OCEAN TOMO
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# LOT #136

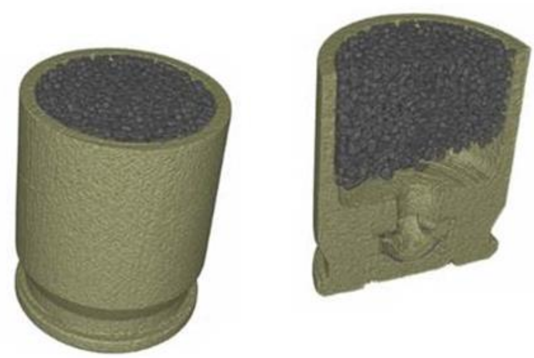
## Ultra High Definition Spatial and Energy Resolution

OCEAN TOMO
BID-ASK™ MARKET

*Ultrahigh Definition, Energy-Resolved*

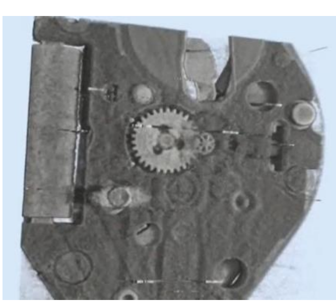
# Neutron Imaging

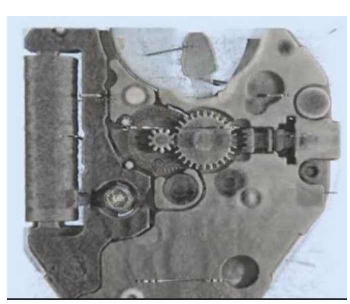
## A unique business opportunity within the nuclear instrumentation market

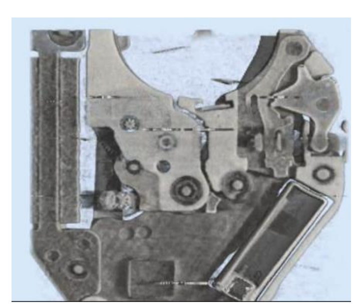


Nondestructive neutron tomography enabled by NOVA patented NeuView$^{TM}$ technology

( Video of Swiss watch 'deep dive' can be viewed at novascientific.com/technology )







LEADERS IN MICROCHANNEL BASED NEUTRON DETECTION & IMAGING

# The Opportunity

**Ultrahigh Definition, energy-resolved neutron imaging represents a unique business opportunity in the $800 million global neutron detection and imaging market.**

**The growth market for neutron imaging encompasses numerous applications:**

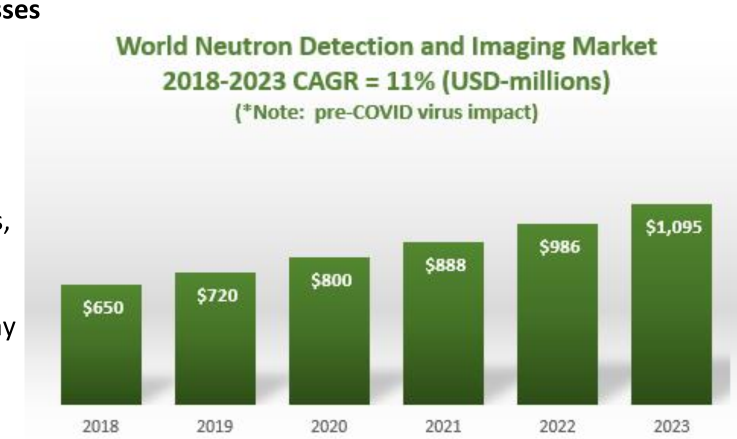
- **Industrial** (NDE/NDT/NDI), which complements and is synergistic with X-ray imaging.
- **Scientific** (incl. research reactors, pulsed sources, neutron generators)

  High resolution neutron imaging /tomography
  Bragg edge imaging
  Energy-resolved imaging at pulsed sources
  Neutron resonance absorption imaging
  Neutron diffraction; protein crystallography
  Spatially resolved strain analysis
  Neutron collimation and scatter rejection
  Beam profiling

- **Nuclear Power**

  Spent fuel inspection
  Control rod imaging
  Instrumentation and reactor training

- **Defense and Homeland Security**




*As of late 2019 and prior to the impact of COVID-19, growth was expected to continue at a rate of 11%+ driven by worldwide expansion in neutron applications as well as non-fission-based fixed site and portable and stationary neutron generator sources.*

**IndustryARC.com**

Together with appreciation of the growth prospects for neutron imaging, there has also emerged concern about current neutron detectors – some already several decades old – which are falling short and inadequate to meet the challenges of the new and sophisticated neutron techniques, hampering forward movement of powerful new and critical imaging, tomography, and energy-resolving neutron methods. Such examples of aging technologies include: traditional film, storage phosphor image plates, CCD cameras, He-3 2D gas detectors, scintillator/PMT combinations, as well as amorphous-Si flat panels.

# About NOVA Scientific

**NOVA Scientific is a premier provider of state-of-the-art neutron imaging detectors with extensive, long-standing experience serving the global neutron science and engineering community.**

Since its inception in 1993, initially focusing on cutting edge R&D for space science and the semiconductor industry, NOVA Scientific has more recently spent the past decade concentrating mainly on nuclear science - specifically to advance the state-of-the-art in neutron imaging and detection, and augmented by over $14 million of U.S. agency R&D funding in just this one area alone (DOE, DoC, DoD, NIH, HS, IC).

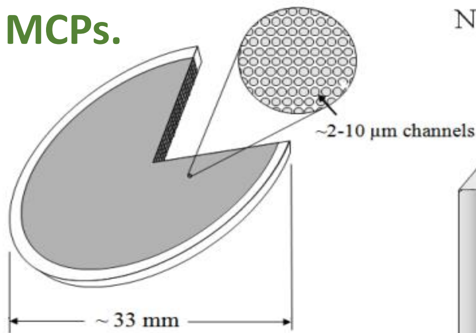
NOVA invented, developed, and extensively patent-protected a powerful, internationally acclaimed neutron imaging and detection approach based on microchannel plate (MCP) imaging detectors, a ground-breaking approach discussed in well over 100 refereed journal articles by leading international neutron researchers. NOVA's approach to neutron imaging and detection provides an unrivalled combination of ultrahigh spatial and timing resolution, while still maintaining very high neutron sensitivity. NOVA's NeuView$^{TM}$ neutron-sensitive microchannel plates (MCPs), have repeatedly and dramatically been shown to enable powerful new application areas for advanced materials studies, with great potential for commercial NDE/NDT/NDI.

Particularly exciting as compared with other neutron detection approaches, is a novel combination of ultrahigh spatial with ultrafast timing resolution capability, in NOVA's key MCP neutron detection element. This uniquely provides *advanced neutron energy resolution* capability in TOF (Time-of-Fight) mode together with a compatible electronic readout – a critical advantage with the new expanding generation of pulsed neutron sources, both large fixed site spallation sources as well as rapidly emerging portable neutron generator technologies.

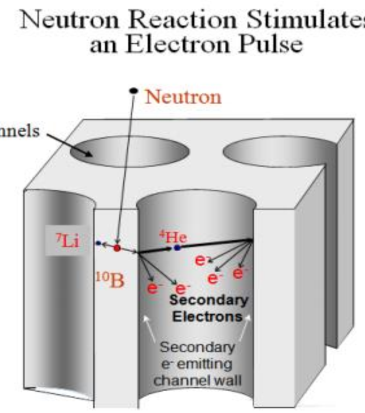
NOVA NeuView$^{TM}$-based MCP neutron imagers are now heavily used and dedicated 'User Facilities' at both the national NIST (left) and Oak Ridge (right, SNS) neutron laboratories in the USA

# About The Technology

## NOVA's Neutron-Sensitive MCPs.



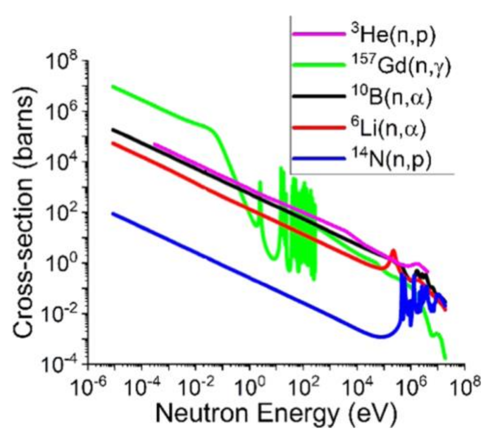

Example MCP structure




NOVA Scientific has been the sole Inventor, developer and provider, worldwide, of commercial neutron-sensitive MCP technology, through its extensively patent-protected innovations in MCP composition, design, and use. NOVA's advances in this area have resulted in exceptional neutron imaging and detection performance, with a revolutionary combination of simultaneous very high spatial and neutron event timing resolution (as low as ≈20 micron FWHM and ≈100 ns, respectively), and at very high intrinsic event rates of up to ≈10 MHz/cm$^2$.

The schematic shown above provides an example of how the neutron detection process works within an MCP. Here, using the $^{10}$B(n,α)$^7$Li capture conversion process for neutrons within an MCP channel wall, short-range (3-4 µm) alpha particles and lithium nuclei are created with considerable energy (~1 MeV). (In addition to enriched Boron-10, NOVA also has extensively used Gadolinium, which releases fast conversion electrons instead of heavy charged nuclei, which equally initiates a secondary electron cascade.) These energetic charged particle reaction products, punching through the secondary emitting surface of the microchannel, then liberate free secondary electrons into the adjacent evacuated channel. Under high voltage, a strong electric field accelerates these secondary electrons further down the microchannel, producing an exponentially growing electron cascade which develops within a nanosecond. A strong charge pulse then exits the microchannel output end onto a 2-D readout.

On the right is a neutron absorption cross-section chart versus energy, which explains the relative response of neutron detectors to different neutron energies using the elements shown. Typical absorber materials used in different approaches to neutron detection, have high cross sections for absorption of neutrons and include He-3 (gas), Li-6, B-10, and Gd-157. Each of these reacts by emission of energetic ionized particles, creating a detectable pulse in the neutron detector.




(Nature.com. Scientific Reports v.9, article number 17551 (2019)

# About The Technology

- To ensure blanket and all-inclusive IP coverage, NOVA has patented the two main methods of incorporating the key neutron absorbers used for detection, into the MCP structure. **Figure 1** shows $^{10}$B, Gd, $^{6}$Li, etc. directly incorporated into the base or bulk MCP materials. Alternatively, **Figure 2** from one of NOVA's issued patents, shows thin film neutron absorbers applied along inner microchannel walls. NOVA's *<u>comprehensive</u>* IP coverage

- Nuclear reactions yielding reaction products create strong secondary electron pulses amplified to large ~$10^{6}$ e- output pulses; neutron event timing down to ≈ 100 ns with ≈ 20 µm spatial resolution.

- Thermal and cold neutron efficiency ≈ 50 to 70%; epithermal efficiency ≈ 10-20%, depending on epithermal energy

- For fast ~MeV neutrons, NOVA has patent coverage for MCPs incorporating hydrogenous materials for knock-on proton reactions, to which MCPs are highly sensitive.

- *Area Sensitivity(per cm$^{2}$)* exceeds $^{3}$He tubes (at 3 atm.) by 1.7x

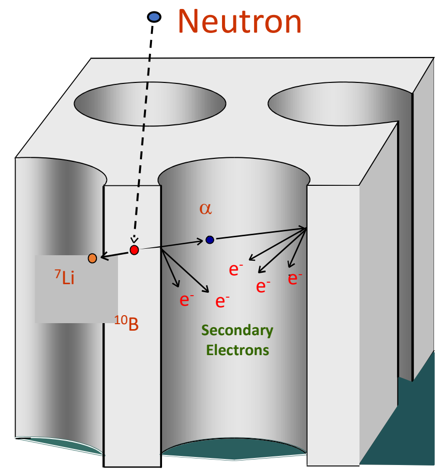



Figure 1

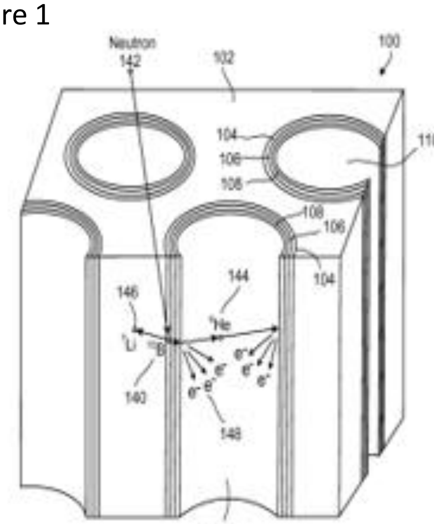
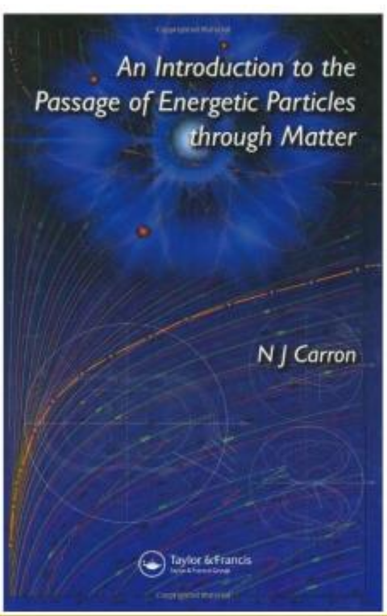



Figure 2




Modeling with Dr. N. Carron supported by US government to assess MCPs as small and medium format SNM detectors.
(DNDO SBIR HSHQDC-11-C-00130)

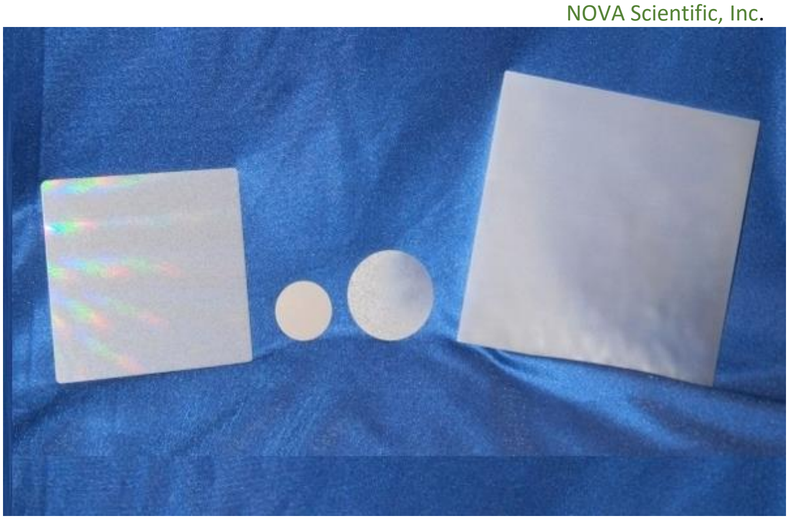
| Detector | Face-on area (cm2) | cts/sec at $E_{thermal}$ | |
|---|---|---|---|
| | | Normal incidence | 60° off normal |
| NVN-7 MCP | 78.5 | 60 | 30 |
| He tube, 3 atm | 76.2 | 37 | 27 |
| B-lined tube | 76.2 | 10 | 7.8 |

**Count rate in a planar *thermal* neutron flux of 1 n/cm$^{2}$/sec.**

# About The Technology

## NOVA's NeuView™ neutron-sensitive MCPs: near-arbitrary format flexibility of up to 150mm

NOVA Scientific, Inc.



**100x100mm 33mm 50mm 150x150mm**
**125 Million 10 M 25 M 280 M**
**( the number of 8 micron microchannels – each an independent electron multiplier)**

Shown above are examples of a few different formats possible for the basic NOVA neutron-sensitive MCP wafer component, which is only 1 mm thick. Neutron-sensitive MCPs, which are optimized with 8 micron microchannels or pores, can be cut to nearly any arbitrary shape or size up to 150mm. Each MCP comprises many millions of parallel, hollow microchannels – each acting as an independent electron multiplier - with the strong nanosecond output pulses easily registered onto a 2D electronic readout. Above is listed the total number of microchannels for each displayed format.

*Note: In recent years there have appeared dozens of refereed articles by neutron researchers worldwide, discussing NOVA's neutron-sensitive MCPs, both how they operate and more broadly in various cutting-edge applications. These can readily be accessed in relevant journals (e.g., Nuclear Instruments and Methods, IEEE Nuclear Science, Journal of Instrumentation, etc.). Various presentations on this technology can also be found online.

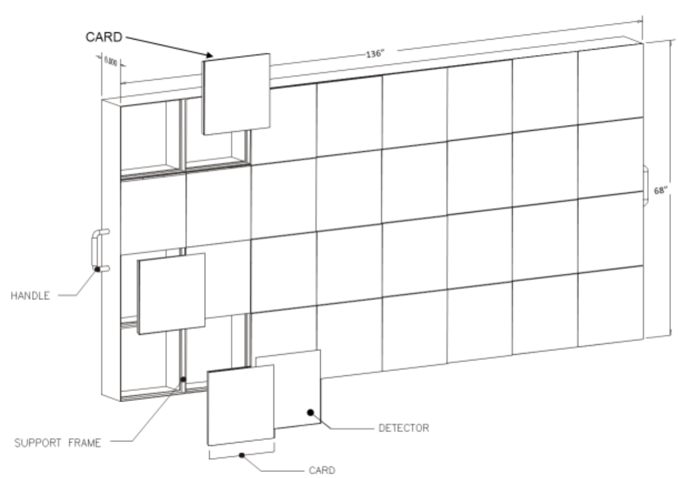
# About The Technology

## Benefits compared to a few other neutron imaging approaches

- **Traditional film** still gives good resolution – but no timing, and not real-time operation (as with MCP digital readout); is increasingly not used as being too slow and unwieldy, outdated.
- **Scintillators coupled to PMTs with photocathodes**: Less efficient, more complex than NOVA MCP direct imagers; considerably slower for data-taking. Economic impact: beam time and associated labor is very expensive. MCPs have major performance advantages for neutron energy-resolved TOF imaging with the different types of pulsed neutron sources.
- Vacuum-based devices such as **MCPs** do not suffer radiation issues present with true solid-state detectors (like **a-Si**)

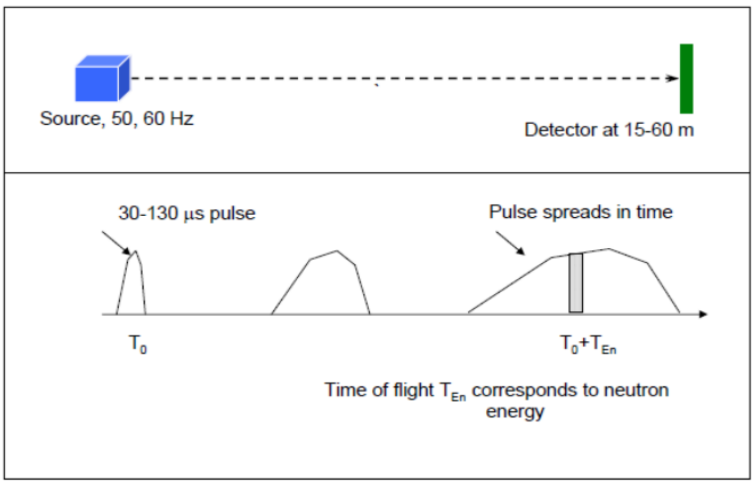
## Performance drivers – the NOVA NeuView™ MCP advantage

- Demand for **higher spatial resolution**, **faster event timing**, and **more efficient** neutron detection at higher energies (NOVA issued patents have many independent Claims covering the full neutron energy spectrum – ultracold through fast).
- Ultrafast timing to identify arrival of each neutron to ~0.1 microsecond; superb TOF performance essential for pulsed neuron sources, spallation, fission reactor-based, and D-D fusion (neutron generators).
- Detector formats moving to larger areas, tiling and arrays; all possible with MCP format flexibility.



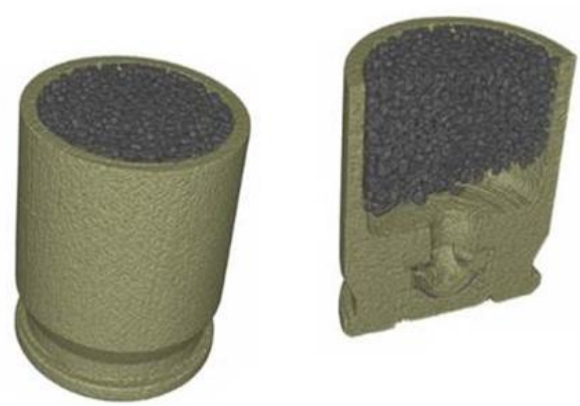
# About The Technology

NOVA's NeuView™ technology, uniquely combing ultrahigh spatial and timing resolution, enable new applications utilizing neutron Time-of-Flight.




The pulsed structure of the new and more powerful neutron beams in neutron research labs worldwide, both from the new spallation sources as well as conventional continuous research reactor beams operated with choppers - enables measurement of neutron energies via the **Time-of-Flight (TOF**) method. The unique ability of MCP detectors to measure the precise energy of each detected neutron coupled with high definition spatial resolution, allows experiments across a very broad neutron energy range simultaneously – from cold and thermal up to epithermal energies. For example, simultaneous detection of multiple Bragg edges can enable highly useful measurements in crystallographic structure, strain, phase, texture, and compositional distribution.

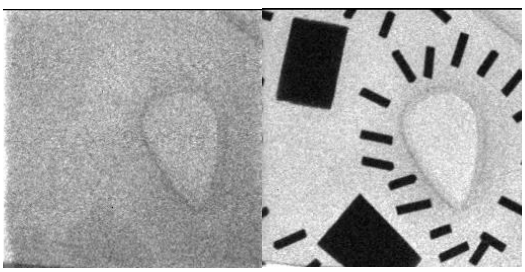
On the right are neutron tomographs of a shell and grains, using NOVA NeuView™ MCPs with Timepix readout, made on Paul Scherrer Institute's ICON imaging beamline in Switzerland. Completely unique to neutron-sensitive MCPs: *simultaneous* time-tagging (< 1 μs resolution) at < 50 μm spatial resolution, is the leading method to do such studies in a time-efficient manner.
This image: 201 projections, 100s each: 5 to 6 hours total.
(Tremsin, Feller, et al. NIM A v.652, 400)



NOVA's NeuView™ MCP-based detectors are the solution to capturing tomographic images in just a few *hours* instead of tens of hours, resulting in large cost savings in hourly beam charges and labor.

# About The Technology

Another example enabling new and more powerful applications in addition to microtomography and Bragg edge imaging is **neutron resonance imaging**.



(a) (b)

Neutron transmission images of an ancient belt mount replica at both the resonance energy of Ag as well as away from it - same area as highlighted
(a) Transmission image obtained with neutrons around 1.6 eV.
(b) Image obtained at 5.3 eV at the silver resonance. Both images are normalized by the open beam and represent the spatial variation of transmission coefficient at the corresponding neutron energy.

(Tremsin, Feller et al., IEEE Nuclear Science Symposium; Valencia, Spain)

Photograph of the belt mount replica used in the experiments (Rutherford Lab UK; Oxford University museums). The dashed boxes show the areas imaged at the 1-100 eV energy range .

Such unique advantages of NOVA’s neutron-sensitive MCPs enable completely new areas of investigation with neutrons through providing simultaneous ultrafast neutron event timing in combination with exceptional spatial resolution. **Eberhard Lehmann** at Paul Scherrer Institute in Switzerland, widely acknowledged as leading the development of neutron imaging in recent years - comments on the impact of NOVA’s neutron-sensitive MCPs:

***“One of the key components of sophisticated new studies has been found in the MCP based pixel detector… Its performance is unique and promising as standard configuration at the new imaging facilities at pulsed sources.”***

*9th Workshop on Neutron Wavelength Dependent Imaging (NEUWAVE- 9)*
*11-14 June 2017, NIST, USA*

**Progress in Neutron Imaging (during/by the NEUWAVE workshop series)**
Eberhard H. Lehmann
*Neutron Imaging & Activation Group, Laboratory for Neutron Scattering & Imaging Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland*

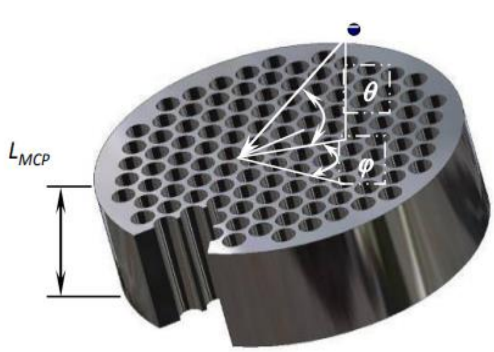
# About The Technology - Collimators

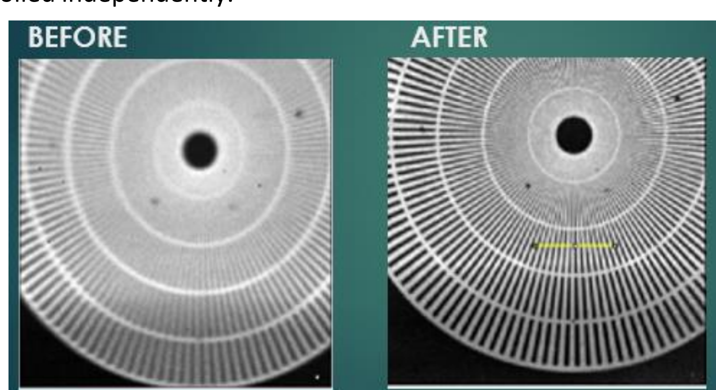
**NOVA Scientific's patented neutron-sensitive MCPs, developed for detection and imaging, simultaneously have enabled an exciting, superior new type of neutron *collimator* – compact, simple, fully two-dimensional - yet offering exceptionally high performance at reasonable cost.**

The angular spread of a neutron beam is usually defined by the quality of neutron collimators used in most neutron scattering experiments, and is also a factor in neutron imaging. Typical neutron collimators for decades have been constructed from a large number of parallel plates coated with neutron absorbing material ('Soller Slits'); usually these plates are several centimeters in length or more. Moreover, to obtain collimation in both vertical and horizontal planes, it is necessary to have two orthogonally aligned collimators placed into the neutron beam, adding to complexity.

NOVA's extensively patented neutron MCP technology, in addition to being transformative for neutron detection and imaging, now also provides a powerful new type of high-performance *neutron collimator* – featuring large microchannel length-to-diameter (L/D) ratios of hundreds to one, benefitting from the extremely precise axial microchannel alignment possible from long-established multidraw fiber optic processing techniques. NOVA's MCP collimators have been used at Oak Ridge National Lab's SNS and HFIR, and Europe's PSI, ISIS, and FRM-11 labs.

Based upon neutron-opaque interstitial microchannel walls and hollow micron-sized microchannels, the thickness of such collimators is on the scale of only few millimeters, with a possible open area ratio of up to 75%. The metric for collimation - the 'rocking curve' – can be sharper with MCPs that that of conventional 0.5 degree collimators, down to only about 0.1 degree, permitting highly selective angular sensitivity. While collimation is performed in two perpendicular planes simultaneously, the geometry of these new collimators can be altered such that the degree of collimation in each direction is controlled independently.




Tests with PSI neutron imaging resolution target, showing improved image resolution with an MCP neutron collimator.
(DOE STTR #DE-FG02-08ER86333)

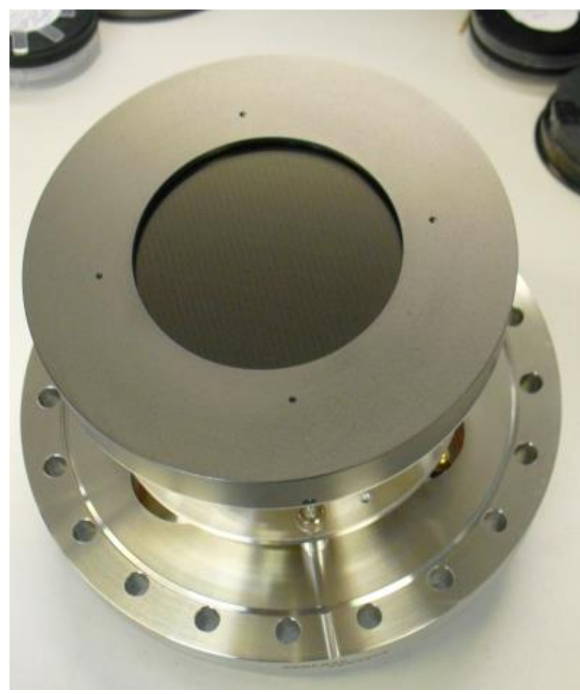
LEADERS IN MICROCHANNEL BASED NEUTRON DETECTION & IMAGING

# Product Integration Example:

## Demountable Neutron Imaging Detector

NOVA's open face or 'demountable' neutron imaging detectors are single flange-mounted devices, combining our NeuView$^{TM}$ MCP technology with a very high-performance user-friendly Delay Line Anode, supplied and integrated by **Surface Concept GmbH** as standard equipment. This combination allows complete flexibility in MCP neutron detector mounting and attachment, either onto a vacuum chamber or evacuated neutron beamline.

| | |
|---|---|
| **Detection Unit** | Neutron-Sensitive MCP / Amplifier MCP |
| **Imaging Area Diameter** | 18 mm up to 150mm, customizable |
| **Output** | Delay Line Anode (standard) Other options available |
| **Spatial Resolution** | <50 µm |
| **Temporal Resolution** | 100 ns |
| **Cold and Thermal Neutron Sensitivity** (5 meV-25 meV) | ≈ 60 % (5 meV) to 45 % (25meV) |
| **Gamma Ray Sensitivity** | ≈ 1 % |
| **Background** | < 1 ct/s/cm$^2$ |



## Distributors

**USA/North America**

PMT | PRECISION MEASUREMENT TECHNOLOGIES

Precision Measurement Technologies (Clearwater, FL)

**Outside of North America**

SURFACE CONCEPT

Surface Concept (Mainz, Germany)

LEADERS IN MICROCHANNEL BASED
NEUTRON DETECTION & IMAGING

**NOVA Scientific's *neutron imaging* patents can be broadly grouped into three separate, closely integrated and synergistic categories:**

- **MCP Neutron Detection (10 active patents)**
- **MCP Gamma Ray Rejection ( 5 active patents)**
- **MCP-based Neutron Generator Imaging (2 pending patents)**

# About The I.P. – Neutron Detection

Shown on the right is the key patent grouping for MCP Neutron Detection. (Note: A few titles add description, unlike the actual patent titles.) This novel fundamental advance, pioneered from the very start solely by NOVA Scientific, emerged from years of very rigorous, protracted and methodical development, motivated by a highly aggressive long-term goal of attaining the ultimate, highest neutron sensitivity possible in MCP structures. NOVA had success in extensively modifying the base materials and even the geometry in some cases, of a previously neutron-blind but powerful, very widely known and extensively used technology for high resolution imaging and ultrafast timing, used for many and critically important research, defense and industrial applications. Prior to NOVA's pioneering advance, previous MCP devices variants had been totally blind to neutrons of all types (energies).

**MCP-based Neutron Detection (10)**

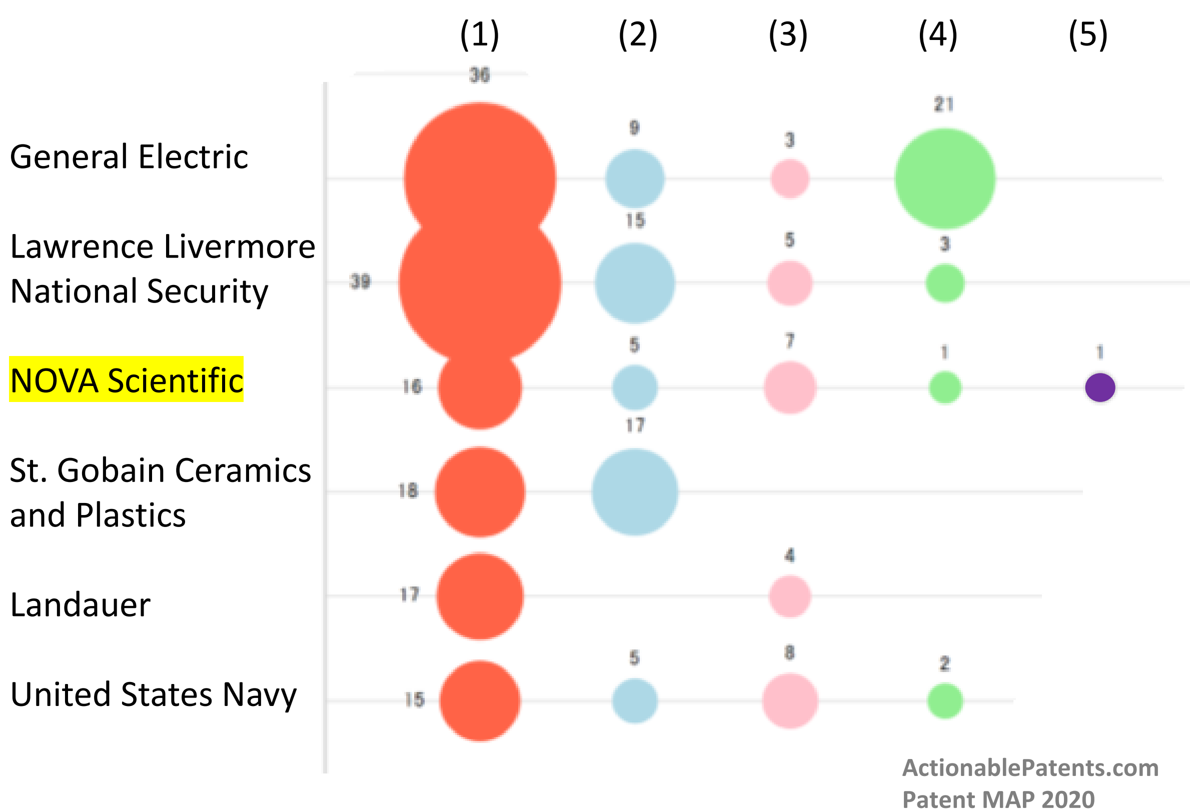
| | |
|---|---|
| Radiation Detectors | 7,508,131 |
| MCP Neutron Glasses | 7,791,038 |
| Electron multipliers and Microchannel Plates | 7,990,032 |
| MCP for Fast Neutrons | 8,221,181 |
| MCP Neutron Glasses | 8,445,858 |
| ALD Coated MCP | 8,507,872 |
| ALD Coated MCP | 8,835,864 |
| Square/Rectangular Pore nMCP | 8,884,237 |
| Neutron Detection and Collimation | 9,082,907 |
| Epithermal Glass Modifications | 9,941,438 |

LEADERS IN MICROCHANNEL BASED
NEUTRON DETECTION & IMAGING

# About The I.P. – Neutron Detection

**Below is a 'bubble chart' showing a neutron detection-related patent map ranking, presenting the top tier organizations in descending order when factoring in breadth as well as number. This chart was based on a search of a seminal NOVA neutron detection patent (USP 7,791,038) based on Microchannel Plate technology.**

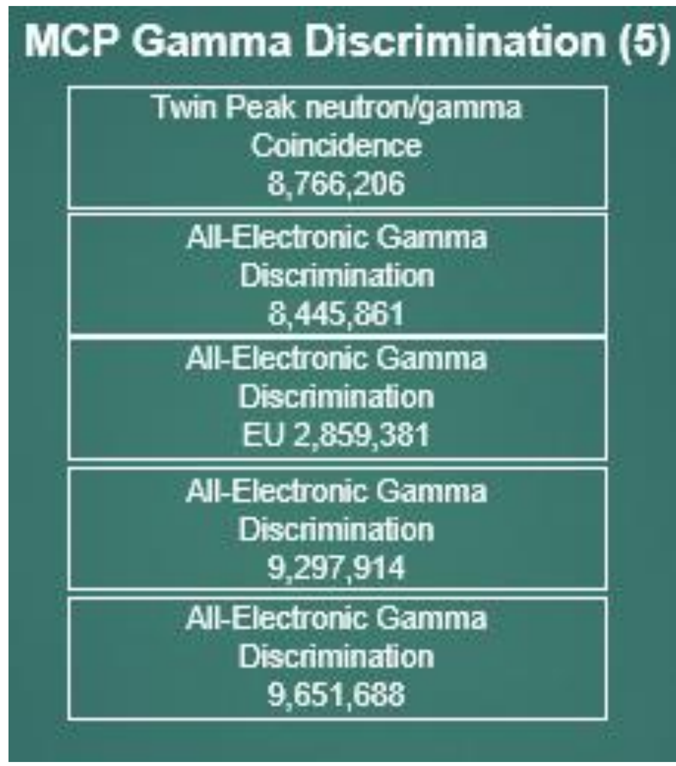
Column ordering for the number of patents issued in:
(1) measuring neutron radiation, which includes (2) with scintillation detectors,
(3) with semiconductor detectors, (4) with ionization chambers, (5) in spectrometry.



# About The I.P. – Gamma Discrimination

Neutron detection for a few specialized applications (e.g., security) may need to occur in a high gamma ray field or background. With government support, NOVA has studied different approaches to preserve the inherently high neutron efficiency of its neutron-sensitive MCPs (based on solid glass instead low-density gas as with $^{3}$He), while at the same time mitigating the MCP response to gamma rays. One approach has resulted in multiple patents being issued to the company - using a highly novel scheme based on waveforms obtained from just the MCP electrical contacts. (*Note: As before, titles here are descriptive, unlike the actual patent titles.)

By avoiding the usual analysis of standard pulse height differences, as typically used in many other neutron/ gamma discrimination approaches – and instead, comparing pulse waveform inversions - unambiguous and binary determination between gamma rays and neutrons can more readily be carried out. This can avoid a reduction in neutron sensitivity which often accompanies the traditional pulse height analysis methods, particularly under pulse pile-up and intense overlap conditions.




This unusual line of attack to neutron/gamma separation grew out of a successful Phase I SBIR project supported by the US Dept. of Energy. Due to the recent shift in priorities at the firm and increased emphasis on neutron generator applications and system performance - some additional work is required to conclude development of the patent-protected approach. Once firmly established, a small value-added outboard electronics module can readily be envisioned.

# About The I.P. – Neutron Generators

**NOVA's key neutron generator-related imaging *system* patent-pending invention -** targeting the growing interest and anticipation of the paradigm shift towards small, compact, and increasingly powerful neutron generators, is as yet unpublished

This global pending patent application enables higher contrast and clarity for MCP neutron imaging together with a small, desk-sized electronic neutron generator system.

Comprehensive global patent filing, **U.S. and Foreign** (global PCT application pending with worldwide rights in 152 countries) modifying the portable neutron generator imaging chain in a way that strongly enhances the imaging power of neutron-sensitive MCP-based imagers. Offering strong and competitive patent protection coupled with NOVA's picket fence of key technology developments – it provides the Buyer a significant barrier to competition for major new business opportunities .

**Neutron Generators using MCPs (2)**

Neutron Generator Based System
Pending Application
Docket 06547-0032001

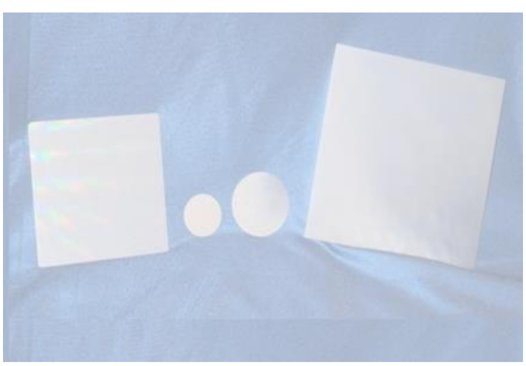
Neutron Generator Based System
Pending Application
Docket 06547-0032WO1

This combination is a perfect fit with a new generation of high neutron output electronic neutron generators, comparable in size and footprint to commercial X-ray analysis instruments and allowing future commercial expansion and proliferation into *any* company, government, or academic laboratory facility. With time, progress in 'NG' technology will provide safe and cost-effective neutron radiography imaging and tomography, for a wide range of NDT/NDT applications.

# NOVA Support and Technology

NOVA Scientific will provide the know-how and access to inventors and neutron specialists, all related intellectual property, trade secrets and trademarks, as well as inventory and ancillary equipment - to accelerate development, global deployment and expansion of its neutron imaging and detection technology.

In addition to NOVA's powerful and unified portfolio of 15 issued patents and 2 key patent applications, the Buyer also will have access to assets to leverage and help fast-track penetration and rapid expansion into the global market for advanced, cutting-edge neutron imaging and detection - for the wide variety of important industrial, scientific, power industry, and security applications requiring the latest advance in neutron detection.



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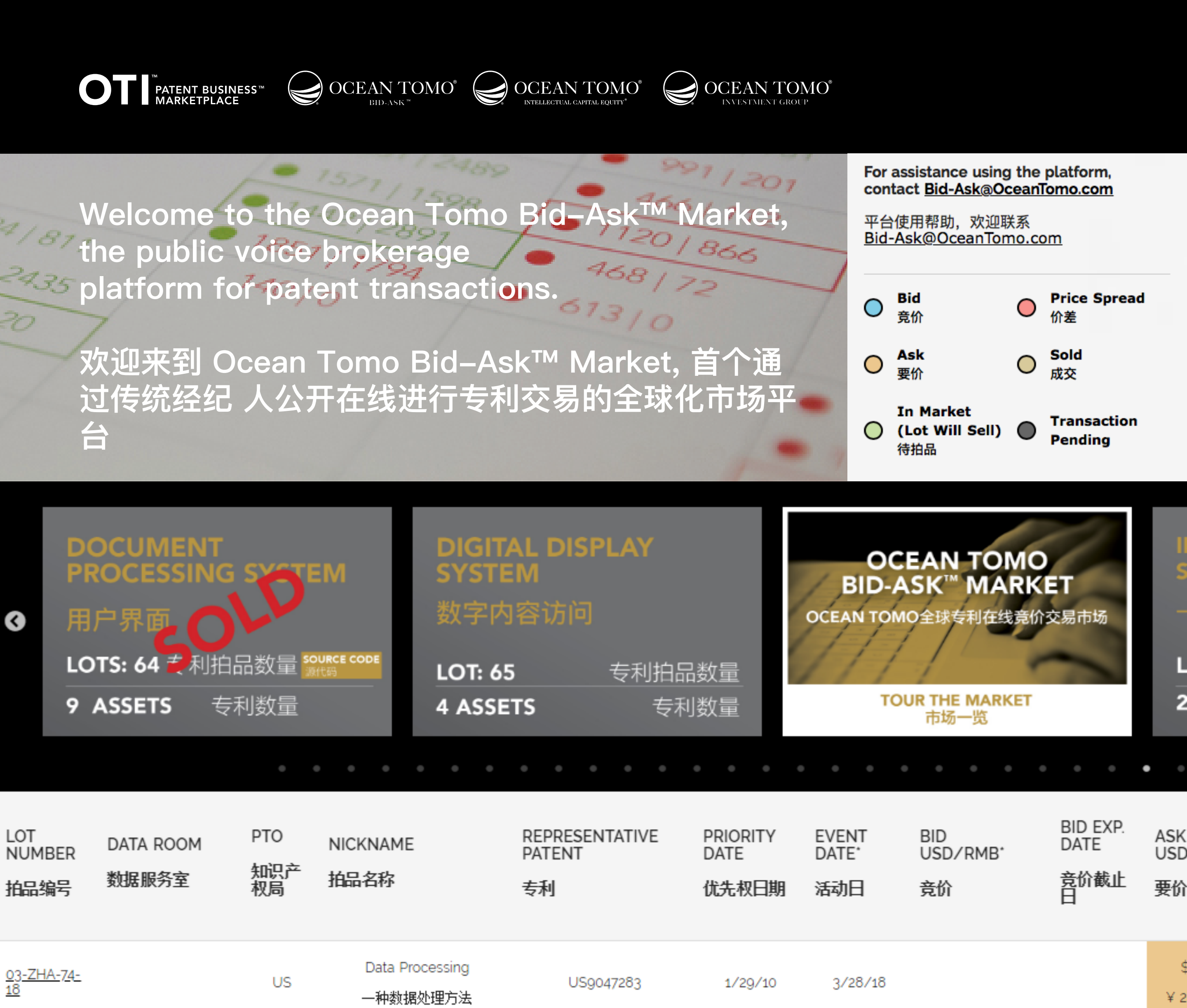


The Ocean Tomo Bid–Ask™ Market (OTBA) was built to further enhance Intellectal Property (IP) liquidity and transaction transparency. OTBA serves a broad community of active buyers and sellers, providing a platform to purchase or sell patents and patent applications globally. This market is supported by Ocean Tomo Transactions and affiliate international voice brokers.

建立OTBA的目的是进一步促进IP资产流通性,提高了IP交易透明度。买卖双方通过 OTBA平台来购买或者出售全球专利权以及专利申请权，Ocean Tomo交易团队和旗 下全球经纪人为平台提供线下提供服务支持，以此建立活跃买卖双方的全球专利交 易市场。

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