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Overview of Tritium Betavoltaic Power for Micro Sensors

Tritium Focus Group Meeting

City Labs Inc.
Homestead, Florida, 33030

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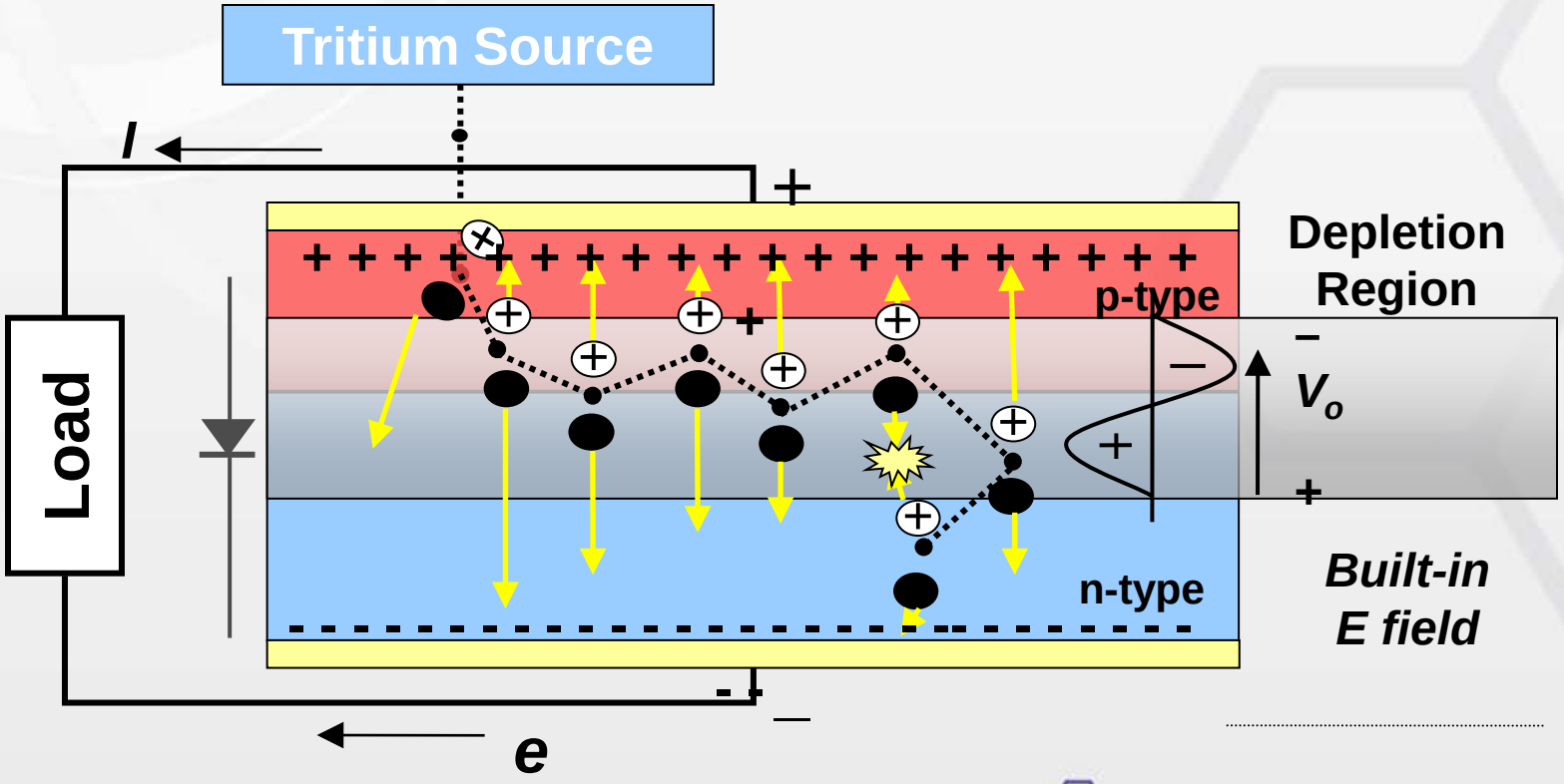
Tritium Betavoltaic Operation (U)

- Electrons (beta particles) are emitted from a tritium source, creating electron-hole pairs within a semiconductor
- Results in the generation of electrical current



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Radioisotope Selection Pitfalls (U)

Isotope	$T_{½}$ (years)	Emission	E_{ave} (keV)	E_{max} (keV)	P_{sp} (μW/Ci)	Element
H-3	12	β^-	5.7	19	34	Hydrogen
Ni-63	100	β^-	18	62	100	Nickel
Pm-147	2.7	β^-, weak γ	62	224	367	Promethium

- **Damage threshold for semiconductors : ~250 to 300 keV**
- **Poor betavoltaic radioisotope choices: Kr-85, Sr-90, Tl-204**
- **Per Dr. Olsen, tritium is the best option for betavoltaics [6]**

6. Olsen, L. C., "Review of betavoltaic energy conversion," Proc. 12th Space Photovoltaic Research and Technology, 256-267.

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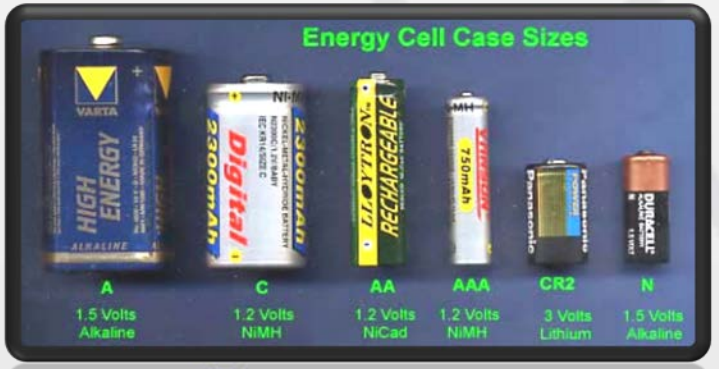
Why use Betavoltaics? (U)

Tritium / Betavoltaic	Lithium / Chemical Batteries
Performance Lifetime: Long (e.g. 15 - 20 years)	Performance Lifetime: Short (e.g. less than 2 years)
Operational under extreme temperatures (-40°C to 80°C) (Tested -50 °C to 150°C)	Performance diminished at extreme temperatures (-40°C to 80°C)
Thermally & Environmentally Independent lifetime, corrosion resistant	Lifetime susceptibility to extreme temperatures, humidity & corrosive environments
Suitable for low power robust applications (nanoWatts - microWatts) Power burst via secondary trickle charging (milliWatt – Watts)	Suitable for higher power applications (milliWatts - Watts)



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End-User Regulatory Requirements (U)

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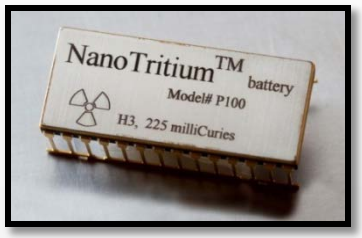

- Receipt of City Labs' NanoTritium™ Betavoltaic requires no specialized training
- Receipt of City Labs' NanoTritium™ Betavoltaic requires no prior radioactive licensure
- City Labs' Betavoltaics fall into the same regulatory licensure class as tritium exit signs
- Betavoltaics should be used as outlined in user manual
  - Betavoltaics should be disposed of as outlined in user manual

Approval as a Generally Licensed device represents a significant milestone – a goal that has not been achieved by any other Betavoltaic manufacturer

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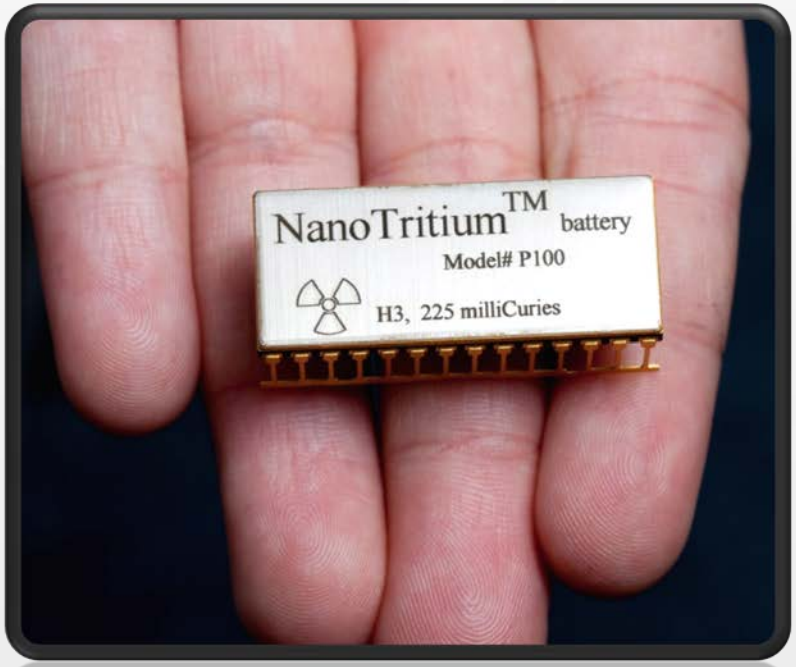
Betavoltaics Available for Purchase (U)



Model P100a specifications:

- **Open circuit voltage ~ 0.8 V, 1.6 V, or 2.4V**
- **Short Circuit Current ~ 60 nA**
- **DIP Form Factor**

(Specifications based upon 25% tritium source purity)

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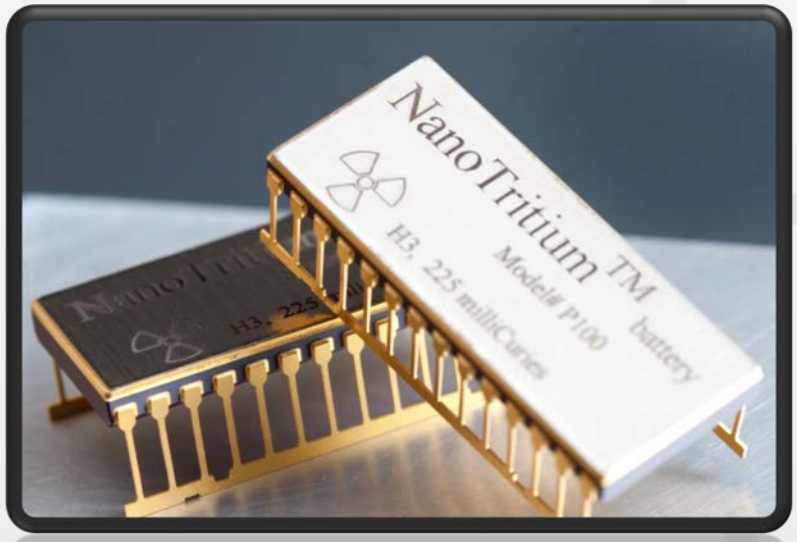
Ordering and Pricing (U)

Order engineering quantities now by contacting:

Denset Serralta, MSEE, CTO
City Labs Inc.
305-909-7593 ext 102
denset.serralta@citylabs.net

- 0.8 V model $3,500 Ea.
- 1.6 V model $4,000 Ea.
- 2.4 V model $4,500 Ea.



*This price represents a 40% reduction in price from 2008 prototype versions

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Low Power Sensors

- Sensors that draw very low power can be actively monitored for longer periods
- Temperatue, Pressure, Vibration can all be constantly monitored
- Detection of a threshold event can trigger a power burst for wireless reporting
- RFID or NFC can be used to periodically check for operation wirelessly

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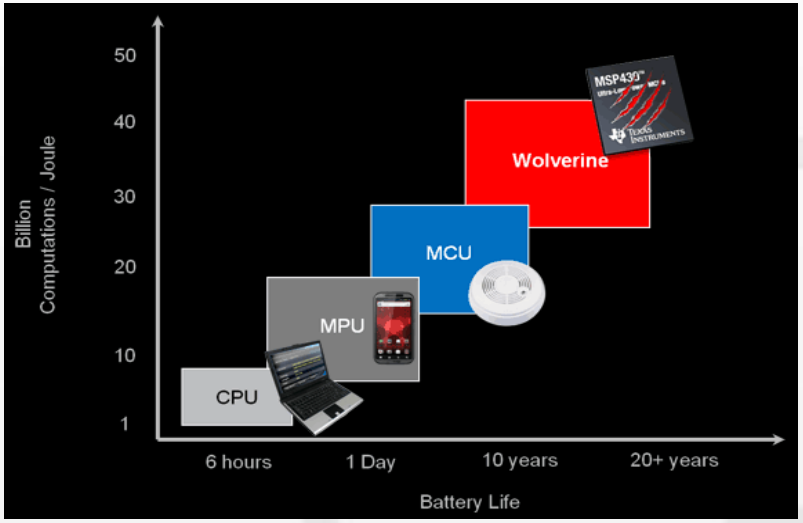
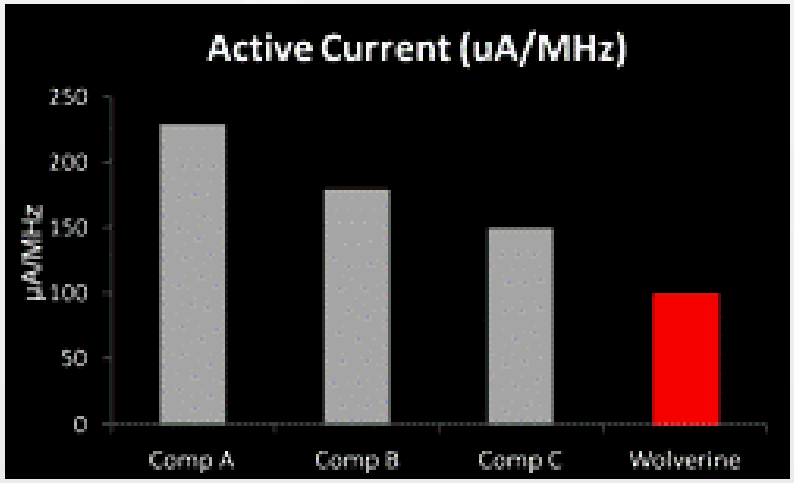
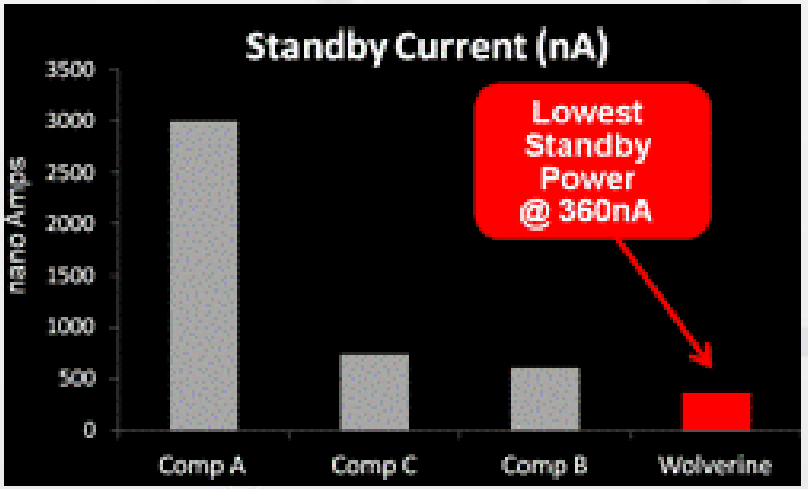
Ultra Low Power Microcontrollers

- Devices that operate in the single digit microAmp range in active mode
- Standby mode of 360nA
- Extends battery life and makes efficient use of available power
- Can be powered entirely by betavoltaics in low power modes, and switch to LiPON for burst power needs







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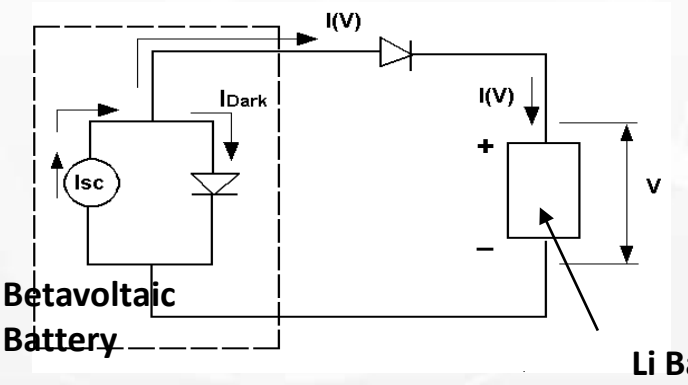
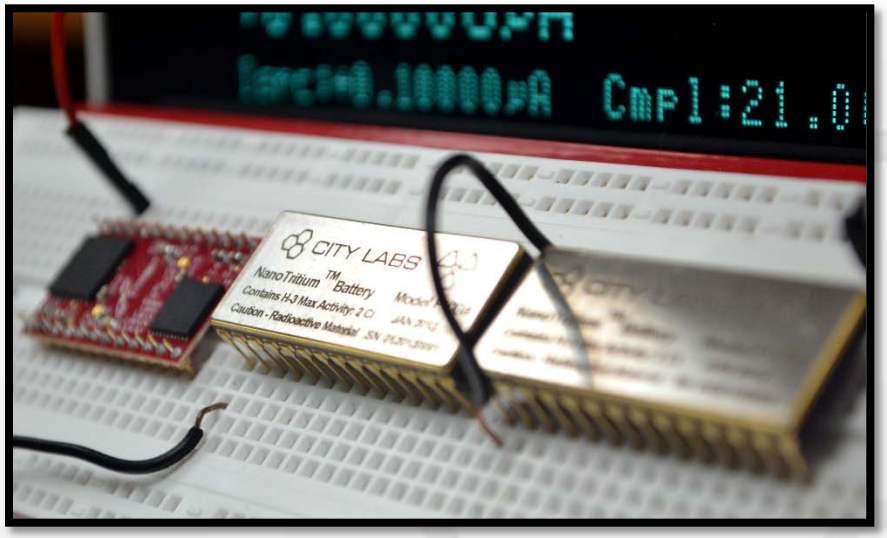
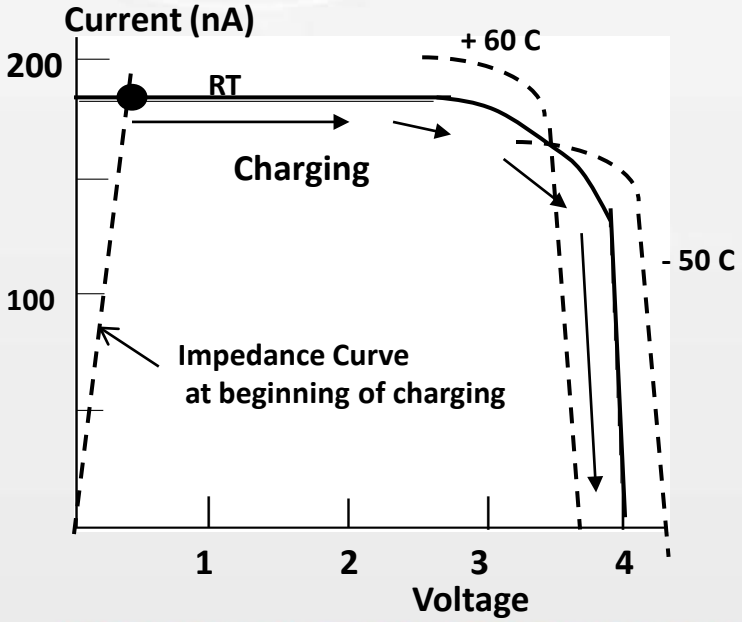
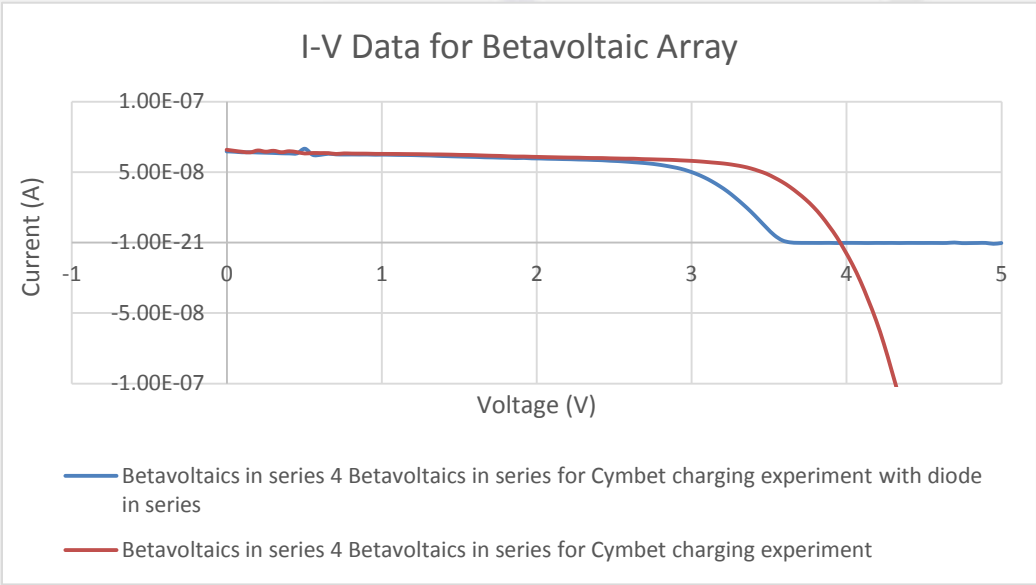
Hybrid Betavoltaic / LiPON Battery for milliWatt Burst Power (U)

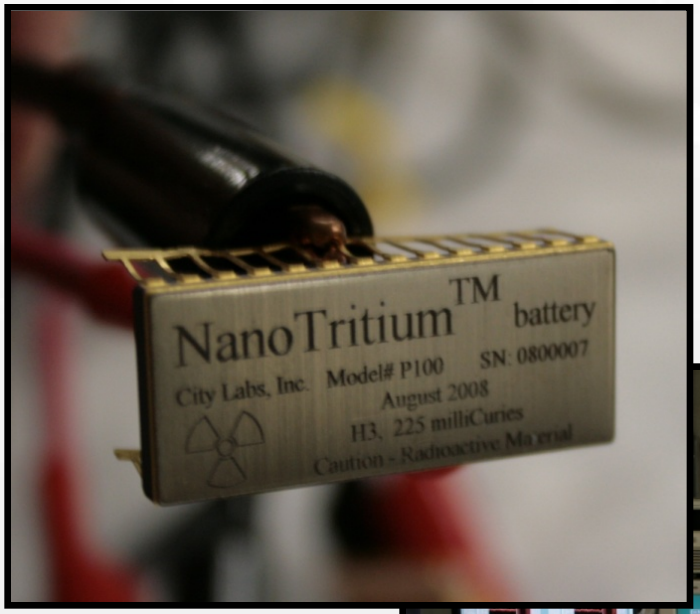


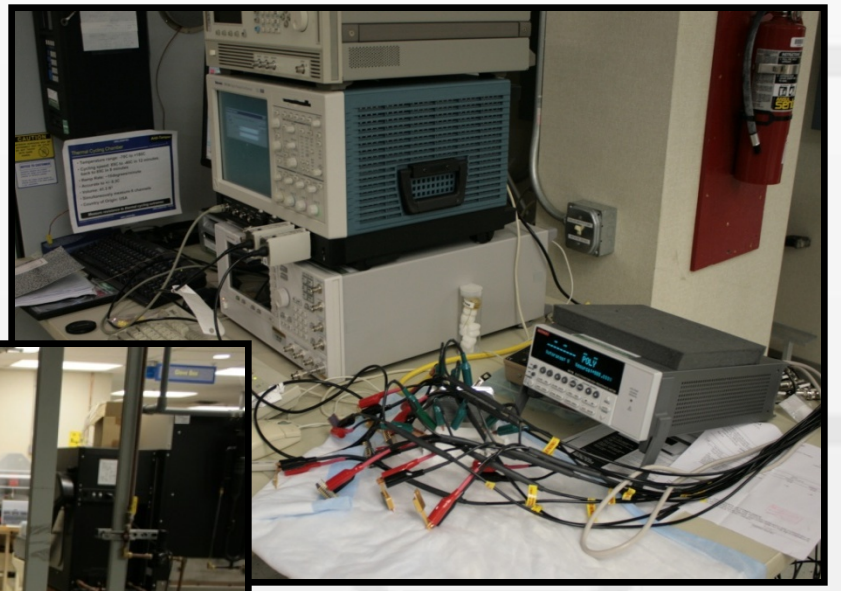


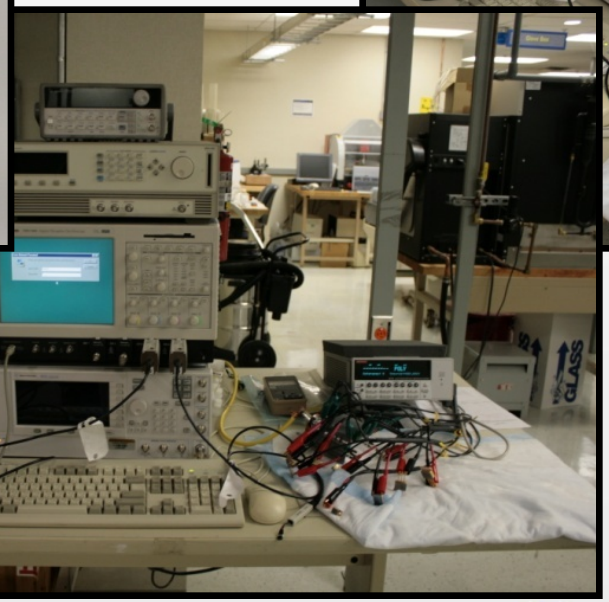




Lockheed Martin's On-going Betavoltaic Battery Data Collection (U)







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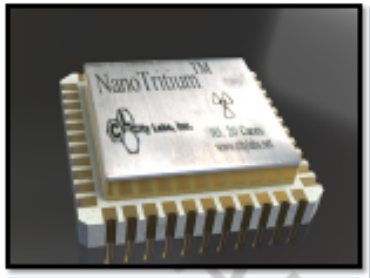
NanoTritium™ Betavoltaic
P200 Series
Extended-Life Models



About City Labs

City Labs, Inc. is an early-stage corporation that designs, develops, and manufactures tritium-powered betavoltaic products for microelectronics, sensors, and other small electronic devices commonly used in aerospace & defense, medical implant, and homeland security markets. City Labs, located in Homestead, Florida, was founded in 2005 and is a privately held Florida corporation.

The NanoTritium™ Betavoltaic

City Labs has developed a tritium Betavoltaic with a lifetime of over 20 years that can power a range of devices where battery replacement is difficult or impossible. City Labs' NanoTritium™ betavoltaic is relatively insensitive to temperature variations and other environmental conditions, because its function is based on the decay of tritium. Tritium is a radioisotope utilized as an illumination source for Exit signs, which are commonly found in schools, theatres, commercial buildings, and aircraft.

City Labs' NanoTritium™ betavoltaic technology is Generally Licensed for sale and distribution within the U.S. and is available for distribution to end-users without requirements for any specialized radiological training or licensure. Potential applications for the NanoTritium™ betavoltaic exist in numerous markets, where long-lasting, continuous, low-power sources are crucial to mission success and operating requirements:

- Homeland Security / Intelligence Sensors
- Ordnance & Structural Integrity / Health Monitoring Sensors
- Sub-Sea Sensors & Actuators
- Space Satellite & Probe Power Sources
- Medical Devices & Implants
- Defense Microelectronics

NanoTritium™ Betavoltaic: Operational Parameters

The NanoTritium™ betavoltaic power source is robust in design to withstand a broad range of conditions that extend beyond the capabilities of conventional chemical battery solutions. Most notably, the NanoTritium™ betavoltaic can operate without deleterious effects over a broad range of extreme temperatures. City Labs' betavoltaics are temperature-rated from -40°C to 80°C; however, independent third-party testing has demonstrated the design robustness of City Labs' NanoTritium™ betavoltaics with data confirming extended operational capability from -55°C up to 150°C.

Temperature Range:	**-40°C to +80°C (tested from -55°C to 150°C)**
External Pressure:	**3.6 psi (0.245 atm) to 14.7 psi (1.0 atm)**
Vibration:	**25 Hz to 500 Hz at 5g Peak Amplitude**

City Labs has pioneered the development of a proprietary semiconductor tailored to maximizing the energy harvested from tritium radioactive decay. Increasing the efficiency of energy harvesting and transport provides for increased power density and design flexibility.

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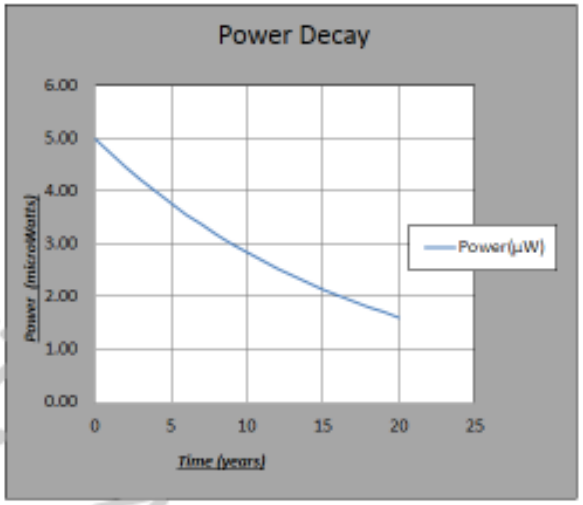
NanoTritium™ Betavoltaic
P200 Series
Performance Characteristics

The Power Decay Curve presented herein displays a typical power response for a standard P200 battery over a 20-year time period. Designers should consider End-Of-Life power requirements when selecting a NanoTritium™ Betavoltaic for their platform.

When utilized in conjunction with super capacitors or within trickle-charge scenarios, power characteristics of charging system and associated storage devices must be considered. Please contact City Labs for applications where burst power or power storage considerations are critical requirements.

This power curve follows a typical exponential decline associated with the decay of tritium contained within the betavoltaic device over the usable lifetime of the platform in which the device is embedded. Power decay curves can be tailored to match platform requirements.



City Labs' NanoTritium™ Betavoltaics can be customized to meet a variety of power needs, and a single package can be individually pre-configured to produce numerous different output voltage / current combinations; this pre-selection option, for example, can provide for a betavoltaic with an open circuit voltage output (Voc) of 0.9 Voc, 1.8 Voc, 2.7 Voc, or 3.6 Voc, where each voltage choice produces a short circuit current (Isc) of up to 2 µA. Alternatively, a 4.5 Voc device can be configured to produce an Isc of up to 1.6 µA. Customized single-package solutions can also be augmented through fabrication of high-powered betavoltaic power arrays that can be designed to interface with both existing and newly configured platforms. A betavoltaic array is simply a bundle of standard P200 units, connected in series or parallel configurations, to achieve a more desired higher output with respect to goals for power, voltage, or current. As an illustration of an array solution, a 3.6 Voc / 10.0 µA platform requirement can easily be satisfied by a 5-unit betavoltaic array configured in a parallel arrangement, where each individual betavoltaic unit provides 3.6 Voc and 2µA Isc.

It should be noted that combined units within an array scheme can be mounted in-plane on a circuit-board; alternatively, the array can be stacked vertically with appropriate interconnects, if areal real-estate on the circuit-board is critically limited.

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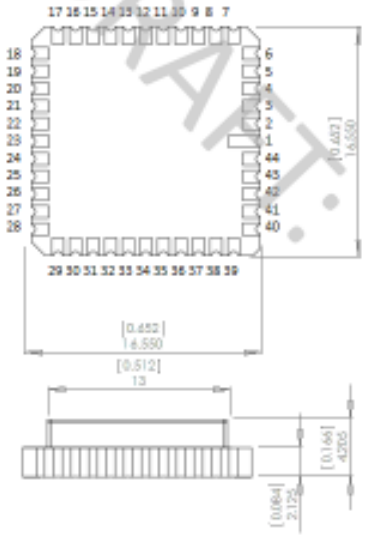
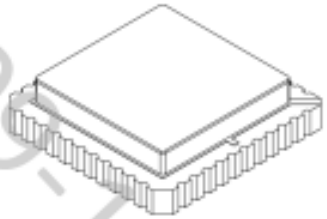
The typical electronics package selected for use is a 44-pin, Leadless Chip Carrier (LCC) package; however, other packages are licensed for use with NanoTritium™ Betavoltaics. An LCC 68 package can also be utilized. Custom packages can be developed to meet challenging design criteria.



LCC 44

LCC 44	
Pin Number	Function
2	Vcc
24	GND



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City Labs Device Model	Availability	Open Circuit Voltage	Short Circuit Current (Beginning-of-Life)	Maximum Power (Beginning-of-Life) (Fill factor: 0.78)	Supported Applications
P200	24 Weeks ARO	0.9 Volts	2.0 microAmps	≈1.4 microWatts	Power burst capacitors / charge pumps
		1.8 Volts	2.0 microAmps	≈2.8 microWatts	1.8 V – 3.6 V models can operate TI MSP430 Wolverine microprocessors in standby mode; active mode operable at sub-MHZ clock rates
		2.7 Volts	2.0 microAmps	≈4.2 microWatts	Maxim DS3655 Security Manager (may require betavoltaic power array / charge pump / LiPON battery backup)
		3.6 Volts	2.0 microAmps	≈5.6 microWatts	STM 1404 Security Supervisor (may require betavoltaic power array / charge pump / LiPON battery backup)
		4.5 Volts	1.6 microAmps	≈5.6 microWatts	Trickle charging of Cymbet or Infinite Power Solutions LiPON batteries for milliWatt power burst capability

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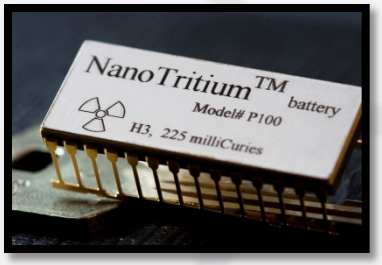
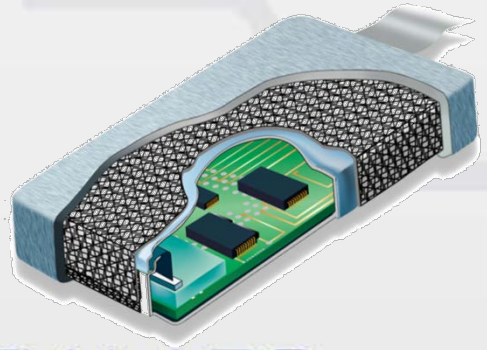
P200 Betavoltaic-Ready Applications (U)

City Labs Device Model	Availability	Open Circuit Voltage	Short Circuit Current (Beginning-of-Life)	Maximum Power (Beginning-of-Life) [fill factor: 0.78]	Supported Applications
P200	24 Weeks ARO	0.9 Volts	2.0 microAmps	≈1.4 microWatts	Power burst capacitors / charge pumps
		1.8 Volts	2.0 microAmps	≈2.8 microWatts	1.8 V – 3.6 V models can operate TI MSP430 Wolverine microprocessors in standby mode; active mode operable at sub-MHZ clock rates
		2.7 Volts	2.0 microAmps	≈4.2 microWatts	Maxim DS3655 Security Manager (may require betavoltaic power array / charge pump / LiPON battery backup)
		3.6 Volts	2.0 microAmps	≈5.6 microWatts	STM 1404 Security Supervisor (may require betavoltaic power array / charge pump / LiPON battery backup)
		4.5 Volts	1.6 microAmps	≈5.6 microWatts	Trickle charging of Cymbet or Infinite Power Solutions LiPON batteries for milliWatt power burst capability





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