Securing the MYRRHA research facility

an accelerator driven system cooled with liquid metal

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Cyber Security Euro-CASE 2017 Conference

Poznan, Poland, November 8th, 2017

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Outline

SCK•CEN: Belgian Nuclear Research Centre

- Nuclear basics
- What is Project MYRRHA?
- MYRRHA technical planning and funding
- Physical Security
- ICT Security
- Reasons to invest in Project MYRRHA

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Belgian Nuclear Research Centre

- One of largest research institutes Belgium
  - 700 employees, scientists and engineers from around world
  - Foundation of public utility
  - Renowned world-wide for nuclear expertise
- Mission: research peaceful applications radioactivity
  - Protection human and environment ionizing radiation
  - Safety nuclear installations
  - Management radioactive waste

- Unique infrastructure:
  - BR2: among most powerful and flexible RR in world; 20-25% world production of medical radioisotopes
  - Venus subcritical lead core reactor driven by accelerator
  - Specialized laboratories: nuclear and non-nuclear

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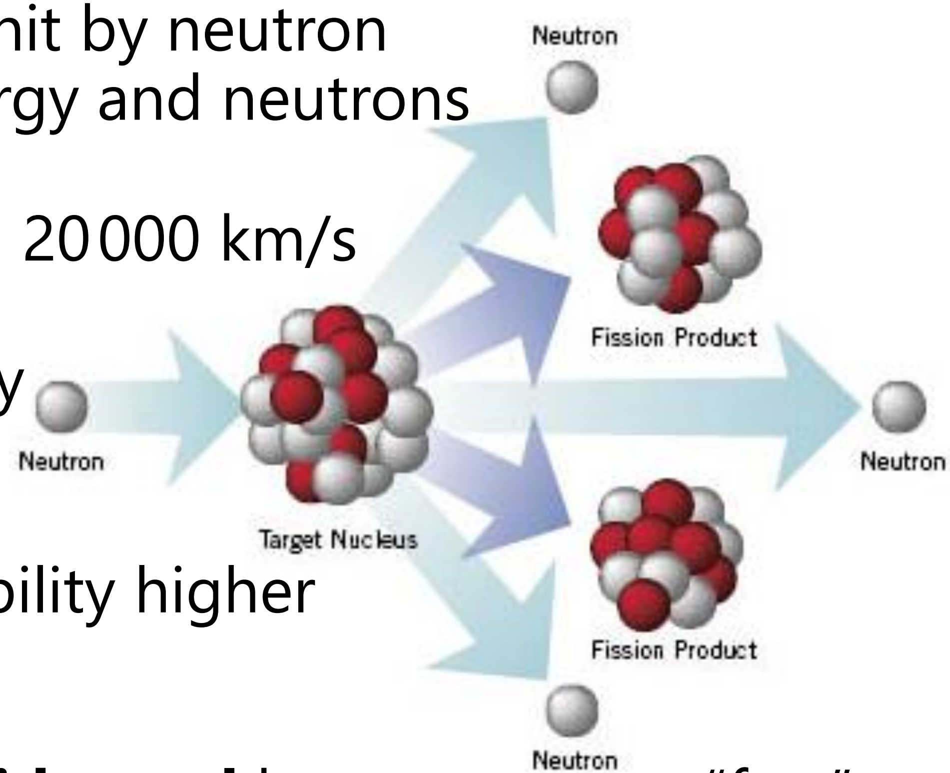
Nuclear basics: thermal vs fast reactor

- **Nuclear fission**: fissile atom hit by neutron splits in pieces, releasing energy and neutrons
- Emitted neutrons are "**fast**" ≈ 20 000 km/s
- After colliding with water they become "**thermal**" ≈ 2 km/s
- U^{235} and Pu^{239} fission probability higher with thermal neutrons



- Using heavy coolant like **liquid metal** keeps neutrons "fast"
  - Can **fission** other heavy nuclei, including **high-level nuclear waste**
  - Can "**breed**" fissile material via neutron absorption, eg: $\mathrm{U}^{238} + \mathrm{n} \rightarrow \mathrm{Pu}^{239}$
  - **Higher burnup** nuclear fuel: **better fuel economy, less waste**

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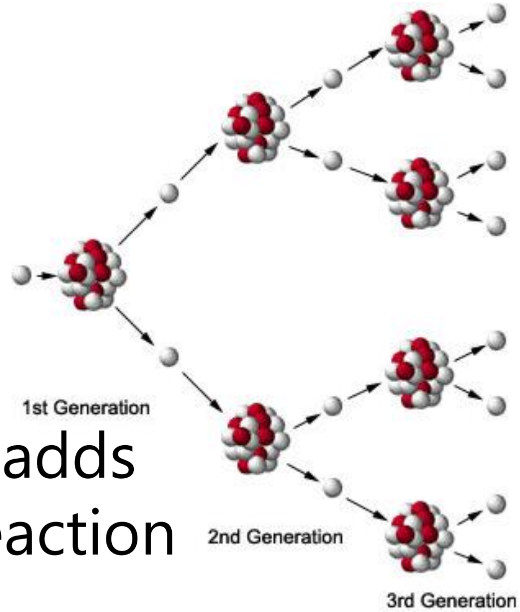
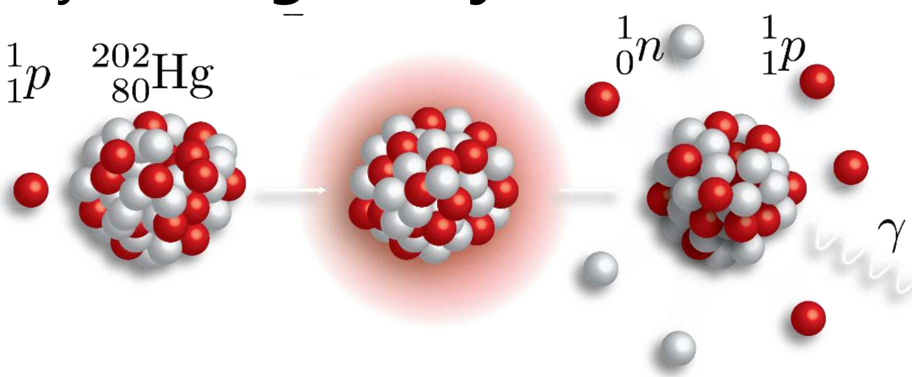
Nuclear basics: critical vs subcritical reactor

- k_{eff} = neutron multiplication factor
  - $k_{eff} < 1$: **subcritical**, chain reaction dies out
  - $k_{eff} = 1$: **critical**, chain reaction stable
  - $k_{eff} > 1$: **supercritical**, chain reaction increases



- Subcritical reactor operates with $k_{eff} < 1$ and adds **neutrons** form **external source** for stable reaction

- **Spallation** produces neutrons by **hitting heavy nuclei** with **high energy protons**
  - More **precise control** reaction
  - Subcriticality: **inherent safety**



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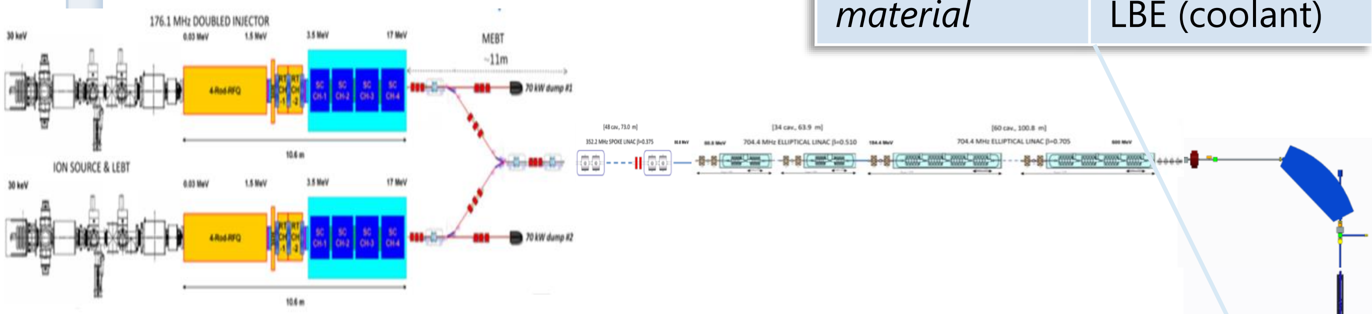
Key technical objective of the MYRRHA-project: an Accelerator Driven System

Construction of an Accelerator-Driven System (ADS) consisting of

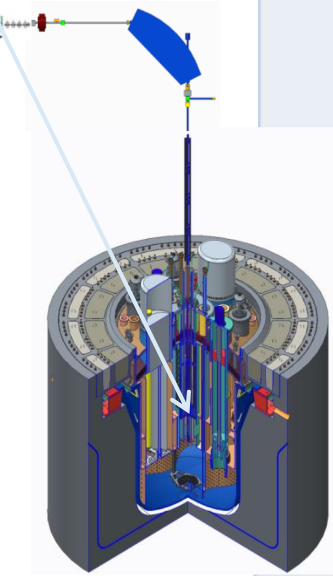
- A 600 MeV – 2,5 mA to 4,0 mA **proton** linear **accelerator**
- A **spallation** target/source
- A **Lead-Bismuth Eutectic** (LBE) cooled reactor able to operate in subcritical & critical mode

Accelerator	
particles	protons
beam energy	600 MeV
beam current	2.4 to 4 mA

Target	
main reaction	spallation
output	$2 \cdot 10^{17}$ n/s
material	LBE (coolant)



Reactor	
power	65 to 100 MW_{th}
k_{eff}	0,95
spectrum	fast
coolant	LBE



Source: SCK•CEN MYRRHA Project Team

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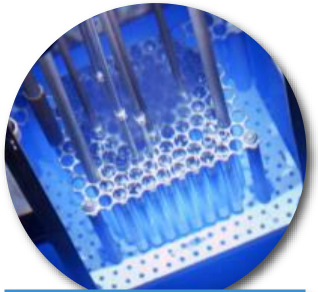
MYRRHA application portfolio



Fission GEN IV

Fusion

SNF*/ Waste

Multipurpose
hYbrid
Research
Reactor for
High-tech
Applications

Fundamental research

Radio-isotopes

SMR LFR

*SNF = Spent Nuclear Fuel

Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan

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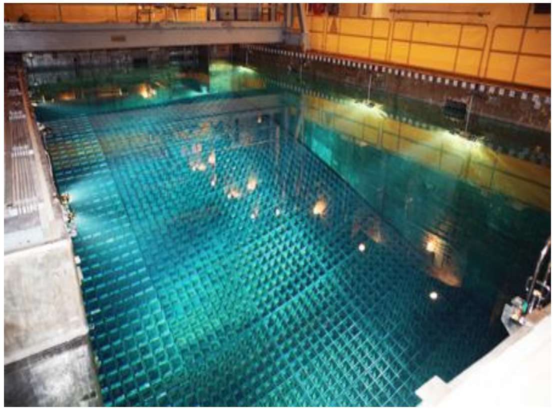
Global challenges for nuclear energy today: Closing the fuel cycle is priority number one

Common needs

- **Burning legacy of the past**
- **Reducing cost of ultimate waste**
- **Better use of resources**
- **Enhance Safety**



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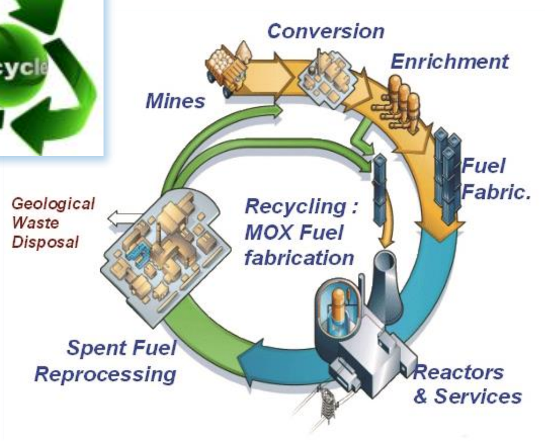

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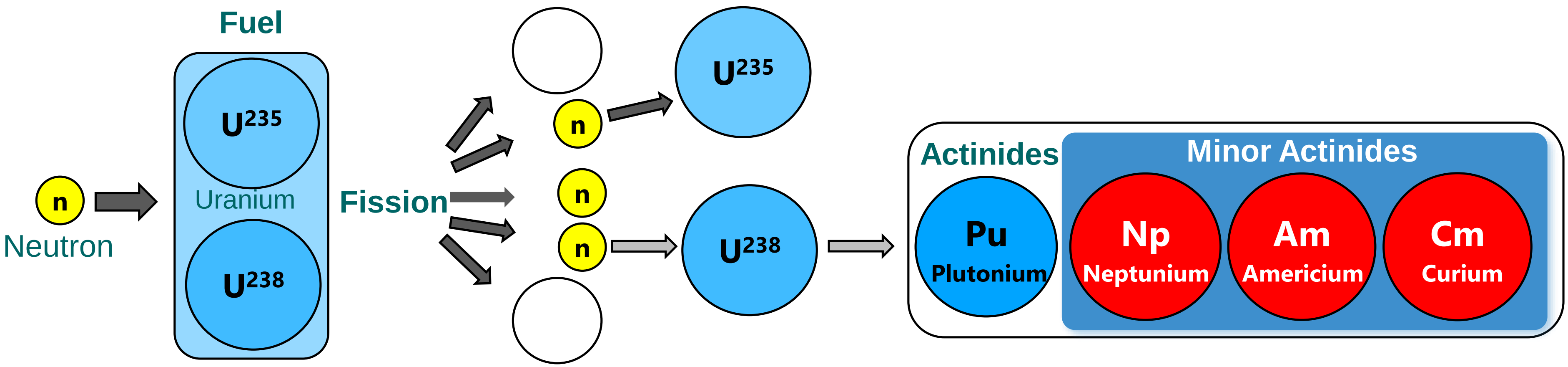
Fission generates High-Level Nuclear Waste



Minor Actinides

high radiotoxicity long lived waste that are difficult to store due to:

- **Long lived (>1,000 years)**
- **Highly radiotoxic**
- **Heat emitting**

Source: SCK•CEN MYRRHA Project Team

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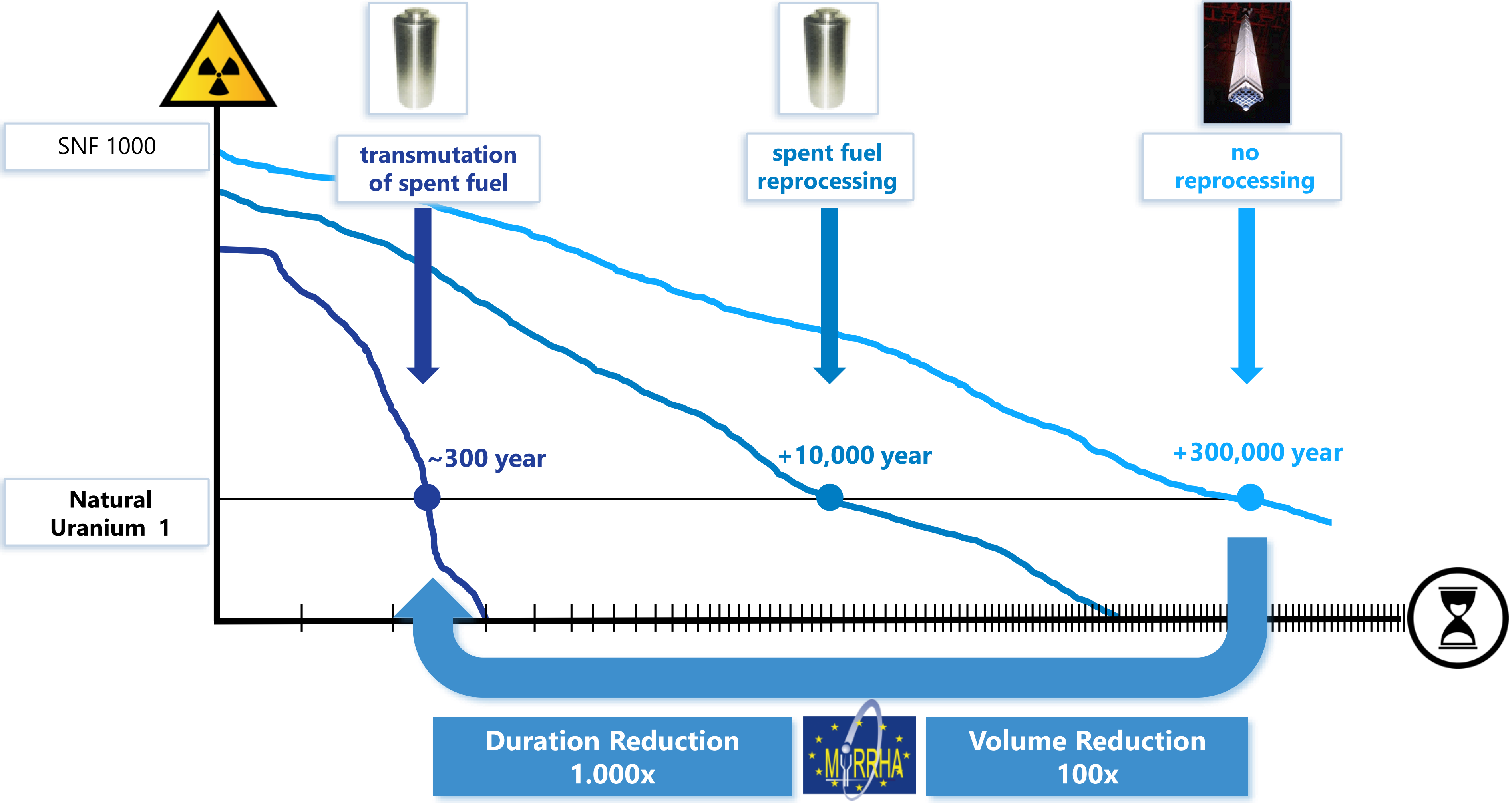
Transmutation is the better solution for Spent Nuclear Fuel



*SNF = Spent Nuclear Fuel

Source: *European Commission Strategy Paper on Partitioning & Transmutation (2005), SCK•CEN MYRRHA Project Team*

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European Strategy for P&T (2005) with objective of possible industrialisation from 2030-35

EU P&T Strategy 2005: *"The **implementation of P&T** of a large part of the high-level nuclear wastes **in Europe needs the demonstration of its feasibility at an "engineering" level**. The respective **R&D** activities could be **arranged in four "building blocks"**:*

P&T building blocks	Description	Name & Location
1 **Partitioning**	▪ Demonstrate capability to process a sizable amount of **spent fuel** from commercial Light Water Reactors to **separate** plutonium, uranium and minor actinides	▪ Atalante (FR)
2 **Fuel production**	▪ Demonstrate the capability **to fabricate** at a semi-industrial level the **dedicated fuel** needed to load in a dedicated transmuter	▪ JRC-ITU (EU) Karlsruhe (DE)
3 **Transmutation**	▪ **Design and construct one or more dedicated transmuters**	▪ **MYRRHA (BE)**
4 **Fuel unloading**	▪ Specific installation to process fuel unloaded from transmuter ▪ Not necessarily the same as type to process original spent fuel unloaded from commercial power plants	

The European Commission contributes to the 4 building blocks and fosters the national programmes towards this strategy for **demonstration at engineering level**.

Source: European Commission Strategy Paper on Partitioning & Transmutation (2005)

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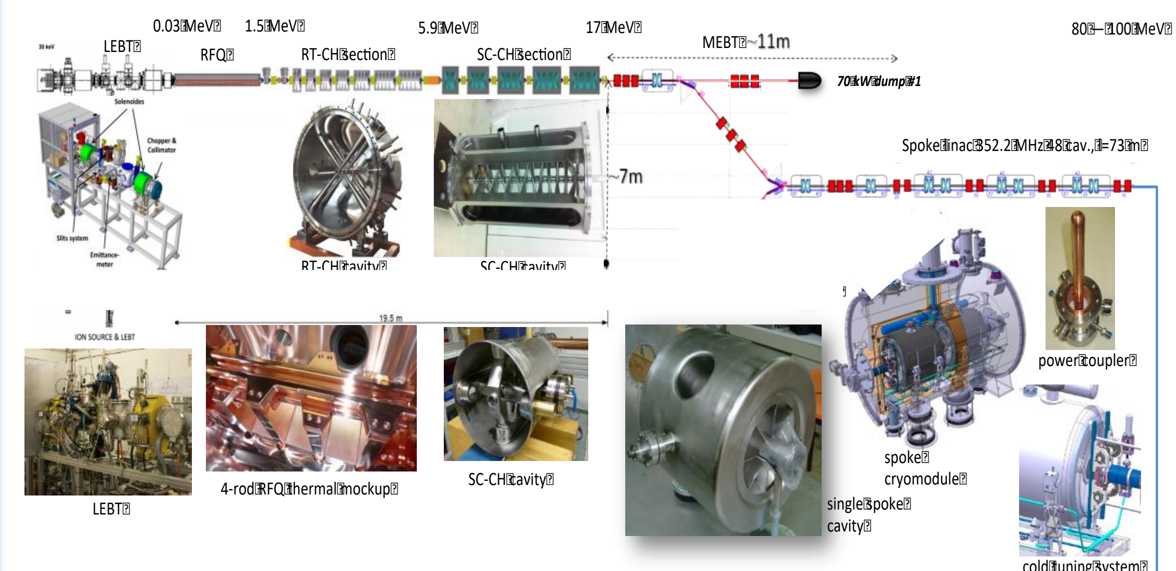
MYRRHA's phased implementation strategy

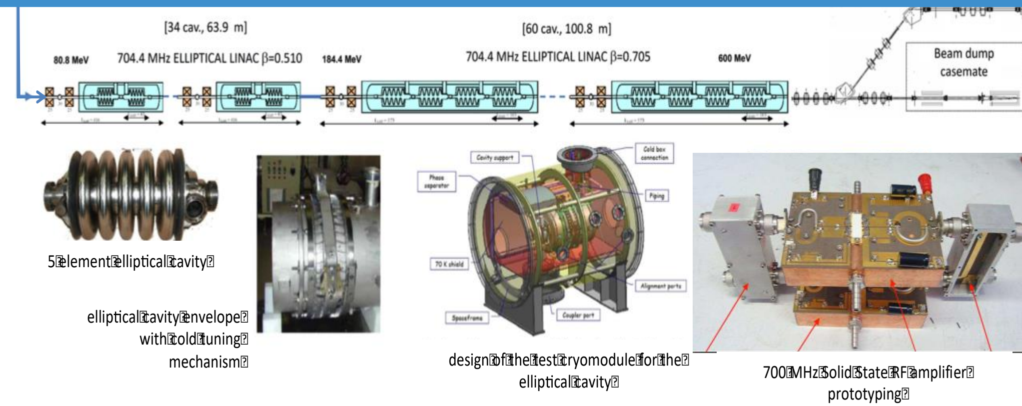
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol end of 2024

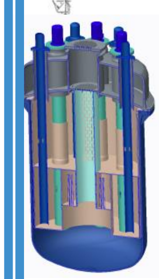
Phase 1 – 100 MeV



Phase 2 – 600 MeV



Phase 3 – Reactor



Source:SCK•CEN MYRRHA Project Team

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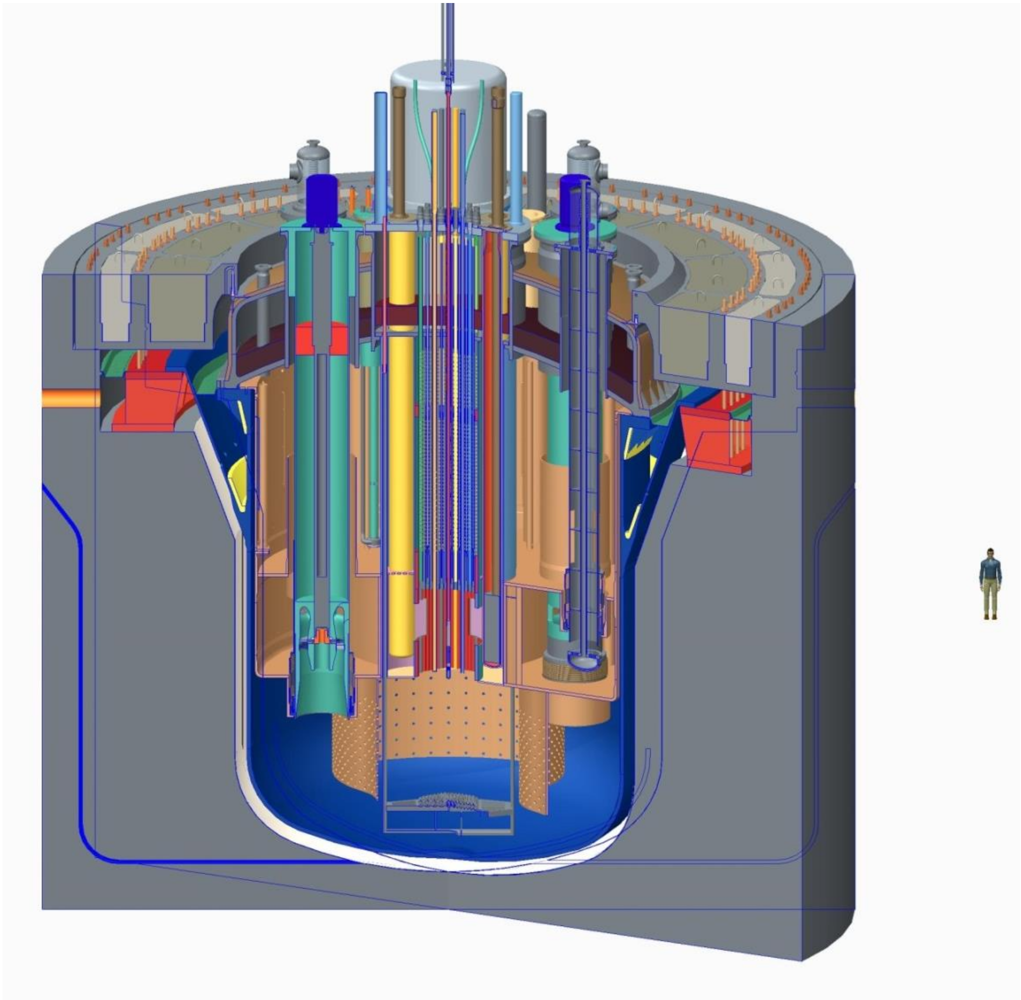
Reactor – Current Primary System design (v1.6)

- Reactor layout
  - Vessel
  - Cover
  - Core barrel and Multi-functional plugs
  - Above Core Structure
  - Cradle, Core Restraint System, beam line and window target
  - Si-doping units, Mo-irradiation units, control rods and safety rods
  - Primary Heat Exchangers
  - Primary Pumps
  - In-Vessel Fuel Handling Machines, Fuel Transfer Devices, Failed Fuel Detection Devices, Extraction Pumps
  - Diaphragm and support structure
  - Reactor pit, Reactor Vessel Auxiliary Cooling System



Source:SCK•CEN MYRRHA Project Team

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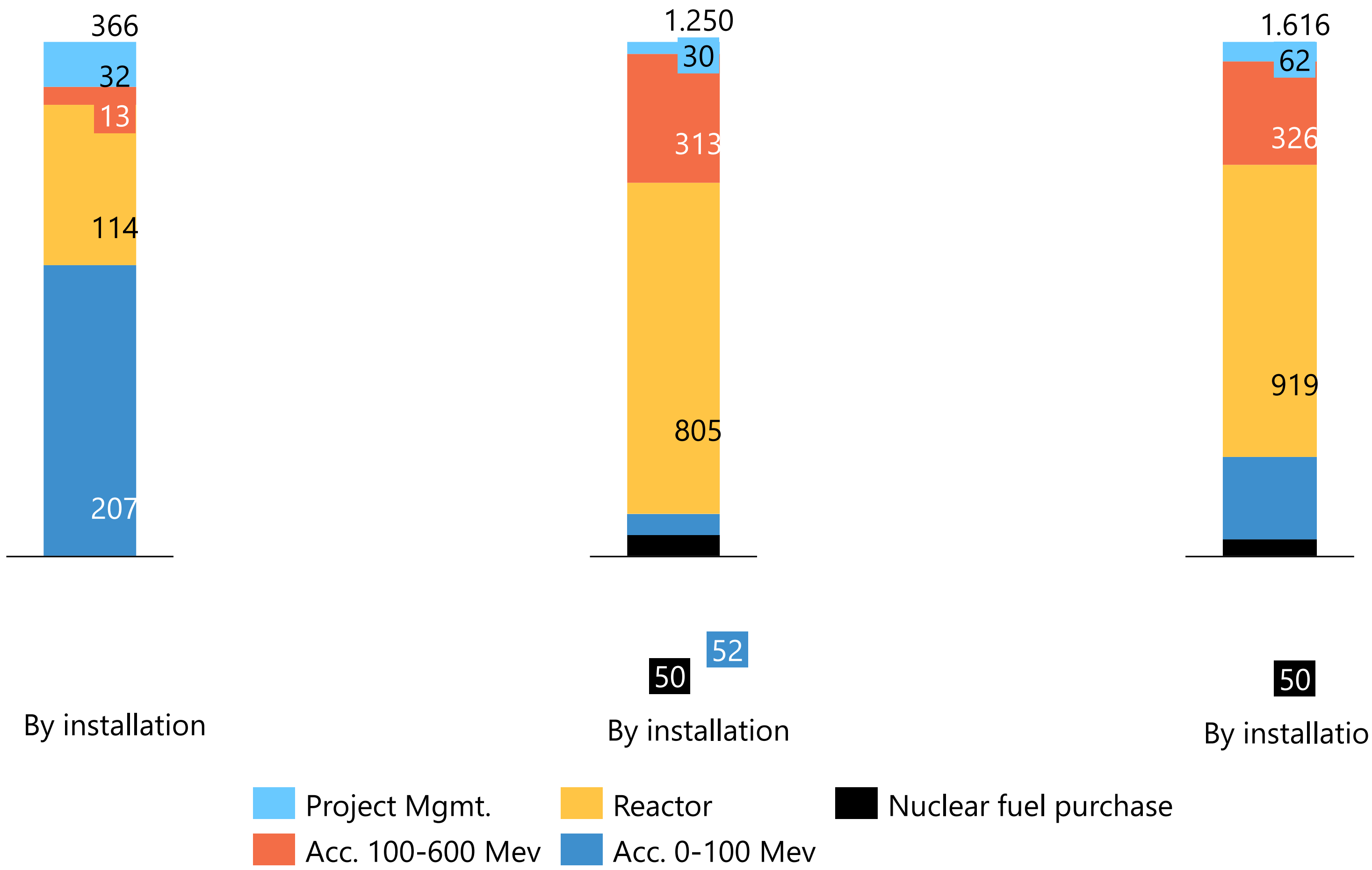
Capital Expenditure: MYRRHA total investment budget

Phase 1 (2016-2024) EUR M | **Phase 2 (2025-2030) EUR M** | **Total (2016-2030) EUR M**



Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan

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ISC: Public
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Physical Security: Regulatory framework

- Physical protection nuclear material required by law:
  - Plutonium, Uranium-233, Uranium-235, Thorium
  - Categorized in three categories depending on
    - Type: Isotope and Enrichment
    - Quantity
    - Irradiated or not
  - Graded security measures depending on category
    - Security area where material is handled or stored
    - Vetting level to access areas or information:
      None – Restricted – Confidential – Secret
- Design Basis Threat and Threat level from Coordination Unit for Threat Analysis (CUTA)

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Physical Security: Main principle

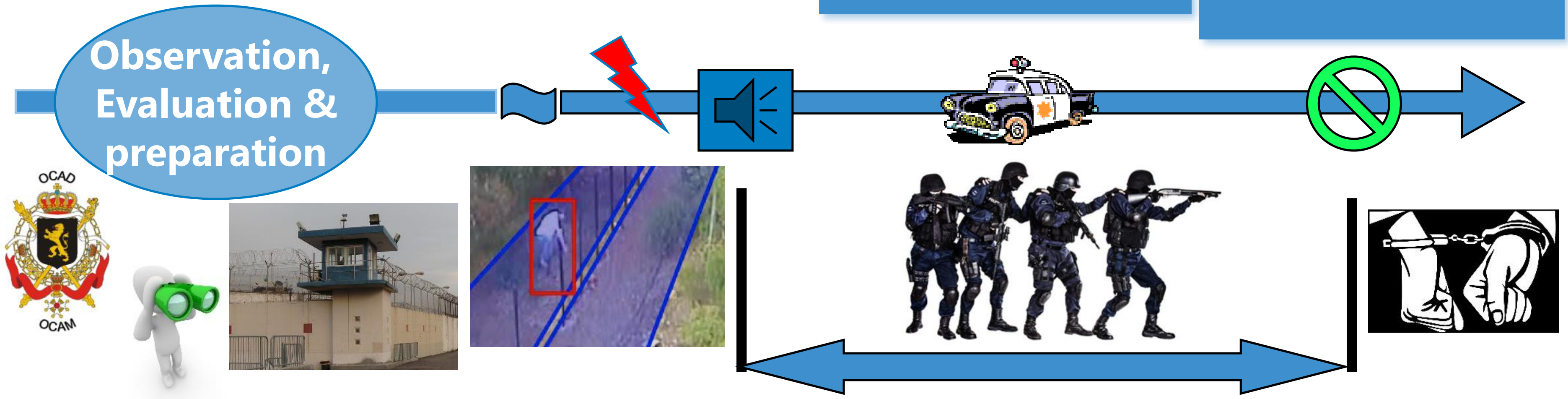
Main Principle: Deter – Detect – Delay – Respond

- Threat level CUTA
- Counter-observation
- Deterrence

- Detect and Analyze
- Alarm
- Start response

Delay while response forces underway

Neutralization attack by response forces



Deter	Detect	Delay	Neutralise

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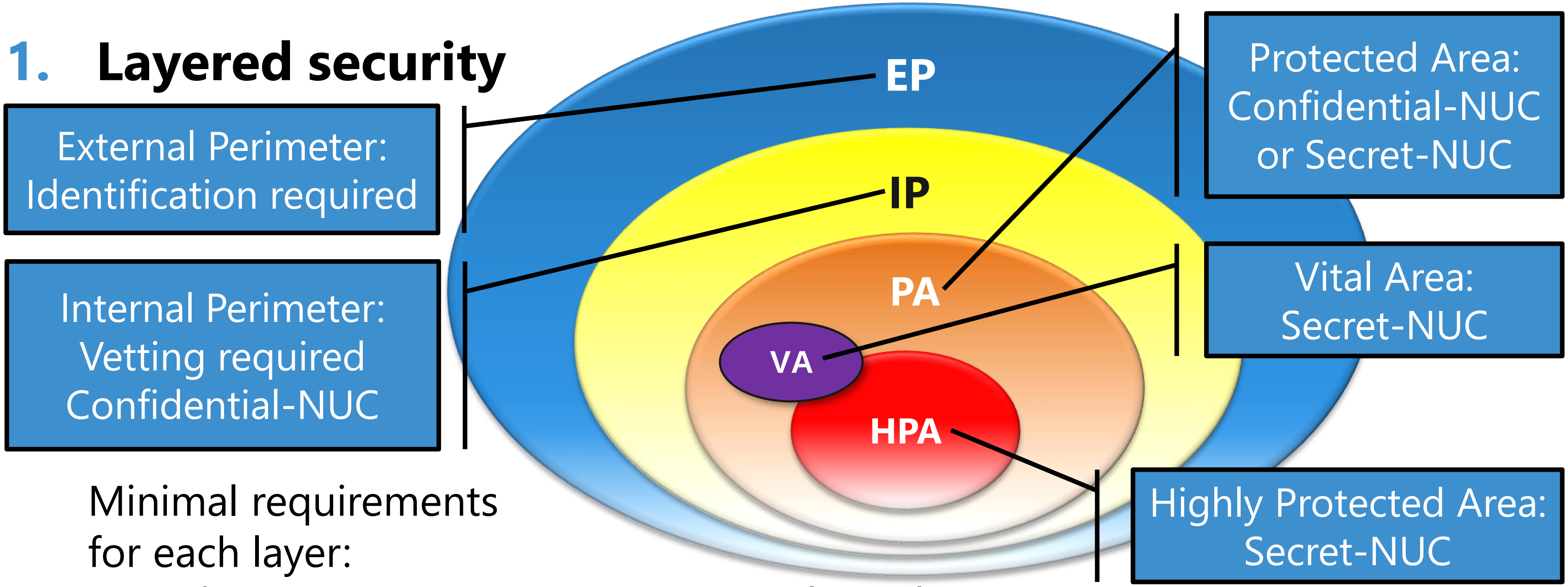
Physical Security: Design principles

1. Layered security



Minimal requirements for each layer:
Boundary – Detection – Access Control – Delay components

2. Defence in depth

Multiple components for each element to assure no single point of failure

3. Balanced Security

Equivalent detection/delay/access control regardless of attack path followed

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ICT Security

Information Security Governance

Policy Framework

Risk based, graded approach

Network Segmentation

Technical Protection

Information Protection

Application Security

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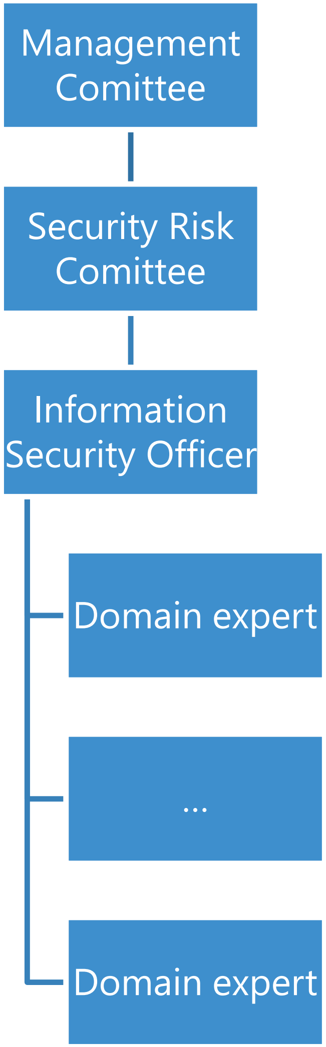
ICT Security: Governance and Policy framework



- Policy Framework based on
  - ISO 27000/27001
    Information Security Management System (ISMS)
  - IAEA NSS 17
    "Computer Security at Nuclear Facilities"

- Security Risk Comittee
  - Reviews and approves ICT Security strategy and policies
  - Management major security risks
  - Chairmain: Information Security Officer
  - Delegates from Management, ICT, Safety, Security, Legal and Institutes with nuclear facility
- Information Security Officer, Security Department
  - Daily management ISMS and ICT Security Risks
  - Design/improve architecture, policies and security measures
  - Steers, follows and audits ICT Security activities

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ISO 27000 Policy Framework

- ISP00 Governance Model
- ISP01 IS Governance
- ISP02 Risk Management
- ISP03 Asset Management
- ISP04 Information Protection
- ISP05 IT Infrastructure
- ISP06 Network
- ISP07 Logical Access Control
- ISP08 Security Incident Mgt
- ISP09 Threat Management
- ISP10 Applications
- ISP11 Human Resources
- ISP12 External Parties
- ISP13 Compliance
- ISP14 Acceptable Use
- ISP15 Change Management

Not all rules can be technically enforced

Essential to control human factor via procedures

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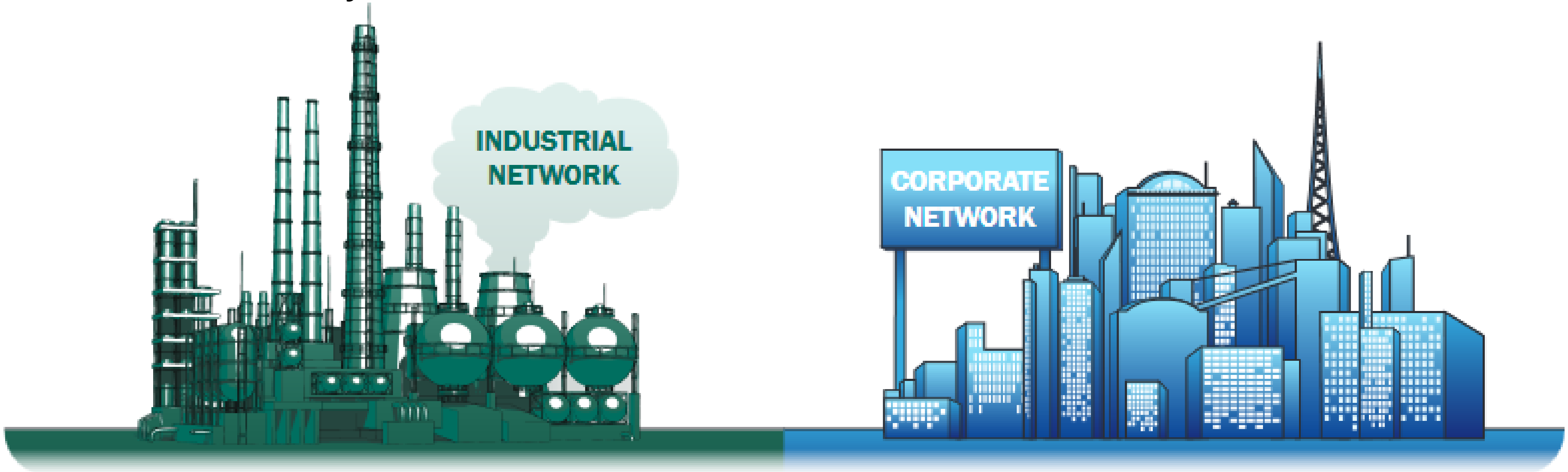
CIA: Confidentialitiy, Integrity, Availability

- CIA: the three pillars of ICT Security
  - **C**onfidentiality
  - **I**ntegrity
  - **A**vailability



1. AVAILABITLITY	1. CONFIDENTIALITY
2. INTEGRITY	2. INTEGRITY
3. CONFIDENTIALITY	3. AVAILABITLITY

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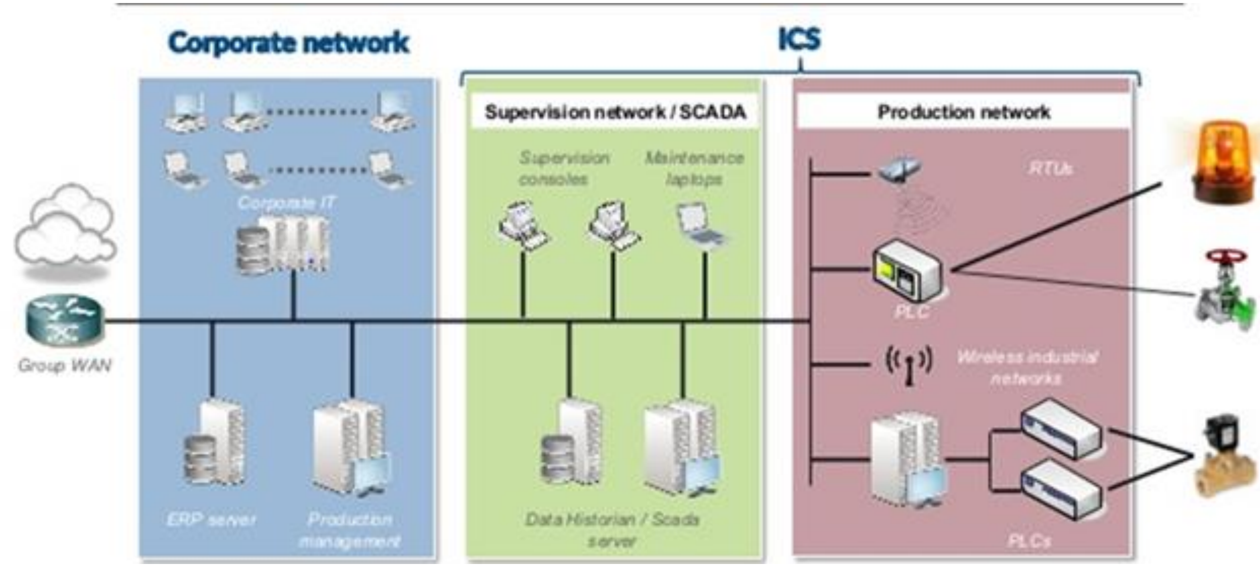
ICT Security: Network Segmentation

- Based on two standards:
  - IAEA NSS 17 Computer Security at Nuclear Facilities
  - IEC 62433 Industrial communications networks – Network and systems security
- Create perimeters in network to segment it in to zones
- Assign security level to each zone according to IAEA NSS 17



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ICT Security: IAEA NSS 17 Network Security Levels

SL	Assignment Principle	Main security requirements
1	Systems coupled to installations with **radiologic** release **risk**	Complete isolation; **strict outward communication only**; fixed network connections without physical access
2	**Critical control** and **monitoring** systems; all **security** systems	Isolated; **only outward communication** but inward acknowledgements allowed; restricted physical access to connections
3	**Important** but not critical systems; **vulnerable** systems	**Strictly monitored** access only after **additional authentication**; only restricted, necessary outward communication; **remote** and **internet access** only **temporary** and under strict conditions
4	Systems under **strict control** of and trusted by ICT; **required** for regular **access** to **SL 3** zones	All network activity strictly **monitored**, including access from SL 5 zones; internet access secured via network and application firewall
5	Systems in Office environment with more freedom; external systems under limited control ICT	Access to internet secured via network and application firewalls
6	Unknown systems; Eduroam, Lakehouse wired network	Access to internet secured via network firewalls, no intranet access

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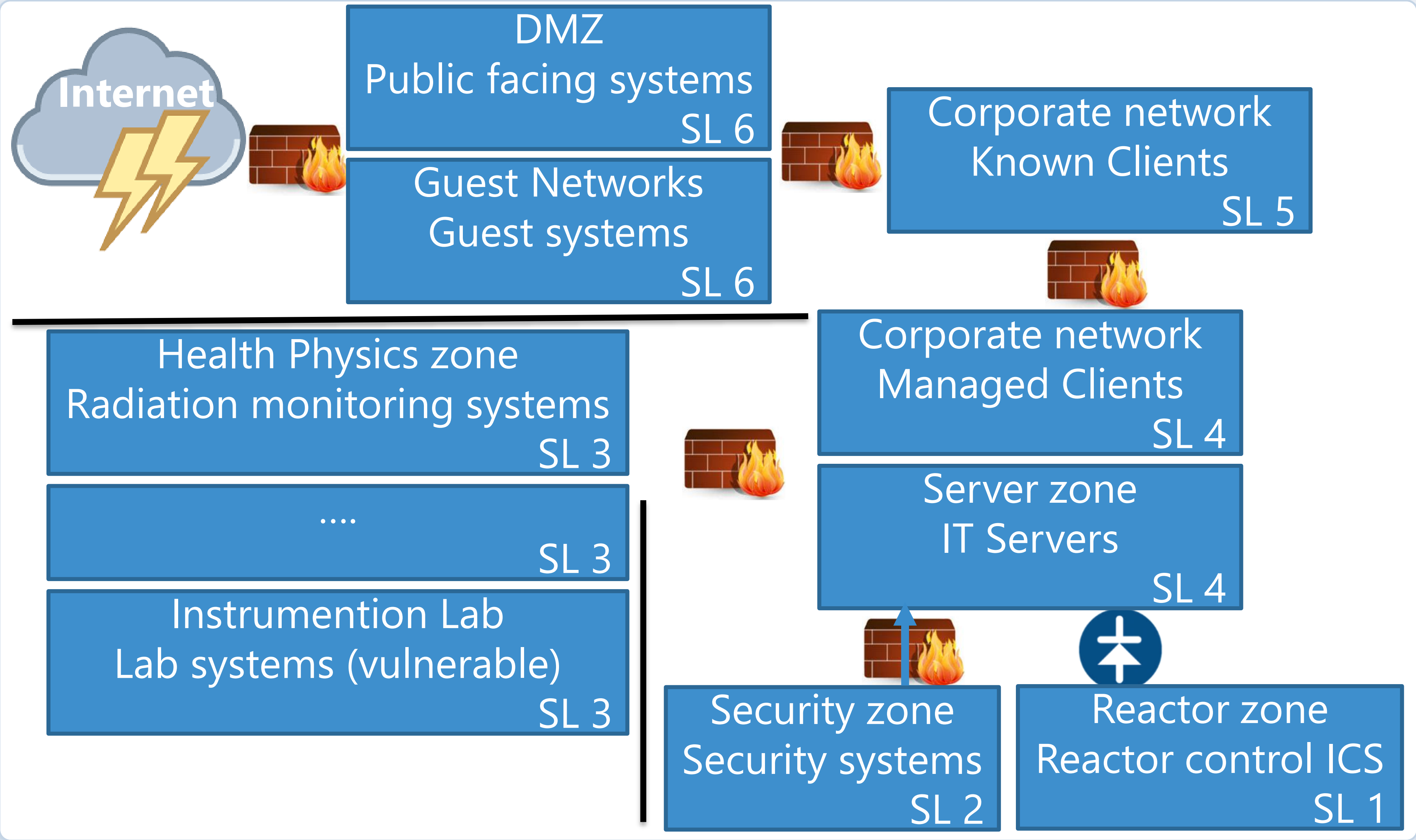
ICT Security: Reference Network Architecture



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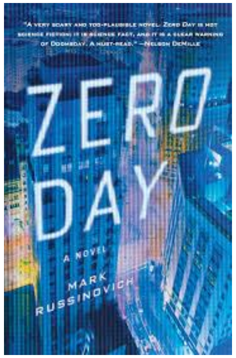
ICT Security: Network segmentation considerations

- Air gaps: secure but hard to manage
- SL1-2 zones: no inward communication policy but also impossibility:
  → Strict procedures for external media (=conduit!)
  → Security awareness



- Zero-days network infrastructure threat up to SL 2 zones
- Safety tresholds guarded by ICS can be breached (Remember StuxNet…)
  → Critical safety functions: secondary treshold guarded by analog systems should be considered

- Physical Access: always a threat

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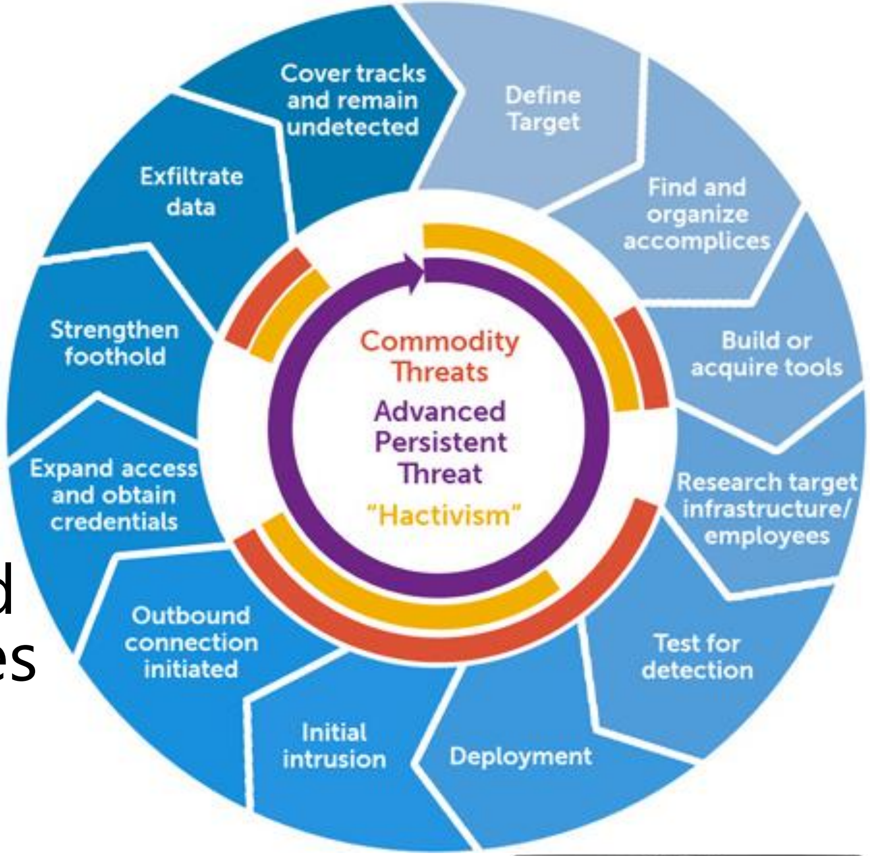
ICT Security: Technical Protection

- Strong authentication
- Clear processes for
  - System hardening
  - Vulnerability management
  - Anomaly detection, special attention for APTs
- Deploy and integrate standard tools with associated processes
  - Log centralization and SIEM for automatic incident detection
  - Vulnerability scanning
  - Periodic penetration testing
  - Anti-APT tools: IPS and IDS



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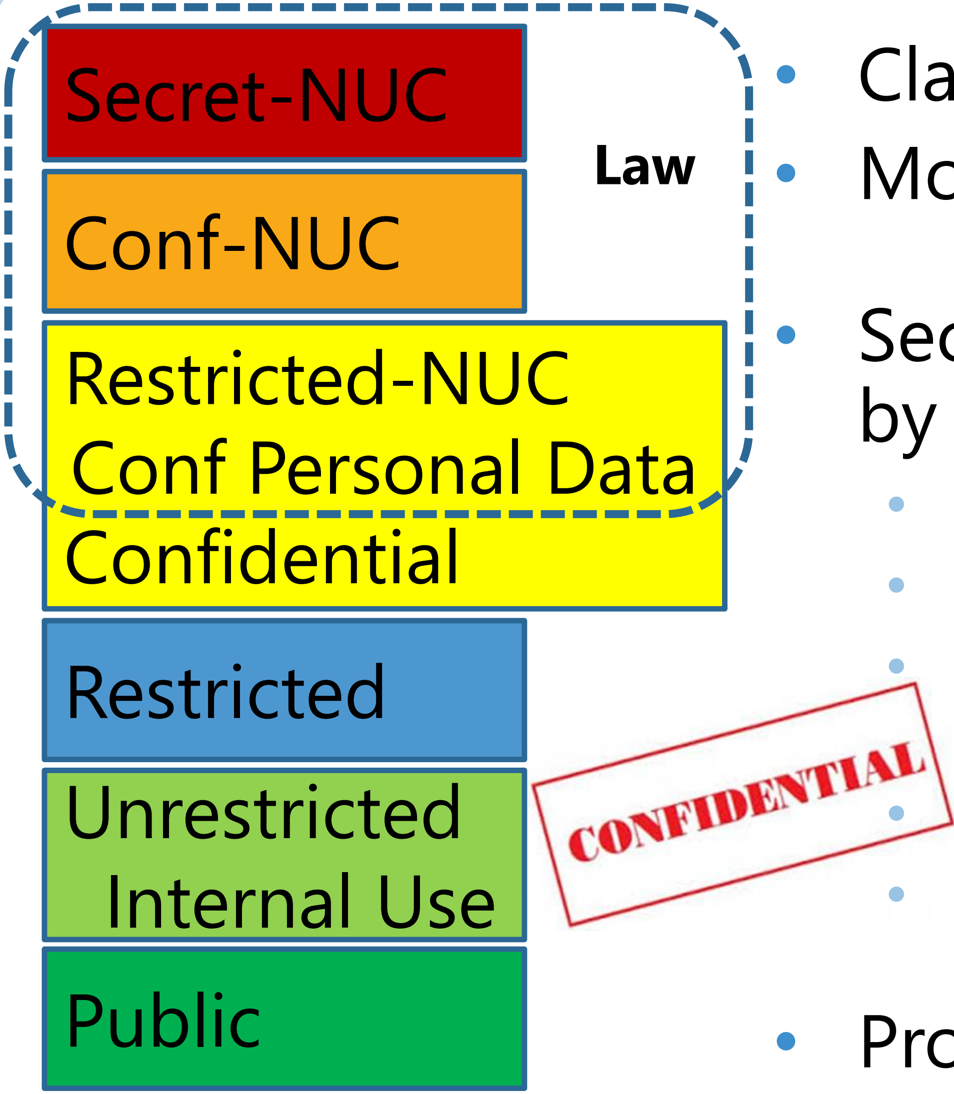
ICT Security: Information Protection



- Classification scheme
- Most sensitive required by law

- Security controls determined by color:
  - Create, Consult, Edit, Destroy
  - Private vs Personal vs Corporate
  - Owner, Determination/Expanding Need-2-know/hold/handle
  - Storage, Print/Scan/Copy
  - Distribution, transmit/receive

- Protect **C** but also **I** and **A**

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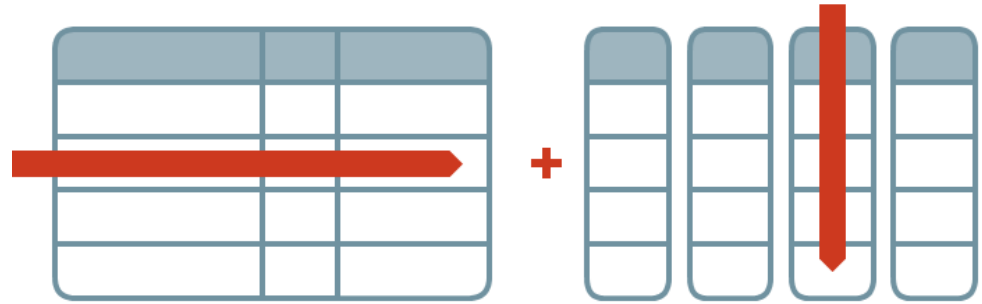
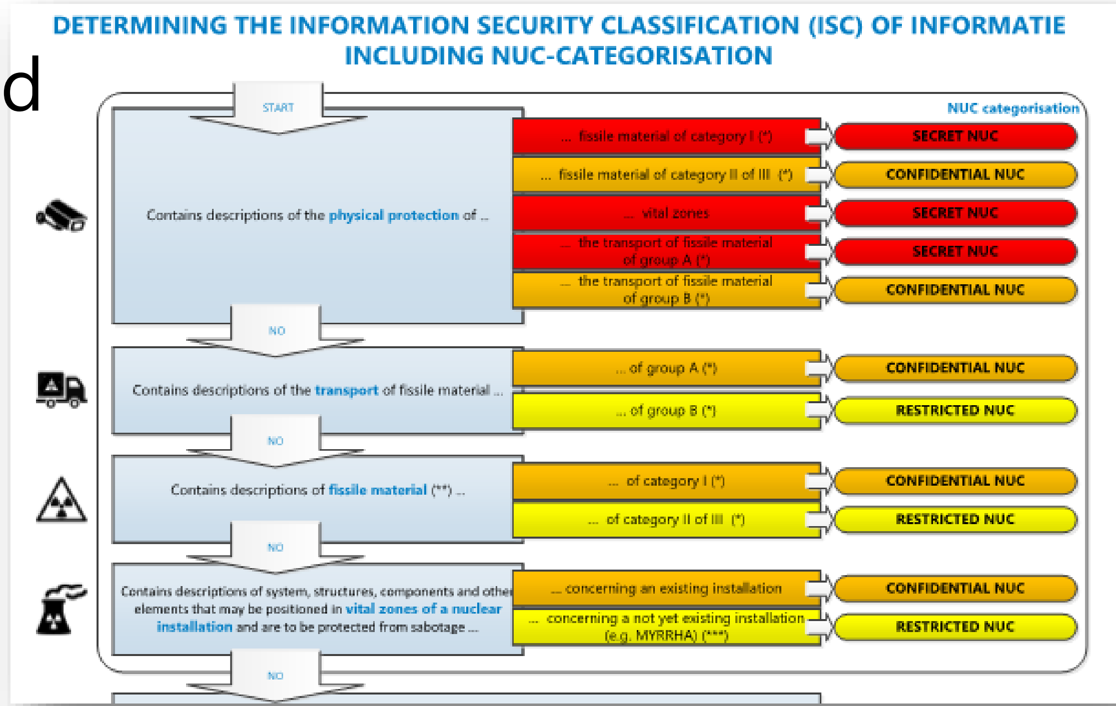
ICT Security: Information Protection

- Security Control Matrix
  - Horizontal: action centered
  - Vertical: label centered



- Mostly procedural: clear instructions and tools paramount



- Human Factor

- Reduction to Physical Access

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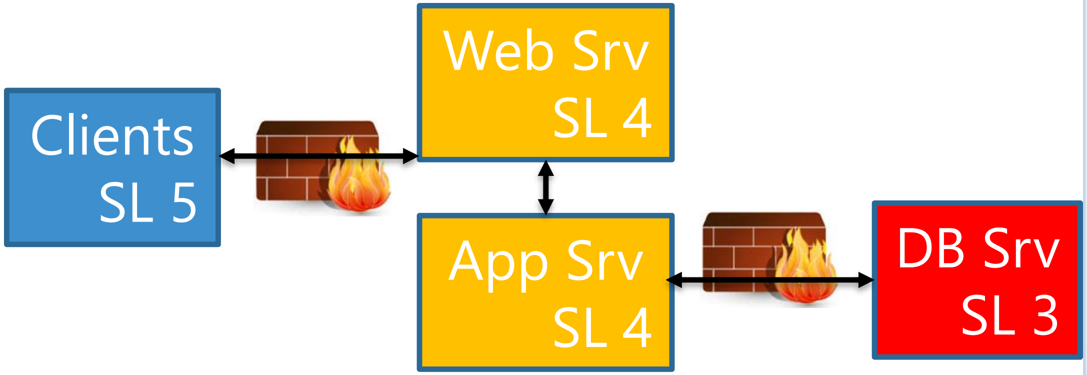
ICT Security: Application Security

- Applications: portal to
  - Information (eg ERP, Doc Mgt)
  - System control (eg HMI)
- Security COTS often obscure
  - Penetration testing
- Secure coding guidelines
  - OWASP, SAMM
  - Threat modelling
- Multi-tier setup



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Reasons to invest in Project MYRRHA

1 **Solution for nuclear legacy:** MYRRHA closes the nuclear fuel cycle with a sustainable and economic solution for spent nuclear fuel legacy (over 180,000 tons* globally)

2 **Crucial medical radio-isotopes:** MYRRHA saves lives in the form of medical radio-isotopes which are crucial for radio-diagnostics and radio-therapy

3 **Direct financial return:** investment re-paid over lifetime, pay-back time of 24 years

4 **Indirect financial return:** MYRRHA creates over 2,500 full-time jobs

5 **Economics from Intellectual Property:** Valorisation and commercialisation of components of MYRRHA, e.g. radio-isotopes, SMR, Oxygen sensor and control,…

6 **Contributes to strategic EU objectives:** MYRRHA recognized by EU to support objectives of a knowledge-based economy (on ESFRI Roadmap, MYRRHA is 1 out of only 4 EU Research Infrastructures in category "Energy") and Energy Union (SET Plan)

7 **Large R&D network:** MYRRHA is embedded in a worldwide R&D network from academia, research organisations and industries

Source: "The MYRRHA ESFRI Project" report by EC Commissioner G. Oettinger and Secretary of State M. Wathelet, May 2013; SCK•CEN MYRRHA Project Team, MYRRHA Business Plan
*Note: *Excluding weapon-grade material*

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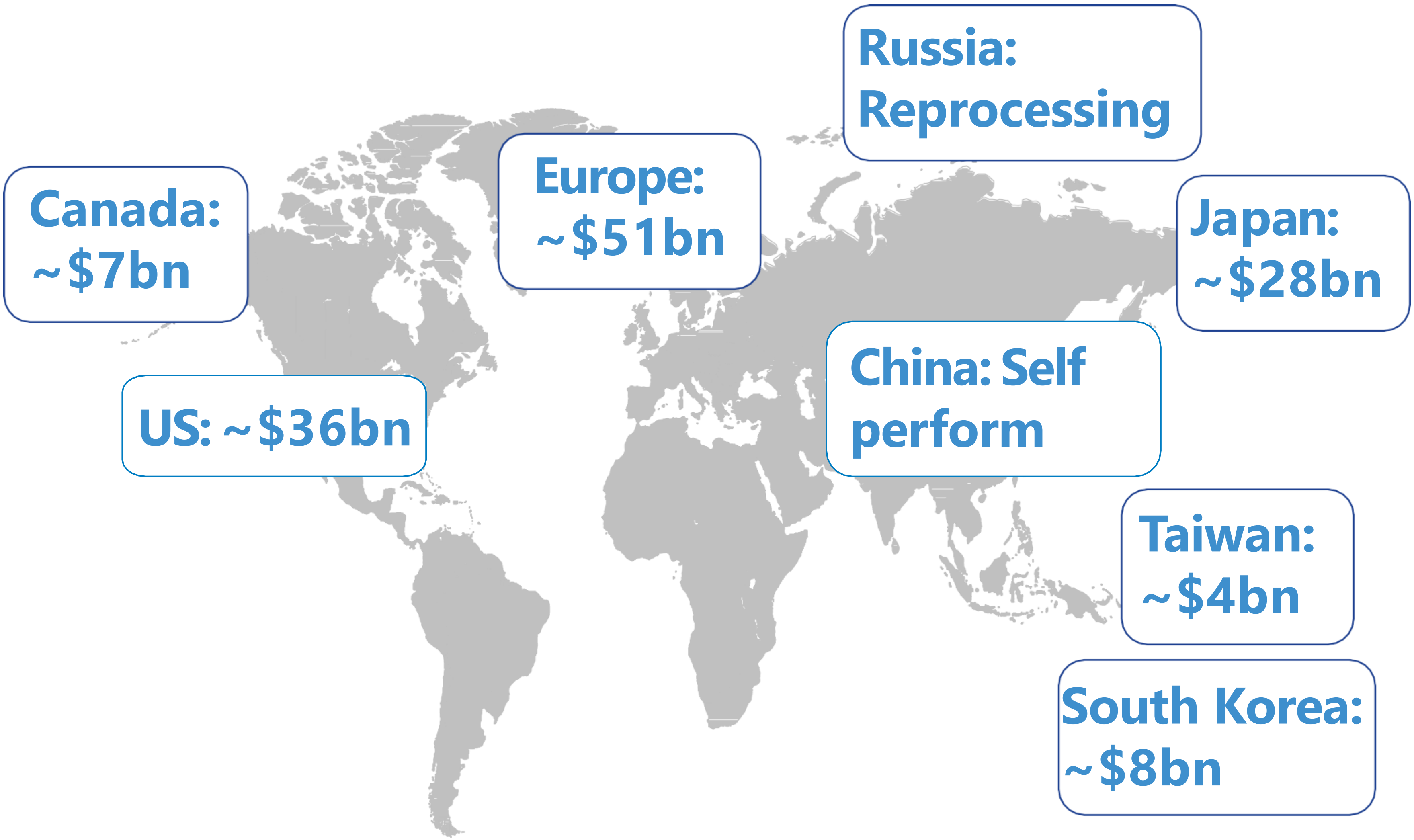
1

Cost estimates for Western World legacy of 180,000 tons of spent nuclear fuel with existing technology exceed USD 100bn



Source: Presentation by General Electric Hitachi (David Powell) at the Agoria SMR Event in Brussels on November 8th 2016. Based on http://fissilematerials.org/library/rr10.pdf, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51035-NuclearWaste_Testimony.pdf *Japan Times,* http://www-pub.iaea.org/MTCD/publications/PDF/te_1100_prn.pdf
OECD Nuclear Energy Agency, Nuclear Energy Data Annual, ***2009***

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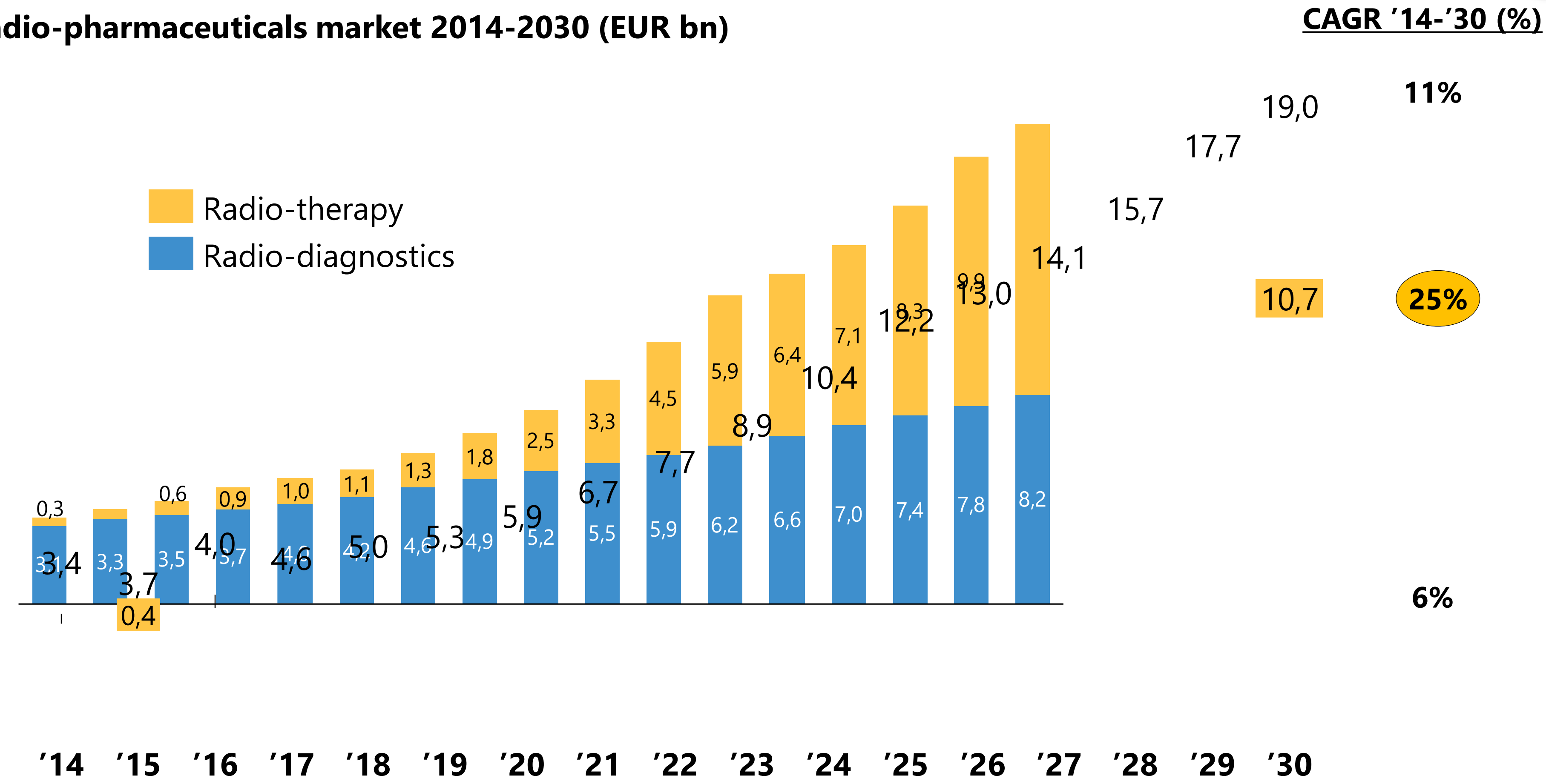
MYRRHA guarantees continuity of medical radio-isotope production, both Mo-99 and innovative therapy isotopes

2

Radio-pharmaceuticals market 2014-2030 (EUR bn)



The end-market (i.e. at patient level) for radio-pharmaceuticals is projected to grow at 11% per year until 2030, with Radio-therapeutics driving the growth at 25% per year

Source:MedRaysIntell Nuclear Market report 2015

ISC: Public

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MYRRHA is recognized in Europe to contribute to strategic objectives of both Energy and Knowledge economy

ESFRI
European Strategic Forum for Research Infrastructure

SET Plan
European Strategic Energy Technologies Plan

EIB InnovFin	MYRRHA is selected by the **European Investment Bank (EIB)** as a potential project for financing and benefits from advisory services from EIB InnovFin
Juncker Plan	MYRRHA is on the list of projects candidate to be financed by the **European Fund for Strategic Investments** (**EFSI**, also called **"Juncker plan"**)

Source: European Strategy Forum on Research Infrastructures (ESFRI), European Strategic Energy Plan (SET), EIB InnovFin, SCK•CEN MYRRHA Project Team

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MYRRHA is embedded in an international R&D network

CHINESE ACADEMY OF SCIENCES
NATIONAL NUCLEAR CENTER OF THE REPUBLIC OF KAZAKHSTAN
KAZATOMPROM
НАЦИОНАЛЬНАЯ АТОМНАЯ КОМПАНИЯ

AnsaldoNucleare
EMPRESARIOS AGRUPADOS
AREVA
iba
OXFORD TECHNOLOGIES
TRACTEBEL Engineering GDF SUEZ
NNC
SENER
ADEX Adaptive Predictive Expert Control

SCK•CEN
CSIC
KIT
itn
cnrs
cea
ENEA
NRG
PAUL SCHERRER INSTITUT PSI
ÚJV
INRNE
JRC
CIEMAT
Forschungszentrum Jülich
Forschungszentrum Rossendorf
INFN

ULg Université de Liège
KTH
UPPSALA UNIVERSITET
UCL Université catholique de Louvain
KATHOLIEKE UNIVERSITEIT LEUVEN
GSI
enen
Escuela Universitaria de Ingeniería Técnica Topográfica
UNIVERSIDAD POLITECNICA DE VALENCIA
USC
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Source: SCK•CEN MYRRHA Project Team

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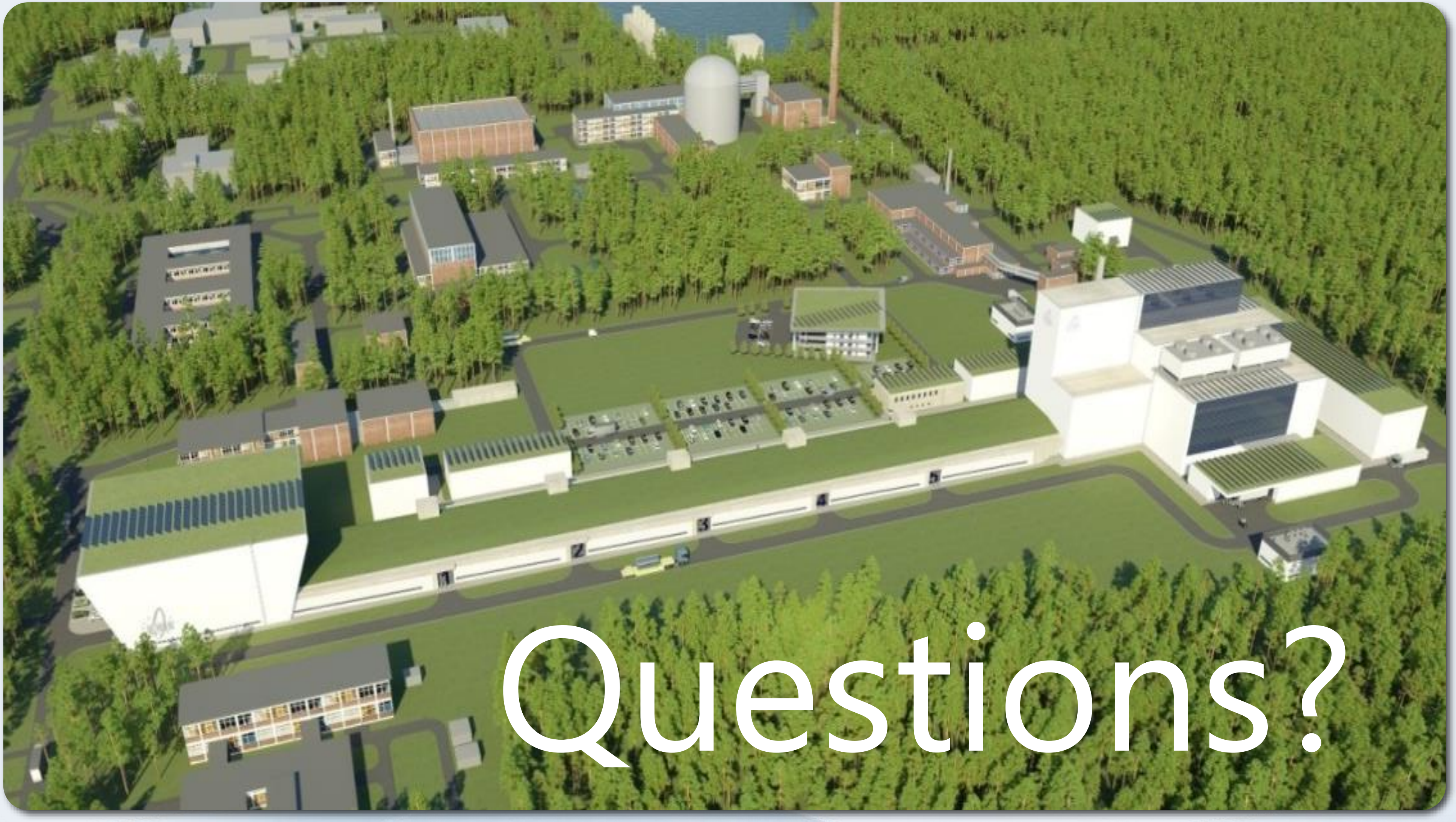
A jump in the future for pioneering innovation in Belgium
For sustainable nuclear energy in Europe



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