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Response to NAS Request for Information on Chamber Repetition Rate

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Requested Information

"Provide further information on the issues of repetition rates and chamber clearing issues for dry wall and liquid wall chamber concepts for IFE; namely what are the issues, possible solutions and needed R&D?"

I. Summary of Requirements

The fundamental requirements with respect to an IFE chamber's ability to operate at the prescribed pulse repetition rate are to repeatedly and reliably:

1) Re-establish chamber conditions that allow for the delivery of the target with the required precision and without damaging the integrity of the target (e.g., excessive heating and/or mechanical loads);
2) Re-establish chamber conditions that allow for delivery of the driver energy to the target with the specifications required by the target physics (e.g., total energy, uniformity, pulse shape, etc.), including high rep-rate target tracking and beam pointing for lasers and heavy ion drivers;
3) Re-establish in-chamber conditions that may be used to protect chamber structures from target emissions (e.g., liquid films, liquid jets, and gases) and/or assure survival of the first wall subjected to pulsed energy loads.

Integrated designs are required to evaluate tradeoffs between potentially conflicting requirements, and the issues extend beyond the question of pulse repetition rate. The response below, however, primarily focuses just on the above aspects of the chamber designs. As such, we do not list "possible solutions", but rather "mitigating actions" which then need to be evaluated as a self-consistent set.

II. Target Delivery

Evacuated dry wall chambers

Issues:

- The target must be able to withstand high acceleration loads during injection.
- Typically the key issue is target heating during injection due to exposure radiation from the hot chamber walls and from the gun barrel.
- There will also be some residual target materials and potential gas propellant from previous shots in the chamber that could add to target heating and affect its trajectory.

Mitigating Actions:

- Use of IR reflective coatings on the target to reduce heating by the wall.
- Use of protective sabots to aid injection and thermal protection.
- Design vacuum pumping system to efficiently remove post-shot target material.

R&D:

- Integrated chamber/target/injection design to determine limits on the design space.
- Modeling of target mechanical loads and heating during injection.
- Experiments to demonstrate target injection, eventually with cryogenic targets under simulated chamber conditions with hot walls.
- Design, modeling and testing of sabot concepts.
- Modeling and experiments on the impact of remnant gases, including turbulence, on the trajectory of the target.

Gas filled chambers

Issue:

- The target must be able to withstand high acceleration loads during injection.
- Here the gas fill dominates in-chamber conditions and will have a greater impact on target heating and trajectory than evacuated chambers.

Mitigating Actions:

- Use hohlraum targets that are more thermally and mechanically robust.
- Include target design features that enhance thermal protection (e.g., IR shields).
- Limit gas density and chamber radius to values that the target survives.
- Design injector and target for highly reliable injection (e.g., spin stabilized).

R&D:

- Integrated chamber/target/injection design to determine limits on the design space.
- Modeling of target mechanical loads and heating during injection.
- Experiments to demonstrate cryogenic target injection in simulated chamber conditions.
- Modeling and experiments on the impact of chamber fill gas, including possible turbulence, on the trajectory of the target to determine if it can be delivered within specifications.

Liquid wall and thick liquid chambers

Issues:

- The target must be able to withstand high acceleration loads during injection.
- Liquid vapor filling the chamber contributes to target heating and impacts on trajectory.
- One must assure that if liquid drops are present, they do not interfere with target delivery.
- For Z-IFE, the key issue is the mechanics of delivering the combined RTL/target system.
- Resetting of the liquid sheets to allow subsequent target injection.

Mitigating Actions:

- Use hohlraum targets that are more thermally and mechanically robust.

- Include target design features that enhance thermal protection.
- Oscillating jets, as proposed in HYLIFE-II, to dynamically clear remnant droplets from target injection path.
- Combination of target yield and chamber radius that limits ablation to acceptable levels (e.g., in the vortex chamber).

R&D:
- Integrated chamber/target/injection design to determine limits on the design space.
- Modeling of target mechanical loads and heating during injection.
- Experiments to demonstrate cryogenic target injection in simulated chamber conditions.
- Demonstration of ability of liquid feature to re-establish in a manner that provides a clear target injection path.
- Modeling and experiments on the impact of liquid vapor, including turbulence, on the trajectory of the target to determine if it can be delivered within specifications.
- For Z-IFE, demonstration of target insertion method under prototypic conditions.

III. Drive Energy Delivery

Evacuated dry-wall chambers

Issues:
- For direct drive targets (laser or HI), uniform beam delivery could also be affected by residual vapors, droplet formation and turbulence from remnant target materials.
- For laser driver, the final optics are in direct line of sight of target emissions and thus subject to possible degradation from target debris, thin-film deposition, and x-ray and charged particle damage.
- Target tracking and beam point must be accomplished in the fusion environment.

Mitigating Actions:
- High vacuum pumping rate to minimize residual gases – at a level consistent with available pumping technology and acceptable ancillary electricity use.
- Choice of driver configuration (wavelength, technology, etc) that minimizes the propagation and engagement problems.
- Use of magnetic deflection technologies to protect the final optics.
- Choice of optics that are least susceptible to surface perturbation and alignment error.

R&D:
- Development of integrated target tracking and beam pointing for the selected target and driver combination.
- Modeling of post-shot chamber evolution and beam propagation.
- Demonstration of prototype injection, tracking and engagement.
- Experimental testing of magnetic deflection schemes to assess efficiency, reliability, and robustness in a prototypic fusion EMP environment.

Gas filled chambers

Issues:

- The fill gas will have a degrading affect on either laser or ion beam delivery.
- For laser driver, the final optics are in direct line of sight of target emissions.
- Target tracking and beam point must be accomplished in the fusion environment.

Mitigating Actions:

- Select the gas type, gas density, chamber radius and beam propagation distance such that the degradation of beam energy and quality is acceptable.
- Use buffer gas to protect final optics from short range target emissions.
- Choice of driver configuration (wavelength, technology, etc.) that minimizes the propagation and engagement problems.
- Minimize chamber pumping requirements by appropriate system-optimization of target design and driver, in order to remove the need to reset the whole chamber between shots.
- Choice of optics that are least susceptible to surface perturbation and alignment error.

R&D:

- Development of integrated target tracking and beam pointing for the selected target and driver combination.
- Modeling of post-shot chamber evolution and beam propagation.
- Demonstration of prototype injection, tracking and engagement.

Liquid wall and thick liquid chambers

Issues:

- The liquid vapor density in the chamber will have a degrading affect on either laser or ion beam delivery.
- One must assure that if liquid drops are present, they do not interfere with beam delivery.
- For laser driver, the final optics are in direct line of sight of target emissions and also exposed to possible liquid droplet impact and/or condensation.
- For Z-IFE, the key issue is the mechanics of delivering the combined RTL and target system and connections to the pulse power source.

Mitigating Actions:

- The type of liquid and its operating temperature must be selected to meet the requirements.
- Oscillating jets, as in HYLIFE-II, to dynamically clear remnant droplets from beam paths.
- Use of rotating shutters to protect final optics from high velocity liquid impact.
- Combination of target yield and chamber radius that limits ablation to acceptable levels.

R&D:

- Liquid hydraulic experiments to simulated required flow features.
- Demonstration of ability of liquid feature to re-establish after disruptions simulating target effects.

- Modeling and experiments of post-shot chamber evolution and beam propagation.
- Development of integrated target tracking and beam pointing for the selected target and driver combination.
- Demonstration of prototype injection, tracking and engagement.

IV. Chamber Protection

Evacuated dry wall chambers

Issues:

- Evacuated chambers do not introduce protective measures, and so the pulsed response of the first wall and chamber structures must maintain their integrity at the prescribed rep-rate, e.g., ability to maintain W armor peak temperature below acceptable value.
- Without mitigation, a dry wall is subjected to an unacceptable flux of ions that rapidly defoliate the wall, likely leading to short-term failure.

Mitigating Actions:

- W armored steel walls, including possible engineered (textured) tungsten surface if it is possible to be manufactured at large scale.
- Magnetic diversion of target ions to reduce first wall peak heat load and mitigate ion-defoliation.

R&D:

- Development of acceptable first wall materials and cooling schemes to take pulsed heat loads.
- Experiments on the long-term survivability of textured surfaces under neutron irradiation, high heat flux, x-ray and ion bombardment, and chemical deposition of debris
- Development of joining, forming and bonding/welding techniques for micro-structured surfaces
- Experimental testing of magnetic deflection schemes to assess efficiency, reliability, and robustness in a prototypic fusion EMP environment

Gas filled chamber

Issues:

- The adequate gas density must be maintained (or replenished) in the chamber to achieve the protection goals of stopping target ions, debris and a high fraction of the x-rays.

Mitigating Actions:

- Design vacuum system and gas injection systems to maintain the desired fill gas conditions for the selected chamber yield and chamber radius.

R&D:

- Integrated design of vacuum pumping and gas injection systems.
- Modeling and experimental simulation of response of a gas filled chamber to pulse energy release and heating.

Liquid wall and thick liquid chambers

Issues:

- The protective liquid layers and jets must be reconstituted after the disruptive effects of the target emissions (e.g., ablation, vaporization, isochoric disruption due to neutron heating).
- Protection of the top of the chamber, where typically it is not possible to flow liquid (either due to RTL insertion, or due to the inherent geometry)
- Diversion of the liquid sheet around beam ports (for laser or ion beam IFE)

Mitigating Actions:

- Injected film flow with small recovery distances.
- High velocity injected jets.
- Layered liquid sheets to absorb the blast.
- Vortex flow and a combination of yield and radius that prevents neutron induced disruption.
- For Z-IFE, low pulse repetition rate (~0.1 Hz) allows more time for reestablishing liquid protection.

R&D:

- Modeling to establish predictive capability of the liquid responses.
- Scaled liquid hydraulic experiments (with stimulant fluids and eventually actual fluids) to demonstrate flow configurations and their response to pulsed energy loads.
- Large scale experiments to test the response of liquid flow and reset under prototypic conditions
- Blast experiments and modeling to develop mitigation measures for the top and bottom of the chamber (where multiple liquid sheets are not possible)