Energy harvesting methods for powering Wireless Sensor Networks used to monitor nuclear environments: an overview

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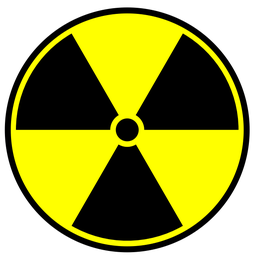
Introduction



Nuclear hazard symbol ([1], public domain)

Nuclear environment:
- hazardous environment,
- possibly life-threatened,

vs

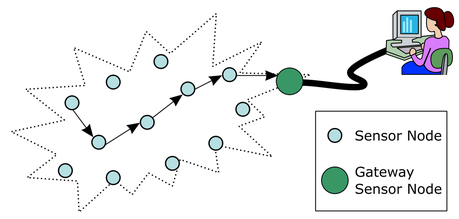
- safety for human beings,
- safety for nature.

→ monitoring is REQUIRED

→ NOBODY wants to do it

Solution = Wireless Sensor Networks (WSNs):
- group of sensors,
- **autonomous**, and
- wireless connected together.

WSNs —> long-distance monitoring



Wireless Sensor Network ([2], public domain)

How to make sensors autonomous with energy harvesting

Main issue: battery replacement (needs human intervention, hence risk). Can we avoid it? YES, thanks to **energy harvesting**.

Definition of "energy harvesting": energy present in the environment surrounding the sensor and that can be harvested, i.e., used, to power the electronic circuit composing the sensor.

Main characteristics of harvested energy sources:
- the instantaneous available amount of energy is usually low,
- the available amount of energy is time-variant,
- the primary energy is usually not electric and must be converted.

Currently, 4 main energy sources can be harvested for general applications:

Light

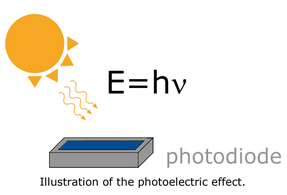


Illustration of the photoelectric effect.

- photoelectric effect
- P_{typ} = 1 m — 100 mW/cm²
- photodiode

Heat

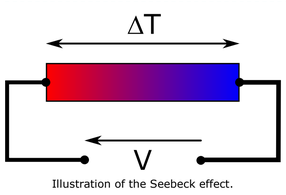


Illustration of the Seebeck effect.

- Seebeck effect
- P_{typ} = 10 µ — 100 mW/cm²
- thermocouple, heat exchanger

Vibrations

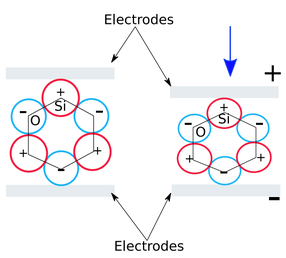


Illustration of the piezoelectric effect.
Courtesy of Marie-Sophie RENOIRT (UMONS).

- piezoelectric effect
- P_{typ} = 10 µ — 10 mW/cm²
- MEMS, magnet

EM waves (RF)

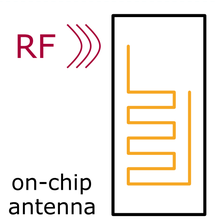


Illustration of the energy harvesting performed on RF waves.

- EM propagation
- P_{typ} = 1 n — 100 µW/cm²
- antenna

How to use energy harvesting in nuclear environments

No need for battery!

Source: [3]

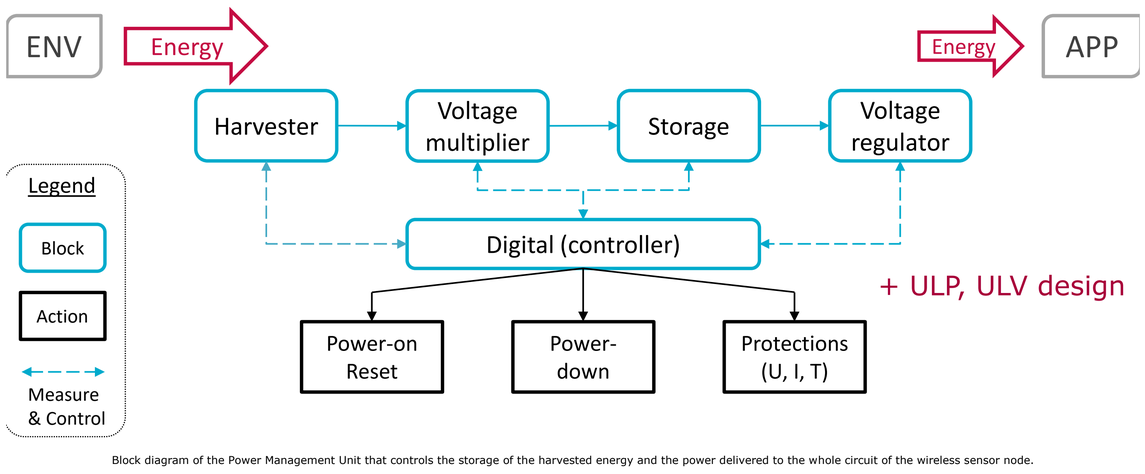
However, other questions arise:
1. are the aforementioned energy sources available in some or all nuclear environments?
2. how can we manage the harvested energy to deliver the required power to the wireless sensor node?
3. are there specific techniques to design circuits using energy harvesting?

Source: [4]

Verification of energy sources available in nuclear environments

Nuclear environments	Available energy sources			
	Light	Heat	Vibrations	RF
Nuclear reactor's core	?	V	X	?
Nuclear reactor's vicinity	V	V	?	V
Medical treatment	V	V	V	V
Food sterilization	V	V	V	V

Management of energy harvesting and power delivery



Block diagram of the Power Management Unit that controls the storage of the harvested energy and the power delivered to the whole circuit of the wireless sensor node.

Conclusion and future work

Context, application: nuclear environments = hazardous, possibly life-threatened —> require monitoring for human-beings and nature safety.
Solution: Wireless Sensors Networks (WSN) —> group of autonomous sensors that can perform long-distance monitoring.
First problem to address = to make sensors autonomous:
- energy harvesting methods can be used but the availability of energy sources in the environment of the target application must be verified,
- the management of the harvested energy storage and power delivery to the whole circuit of the sensor node must be properly handled.

Future work = explore the opportunity of harvesting energy that is specific to nuclear environments.

References for figures:

[1] Clker-Free-Vector-Images, *nuclear-34997*. 2012.
[2] Adi Mallikarjuna Reddy V, *Wireless Sensor Network*. 2007.
[3] Meme Generator, *Harvesting is Awesome - emmet lego movie*.
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References to the literature:

[1] D. Steingart, "Power Sources for Wireless Sensor Networks," in *Energy Harvesting Technologies*, S. Priya and D. J. Inman, Eds. Boston, MA: Springer US, 2009, pp. 267–286.
[2] U. Kulau, D. Bräckelmann, F. Büsching, S. Schildt, and L. Wolf, "REAPer — Adaptive Micro-Source Energy-Harvester for Wireless Sensor Nodes," in *2017 IEEE 42nd Conference on Local Computer Networks Workshops (LCN Workshops)*, 2017, pp. 1–8.
[3] S. Xing, I. Anakok, and L. Zuo, "Optimized MPPT-based converter for TEG energy harvester to power wireless sensor and monitoring system in nuclear power plant," in *Smart Materials and Nondestructive Evaluation for Energy Systems 2017*, Portland, Oregon, United States, 2017, vol. 10171.