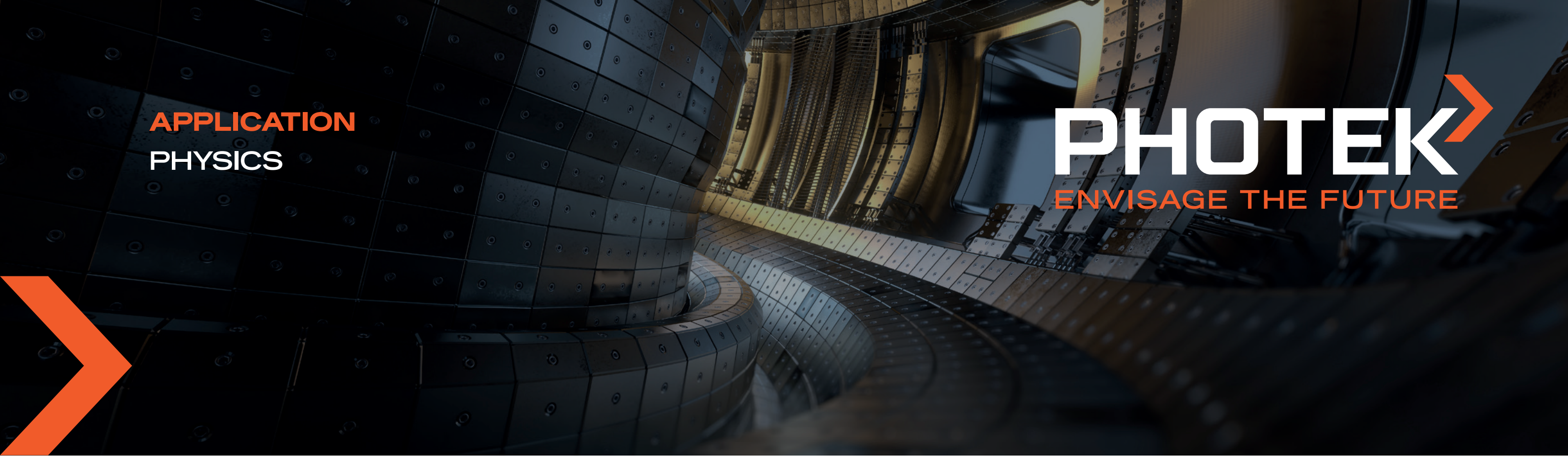

APPLICATION
PHYSICS

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Neutron Time-of-Flight (nToF) Diagnostics for Fusion Research

Physicists have pursued fusion technology for decades as it promises a potential source of near-limitless clean energy using only isotopes of Hydrogen, the most abundant atom on earth.

Photek has a long history providing the fusion community with ultra-fast light detectors critical to diagnostics used in Inertial Confinement Fusion (ICF). In ICF high power lasers, or a combination of lasers and pulsed power, heat a small capsule with varying amounts of Deuterium and Tritium - isotopes of Hydrogen. This causes the confined plasma to implode, generating the enormous sun-like temperatures and densities required for fusion to occur. During the fusion process the Hydrogen isotopes are converted into Helium and neutrons plus excess energy that can be used to generate electricity.

Three US based facilities at the forefront of ICF are the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in California, the Omega facility at the Laboratory for Laser Energetics at the University of Rochester in New York, and the Z Machine at the Sandia National Laboratory in New Mexico. All three of these facilities utilize Photek products in their nuclear diagnostics, including Photomultiplier Tubes (PMT), Pulse Dilation PMTs (PD-PMT), Image Intensifier Tubes and Streak Tubes.

Photek recommends

- **Photomultiplier Tubes** (PMTs)
- **Pulse Dilation PMTs** (PD-PMT)
- **Image Intensifier Tubes**
- **Streak Tubes**

MCP-Photomultiplier Tube

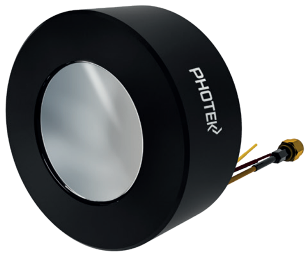
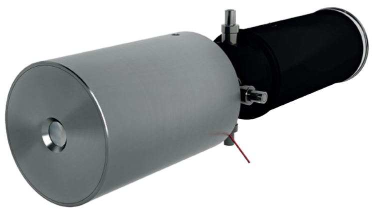


Image Intensifier



Streak Tube

Instrumentation

The ICF implosion happens extremely fast, as fast as tens of picoseconds where one picosecond is 0.000000000001 seconds. This is an extremely short period of time that is very difficult to measure using traditional techniques. It is a billion times faster than normal video rates.

Our detectors are used to probe what's happening in these implosion experiments to provide scientists insights into fusion reaction dynamics, the efficiency of energy production, and the behaviour of plasma confinement. This information is used to improve the ICF process and to reach ever higher releases of energy.

Each implosion generates many neutrons: neutral particles that normally are confined in atomic nuclei along with protons and gamma-rays. The sheer number of these particles generated creates a severe radiation environment around the implosion chamber and can damage many common types of diagnostic instruments. The vacuum tube technology used in Photek detectors can survive these high levels of radiation, also making them a valuable technology for the harsh radiation environment of space. Photek photodetectors not only survive the harsh radiation environment near the ICF implosions, but they are also among the world's fastest light detectors.

Diagnostic Techniques

An important diagnostic technique used in ICF experiments is neutron time-of-flight (nToF). Since the neutrons are directly generated in the fusion process they contain important information about each implosion event.

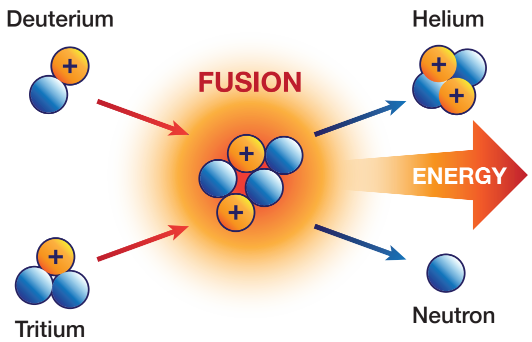
The energy spectrum of the neutrons is particularly useful in diagnosing implosion events. A neutron time-of-flight detector is used to measure the neutron energy spectrum by relating the measured neutron velocity to its energy.

The ICF nToF instruments use very fast organic scintillators, materials that generate light when exposed to ionizing radiation like neutrons and gamma-rays. Photek PMTs view the scintillator and produce a signal that is proportional to the number of particles striking the scintillator.

In an implosion event...

Gamma-rays arrive first since they travel at the speed of light. The neutrons arrive later as they are slower moving. In the experiment the PMTs are typically gated off during the gamma-ray pulse to prevent signal saturation in the PMT, except one PMT which is used to measure the gamma-ray arrival and used as a timing reference.

Prior to the arrival of the highest energy neutrons at the scintillator, hundreds of nanoseconds after the gamma-rays in NIF for example, the PMTs are turned back on and the time history of the neutron signal is recorded for several microseconds, to include the primary fusion neutrons themselves, either Deuterium-Tritium or Deuterium-Deuterium neutrons, and lower energy neutrons created by scattering of the primary neutrons with material in and around the target chamber.



The time to travel a fixed distance provides the neutron velocity, and the energy of the neutron is proportional to the square of the velocity. The signal levels over the full range of neutron energies can span many orders of magnitude, requiring the PMTs to have a very wide dynamic range. Often multiple PMTs are operated at different gains and gated on at different times to enable high precision measurements for the entire neutron signal lasting several microseconds.

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Photek PMTs uniquely excel in both their time response which results in excellent precision of the neutron energy spectrum, and in their ability to be gated on and off in a matter of nanoseconds, enabling a wide dynamic range measurement using several PMTs at different gains. Details of nToF instruments at the NIF, Omega and Z can be found in the attached references[1,2,3].

Future developments

Photek is currently working on several new developments with photomultiplier tubes to help address the ever-growing yield or total energy coming out of inertial confinement fusion implosions.

Since scientists continue to run some experiments with low yield to investigate fundamental research into the ICF process they require the PMTs to span an even larger range of signals. Ideally the nToF diagnostics could use the same number of PMTs to cover this larger range to improve calibration of the instruments.

Photek is working with the fusion community on several exciting new developments to extend the PMTs dynamic range, including real-time control of PMT gain and sensitive area. These advances will allow researchers to move closer to their goal of limitless clean fusion energy. Look for more information on these advances in future posts.

References

1. **Moore, A. S., et al.** "The five line-of-sight neutron time-of-flight (nToF) suite on the National Ignition Facility (NIF)." Review of Scientific Instruments 92.2 (2021): 023516. https://pubs.aip.org/aip/rsi/article/92/2/023516/368632/The-five-line-of-sight-neutron-time-of-flight-nToF

2. **Glebov, V. Yu, et al.** "A new neutron time-of-flight detector for yield and ion-temperature measurements at the OMEGA Laser Facility." Review of Scientific Instruments 93.9 (2022): 093522. https://pubs.aip.org/aip/rsi/article-abstract/93/9/093522/2849086/A-new-neutron-time-of-flight-detector-for-yield?redirectedFrom=fulltext

3. **Chandler, G. A., et al.** "Neutron time-of-flight detectors (nTOF) used at Sandia's Z-Machine." Review of Scientific Instruments 93.11 (2022): 113531. https://pubs.aip.org/aip/rsi/article-abstract/93/11/113531/2849251/Neutron-time-of-flight-detectors-nTOF-used-at?redirectedFrom=fulltext