Ultraintense Lasers as a Promising Research Tool for Fusion Material Testing: Production of Ions, X-Rays and Neutrons*)

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Laser fusion environments are characterized by prompt bursts of high energy neutrons, ions and X-rays which are absorbed by different components of the fusion reaction chamber. In particular, plasma facing components are subjected to extreme conditions and prior to their use in the reactors they must be validated under stringent irradiation tests. However, the particular characteristics of the fusion products, i.e. very short pulses, very high fluences and broad particle energy spectra are difficult to reproduce in test laboratories, making those validations hard to be carried out. In the present work, the ability of ultraintense lasers to create the appropriate characteristics of laser fusion bursts is addressed. A description of a possible experimental set-up to generate the appropriate ion pulses with lasers is presented. At the same time, the possibility of generating X-ray or neutron beams which reproduce those of laser fusion environments is also pointed out and assessed under current laser intensities. It is concluded that ultraintense lasers should play a relevant role in the validation of materials for laser fusion facilities and immediate action for this systematic study is called for.

Keywords: laser fusion, fusion material, plasma facing component, ultraintense laser, ion beam, X-ray, neutron

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1. Inroduction

Laser fusion is currently one of the hopes of humankind to produce energy based on a virtually endless fuel with a very low environmental impact [1]. One of the most important challenges for its realization refers to the design of materials and reactor chambers capable of withstanding the harsh environment of a fusion reactor working 24/7. In each laser fusion reaction, short bursts of very energetic ions (mainly H isotopes, He, C and some high Z elements), X-rays and neutrons are generated (see Table 1) which, if not mitigated by some protection scheme, will damage the plasma facing components, shortening their operational lifetime. Whereas neutrons deposit their energy all across the reactor, causing damage in the long run, X-rays and ions are stopped by the inner wall and front optics, having an immediate effect. From a thermo-mechanical point of view, plasma facing components suffer a sudden increase in their temperature, accompanied by the corresponding stress-strain cycle which occurs in microseconds [2, 3]. This process occurs several times per second, causing a considerable fatigue in the material which eventually leads to cracking, mass loss and irreversible damage. From the atomistic point of view, X-rays might trigger a massive photoelectric cascade in the components and the high energy ions induce defects which accumulate and evolve in time. Apart from the deposition of energy, the impinging ions disrupt the lattice structure of the material, removing layers by physical or chemical sputtering and displacing atoms. Shot after shot, new created vacancies, interstitial and implanted impurities diffuse and aggregate, producing dislocations, voids and nano-bubbles at very high pressures which worsen the mechanical properties and produce swelling and material loss. At even higher fluence of ions and X-rays, the wall surface may be ablated resulting in possible mist formation which may prevent further high repetition laser shots. A complete characterization of these noxious factors also requires the consideration of synergetic effects between the impinging radiation/species and their role in the mentioned processes. Thus, reactions between C and H isotope atoms, non linear high radiation flux effects (fluxes $>10^{20}/cm^2/s$), changes in the physical and chemical properties of the materials and their influence in the evolution of defects need to be studied in a reasonable time scale [4].

Unsurprisingly, the combination of all these effects are extremely complex to model and simulate computationally

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Table 1 Summary of total, partial and average energies and number of particles for a direct drive shock ignition fusion target of 48 MJ [5].

Particle	Total Energy (MJ)	% Total Fusion Energy	Average Energy (MeV/particle)	Total number of particles
Neutrons	35,90	75,0%	11,450	$2{,}0*10^{19}$
X-rays	0,66	1,4%	0,009	$1{,}5*10^{14}$
H	0,27	0,5%	0,143	$1{,}2*10^{19}$
D	3,20	6,6%	0,191	$1*10^{20}$
T	3,55	7,4%	0,235	$9{,}4*10^{19}$
4He	3,63	7,6%	1,334	$1{,}7*10^{19}$
12C	1,68	3,5%	0,760	$1{,}4*10^{19}$

and, for the time being, only thorough empirical investigations can yield a solid and reliable prediction of the behavior of the irradiated components. Paradoxically, the experimental research by the laser fusion community has been limited to just a few programs in the US connected to the NIF project in the nineties and HAPL during the last decade [6, 7]. The difficulty to reproduce the plasma environment of a laser fusion reactor (short pulses, high fluence and high energy spectral ranges of X-rays and ions) is probably the reason why those studies have been so sparse and, when they have been attempted, they did not fully reproduce the adequate conditions. From the available studies, it is pertinent to mention the repetitive thermal load investigations by the Dragon Fire laser [8], the X-ray damage simulated using Z-pinch machines [9, 10] and the ion effects modeled either by RHEPP I at the Sandia National Laboratories [11] or by the inertial electrostatic confinement device at the University of Wisconsin-Madison [12]. It is important to indicate that the large number of investigations on materials and test facilities available from the magnetic fusion community cannot be directly extrapolated to laser fusion due to the intrinsically different plasma conditions [13].

With the advent of ultraintense lasers ($>10^{18}$ W/cm^2) in the last decade, this lack of experimental studies may drastically change in the near future. As it will be described in this paper, current laser systems can produce and accelerate high fluences of protons (10^{13} p/sr/shot) and heavier ion beams with similar characteristics to those of laser fusion [14]. Likewise, beams of ultra short X-rays and neutrons of moderate fluence are already available in laser facilities of multi-hundred Joule pulses (10^{13} photons/sr/shot and 10^{10} neutrons/sr/shot respectively) [15]. Apart from the fluence requirements, these sources provide pulses of short duration and, for low energy laser systems (tens of J or less), a reasonable repetition rate to simulate thousands of shots as those in laser fusion reactors.

In the following sections, we present evidences to support and exploit the use of ultraintense laser systems as adequate tools for the validation of plasma facing components of laser fusion reactors. A description of several studies on the generation and characteristics of laser driven ion pulses, in particular for the species relevant to laser fusion, is included. Besides, the potentiality of ultraintense lasers to generate X-ray and neutron bursts is also discussed, identifying the current achievements and limitations.

The idea of using ultraintense lasers as ionizing particle/radiation source to test components has previously been suggested in the aerospace field [16], in particular to the study of damage of detectors and diagnostic systems. That topic, although not discussed in this work, is also key for the diagnostics in laser fusion reactors and it further stresses the suitability of applying ultraintense lasers as test laboratories for fusion components.

2. Laser Induced Ions

The main characteristics of the ion bursts generated during laser fusion reactions are their short duration (a few nanoseconds at its origin) and their broad energy spectra. When those ion pulses arrive to the reactor walls, typically situated at a distance of a few meters from the explosions, they deposit a high number of energetic (from keV to MeV) particles in about 2 or 3 microseconds. Fluxes of particles in the order of 10^{20} p/cm^2/s and energies higher than 1 MW/cm^2 are expected in laser fusion direct drive targets. In order to provide a meaningful assessment of the behavior of plasma facing components under laser fusion conditions, it is important to reproduce those characteristics as precisely as possible [2, 13]. To date, ions generated by linear accelerators, plasma guns or ion pulsed sources only provide either the appropriate flux, the right energy range or the adequate pulse duration. However, ion pulses generated by ultraintense laser systems can achieve simultaneously all those required conditions. Although there are several laser driven mechanisms to generate ion beams [17], the Target Normal Sheath Acceleration (TNSA) process [14] produces fairly collimated (typically less than 20 degrees), high energy and short duration ion pulses, being very suitable to simulate the laser fusion ion bursts [18].

The production of ion beams by the TNSA mechanism at the rear side of the targets has been described in numerous papers (for example [14, 17]). In summary, the generated ion energy spectrum follows an exponentially decreasing distribution which goes from keV to some MeV, showing a linear relationship between the maximum ion energy and the laser power [19]. Throughout the literature there are numerous experimental examples from both table-top and large laser facilities. In the following subsections, we will review those related to the generation and acceleration of species present in the fusion environment, i.e. Hydrogen, Deuterium, Tritium, Helium, Carbon and high Z atoms.

2.1 Generation of hydrogen isotopes and comparison with experimental results

Laser driven protons are easy to create since they are present in many samples as surface contaminants, as a compound of the target itself (plastic targets) or in the form of coatings on the surface. Among the main parameters which tailor the resulting characteristics of the proton beams we have the laser pulse intensity [19–21], the prepulse [22] and the target material and thickness [23]. In general, most of the investigations on laser driven proton beams aim at achieving proton energies as high as possible (proton beams close to 100 MeV have been generated). However, such high energies are not necessary in our case, being more important the proton fluence generated. In that respect, it is relevant to mention the work of Brenner *et al.* [24] in which the number of protons as a function of constant laser energy and changing intensity was investigated.

First attempts to produce the appropriate fluence and energy spectrum of a proton burst of a laser fusion explosion by means of the TNSA have already been carried out by the authors in the J-KAREN laser facility at the Japanese Atomic Energy Agency. Preliminary results are shown in Fig. 1 in which the experimental energy distribution of the proton beam generated from an laser irradiated Al foil is compared to the proton burst produced in a shock ignition target of 48 MJ [5]. The laser driven proton spectrum corresponds to a laser shot of 18 J measured at about 0.5 m from the target with a Thompson Parabola (experimental details will be available in a forthcoming paper). From a qualitative point of view, the main characteristics of the laser fusion proton beam are met, namely, total energy and particle fluence, spectral energy spread, high particle fluence at sub-MeV proton energies and lower particle fluence at higher energies.

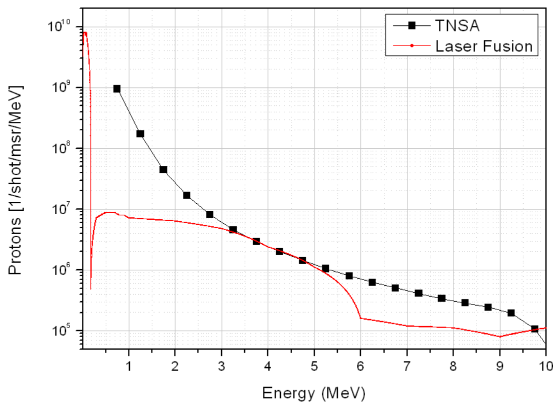

Fig. 1 In red, the proton spectrum generated in a laser fusion reactor (48 MJ shock ignition target) [9]. In black, proton spectrum generated by TNSA at the J-KAREN laser facility in Japan.

Although not meant for ion damage studies, it is also worth noticing that laser generated proton beams at higher energies (10 MeV or even higher [19]) could also be used to partially simulate the damage of materials by neutrons in fusion environments.

Deuterium beams can also be generated in the same way as protons, replacing hydrogenated targets by deuterated ones. Several examples of generation and acceleration of high fluxes of energetic deuteron beams have been reported in the literature, most of them related to the induction of fusion reactions and neutron production. The article of Ledingham and Galster [25] contains a summary on the generation of deuterium beams from solid CD_2 targets [26], deuterated plastic targets [27], heavy water (D_2O) spray targets [28] and deuterium clusters [29, 30]. In the last case, the production of the deuterium beams do not stem from the TNSA mechanism but from laser-driven Coulomb explosions [31], which could be particularly suitable for gas phase elements (see Sec. 2.4).

In principle, the experimental procedure to generate tritium beams follows the same approach as for the other H isotopes. However, to our knowledge, no experimental acceleration of tritium ions by lasers has been reported most likely due to the safety requirements for its handling.

2.2 Generation of carbon beams

The effect of energetic carbon beams on plasma facing components is probably one of the least investigated topics. Carbon atoms are known to barely diffuse in solids and, in the case of plasma facing components, they may react not only with the host material but also with the implanted H isotopes, acting as traps for the radioactive Tritium. Besides, its atomic size commences to play a non-negligible role on the physical and chemical sputtering of the walls. SRIM calculations [32] show that average energy C ions from a 48 MJ shock ignition target [5], induce a sputtering rate of 0,02 atoms per incident C on a first wall of Tungsten which, at a rate of a few hundred of millions of shots a day, may imply the removal of more than a micron of W every 24 hours. It is then very important to properly characterize and calibrate the damage of those impinging C atoms on the front components.

There are some works available in the literature which focused on the acceleration of carbon ions by ultraintense lasers [33]. A very representative example is the paper of P. McKenna *et al.* [34] in which the authors investigated the effect of a range of C containing targets on the resulting C beams. Uniform targets of C, polypropylene, mylar, carbon contaminated Al and Au surface layers and layered Au–CH targets were studied as a function of target thicknesses (from 10 nm to 10 µm). In that study, C ions are shown to be accelerated to energies up to several tens of MeV with particle fluences up to 10^{12}/sr depending of their charge state. Those values exceed the required carbon beam parameters of laser fusion, so more relaxed experimental conditions than the ones used in the experiment (laser intensities of $>10^{21}$ W/cm^2) could be employed for material testing.

2.3 Generation of heavy ion beams

Heavy ions as Au, Pb or U may also be present in laser fusion targets as a mean to improve the energy transfer between the laser beams to the fuel and to prevent the capsule to be over-heated by the background gas in the chamber. So, different quantities of high Z ions are expected to interact with the first wall and front optics. Several studies in the literature agree on the fact that the key parameter for an efficient generation and acceleration of heavy ions by TNSA relies on the removal of proton or light ion contaminants from the target [14]. Using tungsten as a thermally stable target and coating the rear surface with the material of interest, a strong increase in the number and energy of the heavy ion particles have been observed after target de-contamination by thermal heating. Results comparing those experiments with the ones carried out on not-heated Al targets have shown an enhancement of a factor of 5 in the maximum ion energy and an improvement in the conversion efficiency by a factor of 10 [37].

The energy spectrum of the heavy ions produced in laser fusion depends on the kind of ignition scheme (be it central, fast or shock ignition) and target type (direct or indirect drive). Calculations for the ARIES program [35] show that values can range from some keV in the case of Iron up to 20 MeV in the case of Gold. In today's ultraintense laser facilities, accelerations up to >5 MeV/u could be achieved [14] and in the case that higher energies are required, ion pulses generated by other acceleration mechanisms might be employed [17].

2.4 Generation of He beams – the case of gas phase targets

Due to its inert nature, the production of He ion beams by ultraintense lasers requires gaseous targets. In those target systems with under dense plasma, the TNSA mechanism has also been observed [36]. However, the interaction of laser pulses with gaseous targets also implies other acceleration mechanisms which need to be taken into account such as the collision-less shock acceleration and the quasi-static magnetic fields by laser driven fast electron currents which can worsen or improve the quality of the ion beam respectively [37–39]. Besides, as in some of the cases already mentioned for the generation of deuterium pulses, one possibility to accelerate He ions is to resort to Coulomb explosion of irradiated clusters/droplets. Whereas typical acceleration of ions from small clusters by Coulomb explosion is in the order of keV [40], larger ion velocities are attained for nanodroplets (in the order of MeV) [41].

It is important to keep in mind that He implantation, retention and aggregation is considered the main cause of mass loss and mechanical failure in Tungsten as first wall material [42]. So, the possibility to create adequate He pulses with ultraintense lasers for material irradiation may greatly improve our understanding on the damage mechanisms and the identification and control of damage thresholds.

2.5 Synergies between ions: simultaneous irradiations

As mentioned in the introduction, another important aspect to consider when validating plasma facing components is the combined effect of different species on the material. In particular, the implanted species may react chemically among themselves or with the material, leading to changes in the thermo-mechanical and diffusion related properties. These effects become visible as the concentration of species inside the material increases with time. However, there might be a shot by shot effect due to simultaneous implantation which could also play a role (ion-matter interaction at high fluxes may not follow the theoretical models employed to date). An extra advantage of laser driven ion pulses for material testing is the fact that experiments can be designed to allow simultaneous irradiations with different species so that possible synergetic effect can be investigated. Thus, either by splitting a laser beam and illuminate several targets at once or by manufacturing a target containing the required species, one may irradiate materials with different ionic elements at once.

2.6 Investigations under multiple shots

Ultraintense laser systems are also suited for irradiation studies with thousands of ion pulses much in the same way as it occurs in a laser fusion reactor. At present, ultraintense lasers with a moderate energy per pulse (a few J) and a convenient repetition rate (a few Hz) are available in several laser facilities which, with an appropriate target refreshing system, could perform irradiation campaigns for long exposures. Among the developed sample holders to replace the target on a shot by shot basis, one can resort to "rotating-wheel-type" based holders or long foil tapes which unrolled every new shot [19, 34].

2.7 Experimental set-up proposed for laser-driven-ion irradiation of materials

Figure 2 represents a possible scheme for a laser-driven-ion generation system and its use for the irradiation of fusion materials. In brief, the experimental set-up consists of a vacuum chamber in which a TW or PW laser pulse is focused on a solid target thin film for the generation of rear TNSA ions. This part is similar to most current studies on generation and acceleration of ions by TNSA, so the reported knowledge on how the ion spectrum depends on laser energy, laser focalization, laser contrast,

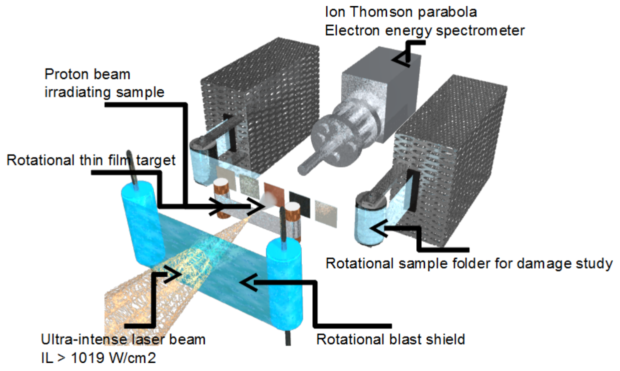

Fig. 2 Scheme of an experimental set-up for laser driven ion irradiation of materials. Laser goes through a blast shield to hit the thin film target. The laser beam triggers the proton beam from the rear target. Then, the generated proton beam (0.1-3 MeV) hits the sample. The samples are mounted on a cartridge/carrousel which can be rotated to expose several materials. The proton and electron beams can be monitored with an Ion Thomson parabola and an electron energy spectrometer.

target thickness and target material can be applied to our investigations [19, 24]. In the case gas targets are needed, in particular for the acceleration of He ions, the solid target should be replaced by a pulsed gas jet synchronized to the laser shot. High repetition rate experiments will require from targets which can be refreshed at the same or faster pace as the laser system shoots. Gas targets do not pose any problem and although positioning of rotating-wheel-type and stripe-type targets with an accuracy of a few microns at a few Hz rep rate may look a challenge, it has already been proved in the VUV lithography field.

Those ions produced either at the rear surface of the target or in a gas puff would be used to irradiate the fusion material placed behind. Target to sample distance is the main parameter here as it determines the ion fluences and fluxes. Thus, it should be adjusted accordingly to the generated ion beam intensity and divergence in order to fulfill the particle fluence conditions required to reproduce those of laser fusion, typically $10^{13}/\mathrm{cm}^2$ (convex targets could also be used to reduce beam divergence). In the case of laser table-top systems in which samples might have to be placed very close to the laser target to meet fluence requirements, it is necessary to introduce filters between target and sample to stop or attenuate the effect of debris or shrapnel produced in the laser-target interaction on the irradiated sample. At the same time, other products of the laser-target interaction, such as electrons and X-rays may hit the sample. Actually, most of the produced E-M radiation is in form of Gamma rays which should deposit their energy in a more diffused way than ions. Fast electrons come with a large dispersion angle, typically 70 degrees, and a mean temperature of 1 MeV or higher, so their energy deposition is also rather disperse compared to ions and should be differentiated easily. In any case, if a complete shielding of the sample from any unwanted laser product is necessary, an adequate set of electric and magnetic fields could be devised to separate the selected ions and guide them to a protected irradiation area. This last case might require techniques still to be developed in order to keep an acceptable ion fluence on sample.

As for diagnostics, detectors which can measure the energy spectrum of the generated ion pulses would be required. Thomson parabola detectors, magnetic analyzers or radio-chromic films (RCF), are among the most employed ones. The characterization of the generated ion beams could be carried out either prior/posterior to the irradiations as long as the system shows a reasonable reproducibility from shot to shot. If a simultaneous characterization is needed, CCD based detectors should be placed behind the sample. In this case, the sample must be either placed off-centered from the ion pulse axis or manufactured with a hole in the middle to allow part of the ion beam to reach the detectors. Other diagnostics such as interferometry or X-ray detectors could be used to monitor the performance of the laser ion production. Even optical systems to measure temperature on the irradiated sample in real time could be desirable.

Since these experiments have not been carried out yet (but for initial trials by the co-authors), there might be important issues overlooked in the present discussion. However, we cannot think of any of them as a serious impediment, being optimistic in the applications of ultraintense lasers for the mentioned irradiations.

3. Laser Induced X-Ray Pulses

X-ray bursts during laser fusion explosions are also a serious threat to plasma facing components. In particular, in the case of indirect drive targets in which typically 25% of the total fusion energy is emitted in form of X-rays, the associated thermal load on the first wall materials and front optics is so high that a gas protection system needs to be employed to avoid immediate melting/ablation of the surface (for a 5 m radius chamber and a "moderate" fusion target of 50 MJ, it is around $4 * 10^{13}\ \mathrm{W/m^2}$). Even in the case of direct drive targets in which only 1-2% of the total fusion energy is carried away in form of X-rays, the fact that all E-M radiation arrives to the plasma facing components at the same time (less than a nanosecond) causes a prompt thermal spike which requires a thorough evaluation of its effect (be it thermo-mechanical or electronic). Figure 3 presents the energy spectrum of the X-ray burst emitted by a 48 MJ direct drive shock ignition target [5]. In total, around $1{,}5 * 10^{14}$ photons are produced which deliver a total of 655 kJ to the chamber walls which, for a 5 m radius chamber, corresponds to a fluence of $2\ \mathrm{kJ/m^2}$ and a sudden temperature increase of 500 K on a Tungsten material. Besides the thermo-mechanical effects, one should be concerned about the possibility of massive photoelectric

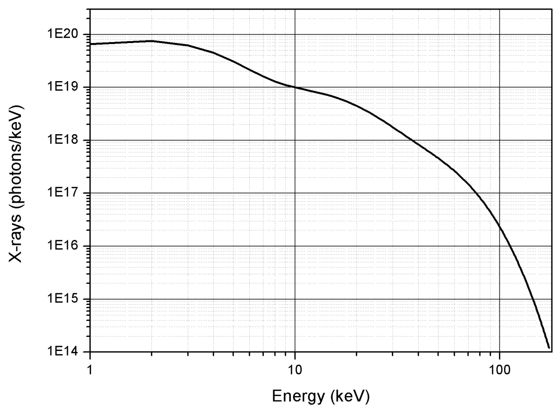

Fig. 3 X-ray spectrum from a 48 MJ shock ignition fusion target [9].

cascades which could charge the wall and induce a strong E-M pulse that might cause extra stresses to the structure of the chamber itself.

The behavior of plasma facing components under intense X-ray pulses has been previously investigated making use of Z-pinch machines. The XAPPER facility at LLNL, based on a plasma pinch, generates 100 eV X-ray pulses of 10 ns with fluences up to 2 J/cm^2 and repetitions of thousand of shots [9]. The Z machine in the Sandia National Laboratories has also been used to irradiate samples with the emission spectrum of a 300 eV black body with pulse duration of 10 ns but just a few exposition shots [10].

Ultraintense laser systems might also be used to test materials under X-ray bursts with more realistic pulse widths (below ns), higher photon energies and repetition rates. In fact, there are several laser induced processes that lead to the generation of X-ray pulses. Synchrotron and Betatron radiation in the X-ray range can be created by accelerating free electrons under an intense laser field [43]. Black body radiation can also be generated by collapsing a hot and dense plasma [44]. However, in order to have high X-ray fluxes, probably the most efficient mechanism is the laser irradiation of high Z solid targets and the posterior interaction of accelerated electrons within the material. As it was earlier discussed, when an intense laser pulse (>10^{18} W/cm^2) hits a target, electrons are accelerated to the order of several MeV by the ponderomotive force. Part of these electrons penetrate the solid target and interact with the atoms losing energy and generating bremsstrahlung (in form of a broad photon energy spectrum) and sharp atomic X-ray emissions (K lines). A combination of both broad and sharp energy X-ray spectra together with the fact that the pulse duration is in the order of the electron pulse (<ns), makes those laser driven X-rays a potential source to reproduce fusion X-ray bursts.

On the one hand, laser driven X-ray atomic line emission has been extensively studied [45 and references therein]. Thus, K alpha generation is known to be optimized when the laser intensity produces electrons with temperatures a few times higher than the K alpha energy and when the laser energy conversion into hot electrons is maximized (in this case, pre-plasmas play an important role [46]). Energy conversion efficiency from laser to K alpha can achieve values of 10^{-4} - 10^{-3}, generating X-ray pulses of >10^{12} photons per laser shot. Placing our test material sufficiently near to the X-ray source, could bring fluxes close to those the fusion environments (the X-ray photon fluence of a 48 MJ target on a wall at 5 m distance is around $5 * 10^8$/cm^2). An appropriate selection of target material would produce X-ray K alpha lines at the needed energies, being possible to tune it, for example, to the maximum in the X-ray energy spectrum of the laser fusion yield (around 3 keV). Even more, one could think of using a compound target so that several K lines are emitted having a broader X-ray spectrum, closer to the one generated in the fusion explosions. On the other hand, radiation by de-acceleration of electrons in the material, i.e. Bremsstrahlung, it is also an intrinsic process in the ultra intense laser-matter interaction which cannot be separated from the atomic line emissions. Some studies can be found in the literature which analyze theoretically and experimentally that emission from ultra intense laser pulses on thin films [47, 48]. Typically seen as an interesting feature to generate high energy photons for photonuclear experiments [49], Bremsstrahlung could also be very valuable as a radiation source with a broad spectral range to mimic the X-ray fusion bursts.

To the light of the cited references, it seems reasonable to assert that an appropriate selection of the most relevant intervening parameters, i.e. laser intensity, laser prepulse, target material and target thickness, reasonable X-ray pulses could be created similar to those of laser fusion. In any case, an in-depth theoretical analysis of those possible parameters would be essential prior to any experimental trial.

4. Laser Induced Neutrons

The lack of an intense 14,1 MeV neutron source to test materials, in particular structural components, is probably the main bottle-neck of both magnetic and inertial confinement fusion approaches from the material research point of view. To date and until facilities as IFMIF [50] are constructed, both communities have to resort to experimental fission reactors, spallation sources or triple ion beam accelerators to investigate the effect of fusion neutrons in materials. However, due to different reasons none of the current test facilities are completely satisfactory and a new and reasonably low cost neutron source would be desirable. Once again, ultraintense lasers may play an important role as a convenient source for the validation of fusion materials as it was already highlighted in the year 2000 [51]. Perkins *et al.* suggested the construction of a laser system of 100-1000 J with a repetition rate of 100-10 Hz that focused on a D-T target could yield a neutron flux of 10^{14}-10^{15}/cm^2/s, values much in the line of what magnetic and laser fusion reactors would generate. Unfortunately, that laser system seems to be too costly and not even feasible due to the pulse energy and repetition rate requirements with the flashed pumped laser technology currently available. However, this might change with the construction of Diode Pumped Solid State Lasers, DPSSL, which, in a few years, may allow for both high pulse energies and repetition rates. Until then, present ultraintense laser systems are restricted to either energetic pulses (>100 J) or high repetition rates (>10 Hz) which produce neutron fluxes inferior to the required level for fusion material analysis.

Nevertheless, the promising progresses reported by several research groups working on laser neutron sources lead us to think that neutron damage studies of fusion materials could be possible soon. The reader is referred to the reviews of J. Galy *et al.* [15] and K.W.D. Ledingham *et al.* [34] for the most recent results. According to Ledingham, the most promising nuclear reactions for generating neutrons using intense lasers are (gamma,n), (gamma, fision), (p,n), d(d,n)^{3}He and d(t,n)^{4}He. Based on those reactions, neutron yields of around 10^9-10^{10} neutrons per shot have been reported for large laser systems (pulses >100 J). In the case of high repetition rate "table-top" systems, the production has been evaluated around 10^6 neutrons/s using the ^{7}Li(p,n)^{7}Be or the d(d,n)^{3}He reactions. One inconvenient of the reactions used is that the generated neutrons are of low energy (<3 MeV). However, very recent experiments based on ^{7}Li(d,xn) reactions have shown that high energy neutrons (up to 18 MeV, closer to the ones generated in D-T fusion reactors) can be generated in a fair amount ($8 * 10^8$/sr) [52], opening the possibility of tests on neutron damage in fusion components at a low repetition rate.

5. Conclusions

In the near future, laser fusion may emerge as a competitive source of energy, demanding the construction of hundreds of reactor power plants in the next decades. But for that to occur, first wall materials able to withstand the radiation environment of the fusion reactor for long periods need to be developed. At present, there are no facilities which can reproduce the fusion condition of the reactors to test and validate materials. In this work, we propose the use of ultraintense laser systems as a promising tool to simulate such conditions, so that components can be tested even under long exposures. In the case of ions, several experimental evidences have been presented which demonstrate that the appropriate beams can be generated by laser triggered TNSA mechanisms. The generation of this kind of ion pulses can be extended to most, if not all, relevant fusion particles such as protons, deuterium, helium, carbon or high Z materials. A possible experiment set-up for such a kind of experiments have been presented. Similarly, different laser driven mechanisms to generate X-rays have been discussed, aiming at providing the main characteristics of the laser fusion X-ray bursts for damage investigations. Finally, the possibility of a laser based neutron source to test not only first wall but also structural elements was revisited.

Apart from the mentioned advantages that ultraintense laser systems may pose for testing fusion components (high fluxes, appropriate energy spectra and repetitive capabilities), the possibility of investigating the simultaneous irradiation of materials with different species in a fairly compact set-up reinforces the suitability of this technique. Thus, in the opinion of the authors, if conveniently financed and explored, ultraintense lasers should play a key role in the development of materials for fusion and greatly contribute to the evolution of the laser fusion technology towards a commercial electric power plant.

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