Belgian Nuclear Research Centre

Virtual reality tools for education and training

Riccardo Rossa

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rrossa@sckcen.be

Motivation

- Access to nuclear facility and nuclear material is not straightforward
  - Availability, safety & security, travel restrictions, ….
- Hands-on activities are essential components in the learning process
  - Exercises and lab sessions are often the most appreciated
- Virtual reality offers a valuable alternative to in-person activities
  - Advances in computing performance
  - Availability of software/hardware
  - Opportunity to increase students engagement

Virtual Reality tools developed by SCK CEN

- Virtual Platform for Safeguards Education and Training (VIPSET)
  - Finding radioactive sources in outdoor environment
  - Safeguards verification for bulk facilities
  - Training course on sampling plan
  - Use of different radiation detectors
  - Model of a nuclear research reactor

- VR tools developed with Unity3D
  - Use of computers rather than VR goggles
  - Available as stand-alone applications
  - Cyber attack removed possibility for web-browser use
    - Work in progress to restore this capability

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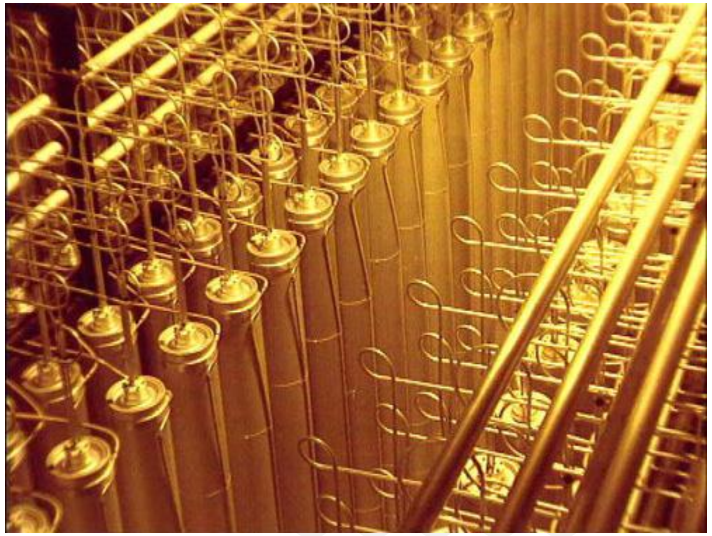
Safeguards in bulk facilities

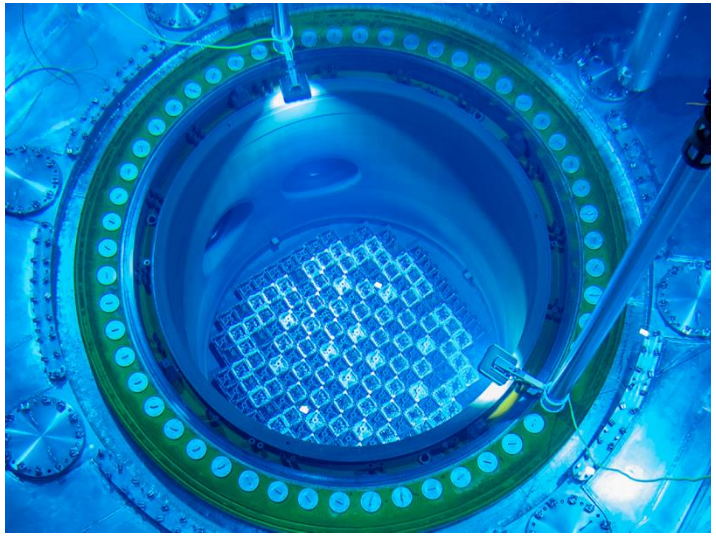
Facility types for safeguards

- Bulk facilities: nuclear material is processed continuously in open form (gaseous or liquid flows)
  - e.g. enrichment and reprocessing plants
- Item facilities: nuclear material is handled in individual items with defined mass and form (e.g. fuel elements)
  - e.g. nuclear reactors and storages

Ref: World Nuclear Association



Ref: US Department of Energy



Material balance area (MBA) evaluation kits

- Developed at PNNL from experience in offering safeguards courses for national inspectors
- Main goal: teach about conducting nuclear material inspections using a hands-on approach without nuclear material or facility

- Versatile kits were developed for item- and bulk-handling facilities
- Characteristics of developed kits:
  - Easy to use and manufacture
  - Easy to transport: fit a Pelican case
  - Use of low-cost but effective materials: ~10kUSD
  - Extensive supporting material for training course

Versatile MBA evaluation kits

MBA evaluation kits for
bulk facilities

MBA evaluation kits for
item facilities

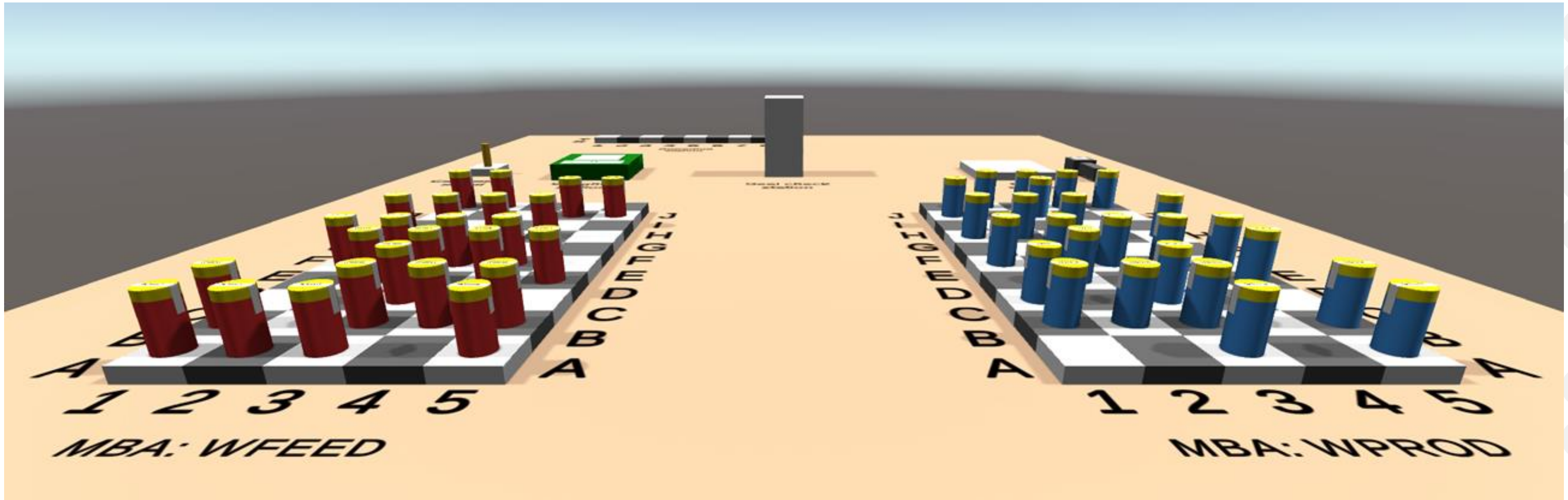
Available exercises in the MBA evaluation kits

- Training scenarios introduce participants to the typical activities conducted and possible defects detected by the IAEA during a Physical Inventory Verification:
  - comparing records and reports,
  - nuclear material accounting,
  - statistical sampling,
  - verification measurements,
  - inventory reconciliation, …..

- The training scenarios can be adjusted based on participant need

The VIPSET virtual facility

- Software for applying safeguards to bulk-handling facilities
  - Work inspired from the MBA evaluation kits developed at PNNL
  - Virtual Reality software representing 2 MBA's
  - Set of supporting documents (e.g. physical inventory, measurement forms,….)



VIPSET facility – supporting documents

DOES NOT REPRESENT AN ACTUAL FACILITY

OFFICIAL REPORT TO THE INTERNATIONAL ATOMIC ENERGY AGENCY
STATE OF SOUTHLAND

EFFECTIVE THROUGH 31 July 2020

Exercise - Bulk facility | Document 2

FACILITY: VIPSET
PHYSICAL INVENTORY LISTING

Line	MBA	Storage Location	Container ID No.	TID Number	Gross Weight (grams)	Element Weight (grams)	Isotope Weight (grams)	Element Code
1	WFEED	A2	FS01002	1610002	576	476	433	HEU - Metal
2	WFEED	B5	FS02005	1705005	690	590	537	HEU - Metal
3	WFEED	A5	FS01005	1610005	660	560	510	HEU - Metal
4	WFEED	E3	FS04008	1812028	537	437	398	HEU - Metal
5	WFEED	B4	FS02004	1705004	521	421	383	HEU - Metal
6	WFEED	B2	FS02002	1705002	550	450	410	HEU - Metal
7	WFEED	D4	FS04004	1812024	574	474	431	HEU - Metal
8	WFEED	C3	FS02006	1705006	510	410	373	HEU - Metal
9	WFEED	D5	FS04005	1812025	623	523	476	HEU - Metal
10	WFEED	B1	FS02001	1705001	607	507	461	HEU - Metal
11	WFEED	B3	FS02003	1705003	690	590	537	HEU - Metal
12	WFEED	E1	FS04006	1812026	675	575	523	HEU - Metal
13	WFEED	A1	FS01001	1610001	539	439	399	HEU - Metal
14	WFEED	I5	FS09002	2003002	587	487	443	HEU - Metal
15	WFEED	G2	FS07019	1911046	694	549	500	HEU - Metal
16	WFEED	G1	FS07018	1911045	603	503	458	HEU - Metal
17	WFEED	A3	FS01003	1610003	680	580	528	HEU - Metal
18	WFEED	E4	FS04009	1812029	566	466	424	HEU - Metal
19	WFEED	I4	FS09001	2003001	580	480	437	HEU - Metal

Exercise - Bulk facility | DOES NOT REPRESENT AN ACTUAL FACILITY | Document 5

INSPECTOR RECORD OF MEASUREMENTS

INSPECTION DATE:		INSPECTED FACILITY:	

Calibration of electronic balance (+/- 3 grams at 1σ)

	Calibration weight ID	Declared weight (grams)	Measured weight (grams)	Difference (grams)	Pass/Fail: (exceeds +/-3σ)	Comments
Before inspection						
After inspection						

			OPERATOR declared			INSPECTOR verification		INSPECTOR evaluation		
Material Form	Cylinder ID	Seal ID	Gross Weight (grams)	Tare Weight (grams)	Net Weight (grams)	Gross Weight (grams)	Gross Weight Difference (grams)	Pass/Fail Weight (exceeds +/-3 σ)	Pass/Fail Seal integrity (yes/no)	Comments

SAFEGUARDS INSPECTOR (Print):		SIGNATURE:	

The VIPSET virtual facility

- Available exercises:
  - Verification of reporting: facility book, official declaration to IAEA, VR environment
  - Statistical sampling: draw sampling plan using an Excel file in the supporting documents
  - Measurements: weight, seal integrity, NDA
  - Reconciliation with operator

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Exercise - Bulk facility — Document 2

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Exercise - Bulk facility — DOES NOT REPRESENT AN ACTUAL FACILITY — Document 6

Southland Production Facility

Shipping Document

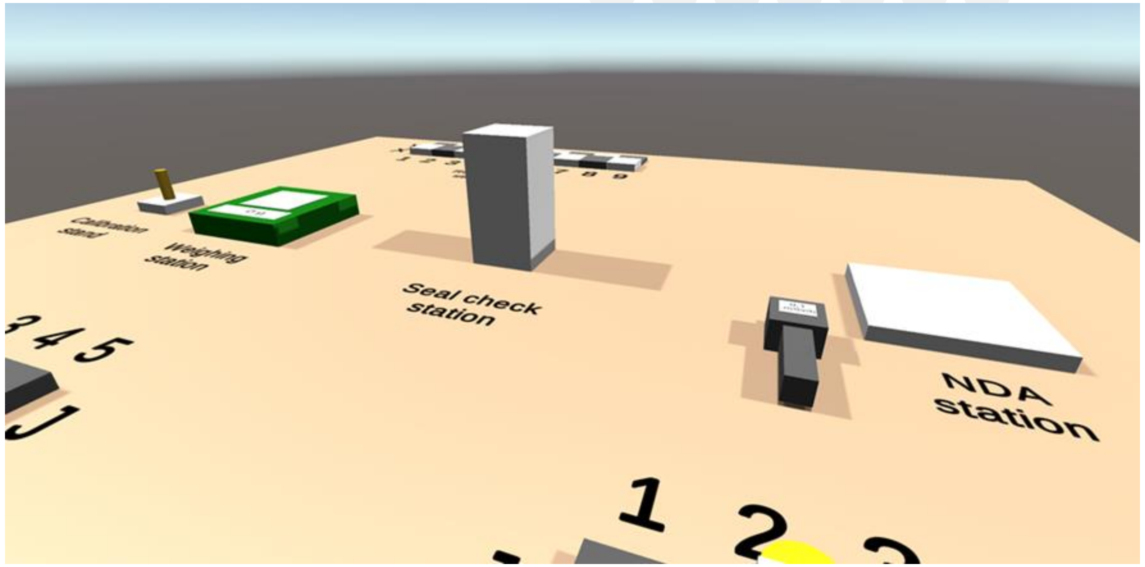
Date: 18 May 2017

Shipped to: VIPSET Facility

Material Form	Container ID No.	Gross Weight (grams)	Tare Weight (grams)	Element (net) Weight (grams)	Isotope Weight (grams)	Element Code
HEU – Metal	FS02001	607	N/A	N/A	461	HEU
HEU – Metal	FS02002	550	N/A	N/A	410	HEU
HEU – Metal	FS02003	690	N/A	N/A	537	HEU
HEU – Metal	FS02004	521	N/A	N/A	383	HEU
HEU – Metal	FS02005	690	N/A	N/A	537	HEU
HEU – Metal	FS02006	510	N/A	N/A	373	HEU

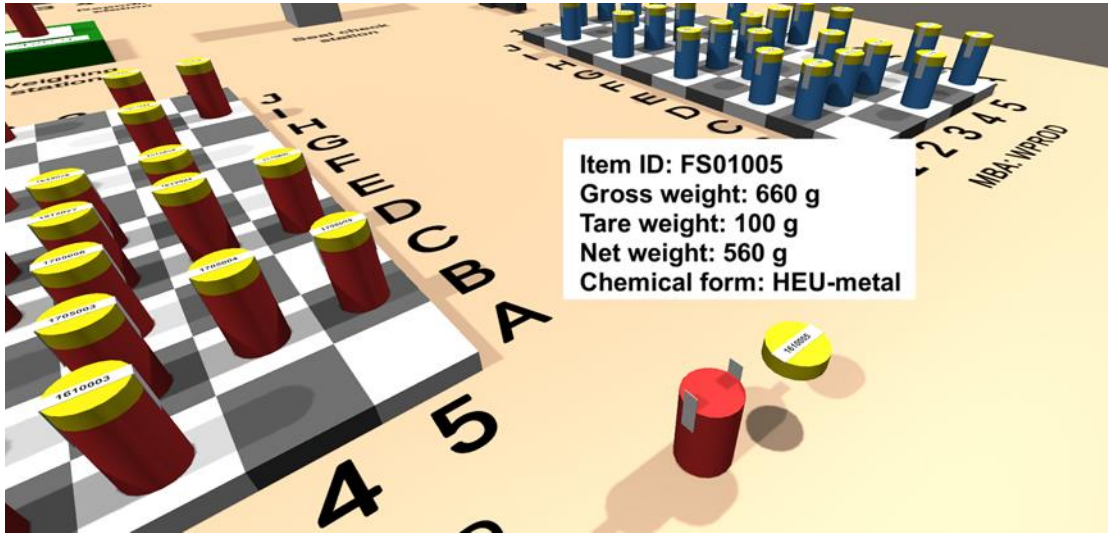
MBA Custodian Signature: __Melissa Orton__________________

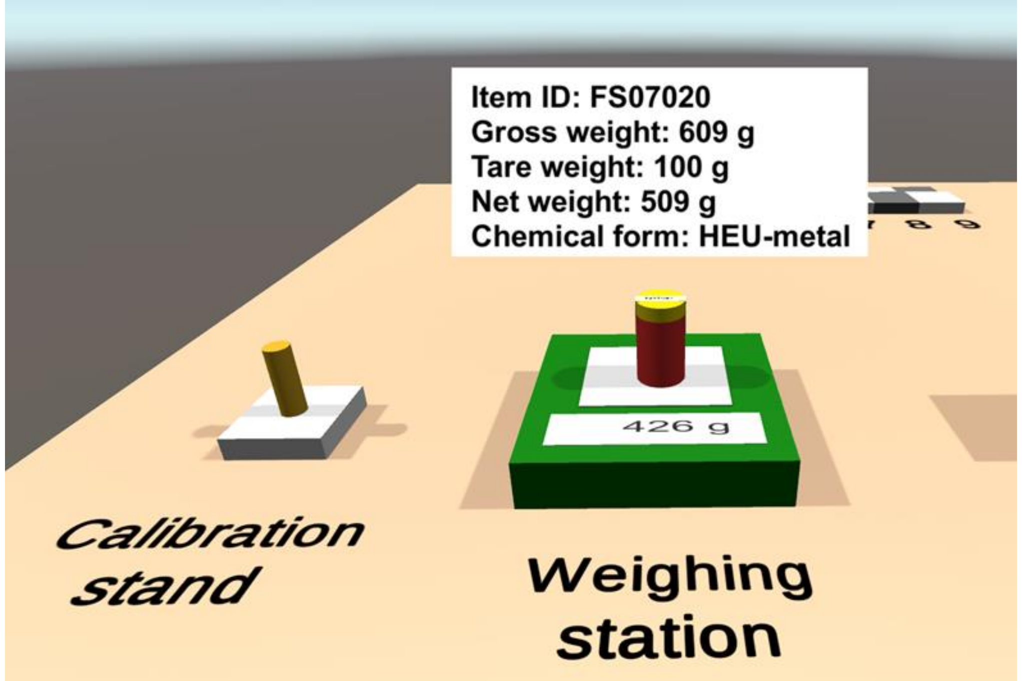
MC&A Manager Signature: __Marc Callaway__________________

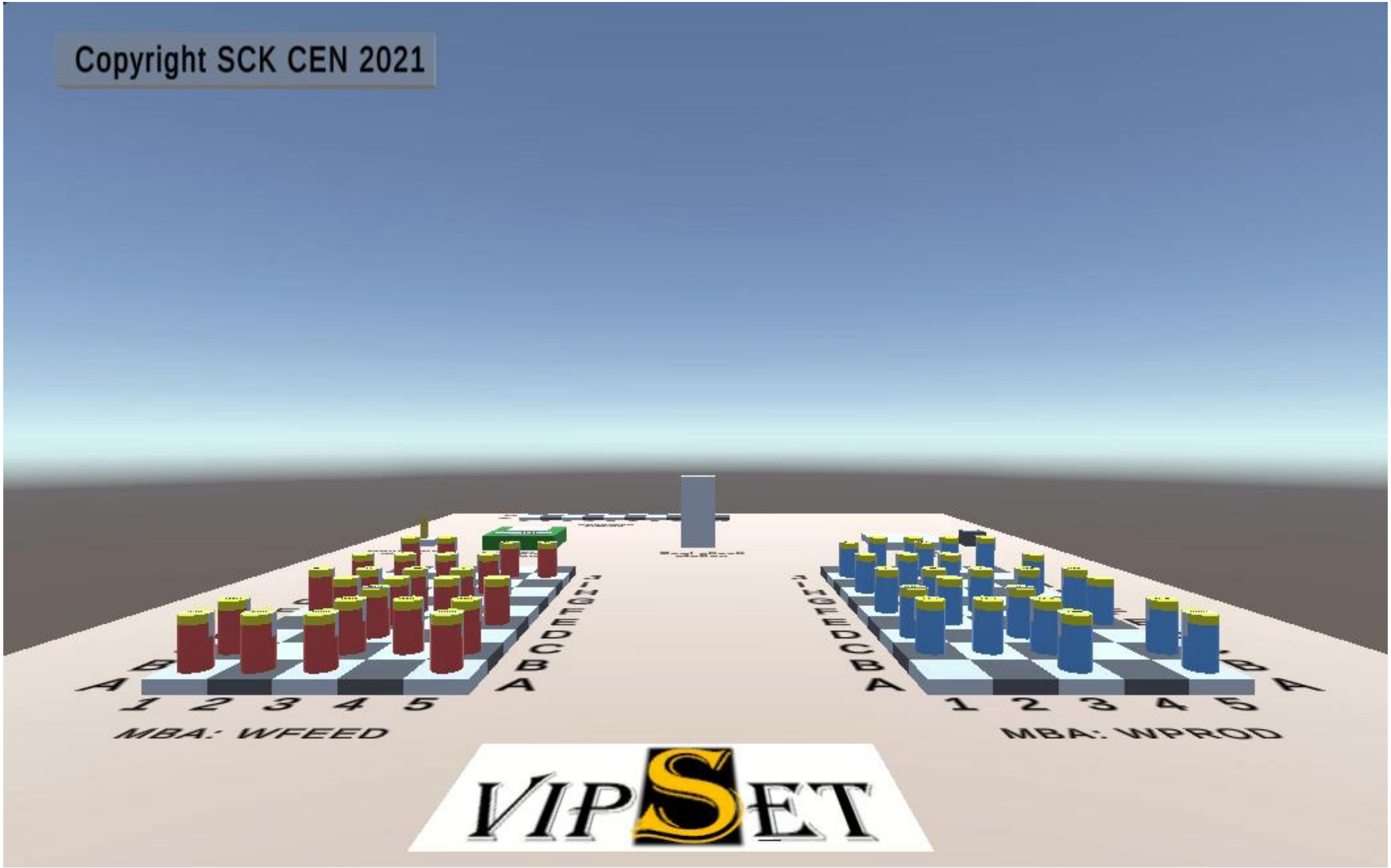


The VIPSET virtual facility

- List of defects implemented:
  - Clerical errors
  - Differences in can positioning
  - Bias, partial, and gross defects
  - Seals incorrectly placed or broken







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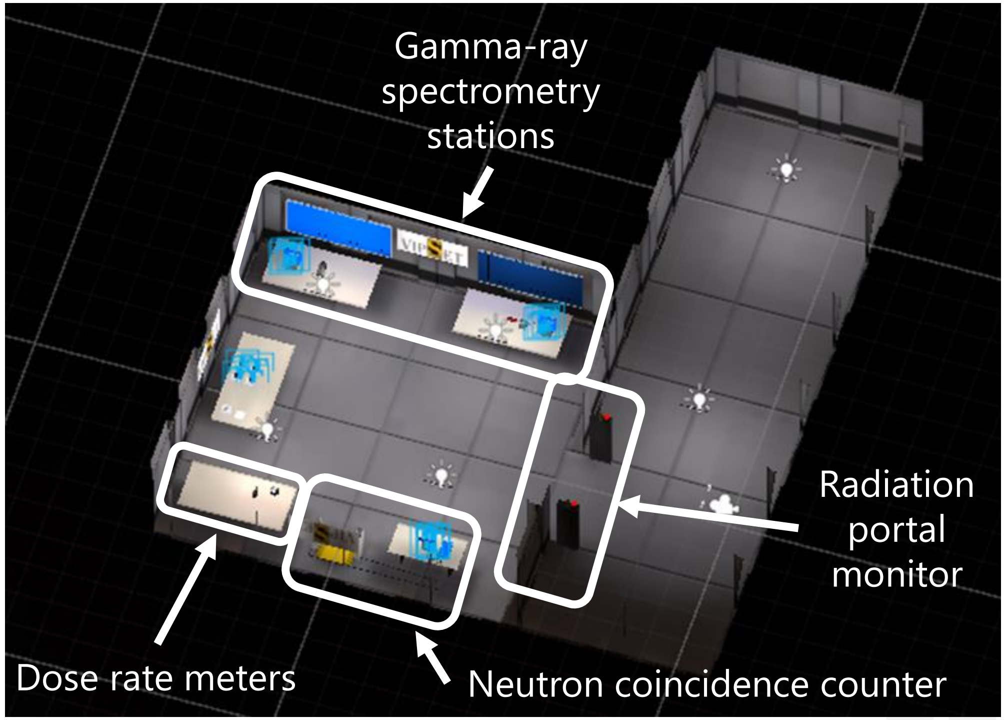
A
B
1 2 3 4 5
MBA: WFEED
MBA: WPROD
VIPSET

Radiation detection

VIPSET for radiation detection

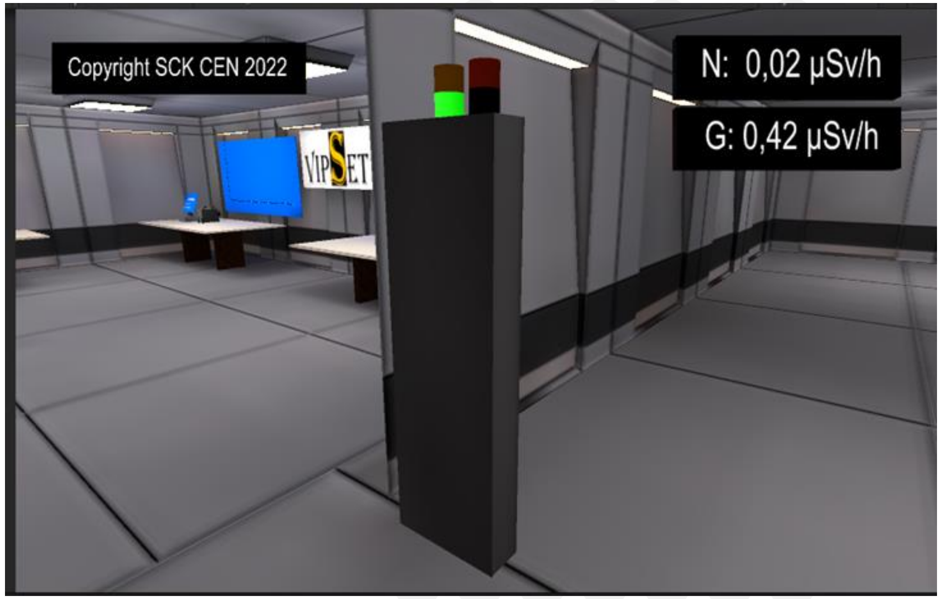
- Simple room with a set of radiation detectors and sources
- Implemented detectors:
  - Radiation portal monitor
  - Portable dose rate meters
  - Neutron coincidence counters
  - Gamma-ray spectrometers
- Available sources:
  - Neutrons: ^{252}Cf, ^{240}Pu
  - Gamma-rays: ^{137}Cs, ^{60}Co

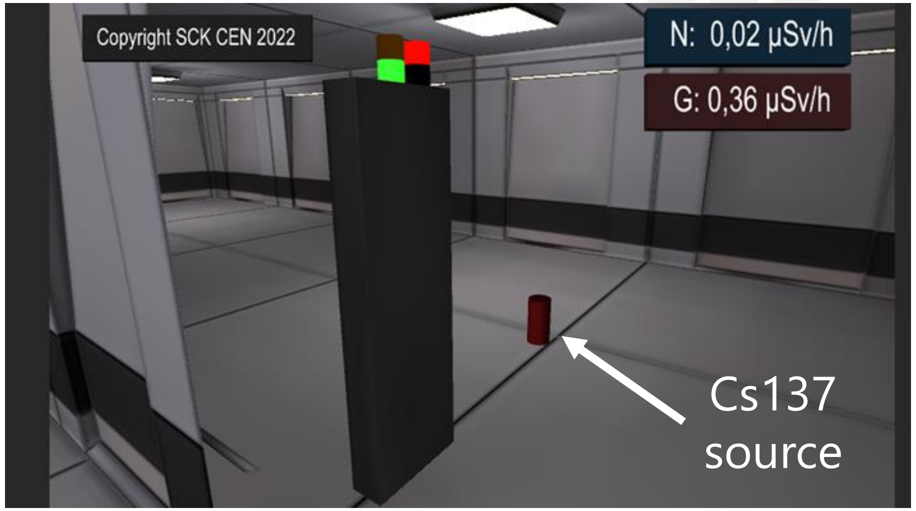


- All detector responses are updated to reflect positions of detectors & sources

Radiation portal monitor

- RPM placed at entrance of measurement room
- Four lights on top of each pillar
  - Green: regular status
  - Orange: system error
  - Red: gamma-ray alarm
  - Blue: neutron alarm
- System error triggered for high background
- Alarms are based on dose rate values
  - Gamma-rays: point model assumptions
  - Neutrons: precomputed Monte Carlo simulations

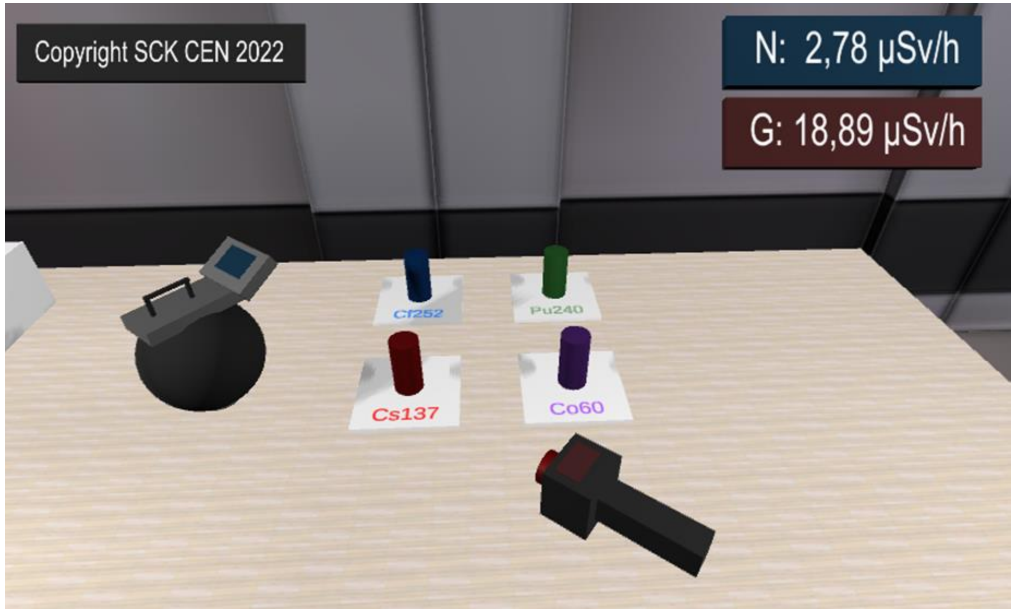




Portable dose rate meters

- Gamma-ray detector
  - Similar to FLIR IdentiFinder
  - Detector response based on point model
  - Attenuation due to shielding also included

- Neutron detector
  - Similar to Berthold LB6411
  - Detector response based on
    precomputed Monte Carlo simulations
  - Influence of moderators to be implemented



https://www.berthold.com/en/radiation-protection/products/dose-and-dose-rate/neutron-dose-rate-probe-lb-6411/
https://www.flir.eu/products/identifinder-r400/?vertical=radiation&segment=detection

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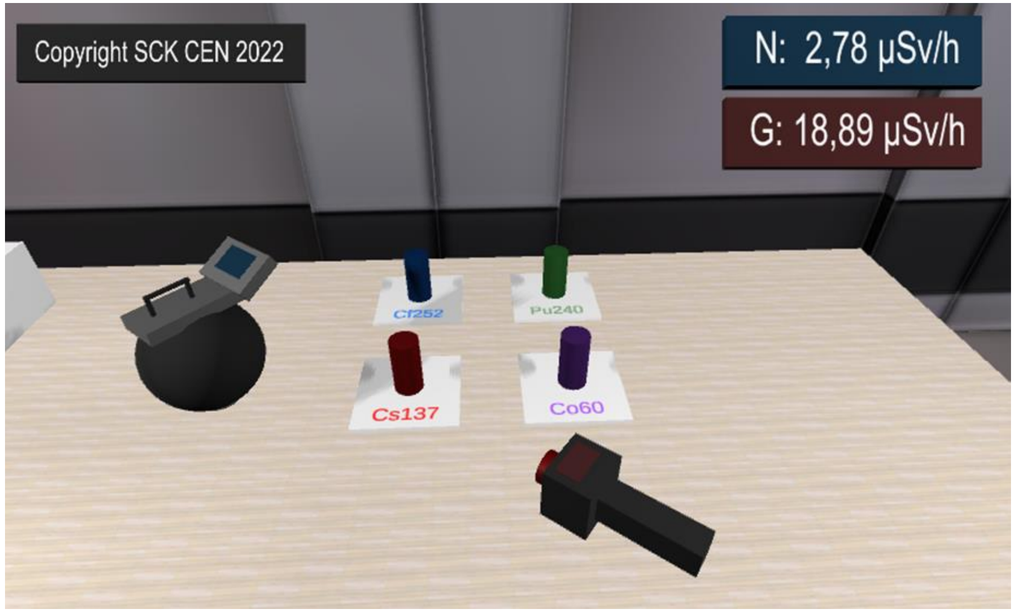
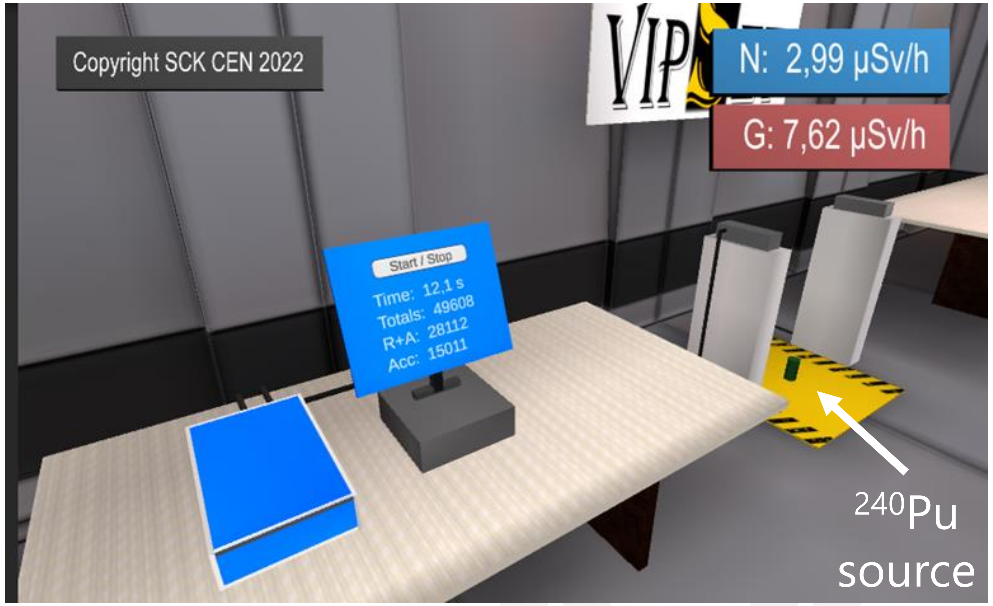
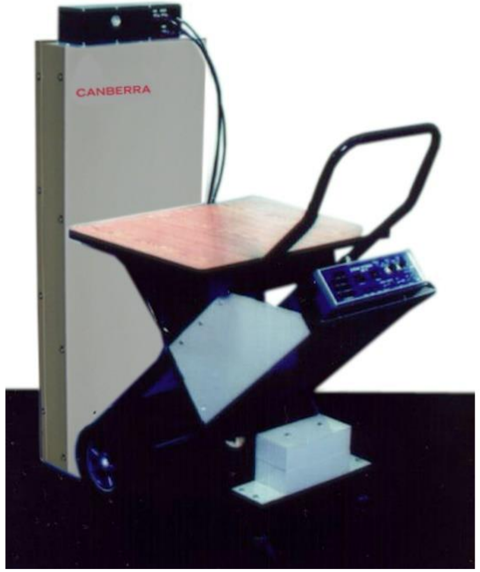


Neutron coincidence counters



- Detectors based on Canberra WM3400 slab counters
- Data acquisition system based on JSR-12 shift register
- Detectors response based on precomputed Monte Carlo simulations
  - Measurement time
  - Total counts
  - Real+Accidental counts
  - Accidental counts



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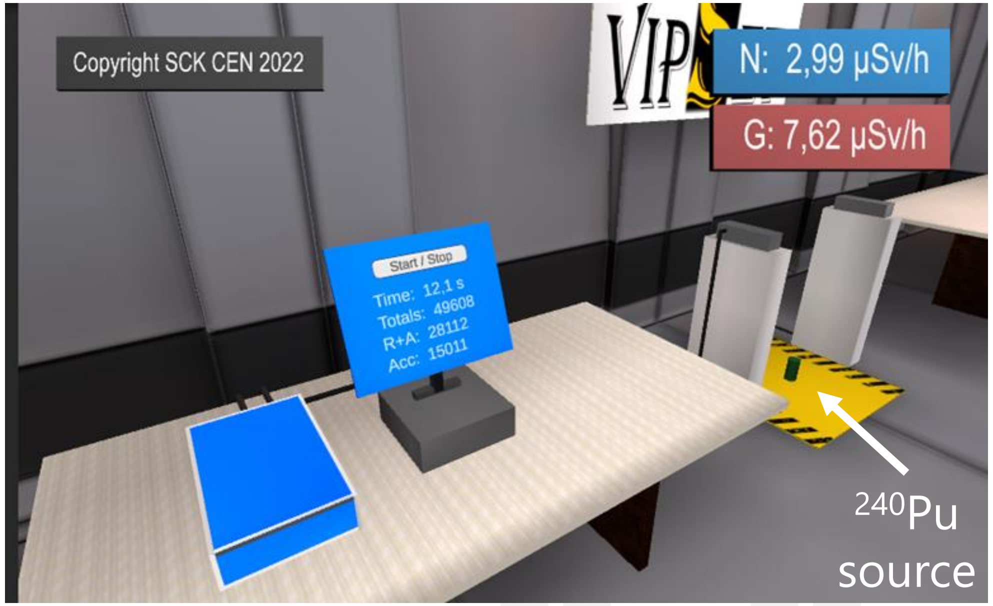
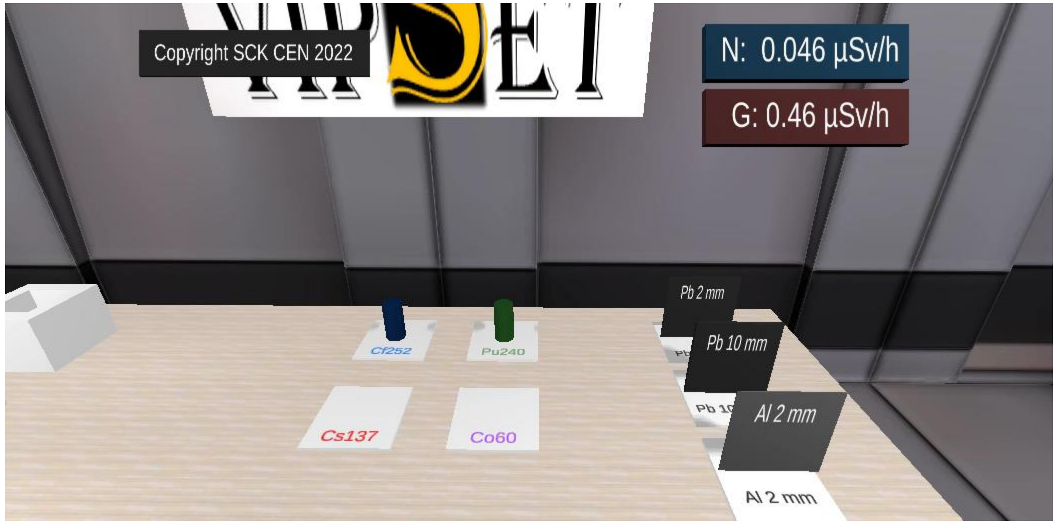
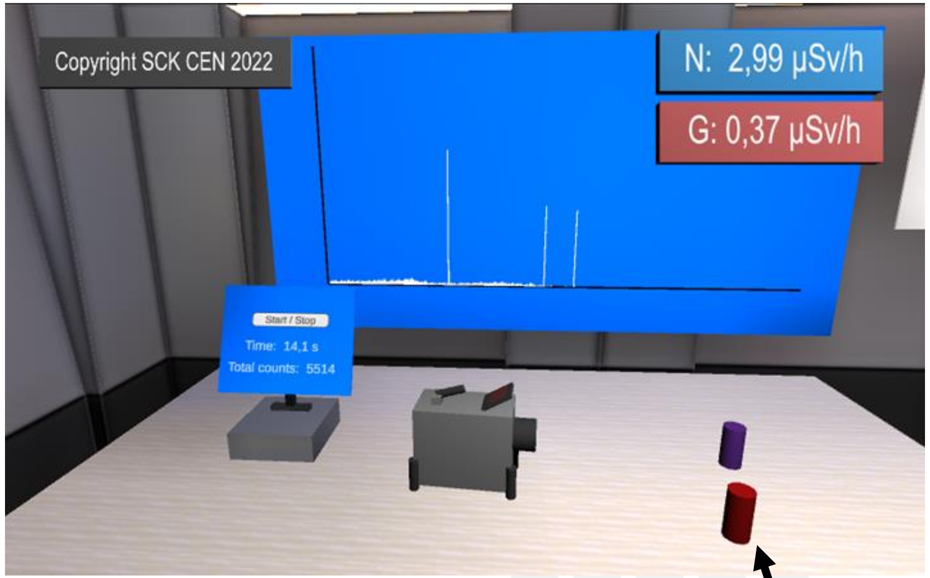


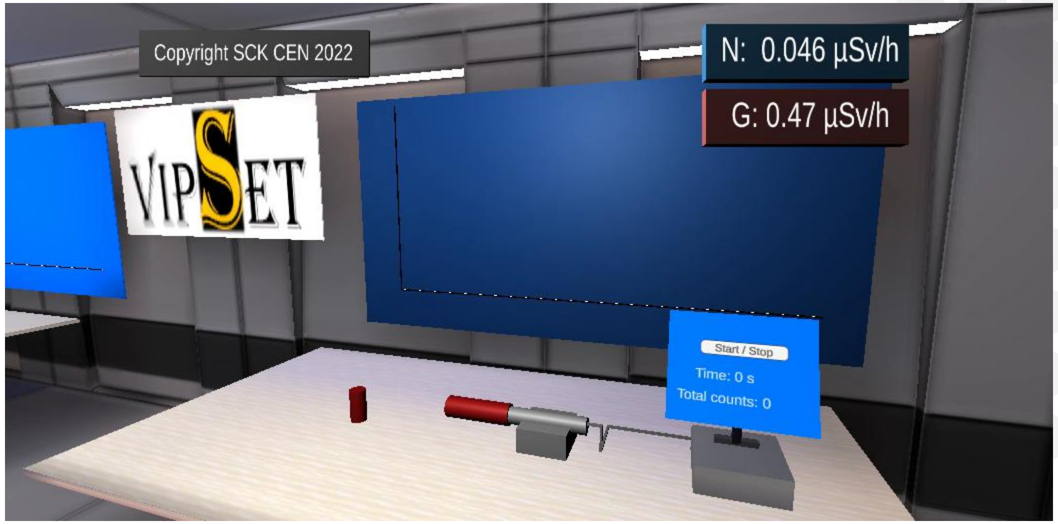


Gamma-ray spectroscopy

- HPGe and NaI detectors already implemented
  - HPGe: portable detector
  - NaI: fixed measurement station
- Detector responses based on Nucleonica
  - Total count rate
  - Energy spectra
  - Presence of shielding
- Data acquisition system:
  - Spectra from MCA with 512 channels
  - Measurement time
  - Total counts



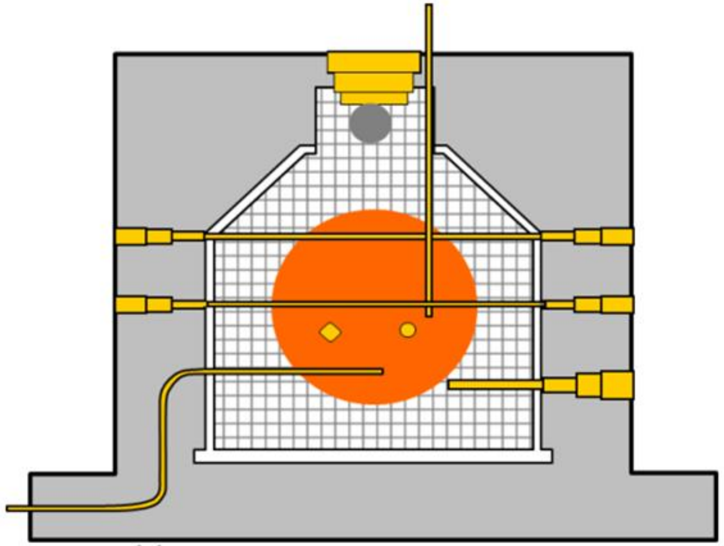
^{60}Co & ^{137}Cs sources



Research reactor

Example of research reactor: BR1

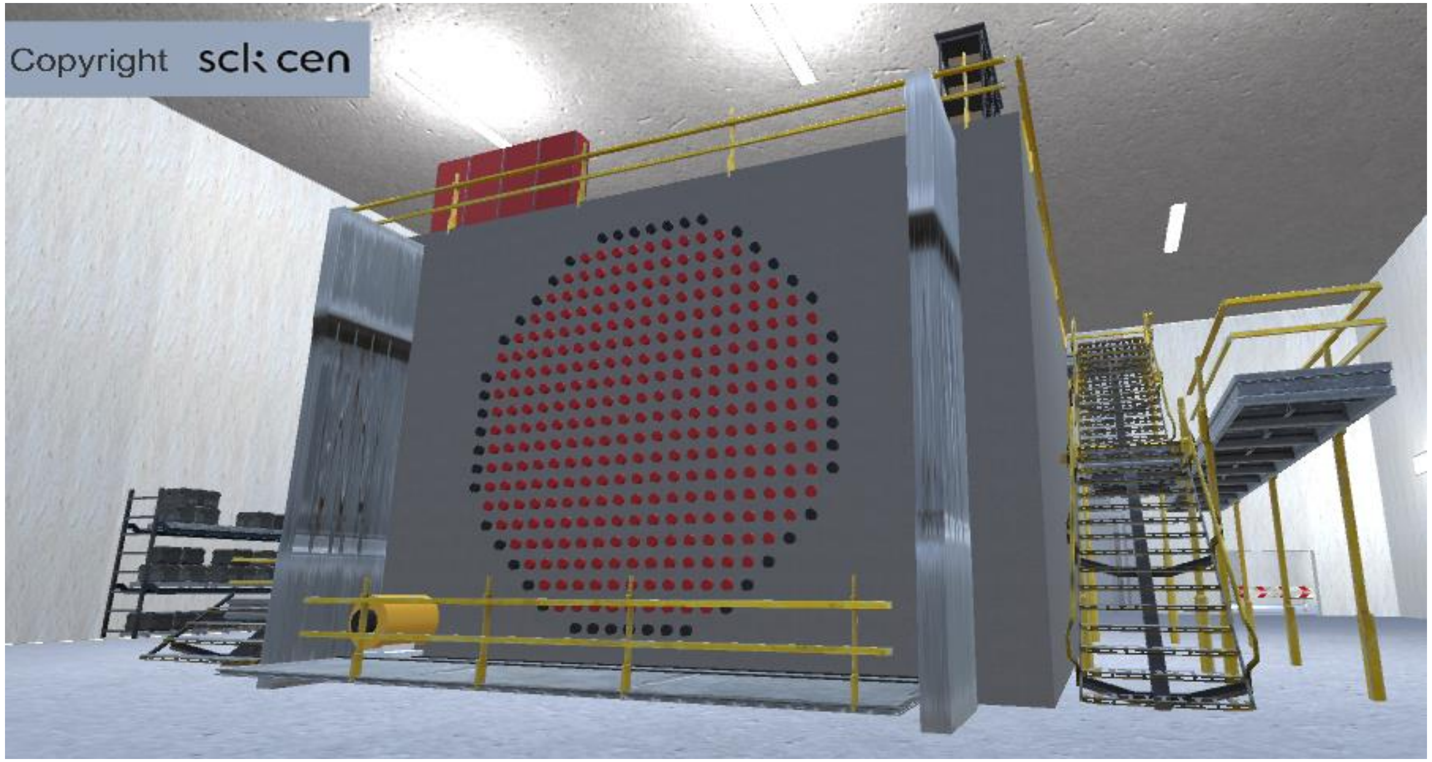
- Oldest research reactor in Belgium
  - First criticality: 11 May 1956
- Maximum power of 1 MW
- Graphite-moderated, air-cooled
  - ~500 t of graphite, ~7x7x7 m^3
- Natural metallic uranium
  - 569 channels loaded with fuel
  - Fuel element length: ~20 cm
  - 70 channels used for experiments

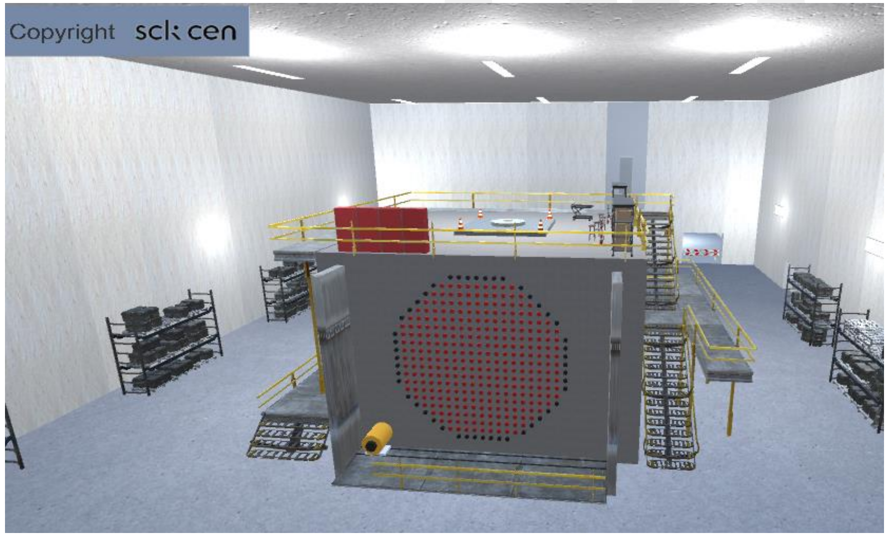


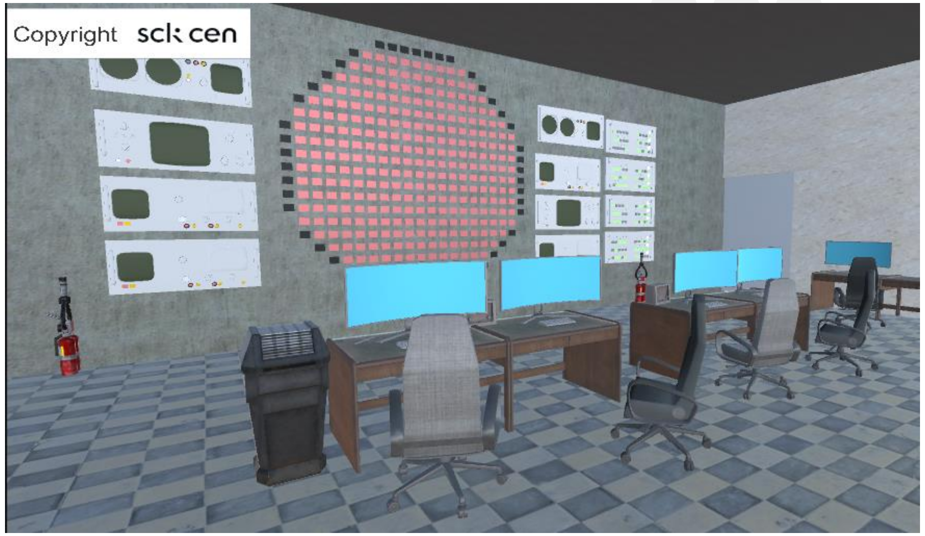
Virtual reality research reactor

- Part of the Belgian support programme to the IAEA
  - Some examples from BR1
  - <u>BUT no design information to avoid security and confidentiality issues</u>

Virtual reality research reactor

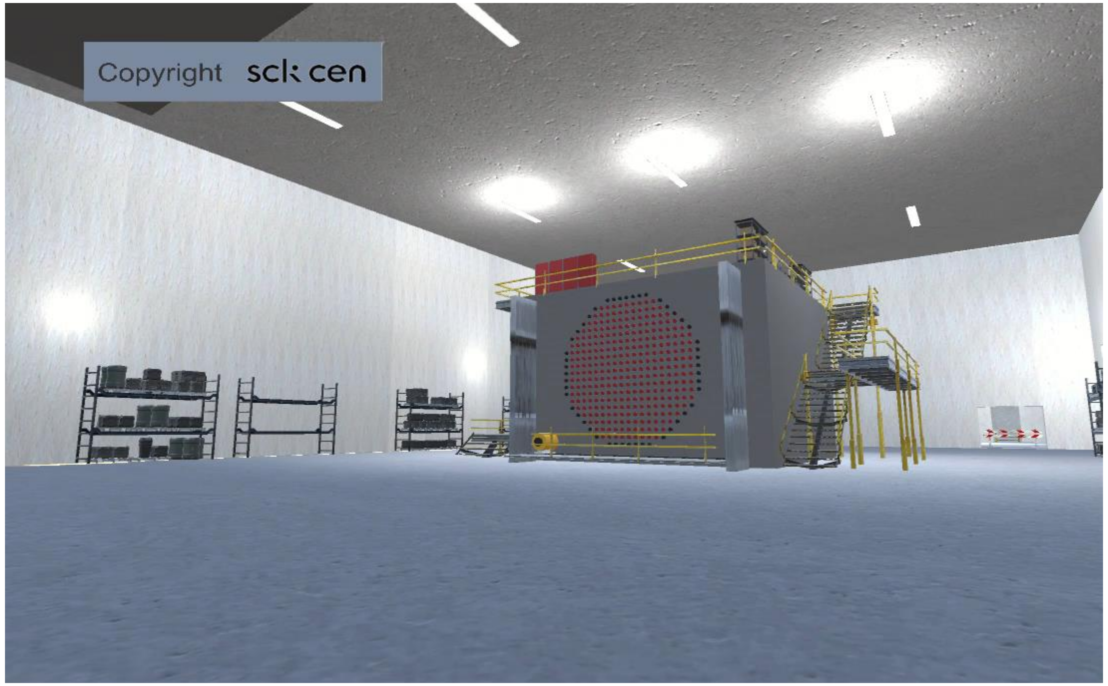


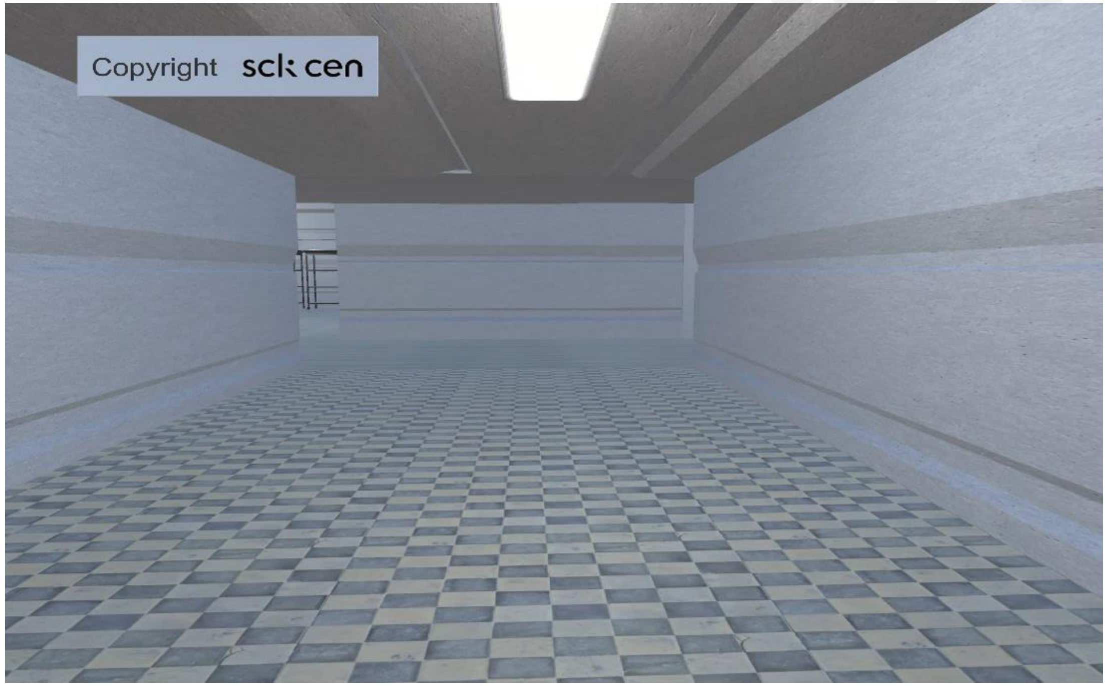




Design information verification

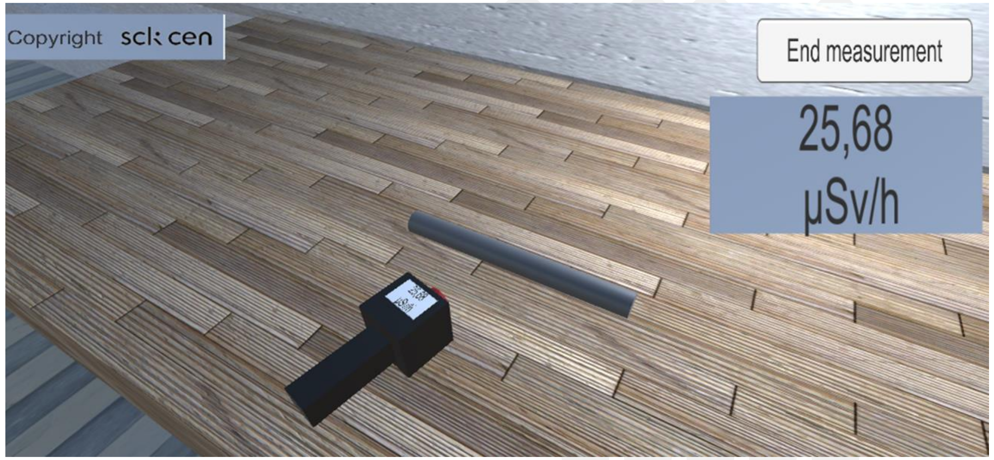
- User can move freely inside the facility
- Supporting documents provided to students to simulate Design Information Verification

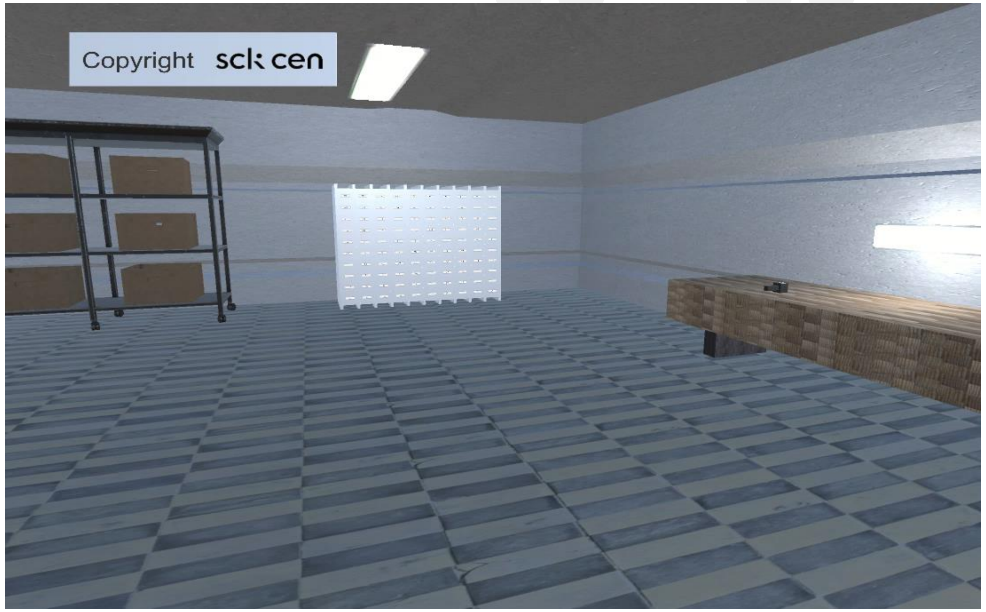




Fresh fuel measurement

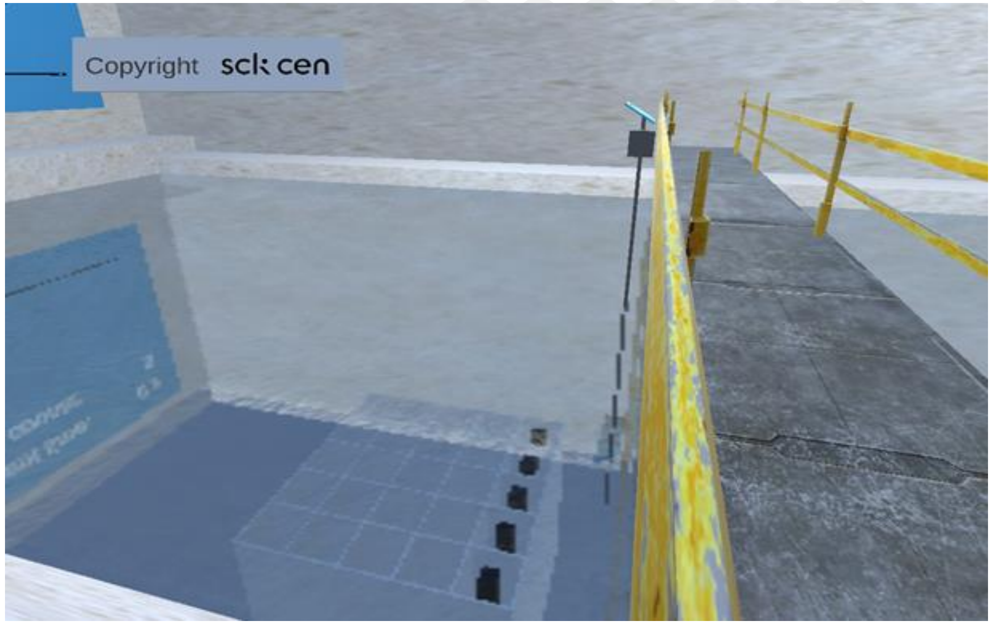
- Fresh fuel storage modelled in dedicated facility area
- Fuel elements modelled as line sources
- Possibility to measure the gamma-ray dose rate from fresh fuel with hand-held detector
- Possibility to verify fuel active length
- Partial and gross defects included in fresh fuel storage





Spent fuel measurement

- Spent fuel storage modelled in dedicated facility area
- Fuel elements modelled as point sources
- Possibility to measure the gamma-ray spectra from spent fuel
- Gamma-ray spectra based on simulations with Nucleonica
- Possibility to verify presence of fission products



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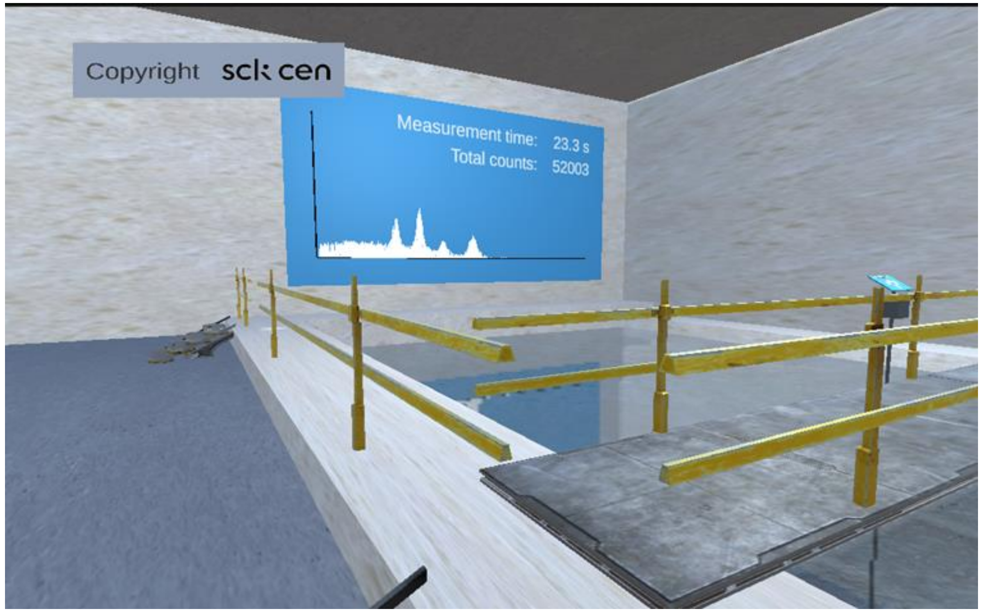

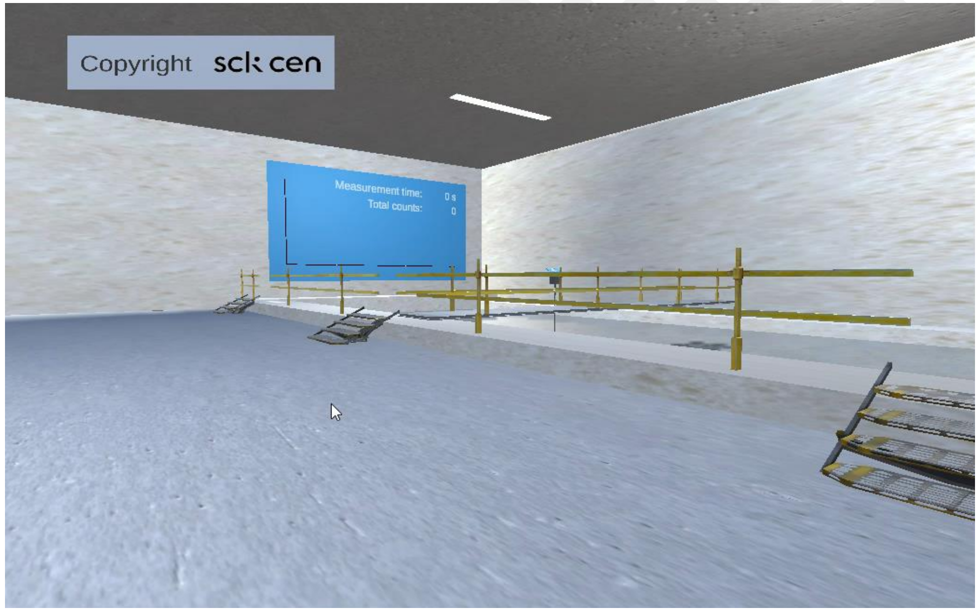

Conclusion

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- Virtual reality tools developed for a range of applications
  - Training for new colleagues
  - Refresher course for experienced staff
- Maximum flexibility considered from early design
  - Stand-alone software
  - Work in progress to restore web-based applications
- Realistic conditions but without confidential information
- Possibility to customize tools according to users
- Open to collaborations to refine and develop VR tools

SCK CEN
Belgian Nuclear Research Centre

Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL