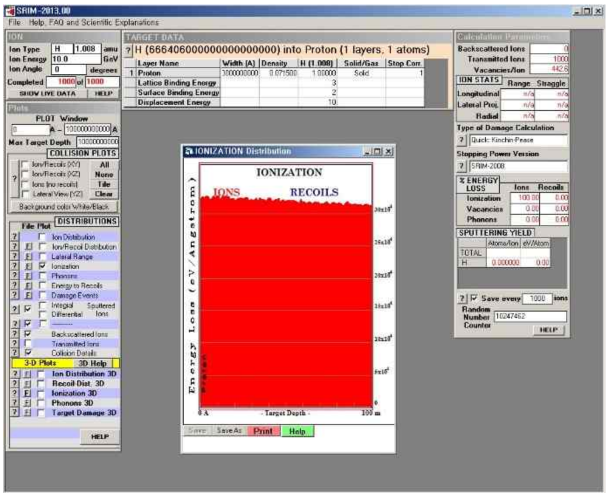


Fig. 4. Simplified configuration of collision induced by the photons.



Ion Type: H 1.008 amu
Ion Energy: 10.0 GeV
Ion Angle: 0 degrees
Completed: 1000 of 1000

PLOT Window: 0 A – 100000000000 A
Max Target Depth: 10000000000

☐ Ion Distribution
☐ Ion/Recoil Distribution
☐ Lateral Range
☑ Ionization
☐ Phonons
☐ Energy to Recoils
☐ Damage Events

H (666406000000000000000) into Proton (1 layers, 1 atoms)

	Layer Name	Width (A)	Density	H (1.008)	Solid/Gas	Stop Corr.
1	Proton	1000000000	0.071500	1.00000	Solid	1
	Lattice Binding Energy			3		
	Surface Binding Energy			2		
	Displacement Energy			10		

Backscattered Ions: 0
Transmitted Ions: 1000
Vacancies/Ion: 442.6

ION STATS	Range	Straggle
Longitudinal	n/a	n/a
Lateral Proj.	n/a	n/a
Radial	n/a	n/a

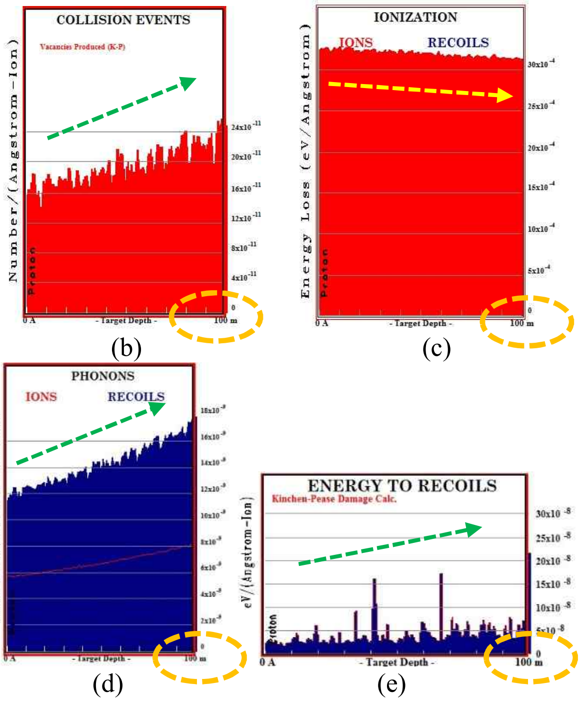
Type of Damage Calculation: Quick: Kinchin-Pease
Stopping Power Version: SRIM-2008

% ENERGY LOSS	Ions	Recoils
Ionization	100.00	0.00
Vacancies	0.00	0.00
Phonons	0.00	0.00

SPUTTERING YIELD	Atoms/Ion	eV/Atom
TOTAL		
H	0.000000	0.00

☑ Save every 1000 ions
Random Number Counter: 10247462

Fig. 5. Simulations of Trim calculations with 10 GeV injected protons.



(b)
(c)
(d)
(e)

Fig. 6. Simulations results of Trim calculations with 10 GeV (a) Collision event, (b) Ionization, (d) Phonons, and (d) Energy to recoils.

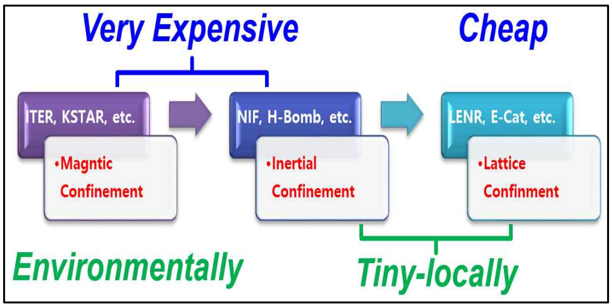


Fig. 7. Comparisons of fusion methods.

Table I: History of energy productions [4-10].

Date	Input	Output
1995	Const. Start	
Mar. 2009	1st Experiment (129 Beams)	
Oct. 2013	1st Energy Output	
Jun. 2018		54 kJ
Aug. 2021	1.95 MJ	1.35 MJ
Dec. 2022	2.05 MJ	3.15 MJ

Table II: History of ITER [14].

Time	Event
1987	USA and USSR agreed to construct
1988	Started to draw
1998	USA withdrawal
2003	USA rejoining

Table III: Comparisons between Tokamak and other trends.

	Tokamak	Other Trends
Plasma	Electromagnetic	Laser, Electricity, Vacuum, Catalyzer, etc.
Place	Environment Oriented	Tiny Region Intensive
Input Cost	Very Expensive	Comparatively Cheap
Output Energy	Larger	Smaller
Excess Energy	Not Yet	Possible