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Entropy is good

Patented Quantum Random Number Generator

The essence of good cryptography

Three components are required to make hackproof encryption:

1. a way to produce random numbers - the unique keys to convert a message
2. an algorithm that converts the message into a string of meaningless characters
3. a channel to securely deliver the first ingredient to the intended recipient without anyone else gaining insight

The second and third components are well-established and widely used by cryptographers, programmers etc.

Tomorrow's technology today

- ***Quantum Computers Will Break the Internet, but Only If We Let Them***

  https://www.rand.org
  https://media.nature.com

- ***The Future of Cybersecurity are the Quantum Random Number Generators (QRNGs)***

  https://spectrum.ieee.org

- Truly random numbers (delivered in billions of binary digits) provide an unbreakable toolset for cryptography

- QRNGs are essential for providing quantum-unbreakable encryption:
  - for internet banking
  - for health-care privacy
  - for internet shopping
  - for internet devices

- QRNGs are crucial for blockchain security (*cryptographic nonce*)

Locality for privacy and secrecy

- To ensure the privacy of any communication, cryptography must be local (e.g., use of the so-called Perfect Forward Secrecy)

https://www.keycdn.com

- Cryptographic keys should use a true random number generator *in-situ* (i.e., on the user device)
- Good random number generators must be built into communicating devices (like computers and cell phones)
- The cybersecurity design: QRNGs embedded into a System-on-Chip (SoC)

Technology must be compatible with standard IC manufacturing

Many hardware options are available, but…

Several methods or devices are offered, e.g.,

- Cloud RNG https://www.random.org based on atmospheric noise
- HotBits https://www.fourmilab.ch based on Geiger counter
- Protego ST https://www.protegost.com noise-based key fobs or chips
- ComScire https://comscire.com tunneling leakage in MOS transistors
- qStream https://www.quintessencelabs.com based on quantum tunneling
- Quantis https://www.idquantique.com based on quantum optical randomness
- QN100 https://quside.com based on quantum optical randomness

Most are not easily incorporated into consumer devices

The suitable devices (*qStream, Quantis, QN100*) are not pure quantum as claimed: their entropy sources are prone to external influences like temperature or voltage changes ☞ *breakable**

* cf. e.g., Abbott A.A. et al. 2014 *Non-uniformity in the Quantis Random Number Generator*, Centre for Discrete Mathematics and Theoretical Computer Science CDMTCS-472 November 2014 or Hurley-Smith D. and Hernandez-Castro J. 2020 *Quantum Leap and Crash: Searching and Finding Bias in Quantum Random Number Generators*. Security, 23 (3). pp. 1-25. ISSN 2471-2566.

Our mission

- **RANDAEMON** builds Quantum Random Number Generators:
  - hardware-based, on an integrated circuit (IC)
  - integrated into SoC
  - fabricated using standard chip manufacturing technology
- **RANDAEMON** uses ultimate entropy source:
  - pure beta decay inside nuclei
  - PIN or SPAD detectors
  - auto-correction and randomization *in situ*
- **RANDAEMON** aims at high throughput for random bitstream

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Why nuclear beta decay?

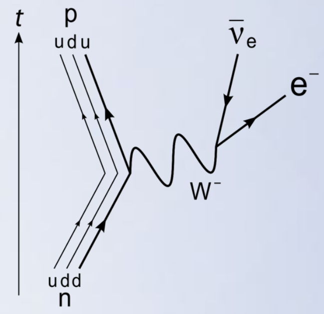
- The pure quantum process inside nuclei
- Decays are random in time (*ticking*) and in space (*direction*)
- Beta radiation (*electrons*) is easily detectable
- The emission of electrons is not affected by normal conditions:
  - *acceleration*
  - *pressure*
  - *temperature*
  - *magnetic and electric fields*
  - *etc. etc.*

The use of beta decay is perfectly suited for local, *in-situ* QRNGs

Safe entropy source

^{63}Ni as a source of randomness:

- pure beta decay: $^{63}Ni_{28} \rightarrow {}^{63}Cu_{29} + e^- + \overline{\nu}_e$
  - maximum electron energy 67 keV
  - average electron energy 17 keV
  - anti-neutrino is practically non-interacting with anything



- range of 70 keV electrons:
  - in the air about 7.3 cm ☞ there's no radiation at the distance of 3" from a source
  - in the water about 78 µm ☞ water layer on eyes or in guts is >*100* µm thick
  - in the tissue about 68 µm ☞ epidermis (dead part of the skin) is typically >*100* µm thick
  - in the metallic Cu about 14 µm ☞ no radiation at all outside of the IC enclosure
- activity per simple device ≤ $3 \cdot 10^{-5}$ Ci
  - if fully digested (?), the dose absorbed would be about 0.75 mSv/year
  - for comparison: *US natural background* is about 3 mSv/year; *Annual Limit on Intake* is 0.5 Sv

No radiation risk during manufacturing, for customers, and recycling

Two related solutions

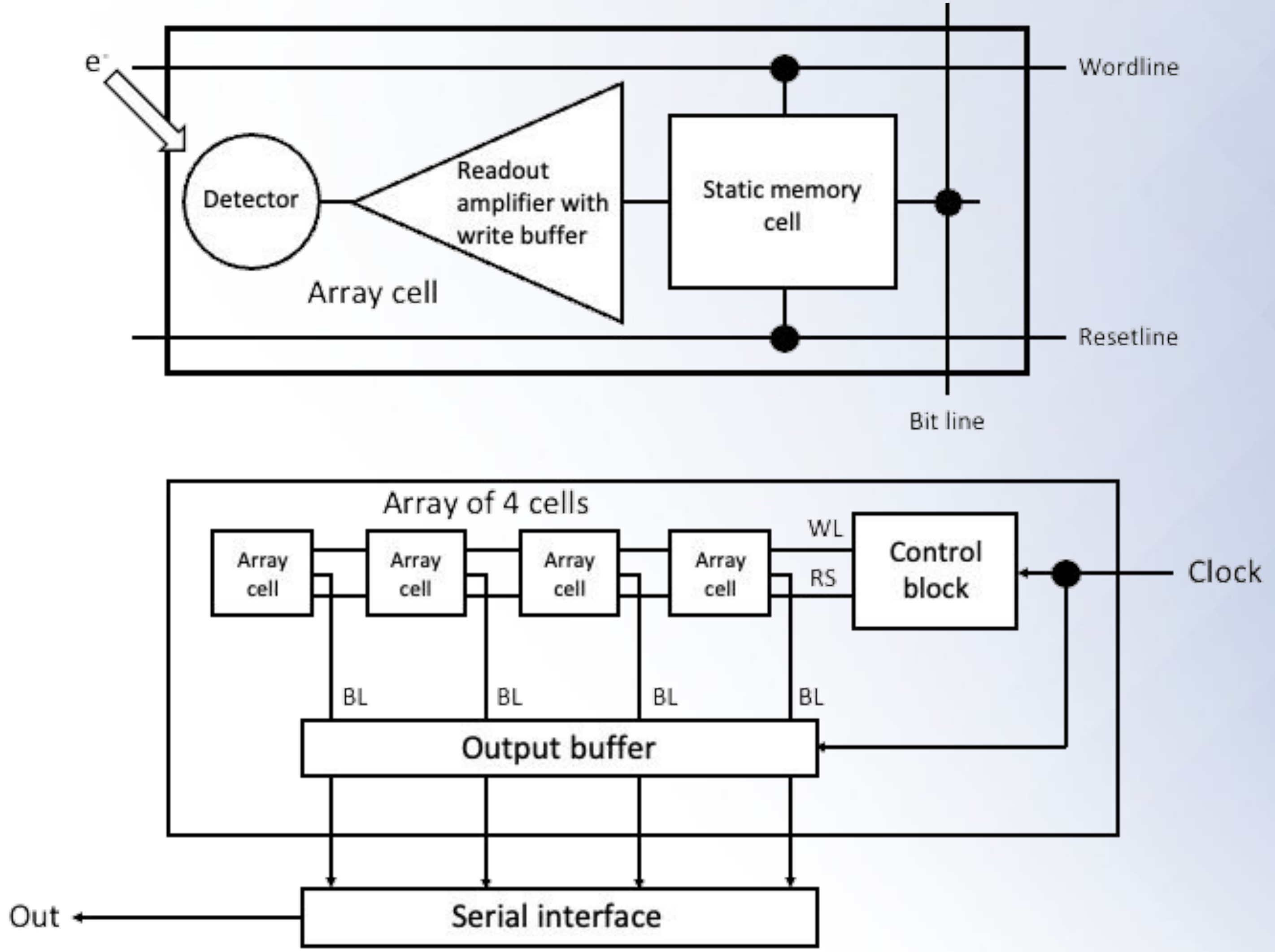
RANDAEMON patented QRNGs designs:

- set of detectors
  - a small number (starting with 1 detector) for simple applications
  - a large number (over 1 million detectors) for demanding applications*
- easily scalable for any application
- standard manufacturing technology ☞ up to 0.25 Gbit/(sec·cm^2)

***Quantum networks need huge amounts of random bits for operation**

https://www.zdnet.com https://www.energy.gov

Structure of „small IC” test PoC design



To make testing easy, *NIST set of [statistical tests](#) can be built-in*

RANDAEMON team

CEO:
Janusz Borodziński

- Ph.D. in electro-chemistry, Warsaw University
- 1987-1988 University College, Cork, Ireland – research associate
- 1991-1993 Université de Sherbrooke, Canada – visiting professor
- Technical director of Apple IMC Poland 1994-2012
- Experienced entrepreneur, consultant, teacher

CFO:
Krzysztof Appelt

- Ph.D. in biophysics, Max Planck Institute, West Berlin
- 1984 – 1985 Assistant Professor UCSD, Dept. of Physics and Chemistry
- 1986 – 2004 R&D executive positions in the pharma and biotech industry
- 2005 – 2015 Founder, CEO & President of Great Lakes Pharmaceuticals, Inc.
- 2018 – 2020 Founder and CEO of Visthera, Inc.
- 2015 – now Director, Airspeed Equity

CTO:
Jan „Kuba" Tatarkiewicz

- Ph.D., D.Sc. in nuclear methods in solid-state physics, Warsaw University
- Physicist (post-doc at MPI FKF Stuttgart), programmer (Monte Carlo code in ORNL library, localization of Mac OS for Poland), IT director (MIT Lab for Nuclear Science, UCSD)
- Author of 50+ papers published in refereed journals
- Several invited lectures at international conferences
- 20+ patents issued
- The entrepreneur started 10 companies; recently MANTA Instruments sold to HORIBA Scientific

Technical advisor:
Wiesław Kuźmicz

- Ph.D., D.Sc. in solid-state electronics, Warsaw University of Technology
- Since 1970 worked at Warsaw University of Technology
- From 1984 to 1985 and in 1989 visiting professor at Carnegie Mellon University
- Professor emeritus, Warsaw University of Technology
- Research interests include the physics of semiconductor devices, development of simulation and EDA tools, and design of VLSI circuits for demanding nontrivial applications
- Author of over 100 research papers and two textbooks

RANDAEMON cooperation

PCI Express card

- RnDity LLC
- Łódź-based private company
- Spin-off from Łódź University of Technology
- Bartek Świercz Ph.D. owner
- https://rndity.com

Chip design

- ChipCraft LLC
- Poland-based fabless semiconductor private company
- Spin-off from Warsaw University of Technology
- Tomasz Borejko Ph.D. lead designer, vast experience with digital security
- http://www.chipcraft-ic.com

Fab

- X-FAB Silicon Foundries
- German company that does prototyping in suitable technologies
- https://www.xfab.com

^{63}Nickel

- Institute of Nuclear Chemistry and Technology
- Aleksander Bilewicz Ph.D., D.Sc. head of the Laboratory of Chemistry of Radioelements
- http://www.ichtj.waw.pl

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RANDAEMON patents' portfolio

- **Issued**
  - Tatarkiewicz J.J. 2019 US Patent 10,430,161 *Apparatus, systems, and methods comprising tritium random number generator*
  - Tatarkiewicz J.J. et al. 2021 US patent 10,901,695 *Apparatus, systems, and methods for beta decay based true random number generator*
  - Tatarkiewicz J.J. et al. 2021 US patent 11,036,473 *Apparatus, systems, and methods for beta decay based true random number generator*
  - Tatarkiewicz J.J. et al. 2021 US patent 11,048,478 *Method and apparatus for tritium-based true random number generator*
  - Tatarkiewicz J.J. et al. 2021 Korean patent 10-2289084 베타 붕괴 기반의 진성 난수 생성기를 위한 장치, 시스템, 및 방법
  - Kuźmicz W.B. et al. 2022 US patent 11,249,725 *Method and apparatus for highly effective beta decay based on-chip true random number generator*
  - Tatarkiewicz J.J. 2022 US patent 11,281,432 *Method and apparatus for true random number generator based on nuclear radiation*
  - Tatarkiewicz J.J. 2022 EU patent 3,776,179 *Apparatus, systems, and methods comprising tritium random number generator*
  - Kuźmicz W.B. et al. Korean patent 10-2429142 베타 붕괴를 이용한 고도로 효과적인 온칩 진성 난수 생성기를 위한 방법 및 장치
  - Tatarkiewicz J.J. et al. 2022 AU patent 2022200920B1 *Method and apparatus for highly effective on-chip true random number generator utilizing beta decay*
- **Pending**
  - Borodziński J.J. et al. 2021 USPTO application 17,687,630 *Method for cost-effective Nickel-63 radiation source for true random number generators*
  - Tatarkiewicz J.J. et al. 2022 USPTO application 17,861,014 *Method and apparatus for highly effective on-chip quantum random number generator using beta decay*
  - Tatarkiewicz J.J 2022 USPTO application 17,897,138 *Method and apparatus for highly effective on-chip quantum random number generator*
  - several of the above issued US patents were applied for in EU, Canada, Australia, and Korea

Thank you for your attention

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