Research Objective:

Laser ablation for surface cleaning has been pursued for the removal of paint on airplanes. It has also been pursued for the cleaning of semiconductor surfaces. However, all these approaches have been pursued by laser ablation in air. For highly contaminated surface, laser ablation in air can easily cause secondary contamination. Thus it is not suitable to apply to achieve surface decontamination for DOE facilities since many of these facilities have radioactive contaminants on the surface. Any secondary contamination will be a grave concern. The objective of this project is to develop a novel technology for laser ablation in liquid for surface decontamination. It aims to achieve more efficient surface decontamination without secondary contamination and to evaluate the economic feasibility for large scale surface decontamination with laser ablation in liquid. When laser ablation is pursued in the solution, all the desorbed contaminants will be confined in liquid. The contaminants can be precipitated and subsequently contained in a small volume for disposal. It can reduce the risk of the decontamination workers. It can also reduce the volume of contaminants dramatically.

The major goals of this project are as follows.

1. To develop novel laser ablation decontamination in liquid technology for safe removal of radioactive and/or toxic contaminants from a surface without producing dangerous secondary pollutants.

2. To study the basic physical principles of laser ablation on a solid-liquid interface.

3. To optimize the cleaning efficiency with various laser conditions.

4. To evaluate the feasibility of laser ablation for surface decontamination in liquid for large scale surface decontamination.

Research Progress and Implication:

After approximate 3 years of a 3 year project, we have nearly finished what we planned to study on laser ablation in liquid for surface decontamination. During the past year, we have given careful study on the mechanism of laser ablation process in liquid with different laser durations. We also gave the estimate on the cost of large scale decontamination.

During the desorption mechanism study, it was found that electrons absorb laser energy in femtosecond domain. The strong absorption of photons by electrons can lead to the electron emission from surface in picosecond region. The ejection of atoms and ions to produce a plasma plume usually is achieved in a few nanosecond. During this period of time, shock wave is produced. The propagation of shock wave can last several hundred nanoseconds to a few microseconds. Particle ejection is often obtained in a few microseconds. For a picosecond laser desorption, the desorption process is mostly through photon induced desorption process. Direct photon absorption process leads to the break of bonding between an electron and an atom or chemical bonding between different atoms. In general, it produce much less than one molecule into gas phase by each photon. Thus. We conclude that it is less efficient in achieving surface decontamination by a picosecond laser. For a long duration laser pulse, the absorption of photons usually leads to a thermal process. The increase of surface temperature causes the melting, vaporization and even an ionization process. It can also produce shock wave which can cause the ejection of particles. When particles are desorbed, the overall efficiency for surface decontamination can be greatly enhanced. For surface decontamination process, a laser with nanoseconds or microseconds duration is more preferred than a picosecond laser.

For laser ablation in liquid, we found three major mechanisms are responsible for the surface desorption. They are (1) absorption of laser from adsorbent such as water is often the first step for the vaporization of this heated liquid film. This process can cause an explosive vaporization. (2) a shock wave desorption due to the quick heat expansion to lead to acoustic wave to enhance desorption and (3) direct photoabsorption by atoms or molecules on surface to lead to a desorption process from the surface. Direct heat vaporization is the primary process for the surface decontamination process. Shock wave produced can enhance desorption process by nearly 50%. Direct photoabsorption process plays a less important role in surface decontamination.Nevertheless, the heating process also contributes to the desorption of contaminants. Particle ejection is required for efficient desorption. Acoustic wave is particularly efficient for particle desorption. Due to the efficient production of acoustic wave, laser ablation in liquid should be more efficient and more reproducible than laser ablation in air for surface decontamination. The most critical factor is the absorbent and the materials on surface to have a strong absorption coefficient at the laser wavelength. However, the absorption of liquid medium for the wavelength needs to be as low as possible.

Up to now, most laser ablation works for surface decontamination in air have been pursued with excimer lasers which have the special properties of high repetition rates, homogeneous beam , a large rectangular laser spot and long lasting operating time. For paint removal from an airplane, a rate of 2 m^2/hour is considered feasible. This rate was achieved based on the multiple cleaning for the same spot. For laser ablation in liquid, the efficiency is expected to increase by about 50%. Thus the cleaning rate can be increased to 3 m^2/hour. An excellent industrial excimer laser with 300 hz can last 1 billion laser shots. For continuous operation, it will last 1000 hours. Taking a 3 m^2/hour cleaning rate, it can clean ~3000 m^2 before the laser needs to be overhauled. The cost of this laser is estimated as $150,000. The average cost is ~ $50/$m^2$ For decontamination process, high multiple cleaning process may not be necessary since the removal of 99% of contaminants tends to place the contamination level below the natural background. If only a single laser shot is needed, the cleaning rate is ~ 1 cm^2/pulse. A laser can clean 100,000 m^2 in its lifetime. The average cost is $1.50/$m^2$. No labor cost or automation equipments are included. The real cost is probably between these two numbers. We consider the average cost of $25~30/$m^2$ can be possible.

Future works:

Since this project is expected to end in a few months, we will finish our experiments and the final report.