Z-Pinch and Laser-Ablation–Driven High-Yield Neutron Source LO-005-20, Year 1

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Challenge

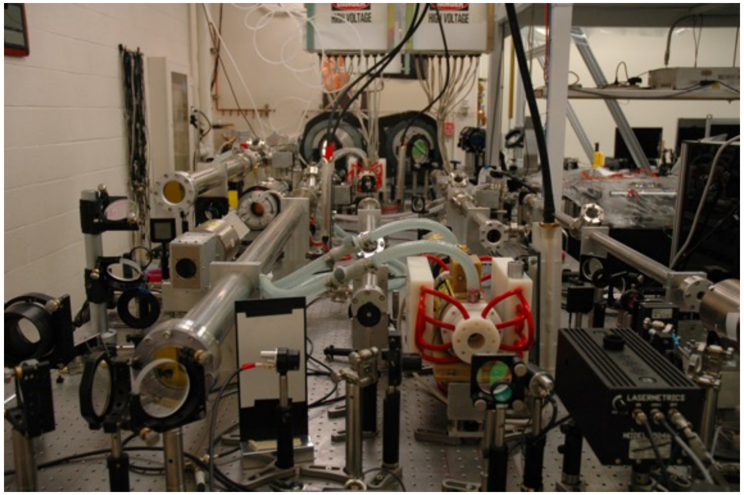
The main objective of the this project is to develop a new high-yield neutron source based on high-energy laser and z-pinch devices, a technique called **Laser Ablation Z-pinch Experiment** (LAZE). The scope of the project covers elaboration of the main principle of the neutron production in LAZE, providing the proof-of-principle experiments, optimization of the preliminary results, and development of the of the new *n*-source based on DPF and commercial high energy laser (*in the last phase of the project*).

A LAZE-driven neutron source can be a game changer in NNSS mission space. Yields better than 10^{13} n/shot with short creation time (<30 ns) can be available from a small, robust, safe, mobile platform without using tritium gas. It will make a substantial impact on many NNSS programs, like SNM detection, active interrogation of materials, neutron radiography and spectroscopy, and neutron diagnostics for subcritical experiments.

Experimental data should help to inform improved models, which include magnetized plasma acceleration mechanism that create suprathermal ions and electrons beams, and help to clarify the of competing neutron production mechanisms.

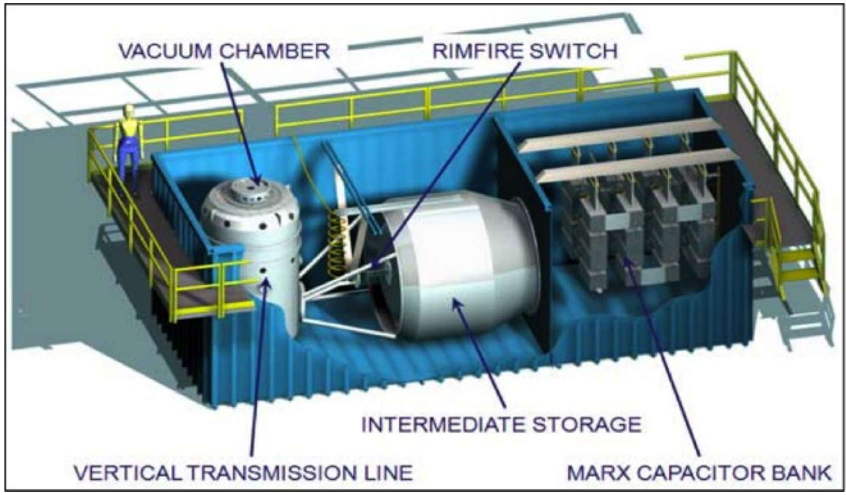
Innovation

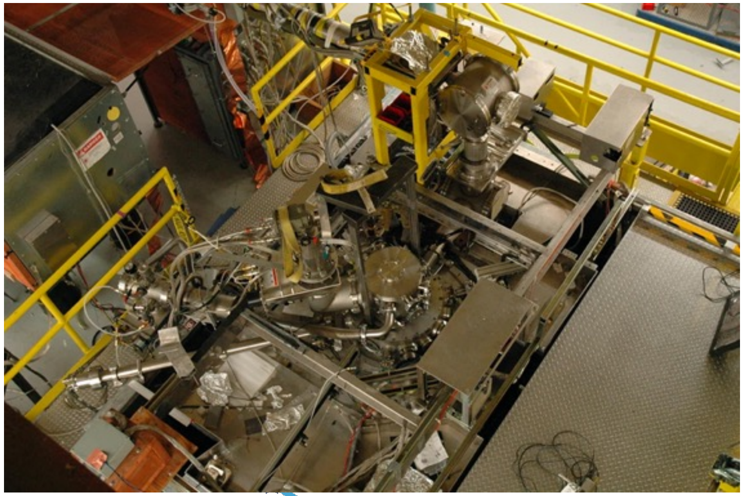
We will develop the innovative LAZE apparatus already installed on UNR's "Leopard" laser and "Zebra" z-pinch machine.



Leopard is an ultra-intense, ultra-short 1057 nm Ti:Sa/Nd:glass laser system capable of delivering 50 J in 300 fs or 90 J in 0.8 ns pulse.

Zebra is 2 TW z-pinch generator which typically produces 1 MA current pulse with a rise time of ~80 ns. It can also operate in long-pulse mode (250 ns, 0.6 MA) or with an increased current up to 1.7 MA using the Load Current Multiplier





This apparatus will be used for producing the high yield of neutrons by using the Leopard laser to pre-ionize an ablation plume target, which is subsequently pinched using the Zebra z-pinch. This robust platform will allow us to develop a number of diagnostics to determine plasma conditions and neutron source parameter

Advantages of the LAZE technique over more traditional Z-pinch targets:

- High shot rate (up to 8 shots per day) with excellent shot-to-shot reproducibility. Laser ablation can use non-traditional z-pinch targets materials (high-Z metals, zeolites, etc.)
- Targets are pre-ionized so coexistence of phases are minimized for a more uniform initial plasma.
- Near solid density H(D) concentrations near the *z*-axis thereby minimizing compression needs.
- Straightforward experimental setup in comparison to wire arrays and gas-valve pinches.
- Setup allows for precise variable timing control between the laser & pinch.
- Impedance matching is excellent, so energy delivery to the target is maximized.
- The laser spot can easily be moved off the *z*-axis for tests of asymmetric configurations.

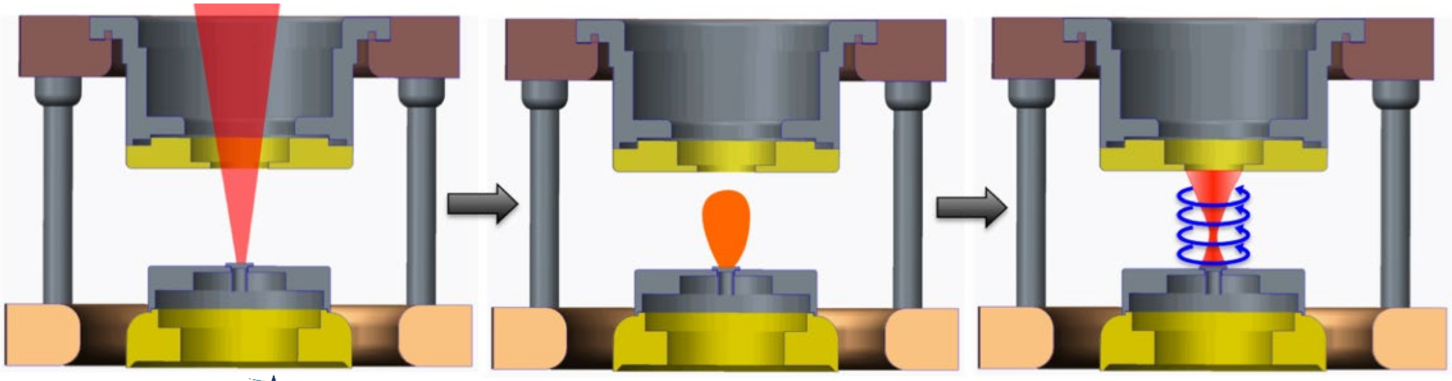
Technical Appraoch

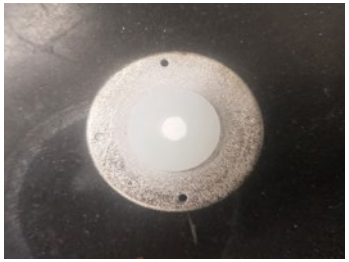
Over the past several years, members of our team have used a wide-variety of H(D)-bearing Z-pinch targets and techniques including gas puffs, interstitially loaded Pd X-pinch wires, and LAZE drivers with solid $(–CD_2CD_2\text{-})_n$ polymers and metallic deuterides (LiD_2 and TiD_2). Initial studies at Nevada Terawatt Facility indicate LAZE approach is feasible and very promising.

Technique	Gas Puff	Loaded Wires	LAZE		
Target type	D_2 - gas	Pd + H(D)	$(–CD_2CD_2\text{-})_n$	LiD_2	TiD_2
n-yield	$3.0 \pm 1.8 \times 10^9$	$2.5 \pm 1.3 \times 10^9$	**$3.0 \times 10^{12} \pm 1.4$**	**$3.2 \times 10^{11} \pm 1.0$**	**$1.5 \times 10^{11} \pm 0.8$**

A principle of experimental technique developed in former Nevada Terawatt Facility in UNR:

1) High-energy Leopard laser deposits energy on a $(C_2D_4)_n$ planar target,
2) Then a plasma plume is launched across the 2 cm A-K gap of z-pinch Zebra device.
3) Zebra is triggered, which pinches plasma on the *z*-axis and accelerates ions into the catcher placed on the cathode and, eventually,
4) The catcher is removed and placed in a coincident gamma detection system to measure half-lives.





LAZE d_6-poly(ethylene) target mounted in the catcher

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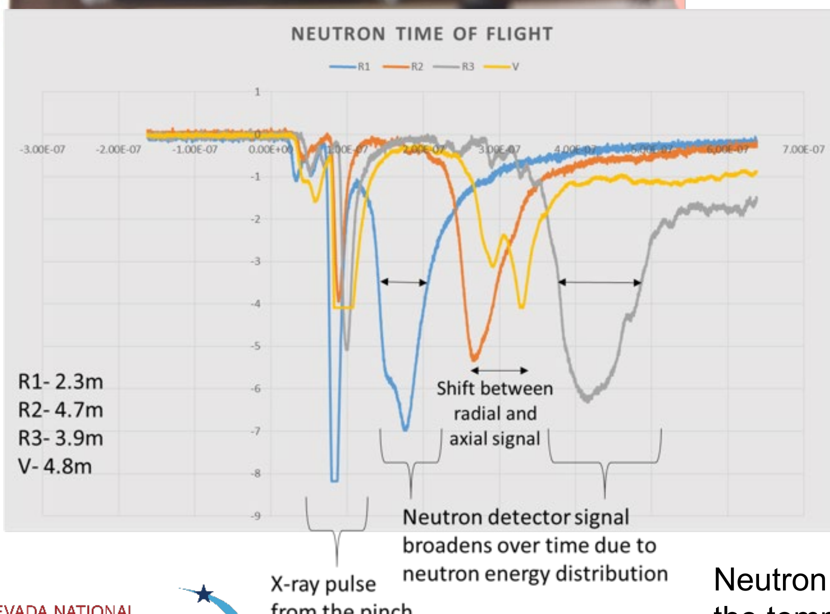
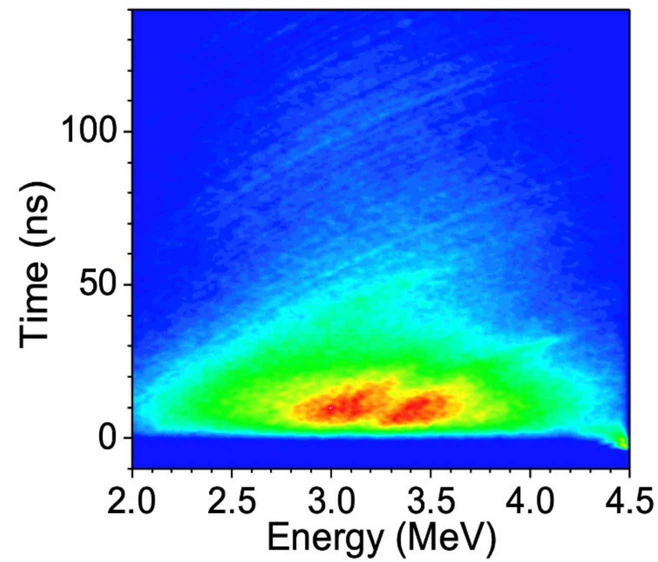
Laser parameters:
Energy: 10 - 15 J @ 1056 nm; Pulse length: 1 ns; Spot size: ~ 100 μm,
Intensity: ~10^{14} – 10^{15} W/cm^2

SDRD SITE-DIRECTED RESEARCH & DEVELOPMENT

Results: Examples of previous results

A bubble neutron detector (BTI) located ~1.5 m from neutron source outside the target chamber was used for order-of-magnitude estimation of neutron yields. The detector sensitivity is 19 mrad/bubble and the number of bubbles registered is ~200. Neutron yields were also measured with calibrated activation detectors.





Time-dependent neutron energy spectrum reconstructed from n-ToF signals from LAZE on a deuterated polymer target. A majority (90%) of the d-d neutrons where produced in under 25 ns.

Neutron time-of-flight (*n*-TOF) detectors were used to measure the temporal distribution of neutrons at various radial and axial positions in order to determine the neutron energy spectrum.

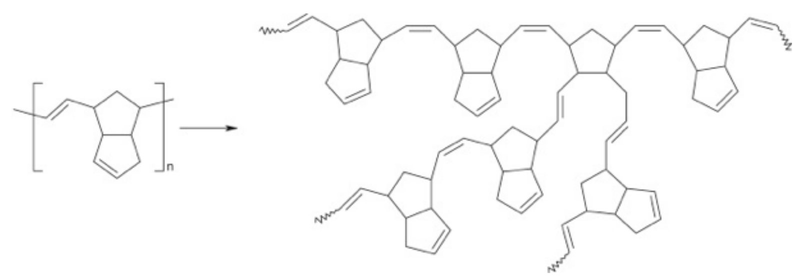
Results

- Collaboration between NNSS and UNR in place (task order signed)
- Detectors and detection instrumentation prepared and ready, including:
  - Bubble neutron detectors
  - Silver activated neutron detectors
  - Four time-of-flight PMT-based neutron detectors assembled, calibrated in MSTS NLV, and sent to Livermore Operations.

(Kudos to X12A Detector Engineering group from NLV)

- Preparation of the Experimental Facility:
  - Leopard laser was aligned and tested, but the one of the small pump lasers (Coherent's Verdi) has to replaced. The new laser was secured and will be installed.
  - Zebra z-pinch generator was tested and optimized for the experiment.
  - Timing setup for Zebra-Leopard coupling was prepare and tested.
  - Experimental hardware is ready for the experiments, including optics, vacuum, targets, targets mounts, detectors stands, electronics, cabling, etc.
- First new target material is ready. The test production of a poly(d_{12}-dicyclopenatadiene) deuterated polymer was performed in collaboration with UNR.

The d-PDCPD has approx. 15 wt% of deuterium. It is solid material, inexpensive with comparison to d-polyethylene (which costs $7000 per 5 grams). It can be used in 3-D printing process to produce well-defined targets.



Results

- The coincidence setup for Positron Annihilation Lifetime Spectroscopy was assembled and tested.
- Undergraduate students from UNR Physics Department were interviewed and two were recruited for the project as students workers for the activities and work at UNR z-pinch and laser facility.

  (*More students are interested, including graduates and post-doctoral researchers*)
- A collaboration with LLNL Dense Plasma Focus group were established. Dr. Erik McKee is the newest project team member; his expertise with MCNP and help with experiments will benefit the project.

The calamitous effect of Covid-19

The pandemic has affected the project to a large extent. The team was forced to work remotely to comply with Shelter-in-Place orders. CA, NV closures and quarantines, travel restrictions, operations scaled back, facility access restrictions have a disrupting effect most pronounced in collaborative experimental and "hands-on" activities.

The loss of two experimental campaigns in the UNR facility originally scheduled for FY 2020 has had a dramatic impact, as we had dedicated months of labor time preparing. As an example, we have new team members in our project (including students), who haven't even met each in person. Needed training has not occurred.

The Covid-19 pandemic delayed the project for at least 6 months.

Summary of Results, Path Forward

- The experimental infrastructure is almost ready for first experiments; action is required for the Leopard laser system to be ready for full energy operation.
- Start the experiments on LAZE-based neutron source with d_6-poly(ethylene) as soon as the travel restrictions are lifted and access to UNR facility is granted.
- Analyze existing data and accordingly plan the experimental campaign in spring or summer of 2021.
- The next experimental campaigns are planned for the late 2021, and the new targets materials will be tested.
- At the end of the 2nd year of the project, we plan to start the process of applying the LAZE technique to the DPF device and continue this during the 3rd year.
- Continue to work with students and immerse them more into the research associated with the project.
- The project experimental campaign schedule was drastically reduced due to Covid-19; a 2nd wave of Covid-19 epidemic could lead to additional delays, unforeseeable now.

Impact

- The paper with first results obtained during past UNR/MSTS collaboration experiments is being drafted.
- The experimental method was planned to be presented at 2020 Nuclear Photonics conference in Japan; unfortunately the conference was cancelled due to Covid-19.
- The new collaboration between NNSS LO and LLNL was established within the project.
- The project became an excellent tool for recruiting students at UNR: we have two students on the team already and more are interested in participating.
- Ongoing discussion with our partners from UNR for a patent application.
- A novel method of production of short-lived positron emitting isotopes based of the LAZE produced neutrons is discussed within the team, and it potentially could be a topic for the new proposal.