FROM RESEARCH TO INDUSTRY

cea tech

TRNG - EVALUATION & CERTIFICATION

WRAC'H 2019 | DUMAS Cécile | 15 avril 2019

OUTLINE

- **Evaluation Lab**
- **Random Number Generators**
- **Evaluation of RNG**
- **Conclusion & Perspectives**

FRENCH CERTIFICATION SCHEME

ITSEF **I**nformation **T**echnology **S**ecurity **E**valuation **F**acility

CESTI **C**entre d'**É**valuation de la **S**écurité des **T**echnologies d'**I**nformation

- **Several ITSEFs and several types of product**

→ Leti into CEA Grenoble: Hardware ITSEF

Leti ITSEF

- Center established in 1999
- Scope of Approval: Hardware ITSEF
  - Electronic Components and Embedded Software
  - Hardware device with security boxes
  - Site certification
- Evaluation Standard
  - Common Criteria : CC version 3.1 ; up to EAL7
- Licensed by private schemes
  - EMVCo, VISA, MASTER-CARD, NXP-MIFARE, BAROC, FIDO

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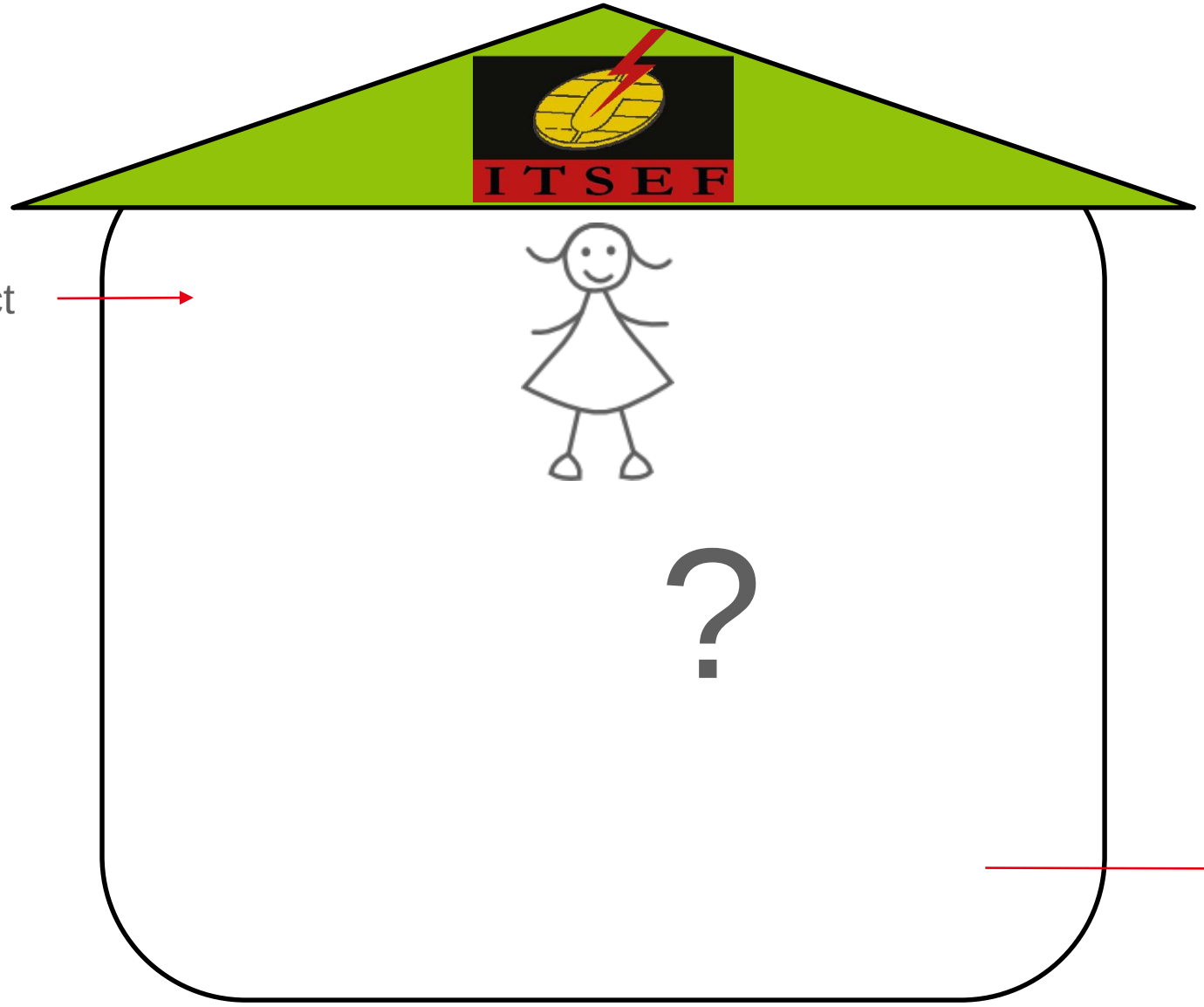
ITSEF – EVALUATION TASKS



ITSEF – EVALUATION TASKS

Product
= Smart card

Applications
- Banking
- Identity
- Health
- PayTV
- …

Functions
- Encryption / decryption
- Signature
- Authentication
- Key generation / exchange
- …

Mechanisms
- Symmetrical algorithms
- Asymmetrical algorithms
- Hash functions
- Random number generator

Hardware / Software

→ Report

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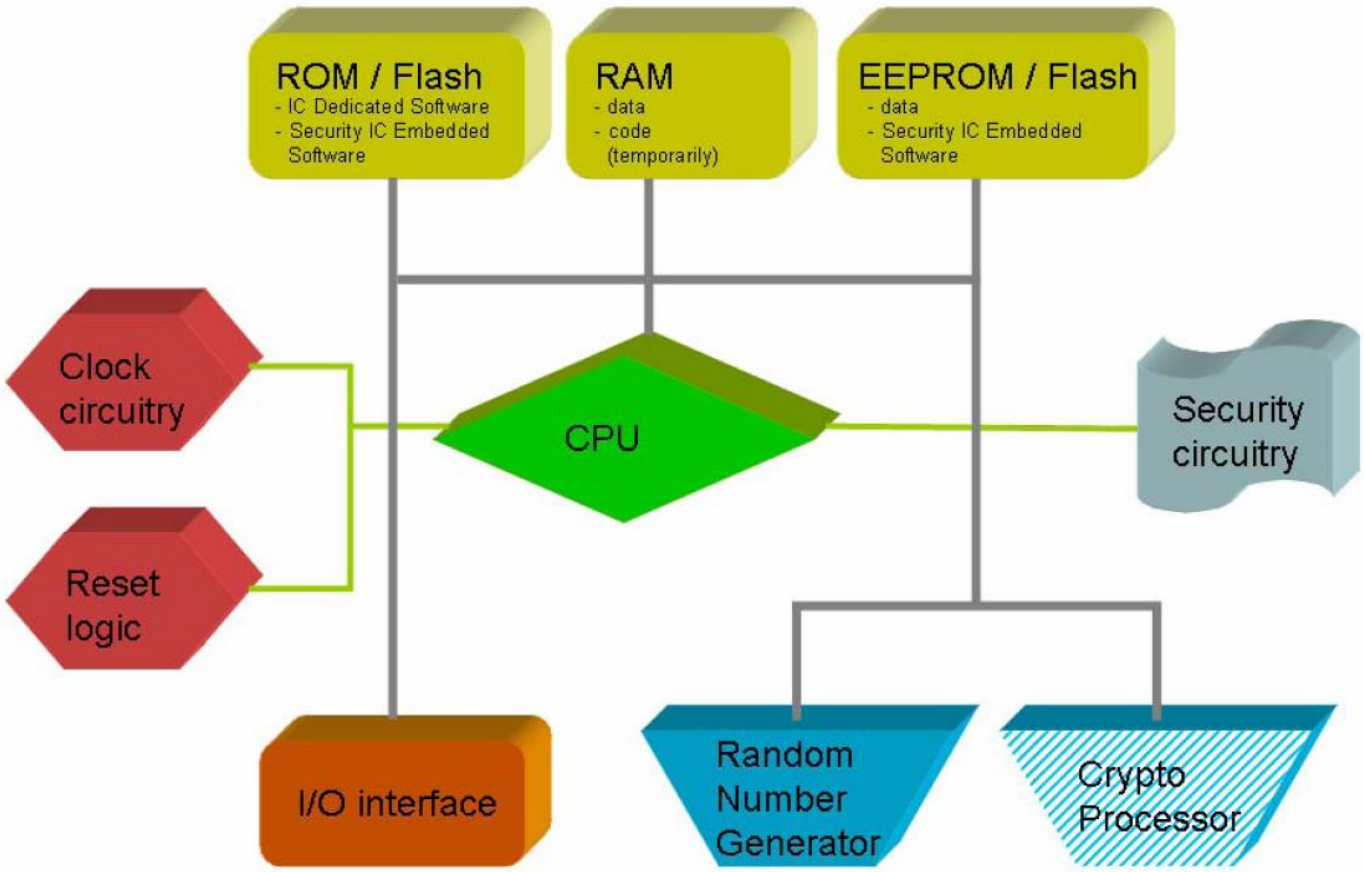


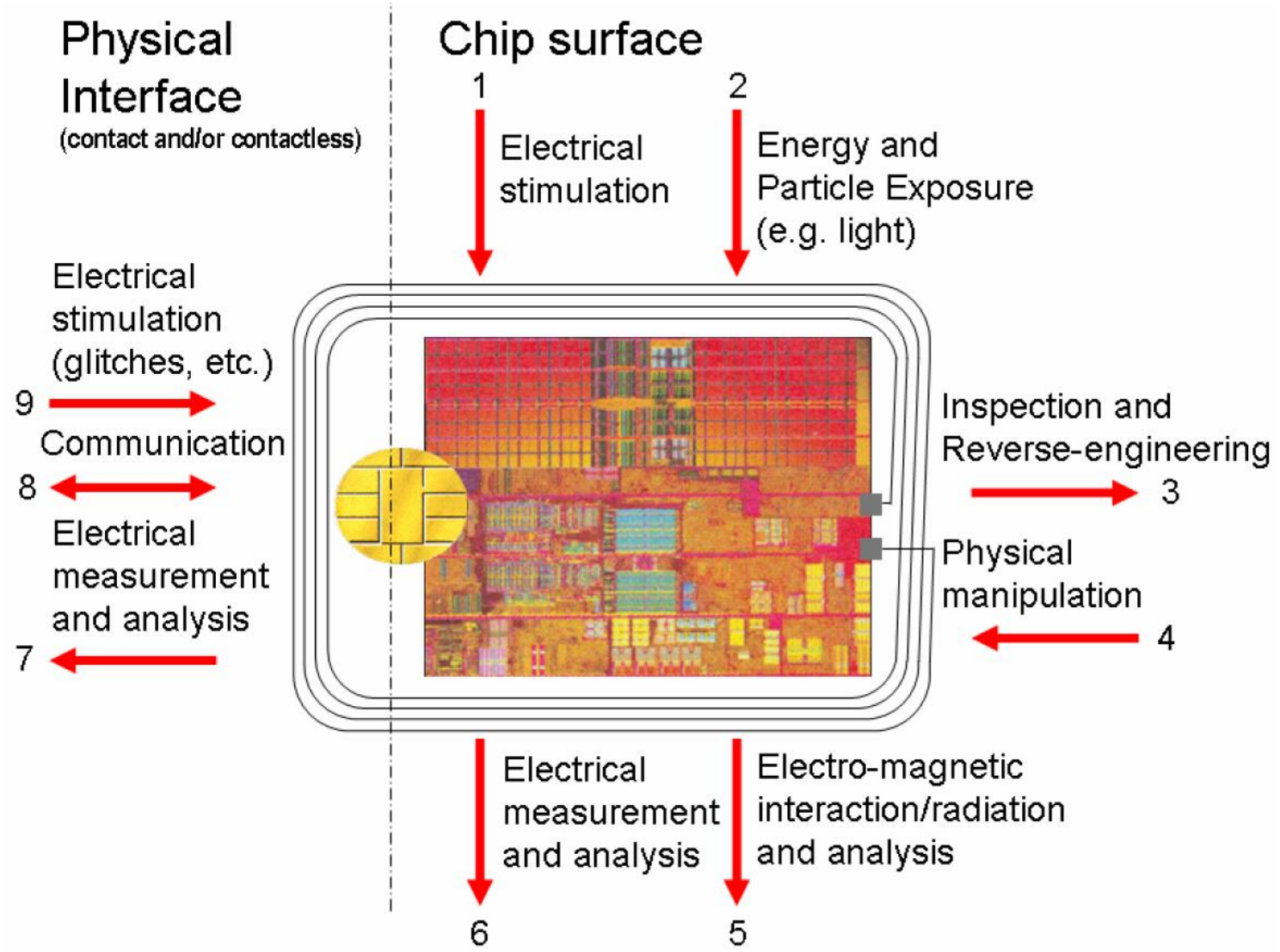
Source: Security IC Platform Protection Profile - BSI-PP-0084

ITSEF – EVALUATION TASKS

Product –
= Smart card

Applications

Banking
Identity
Health
PayTV
…



Source: Security IC Platform Protection Profile - BSI-PP-0084

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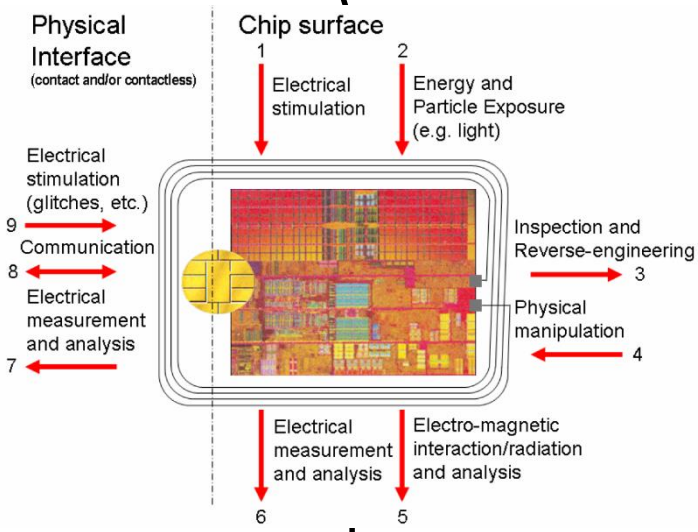
Hardware / Software

Conformity
- Document analysis
- Code analysis



Efficiency
- Functional testing
- Penetration testing

Report

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RANDOM NUMBER GENERATOR

- Random numbers in smart cards
  - Key generation
  - Challenge generation
  - Generation of initialization vectors, nonces, padding, ...
  - Countermeasures against side channel attacks

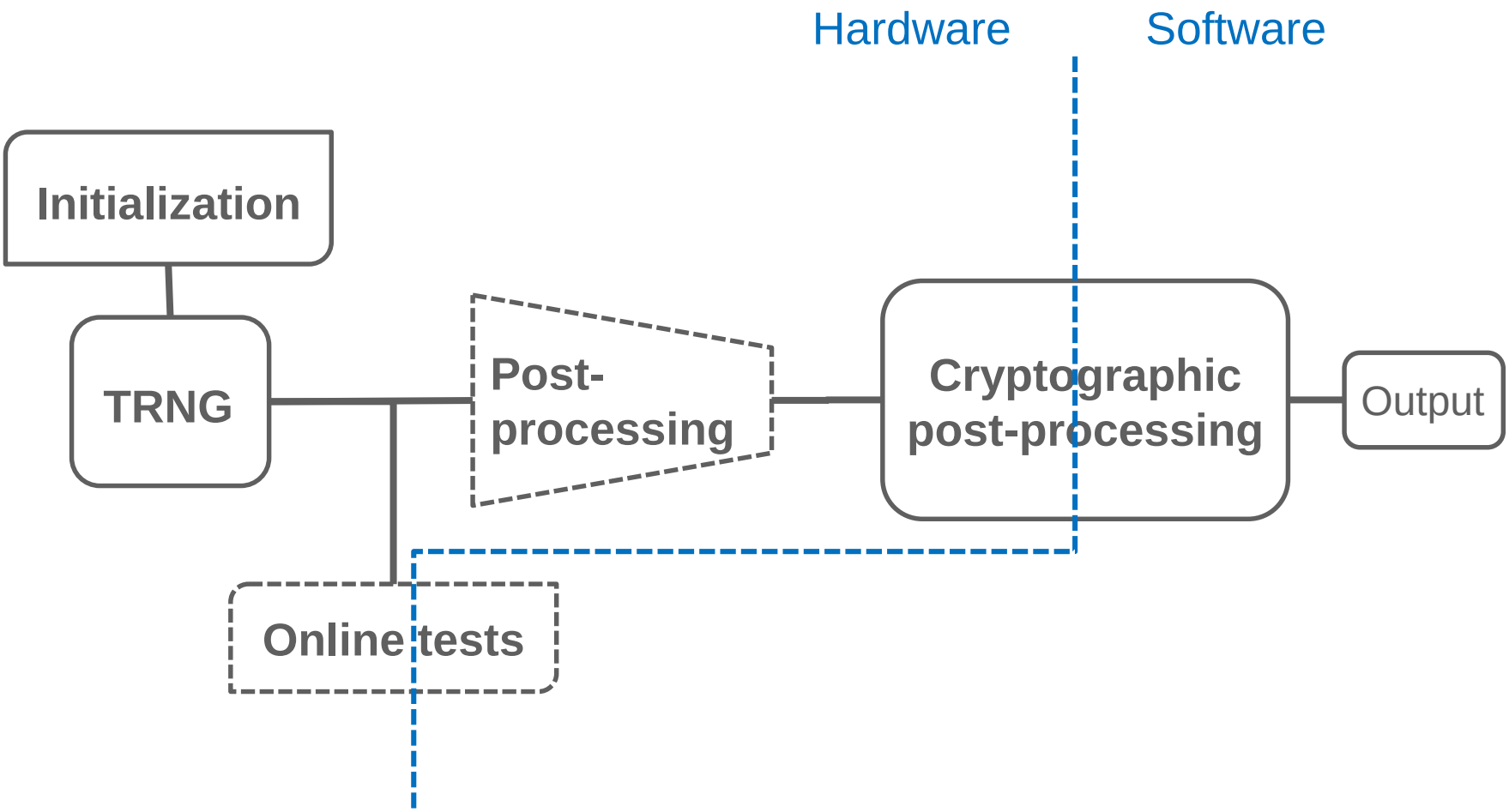
- To play 421, the result of a die roll shall be
  - Uniform
  - Independent
  - Unpredictable

→ **Expected properties of the random numbers**

RANDOM NUMBER GENERATOR

- Deterministic (Pseudo-) random number generators (DRNG)
  - Algorithmic
  - Good statistical properties
- Physical (True-) random number generators (TRNG)
  - Using some physical source of randomness
  - Physics is not deterministic
  - Moderate statistical properties
- Hybrid random number generators
  - TRNG with algorithmic (e. g. cryptographic) post-processing
  - DRNG seeded repeatedly by a TRNG

RNG ARCHITECTURE



RNG – EVALUATION TASKS

Product
= Smart card with a RNG

Conformity
- Document analysis
- Code analysis

- Initialization
- TRNG
- Online tests
- Post-Processing
- Crypto post-processing

- Initialization
- TRNG
- Online tests
- Post-Processing
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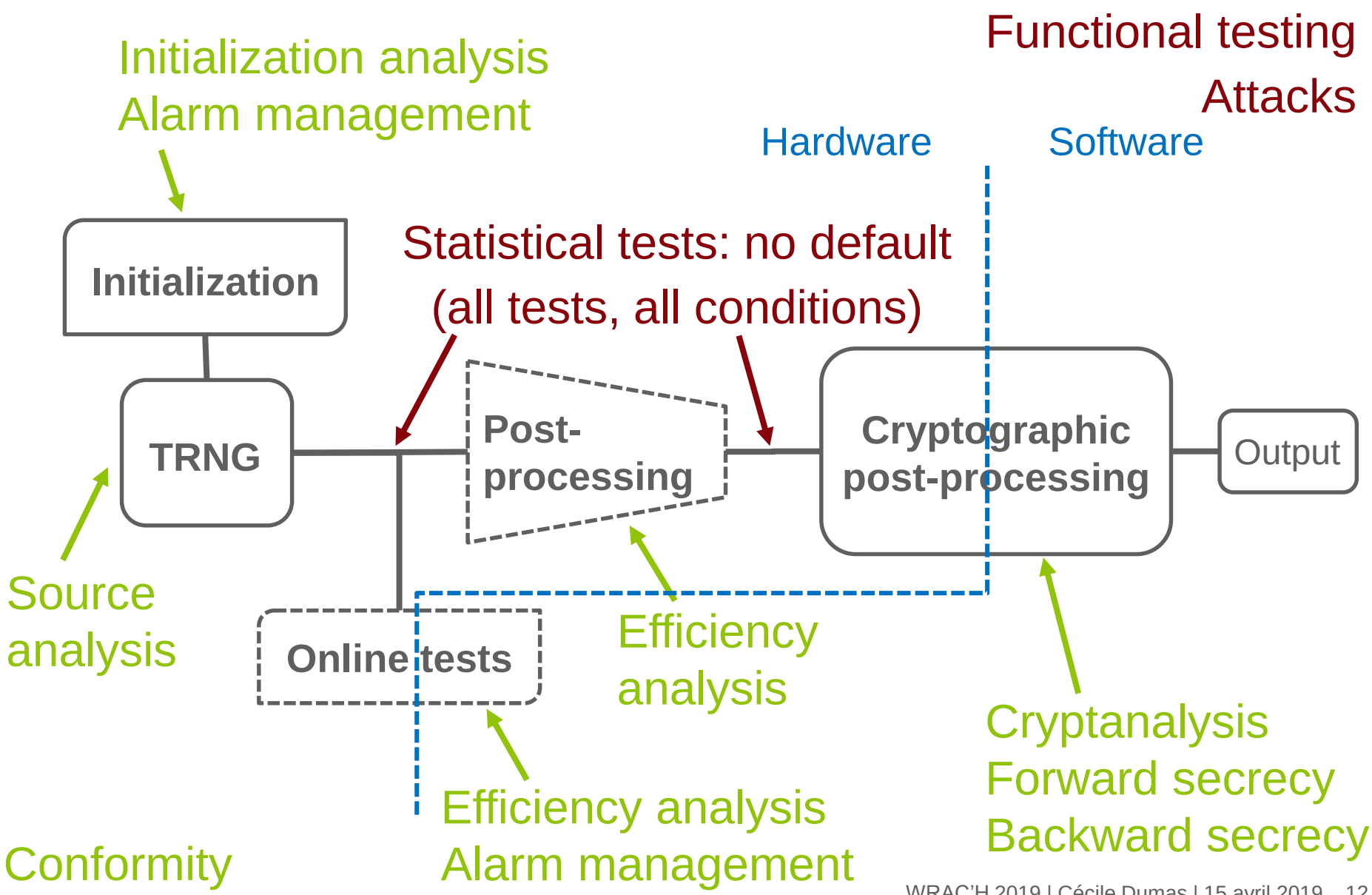
Efficiency
- Functional testing
- Penetration testing
- Statistical testing

TRNG non deterministic !!

Report

RNG EVALUATION TASKS



EVALUATION NORMS

- **Common Criteria**
  - Security Functional Requirements (Family FCS_RNG)
- **Evaluation**
  - RGS - French Scheme
    Référentiel Général de Sécurité
  - AIS 20 31 - German Scheme
    Anwendungshinweise und Interpretationen zum Schema

→Talk of Werner Schindler, BSI Germany, tomorrow

OUTLINE

- Evaluation Lab
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RNG EVALUATION TASKS

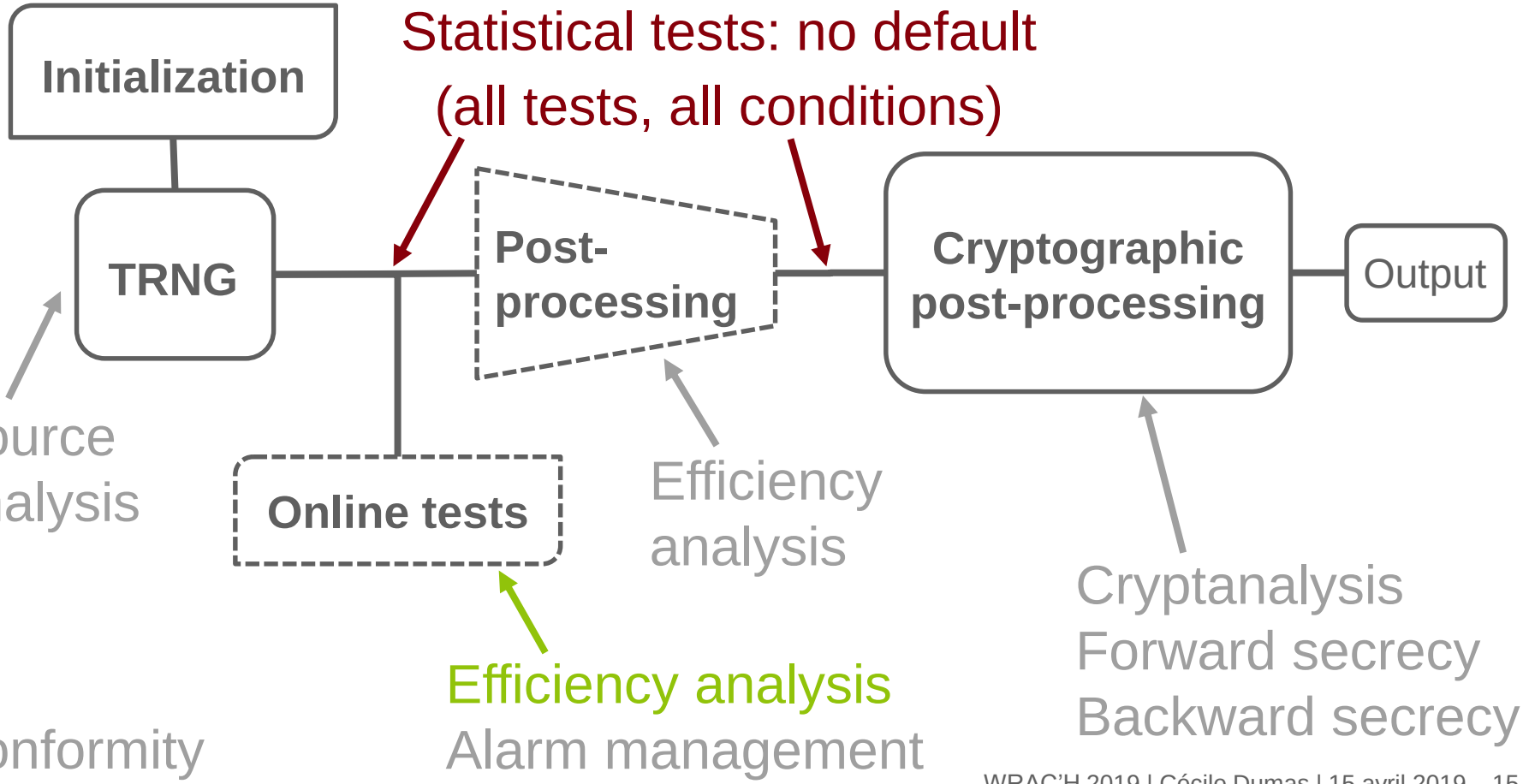
Functional testing

Environment alteration

Attacks

Initialization analysis
Alarm management

THIS TALK



OUTLINE

- Evaluation Lab
- Random Number Generators
- **Evaluation of RNG**
  - **Acquisition**
  - **Statistical Tests**
  - **Online Tests**
  - **Penetration Tests**
- **Conclusion & Perspectives**

RANDOM NUMBERS ACQUISITION

- **Need to acquire random numbers**
  - After source
  - After post-processing
  - All configurations (voltage, clock frequency, etc.)

  → Acquire several sequences

- **Statistical testing**

  → Acquire several very large sequences

  → Acquire several very large continuous sequences

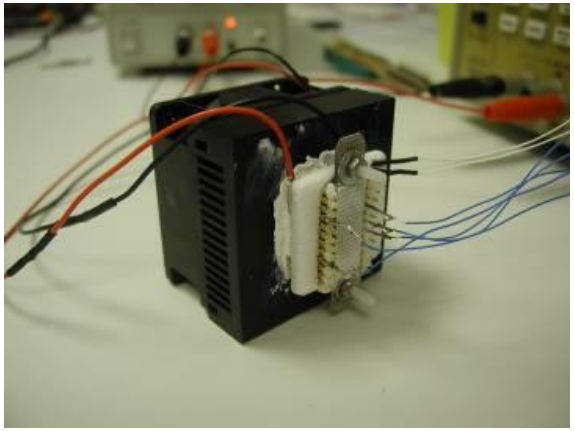
- **Several devices have to be tested**

RANDOM NUMBERS ACQUISITION

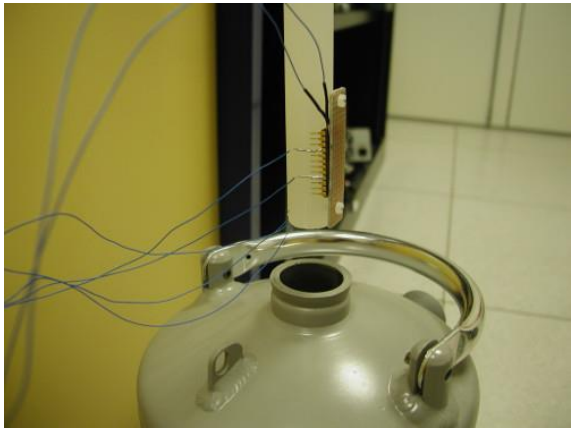
- **All environmental conditions have to be tested**

Source: M. Sourcarros, Analyse des générateurs de nombres aléatoires dans des conditions anormales d'utilisation, rapport de thèse - 2006

Resistor heater
ambiant ~ 120°C



Peltier cooler
-25°C ~ ambiant



Liquid nitrogen
-190°C ~ ambiant

- **Acquisition compaign of several very large continuous sequences**

RANDOM NUMBERS ACQUISITION

- **Acquisition effort for the developer**
  - The random numbers must be accessible from the source
  - The random numbers must be output without stopping the TRNG

  or
  - Large sequences must be stored before outputting

- **Acquisition effort for the evaluator**
  - 30-50 files
  - 100 MB per file → ~ 4 GB
  - 2-3 hours per file → ~ five days
  - The data is stored for a long time

  → At each evaluation we keep 4 GB of really nothing, for a long time!

OUTLINE

- Evaluation Lab
- Random Number Generators
- **Evaluation of RNG**
  - Acquisition
  - **Statistical Tests**
  - Online Tests
  - Penetration Tests
- Conclusion & Perspectives

STATISTICAL TESTS

- **Uniformity, independence, unpredictability**
  - No universal test
    Focus on one property of uniform i.i.d. random variables

- **Statistical test**
  - Defines a random variable and the expected range of values.
  - Test result = FAIL or SUCCESS
  - SUCCESS = No detected defect ≠ Randomness

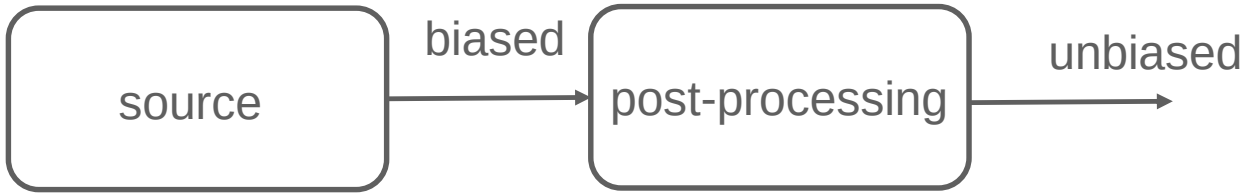
- **Batteries**
  - FIPS140-1 and FIPS140-2 ⇐ 20,000 bits
  - DIEHARD ⇐ ~80,000,000 bits
  - NIST SP800-22 ⇐ ~1,000,000,000 bits
  - AIS31 test suite ⇐ ~100,000,000 bits
  - Tests U01 (L'Ecuyer)

  - Characterization tests → Selection of devices under tests
  - Adapted tests

Leti ITSEF statistical tool

ADAPTED TESTS

- **An example: a biased source**



  - How evaluate this Bernouilli source?
  - Majority of statistical tests fail

Example
$P_1 = 0.46$ before post-processing
- AIS31: T1, T2, T3, T6, T8 fail
- TestU01: 50 / 57 tests fail

  - Other defaults than bias?

- **Need to know the statistical properties of the source**
  - Is the post-processing sufficient?
  - Bring confidence in the source modelling

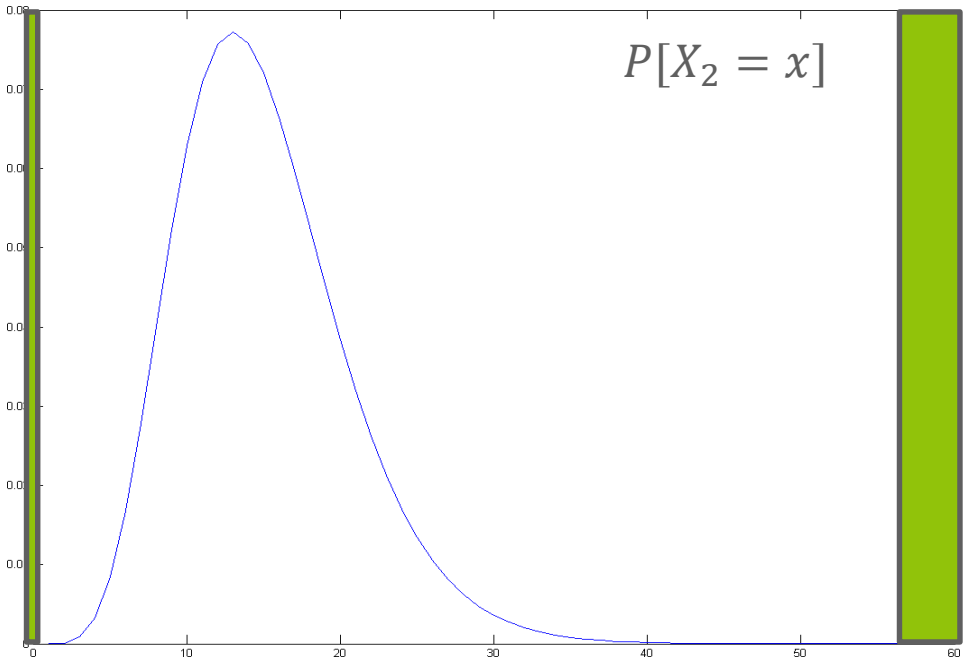
→ **Adapted tests**

ADAPTED TESTS

- **Tests adapted with the Bernouilli distribution**

- **Example poker test (FIPS140-1, AIS31 T2):**
  - $X_2 = \frac{16}{5000} \times \sum_{i=0}^{15} f(i)^2 - 5000$ $f(i)$ pattern occurrence number follows a χ^2 distribution with 15 degrees of freedom
  - The test passes if $1.03 < X_2 < 57.4$
  - This corresponds to:

$Pr[X_2 > 57.4] = 7.0184 \times 10^{-7}$
$Pr[X_2 < 1.03] = 3.1236 \times 10^{-7}$

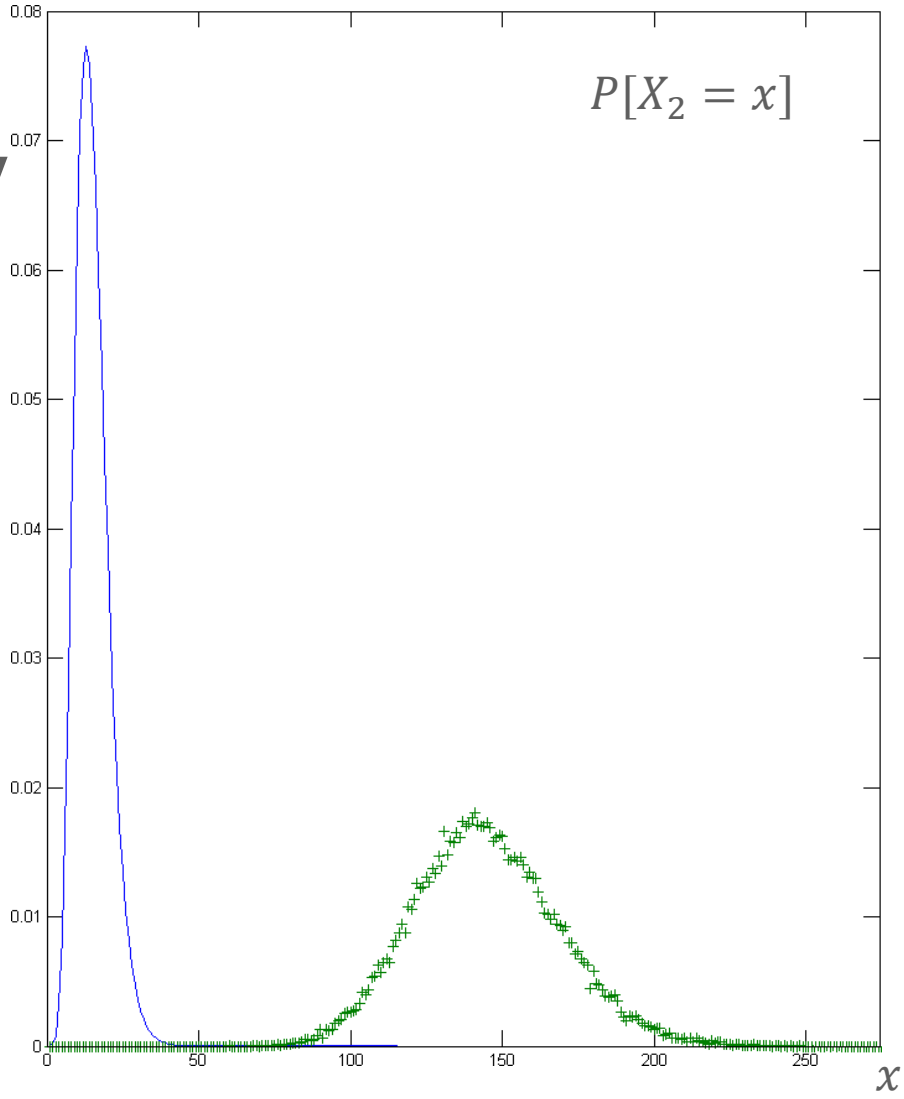


ADAPTED TESTS

- **With the biased sequence**
  $$P_1 = 0.46$$
  the test fails with high probability

- Expected probability of the pattern frequency

$$p(i) = \frac{1}{16}$$



ADAPTED TESTS

- **Adapted poker test**
  - Expected probability

    $p(i) = {P_1}^{\pi(i)}(1-P_1)^{4-\pi(i)}$

    where $\pi(i)$ is the Hamming weight of i

  - $X'_2 = \sum_{i=0}^{15} \frac{\left(f(i)-5000\times p(i)\right)^2}{5000\times p(i)}$

    follows a χ^2 distribution with 15 degrees of freedom

  - The test collects several X'_2 and compares them to the expected distribution

Examples

$p(0000) = (1-P_1)^4$

$p(0001) = P_1(1-P_1)^3$

$p(0011) = {P_1}^2(1-P_1)^2$

ADAPTED TESTS

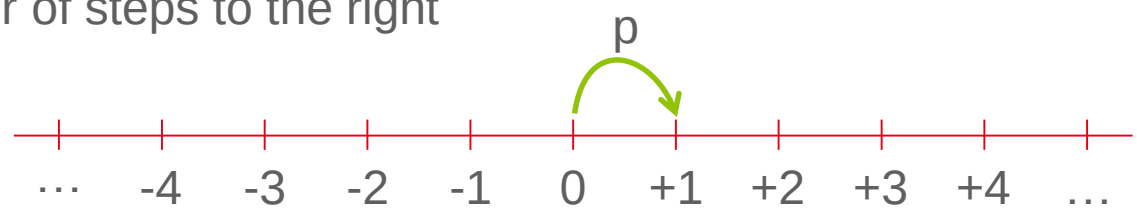
- **Repetition of Poker test (FIPS140-1, AIS31 T2)**
  - Number of patterns

de44432885f6e081ed69b565788e38e9…

- **Repetition of Runs test (FIPS140-1, AIS31 T3)**
  - Number of runs and gaps

1111011010110111010110101101011110001000

- **Random Walk (TestU01)**
  - Statistic H: number of steps to the right



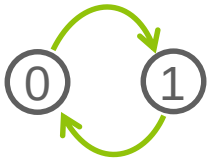
- **Hamming Weight (TestU01)**
  - Number of $\pi(i)$ values

de44432885f6e081ed69b565788e38e9…
33111211112423011332232223113213 2

  - Number of $(\pi(i), \pi(j))$ values

de44432885f6e081ed69b565788e38e9…
33111211112423011332232223113213 2

ADAPTED TESTS

Generated method	P_1	AIS31 failed Tests	TestU01 failed tests	Adapted tests for $P_1 = 0{,}46$
Biased sequence	0.46	T1, T2, T3 T6 T8	50 / 57	4 tests pass
Markov order 1 $\alpha = 0.5$  $\beta = 0.58$	0.46	T1, T2, T3 T5 T6 T8	51 / 57	4 tests fail
Biased sequence with 1/10 pattern 0100 replaced by 0010	0.46	T1, T2, T3 T6 T8	50 / 57	3 tests pass 1 test fails (adapted Poker)

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ONLINE TESTS

- **Goal: detect non-tolerable statistical weaknesses of the source**
  - → Degradation
  - → Expected default
- **Is this online test suitable to detect this default sufficiently soon?**
  - → How many random bits are generated before detection?
- **Detection depends on the call frequency of the online tests**
  - → How many online tests are performed before detection?
  - → Minimal number of online tests to ensure a good probability of detection?

→ **Estimation of the probability of detection of the online test** p

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→ **Estimation of the probability of detection of the online test p**

$N =$ number of online tests to reach a detection

N follows a geometric law of parameter p

$P[N \leq k] = 1 - (1-p)^k$

If a good probability of detection is 95%

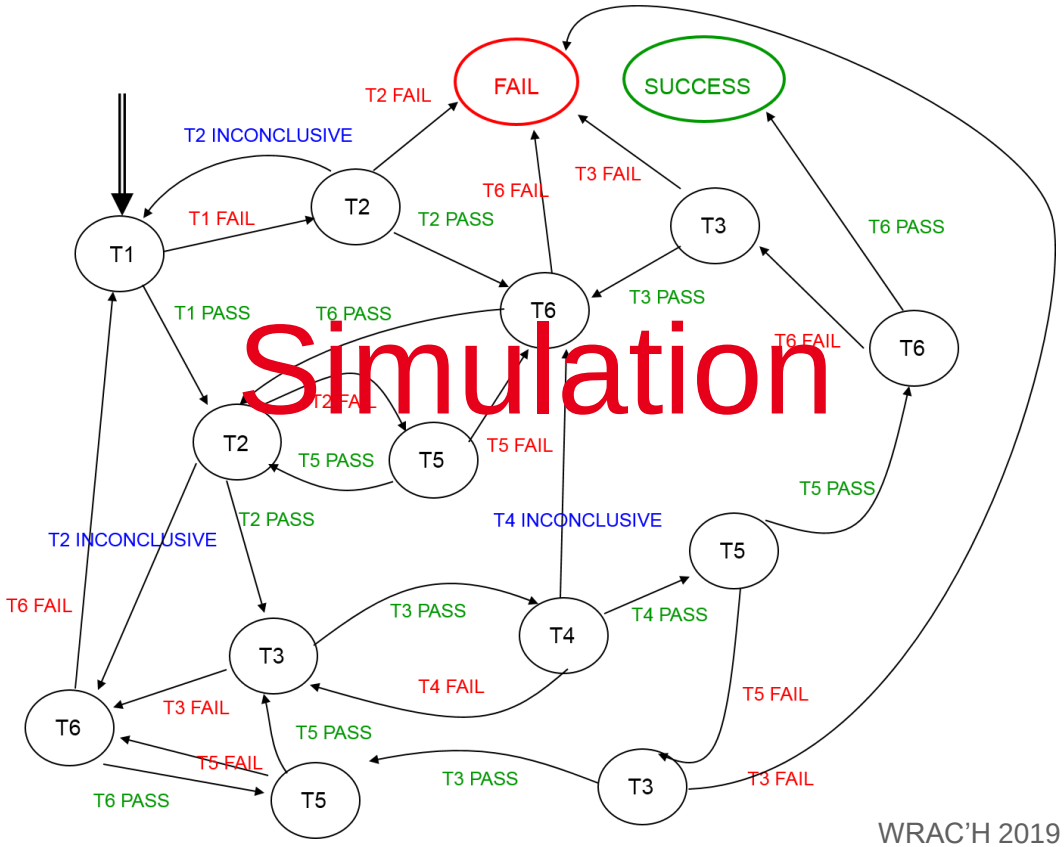
$$k = \frac{\log(1-0.95)}{\log(1-p)}$$

ONLINE TESTS

- Estimation of the probability of detection of the online test p

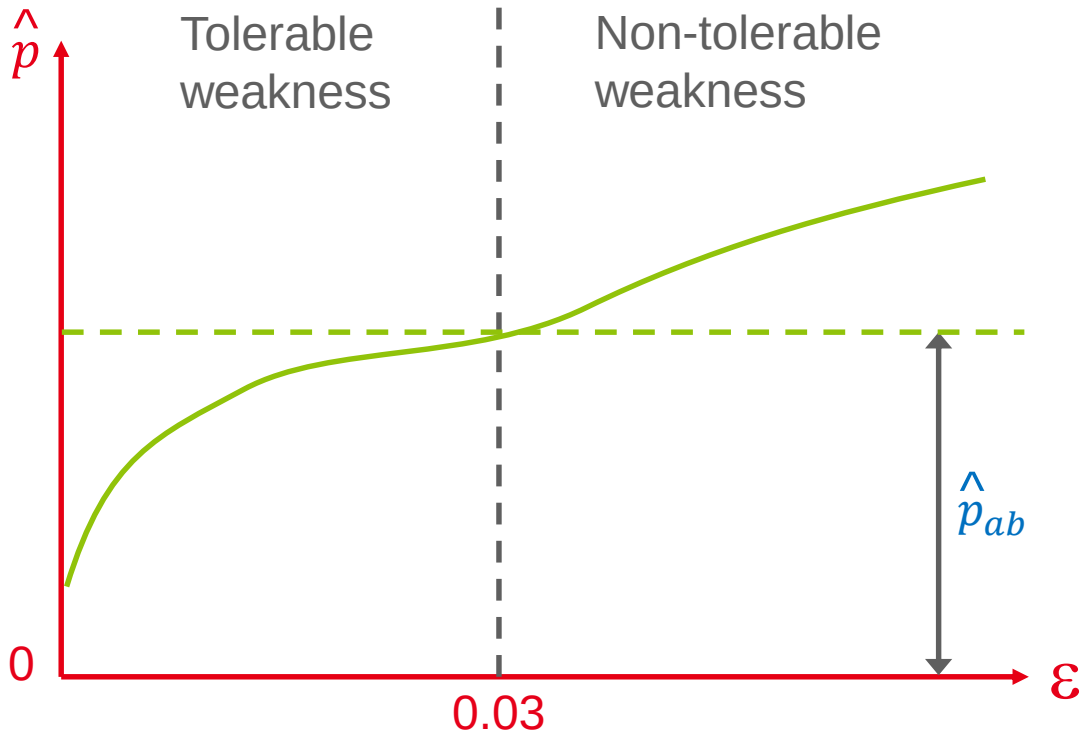
→ Study of the statistics defined by the online test

- But sometimes the online test is a very complex procedure!



ONLINE TESTS - SIMULATION

- **Simulation of the Online test**
- **Simulation of a source with increasing degradation**
  → For example increasing bias ε
- **Estimation of probability of detection** p
  → $\hat{p}$ = Mean number of times the online tests returns FAIL



$\hat{p}_{ab}$ probability of the detection of a non-tolerable weakness

$$k = \frac{\log(1 - 0.95)}{\log(1 - \hat{p}_{ab})}$$

→ Minimal number of online tests for 95% of detection

→ Minimal number of generated bits for 95% of detection

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ATTACKS

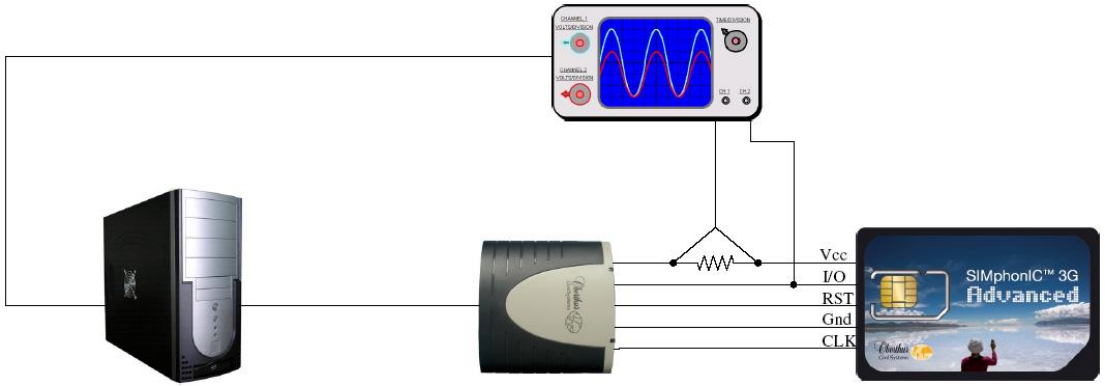
- **Threats**
  - Total failure
  - Randomness quality degradation
  - Random number leakage

- **Attack methods**
  - Observation
  - Perturbation
  - Environment alteration
    - Temperature
    - Clock frequency
    - Voltage

} A combination of these methods

PROFILING ATTACK ON RNG: PRINCIPLE

- **Measure during random number generation**
  - Power consumption
  - Electromagnetic radiation
  - …

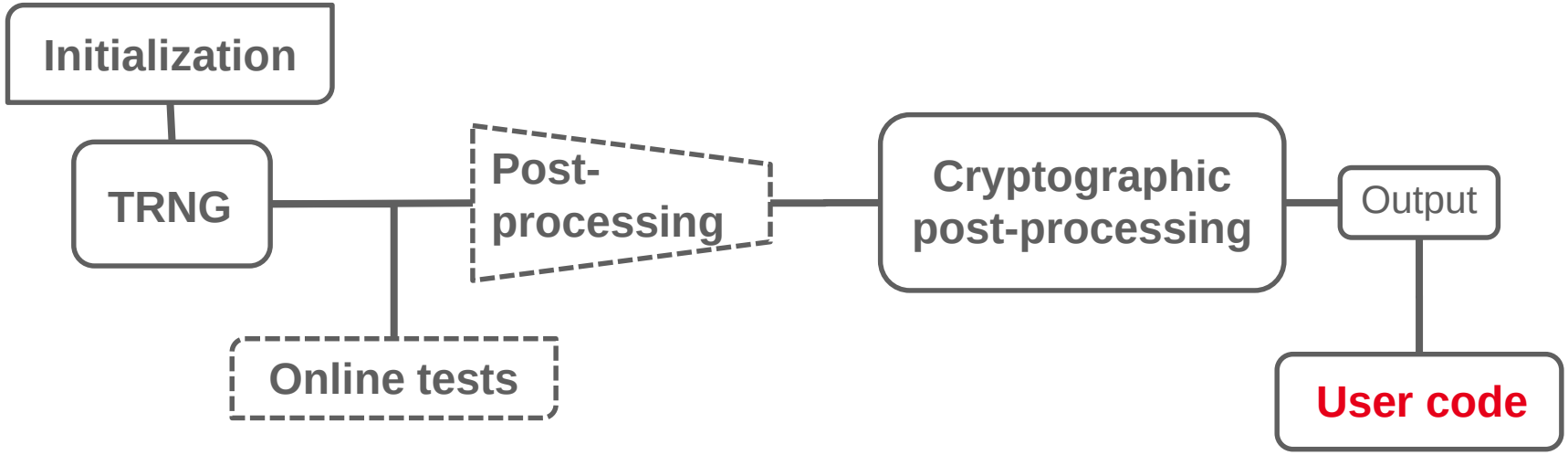


Source: C. Giraud, Attaques de cryptosystèmes embarqués et contre-mesures associées, rapport de thèse - 2007

- **Two phases**
  - Profiling
    - Characterization of the leakage with respect to known bits (learning)
  - Attack
    - Retrieving unknown random bits thanks to the profiling

PROFILING ATTACK ON RNG: REMARKS

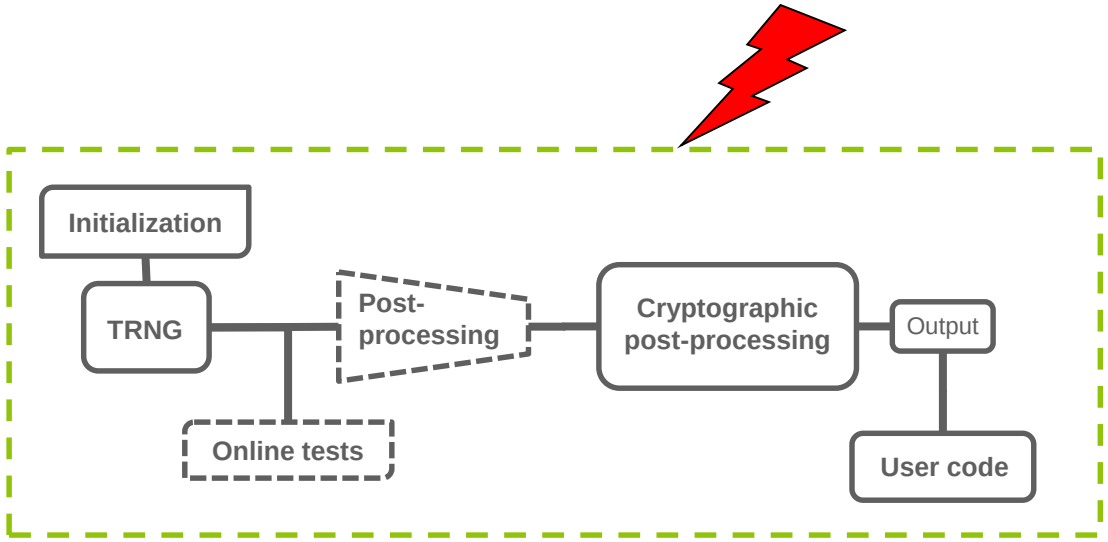
- **A random is not generated twice! (a priori)**
  → Success in only one observation
- **The RNG continously generates random numbers**
  → Difficulty of synchronization
- **Caution**



→ Everything may leak!

PERTURBATION ATTACK ON RNG

- **Fault injection**
  - Laser



- **Perturbation**
  - Random number register
    example: reset a bit
    → Need of multiple faults
    → Need of statistical tests

  - Control registers
    example: change the configuration
    → Need of only one fault
    → Visible effect

  - The user code
    examples:
    - Bypass the call of RNG
    - Bypass the post-processing
    - Bypass the call of the Online test

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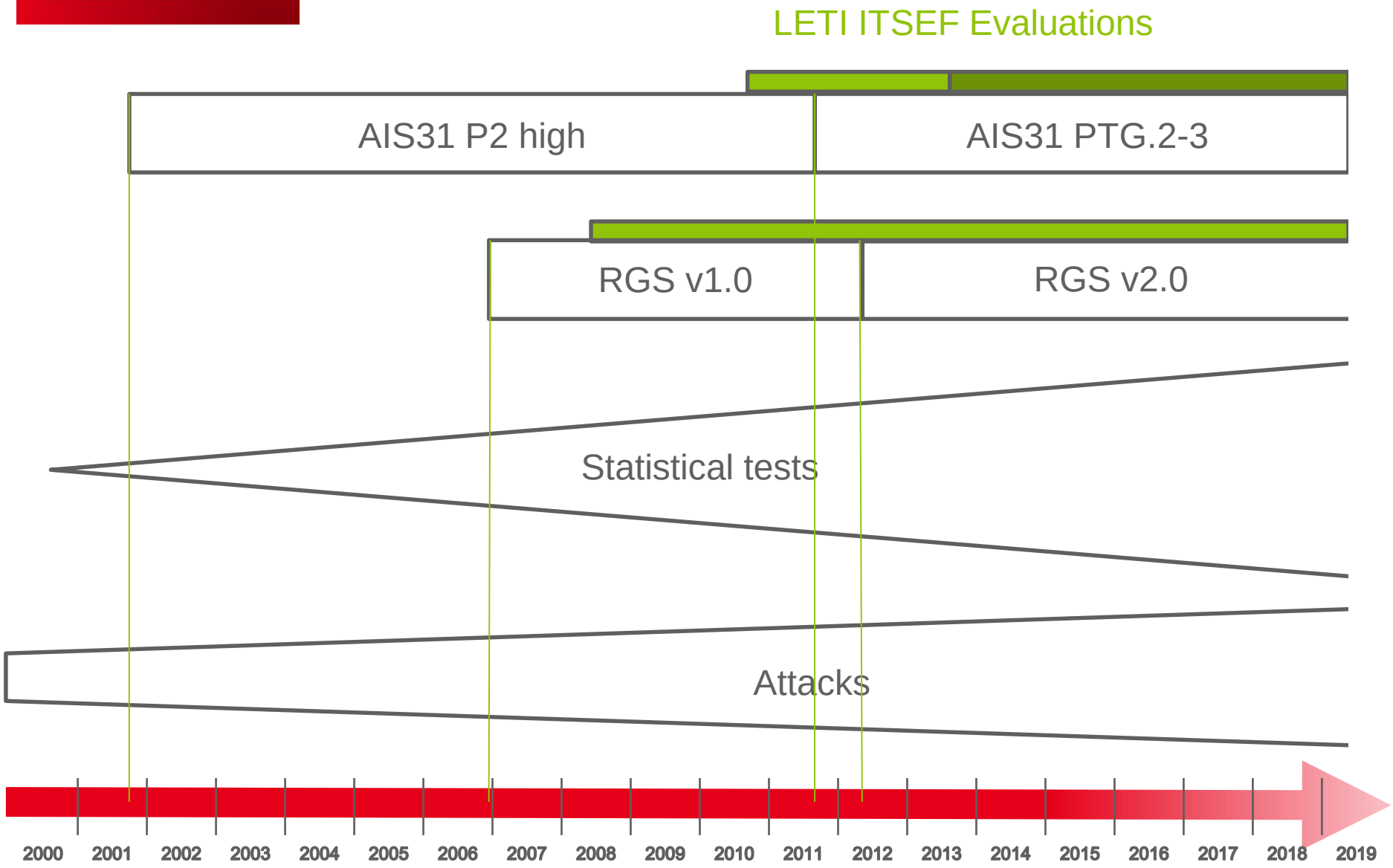
CONCLUSION


LETI ITSEF Evaluations
AIS31 P2 high
AIS31 PTG.2-3
RGS v1.0
RGS v2.0
Statistical tests
Attacks
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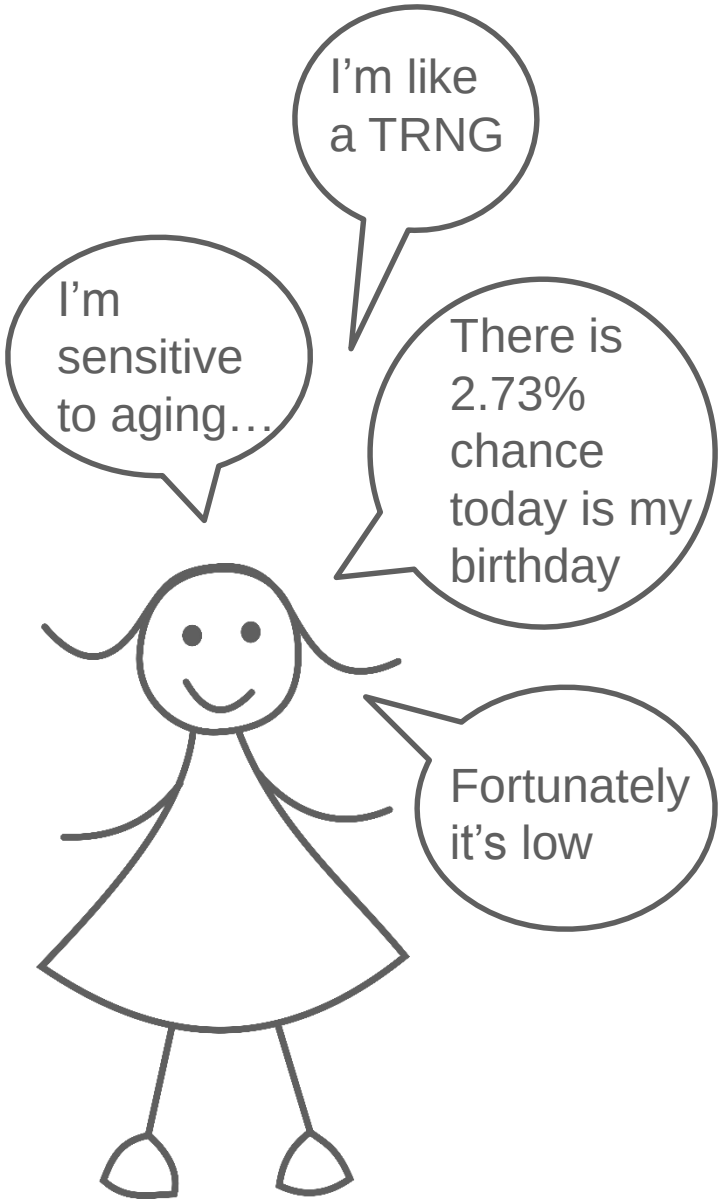

THANK YOU!

QUESTIONS?

Commissariat à l’énergie atomique et aux énergies alternatives
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www.cea-tech.fr

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