Radwaste monitoring: detectors and system developments

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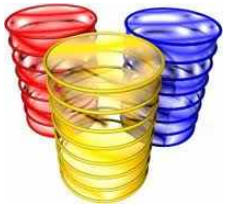
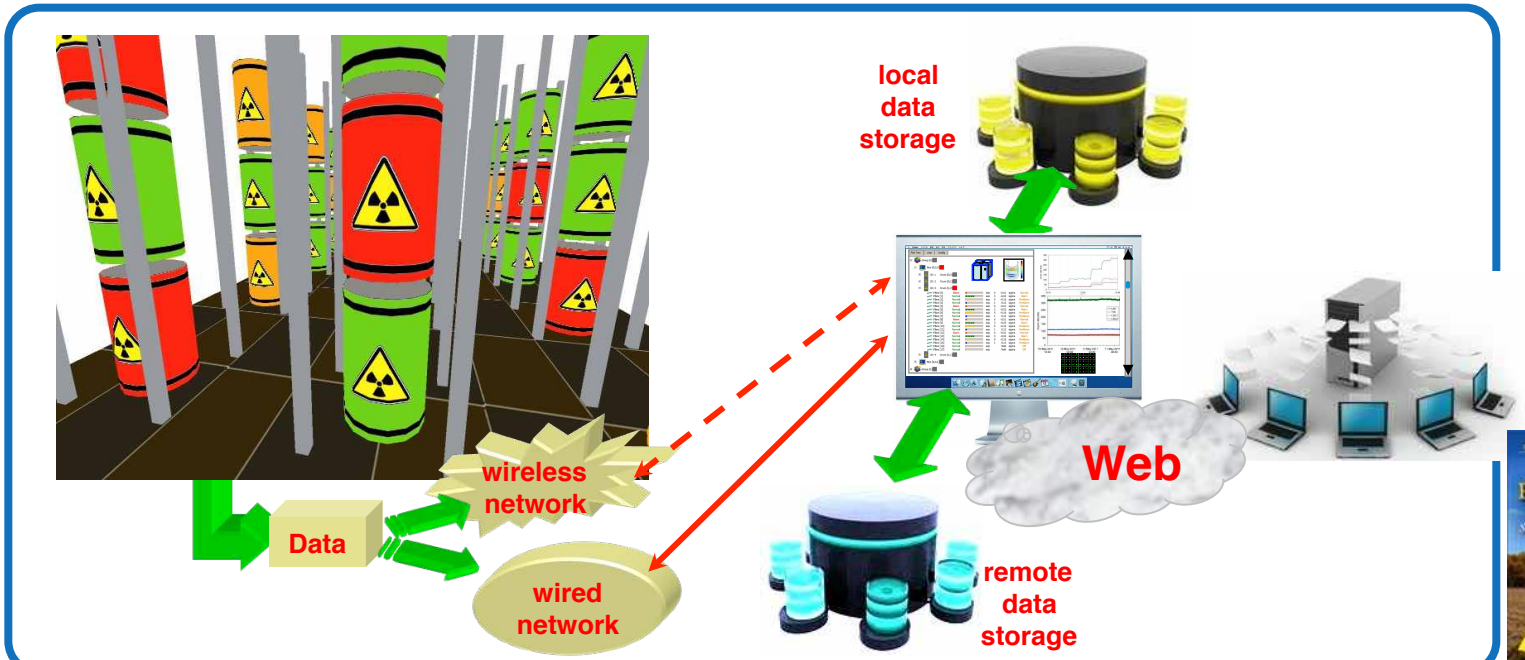
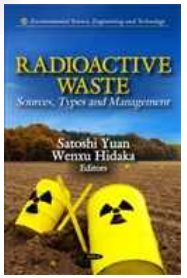


Real-time online monitoring of radioactive waste





DMNR Detector Mesh for Nuclear Repositories

the problem

radwaste produced worldwide
usually packed into special drums

the storage site should be monitored for leaks or breaks, to prevent possible contamination of the environment and/or people

online monitoring can minimize the need of human intervention inside (ALARA)

No repository with online real-time monitoring (to our knowledge)

radwaste confined into "*long lasting*" drums?

DMNR: the system

- On-line monitoring of short/medium term radioactive waste storage
- Application of non-conventional detectors for decommissioning

DMNR: goals

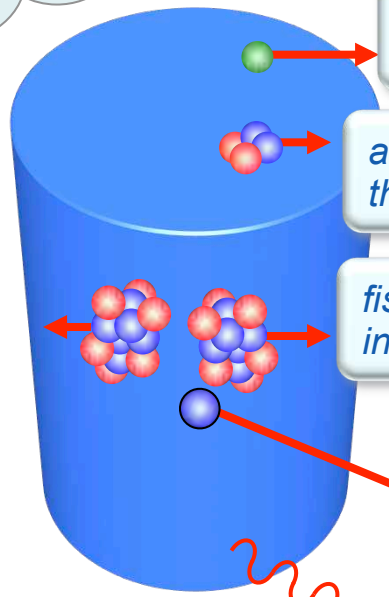
- real-time continuous activity monitoring & recording
- on-line availability of data to control authorities, fire departments, local and national governments, etc.
- radwaste handling by means of advanced tools and procedures suitable for reducing the risks to the local workers and to the population

What comes out of a waste drum?

They know, they know, but...
I'll tell them anyhow!!!

I love fuel rods

basic radioactivity coming out is gamma rays



beta particles are mostly stopped inside the material and in air

alpha particles are immediately stopped inside the material

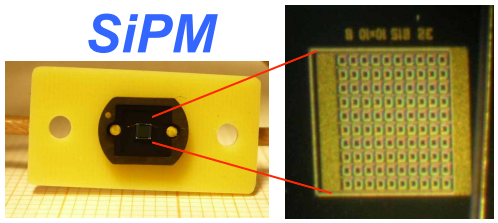
fission fragments are immediately stopped inside the material

neutrons (from fission) come out very easily but at very small dose. The amount of fissile material in the drums is small: it is removed before packing the drums (not so for spent fuel rods)

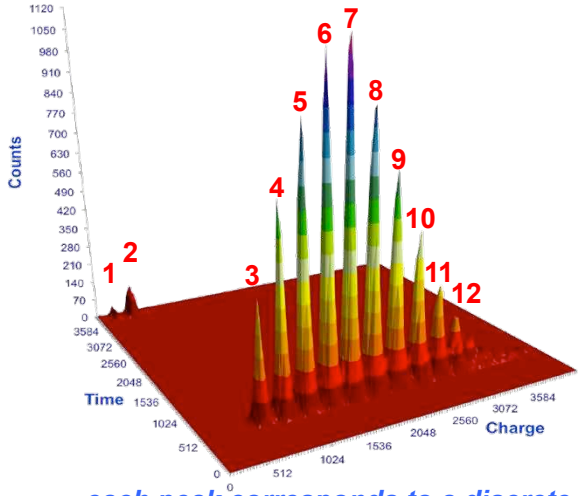
gamma rays are penetrating, therefore they come out easily and abundantly

the detector:
scintillating fiber + 2 SiPM

SiPM



the SiPM can detect the very short scintillation light pulse produced by gamma interaction

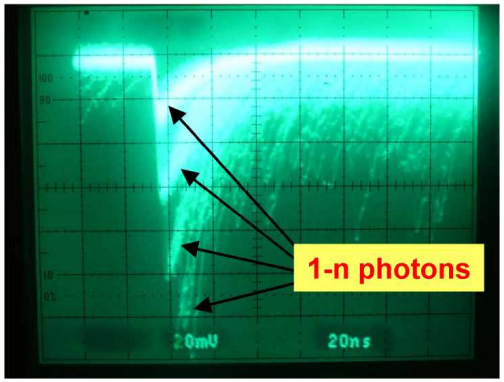


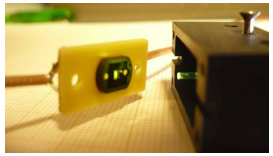
each peak corresponds to a discrete number of detected photons

1-cell ⇒ charge = k
n-cells ⇒ charge = nk

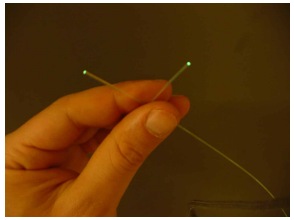
low bias voltage (30V)
high gain

1 photon gives rise to a signal of about 10^6 electrons

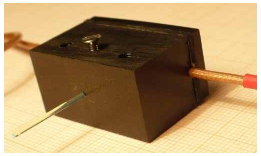




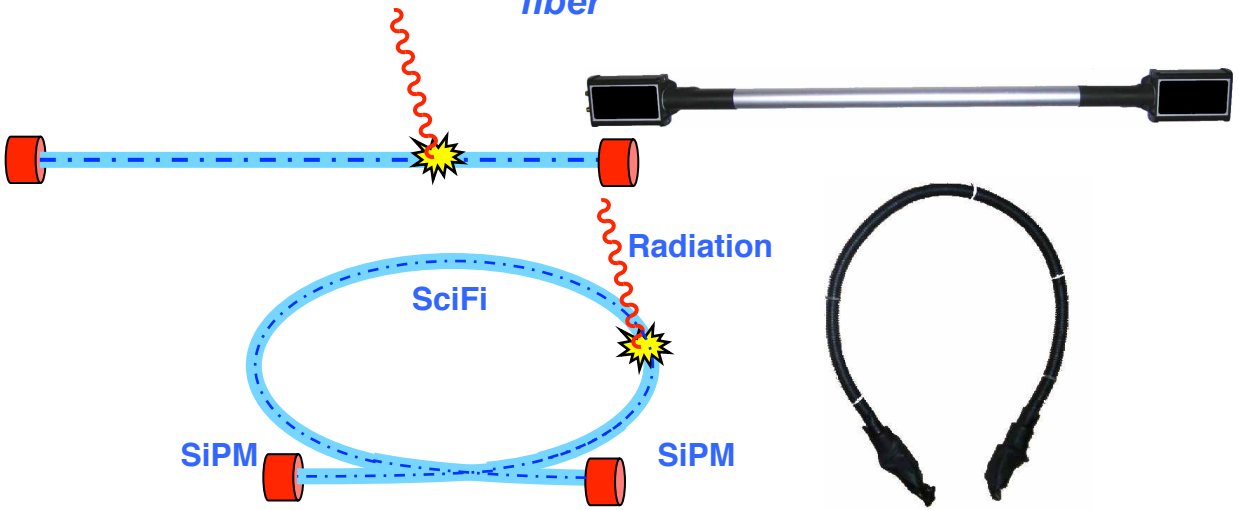
SiPM



fiber



SiPM



Sensor features

radiation hardness ≈100-1000 years close to a drum with 10-100 mGy/h

robustness yes, plastic scintillators; SiPM not damaged by ambient light exposure

low efficiency ≈0.1%

high sensitivity: few photons

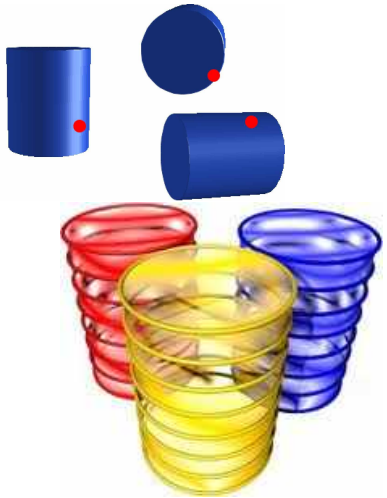
reliability yes

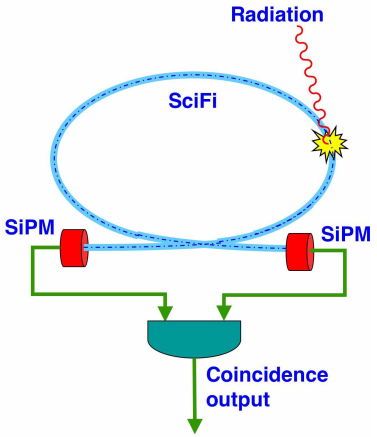
(possible position sensitivity) yes

ease of handling yes

low cost yes

the left-right coincidence suppresses spurious counts

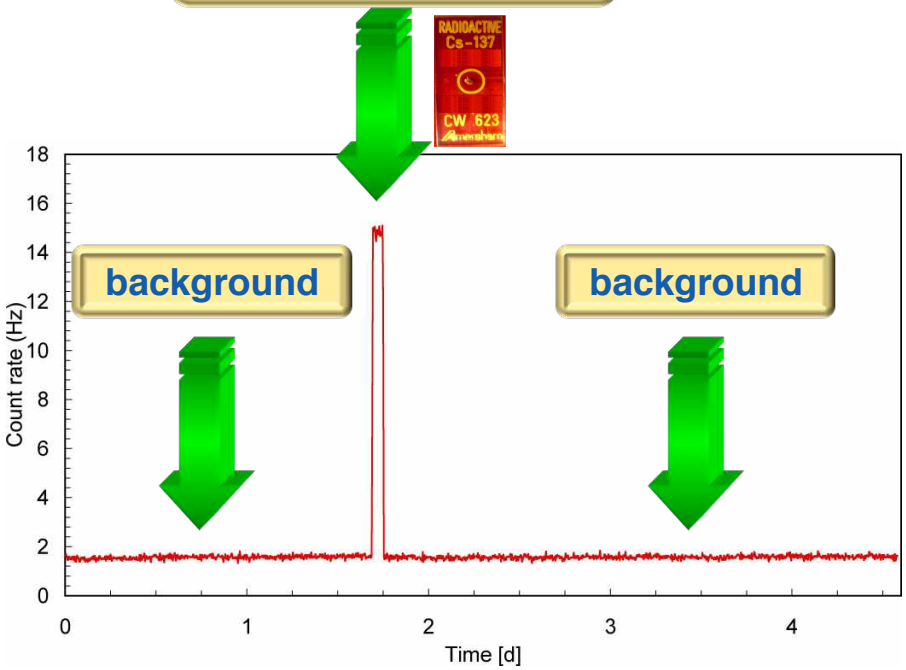




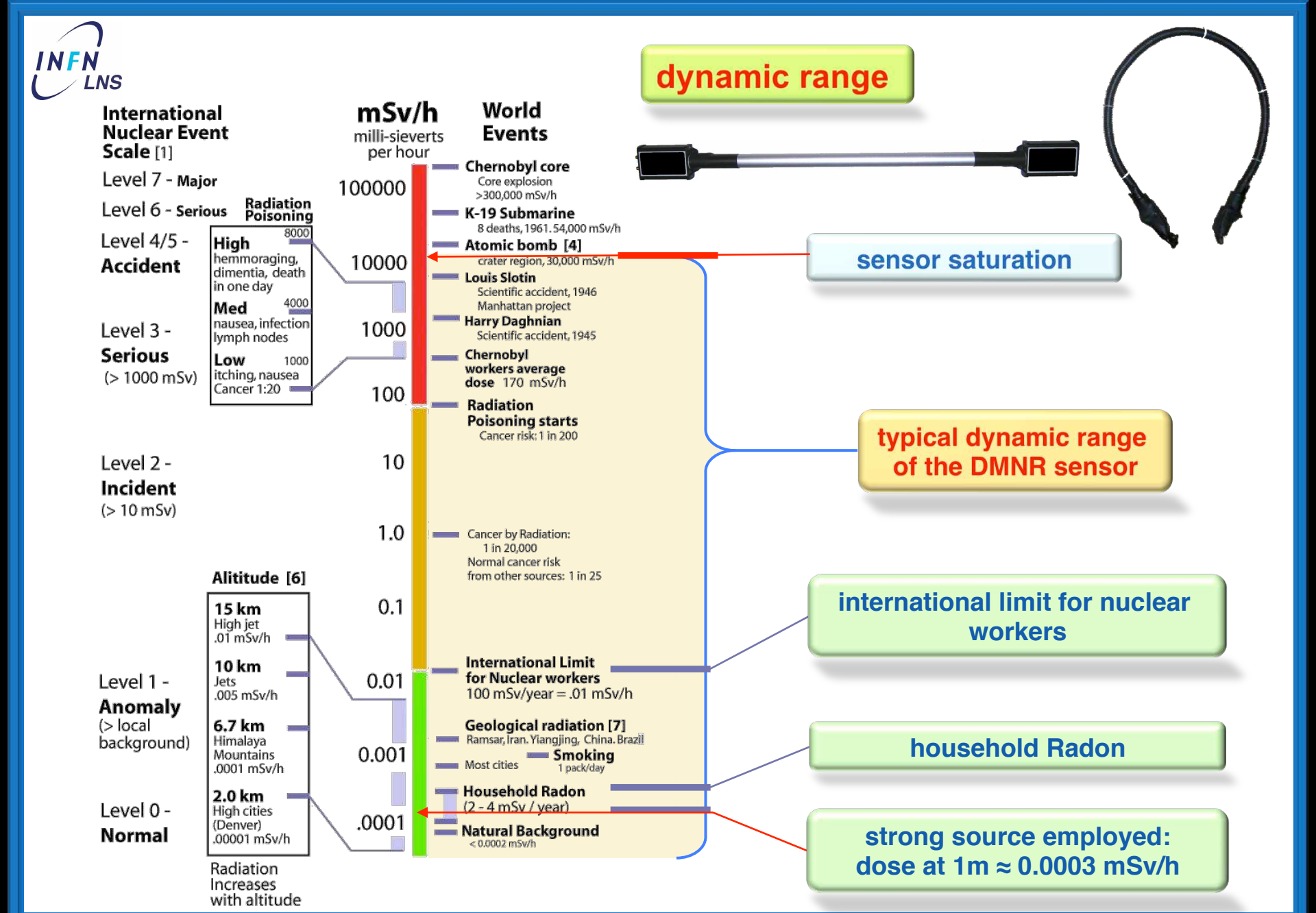
a mesh of scintillating fibers read-out at both ends by means of Silicon PhotoMultipliers (SiPM)

bench tests

gamma source
2.7MBq at 10cm

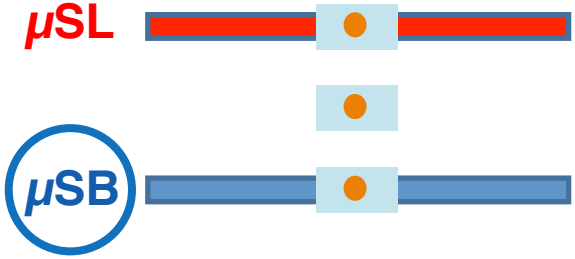


3D reconstruction by
crossed fibers

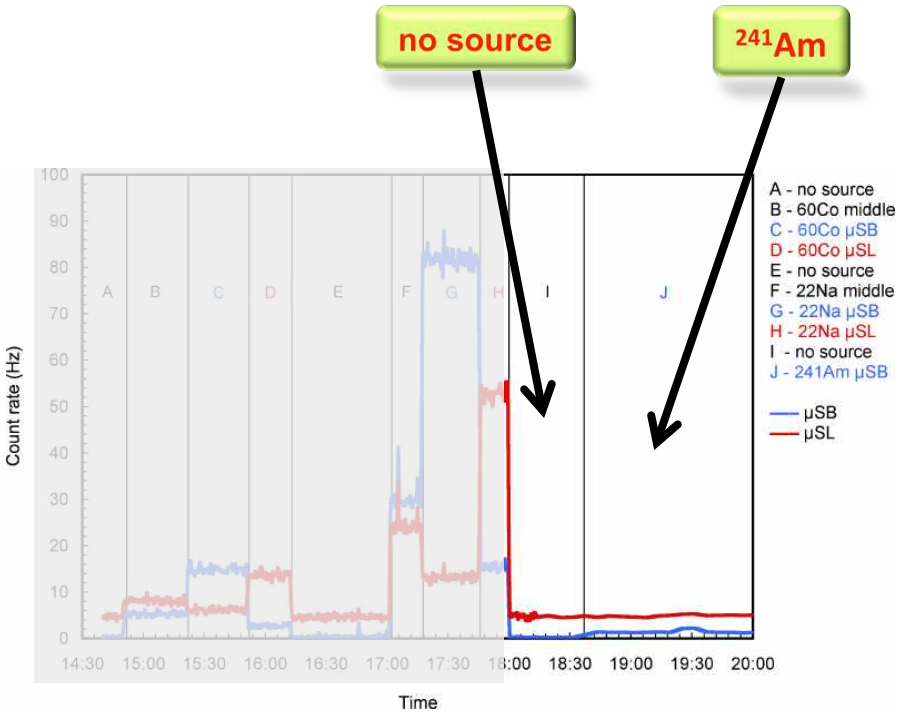

dynamic range
International Nuclear Event Scale [1]
Level 7 - Major
Level 6 - Serious
Level 4/5 - Accident
Level 3 - Serious (> 1000 mSv)
Level 2 - Incident (> 10 mSv)
Level 1 - Anomaly (> local background)
Level 0 - Normal
Radiation Poisoning
8000 High hemmoraging, dimentia, death in one day
4000 Med nausea, infection lymph nodes
1000 Low itching, nausea Cancer 1:20
Alititude [6]
15 km High jet .01 mSv/h
10 km Jets .005 mSv/h
6.7 km Himalaya Mountains .0001 mSv/h
2.0 km High cities (Denver) .00001 mSv/h
Radiation Increases with altitude
mSv/h
milli-sieverts per hour
100000
10000
1000
100
10
1.0
0.1
0.01
0.001
.0001
World Events
Chernobyl core
Core explosion >300,000 mSv/h
K-19 Submarine
8 deaths, 1961. 54,000 mSv/h
Atomic bomb [4]
crater region, 30,000 mSv/h
Louis Slotin
Scientific accident, 1946 Manhattan project
Harry Daghnian
Scientific accident, 1945
Chernobyl workers average dose 170 mSv/h
Radiation Poisoning starts
Cancer risk: 1 in 200
Cancer by Radiation: 1 in 20,000
Normal cancer risk from other sources: 1 in 25
International Limit for Nuclear workers
100 mSv/year = .01 mSv/h
Geological radiation [7]
Ramsar, Iran. Yiangjing, China. Brazil
Most cities
Smoking 1 pack/day
Household Radon
(2 - 4 mSv / year)
Natural Background
< 0.0002 mSv/h
sensor saturation
typical dynamic range of the DMNR sensor
international limit for nuclear workers
household Radon
strong source employed: dose at 1m ≈ 0.0003 mSv/h

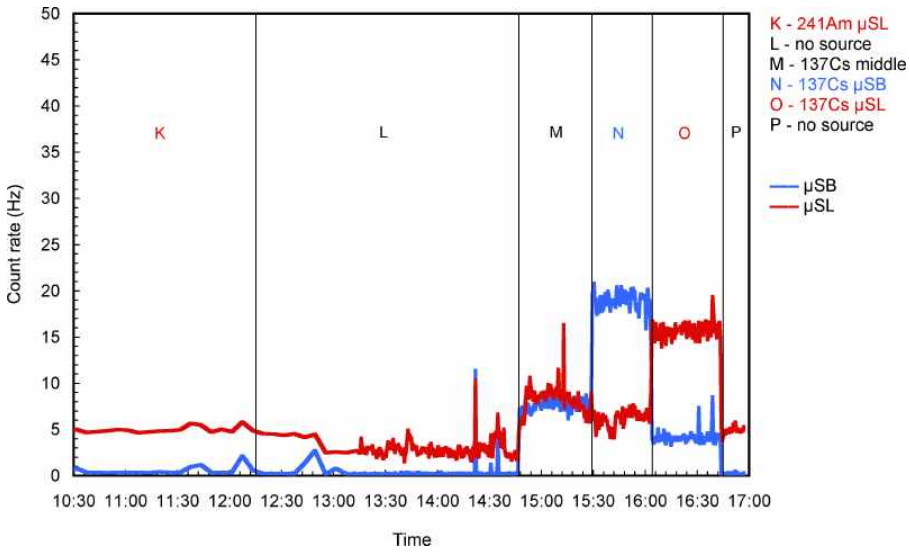
new low-noise μSB sensors

tests with ^{241}Am, ^{22}Na, ^{137}Cs, ^{60}Co sources



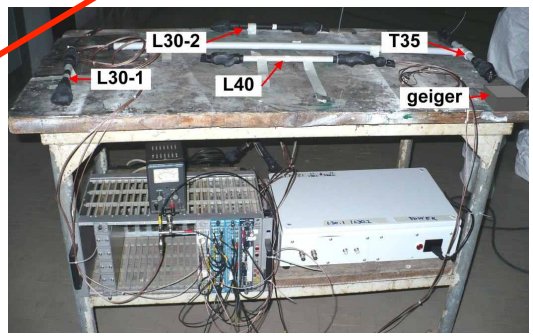
intrinsic efficiency: between 10^{-2} and 10^{-6}

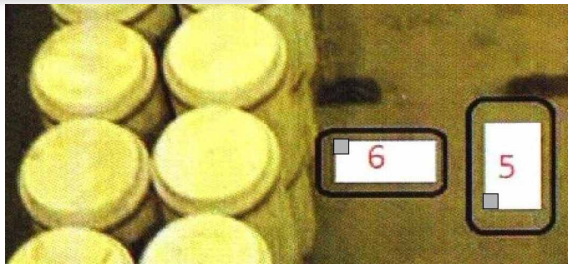




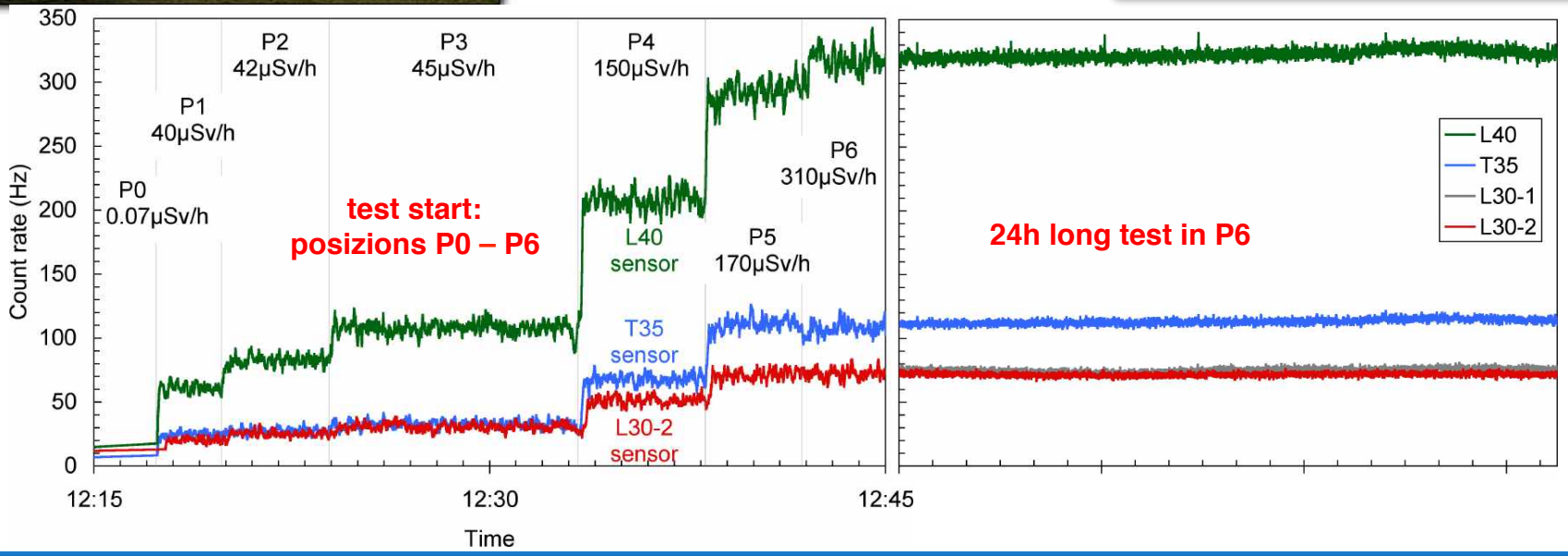
test with real radwaste drums

temporary storage inside the former power plant of Garigliano at Sessa Aurunca (SOGIN S.p.a.)



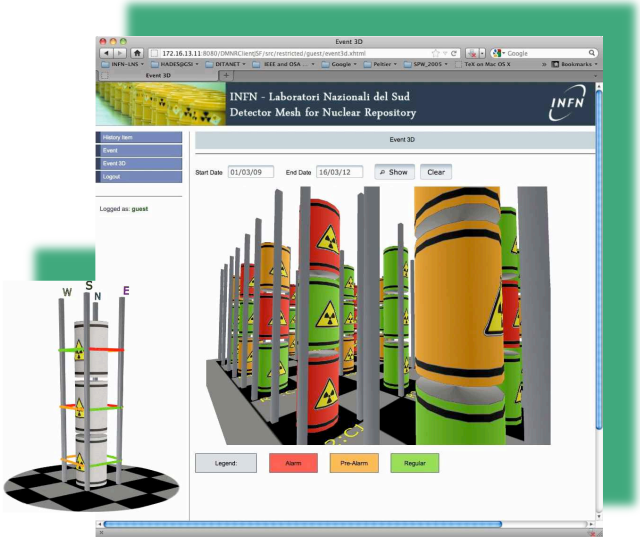


4 sensors (+geiger) on a pushcart placed at 7 positions (P0-P6) with increasing dose rates



Technology transfer

collaboration agreement
INFN - SOGIN
signed on 8-Nov-2012
duration: 2 years

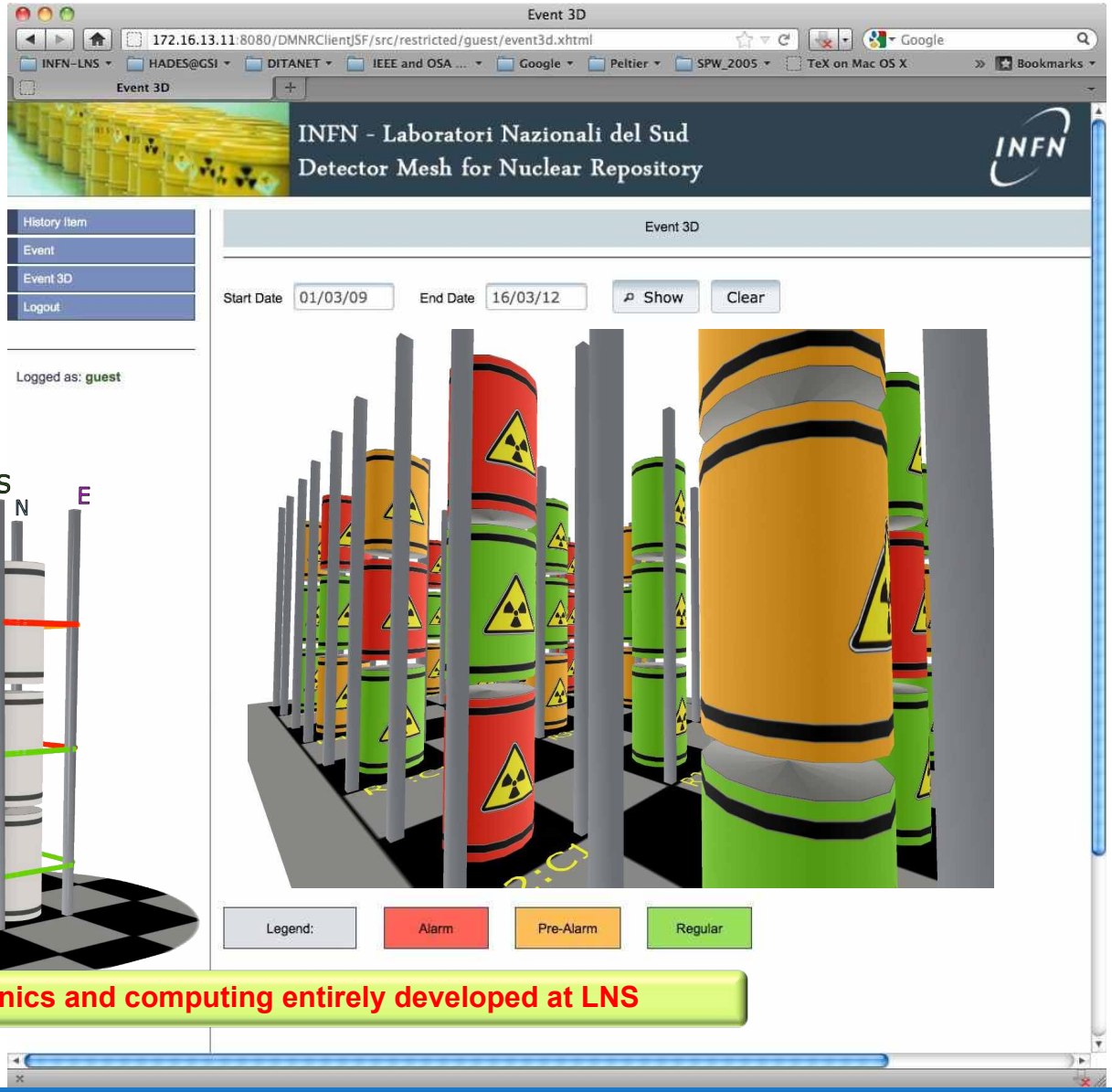


implementation of a prototype DMNR monitoring system in a new radwaste repository (Garigliano former power plant)

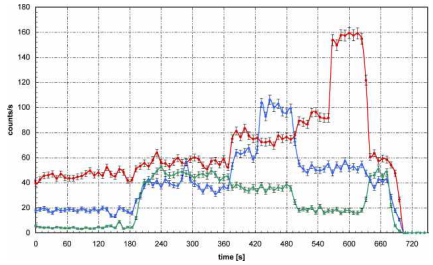
user interface

- *online display and data check*
- *counting rate channel by channel*
- *programmable alarm levels*

details available in real time down to the single drum and to the single fiber around a drum



direct connection to the sensor database



3D virtual navigation tool

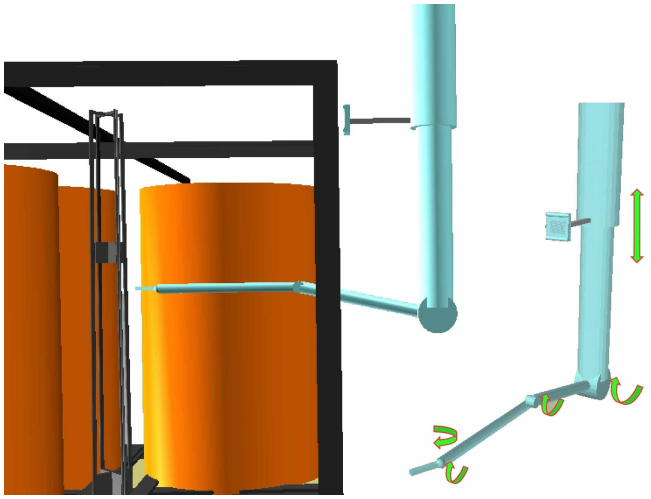
electronics and computing entirely developed at LNS

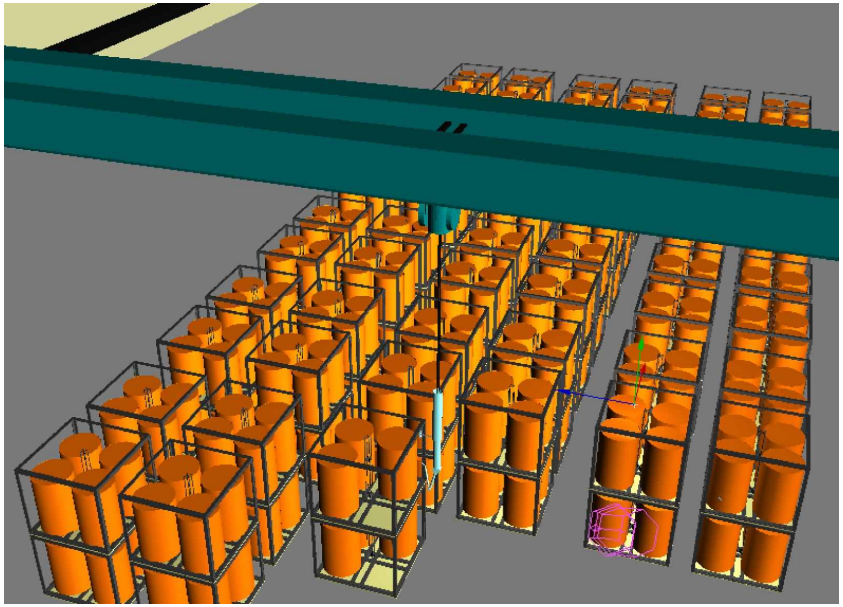
drum inspection: new remotely controlled robotic arm

5 degrees of freedom

payload:

inspection video camera
gamma detector



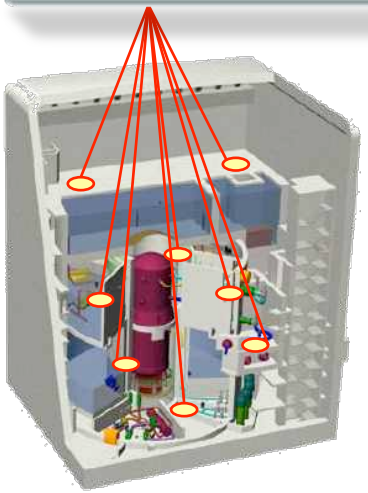


young student L.Russo
winner of a SIF award to
participate in E2C 2013
conference in Budapest

Collaboration with JRC & Euratom: neutron detection

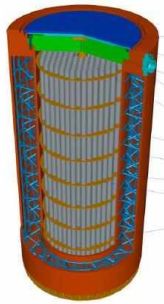
(INFN patent pending RM2013A000254)

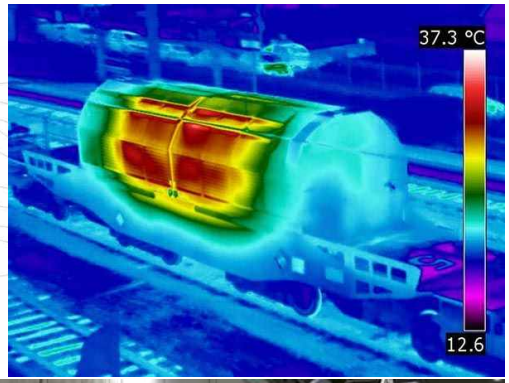
out-of-core monitoring in NPP

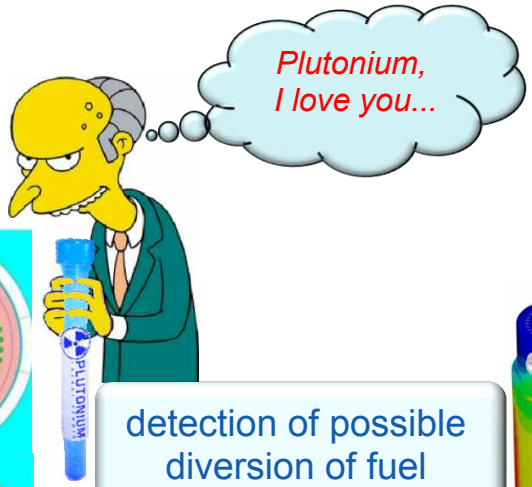


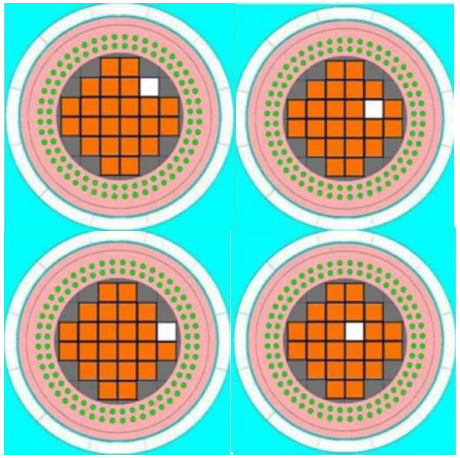
why neutrons?

spent fuel monitoring in place and/or during transportation

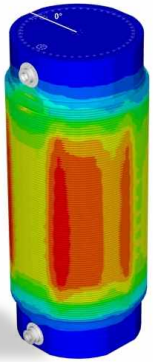








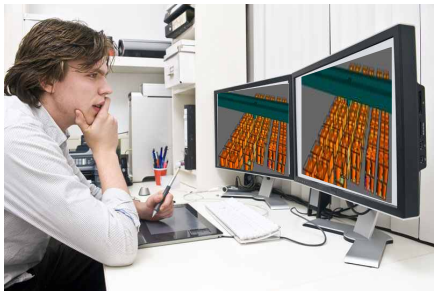
detection of possible diversion of fuel elements from Castor containers

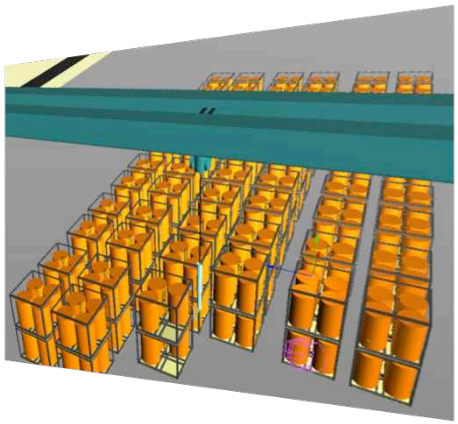


(P.Peerani, M.Galletta, Nuclear Engineering and Design 237 (2007) 94-99)

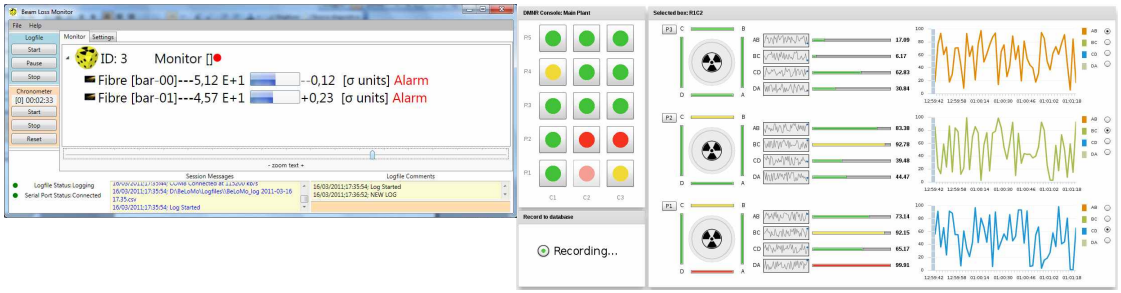
preventing the smuggling of nuclear fuel

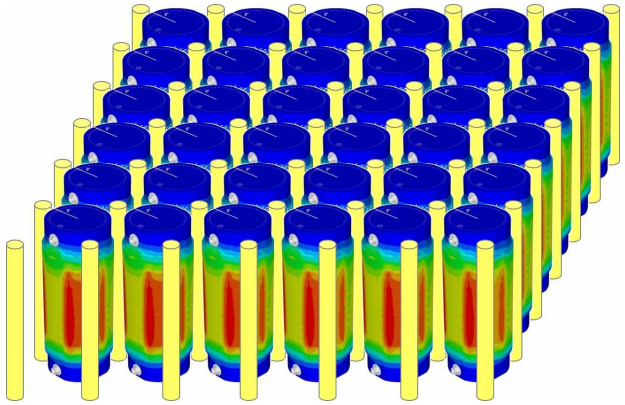
ensuring continuity of knowledge





current monitoring method: video camera

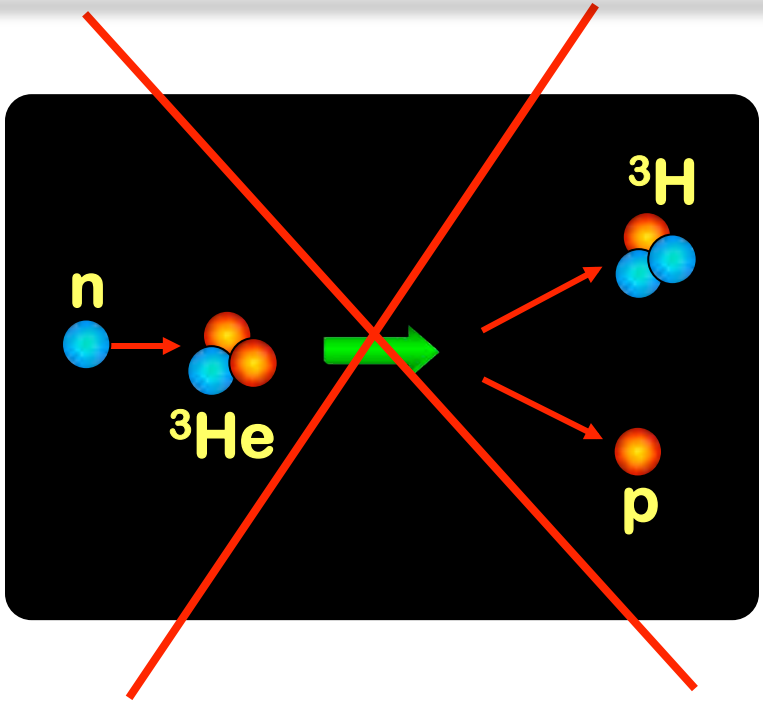




our idea: granular, real time, automatic

How?

materials for thermal neutron conversion: ^{3}He



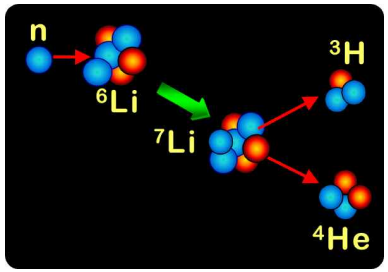
$\sigma(0.025)$
$\approx$ 5330 b

available energy
0.76 MeV
no gamma rays

perfect gas detector but... worldwide lack of ^{3}He

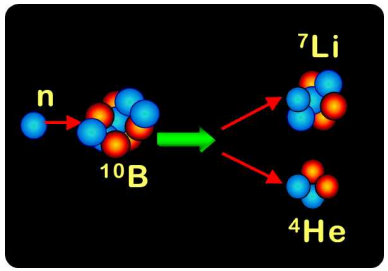
materials for thermal neutron conversion: which one?

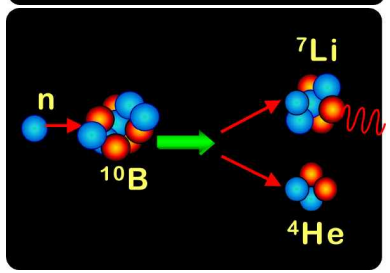
^{6}Li



$\sigma(0.025)$
$\approx$ 940 b
available E
4.78 MeV

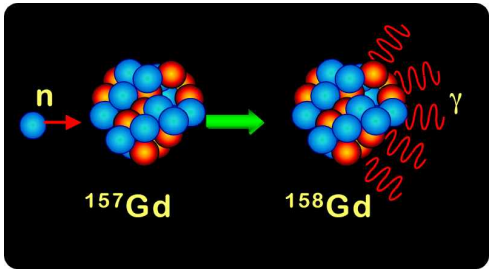
^{10}B





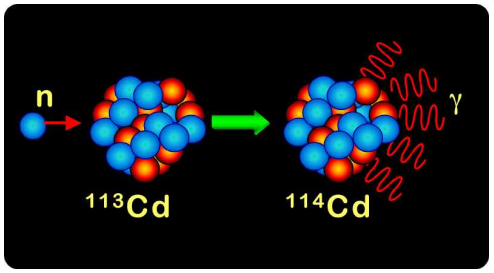
$\sigma(0.025)$
$\approx$ 3840 b
available E
2.79 MeV
(and gamma rays)

^{157}Gd



$\sigma(0.025)$
$\approx$ 240 kb

^{113}Cd



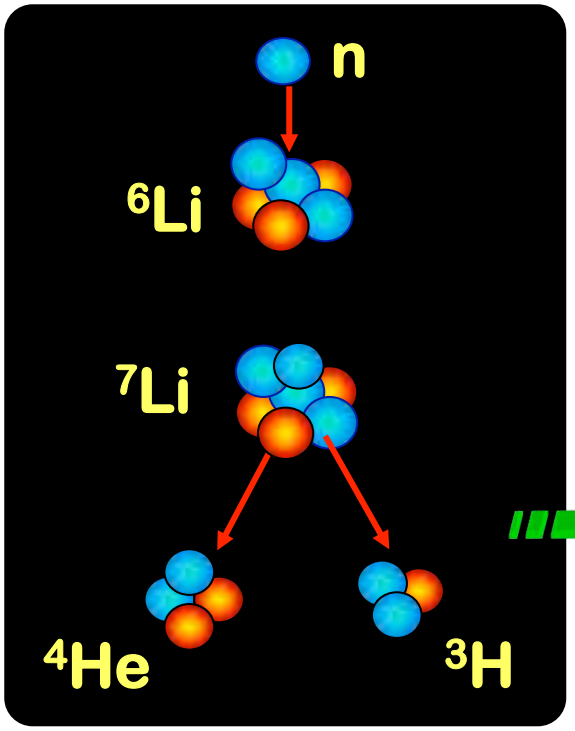
$\sigma(0.025)$
$\approx$ 20 kb

large available E
but in form of gamma rays:
difficult neutron identification

physical process

^{6}Li – natural abundance: 7%

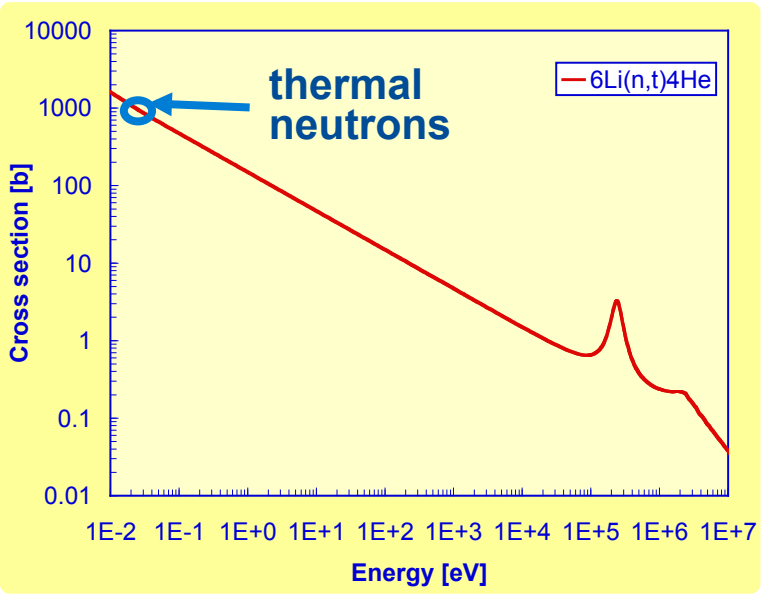
a ^{6}LiF converter captures a neutron...



2.05 MeV **2.73 MeV**

...and produces ^{4}He ed ^{3}H which can be detected

Cross section ≈ 940 b



detection of ^{3}H and/or ^{4}He

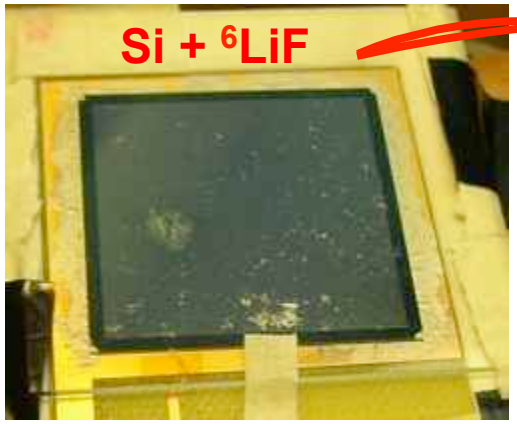
how?

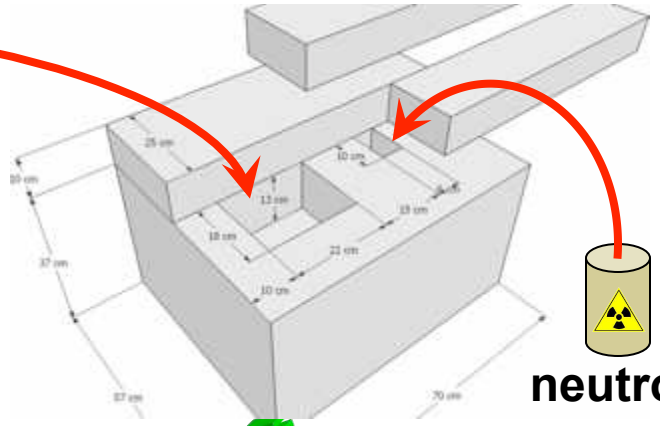
HELNEM

^{3}He-free Lithium-based NEutron Monitors

with removable converter

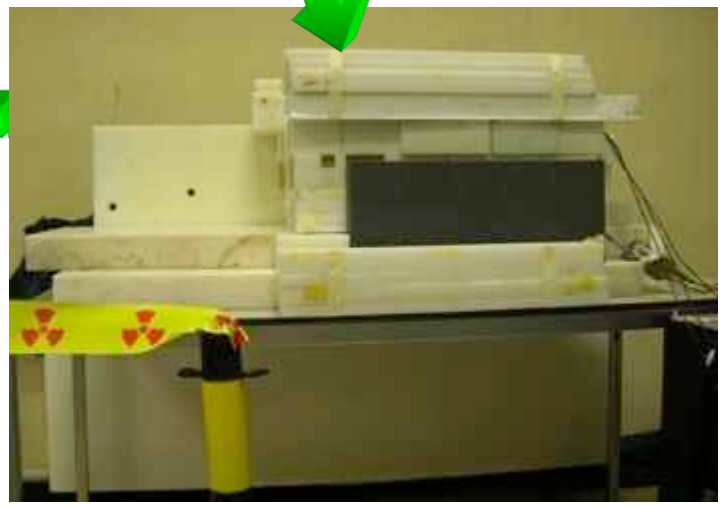
AmBe neutron source 1.6E6 n/s thermal flux ≈ 150 n/s/cm²

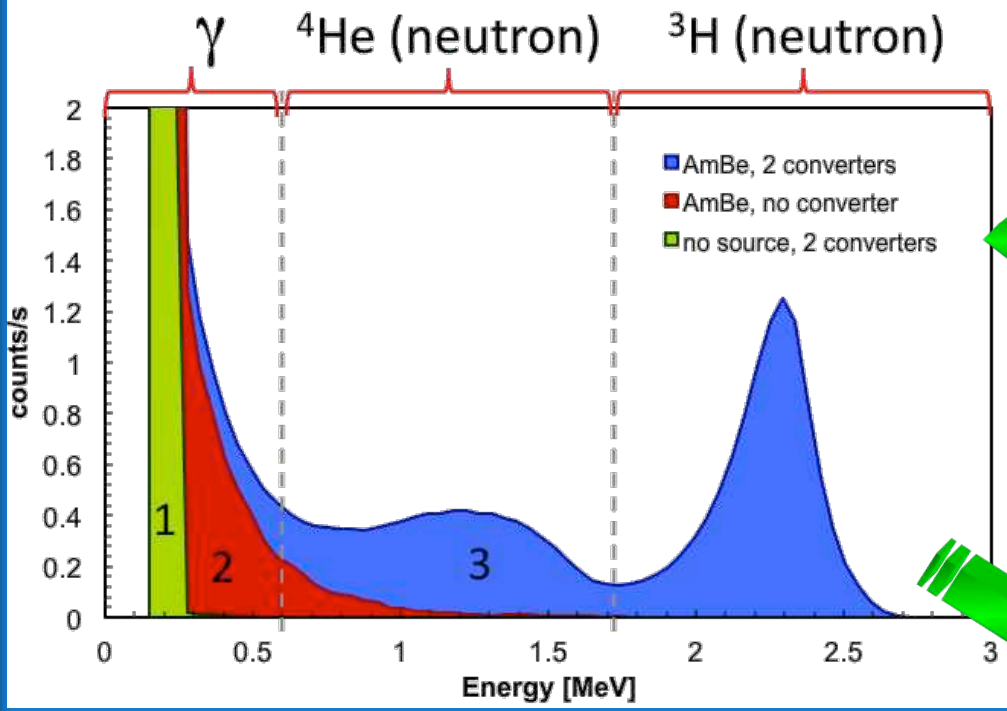




neutron source

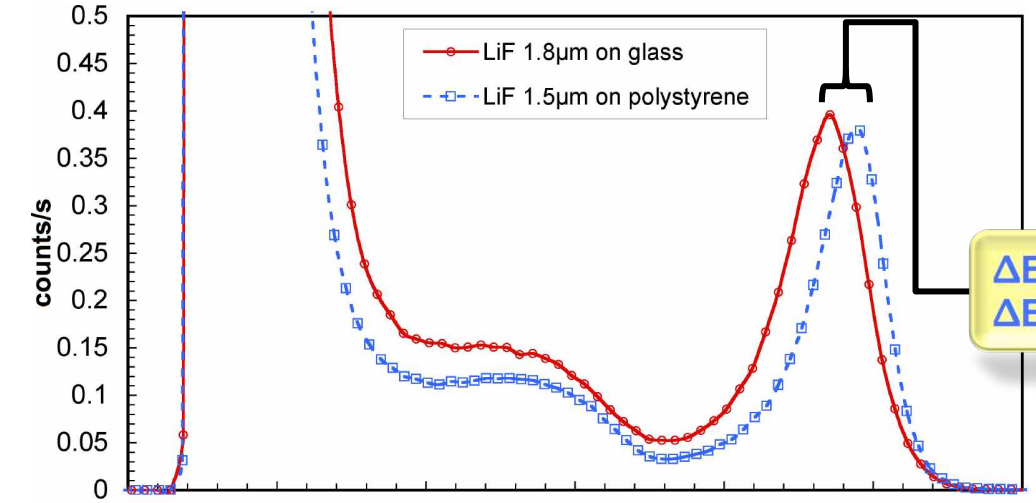
PET moderator





expected ≈ 4 cps measured 3.3

Si detector + ^{6}LiF



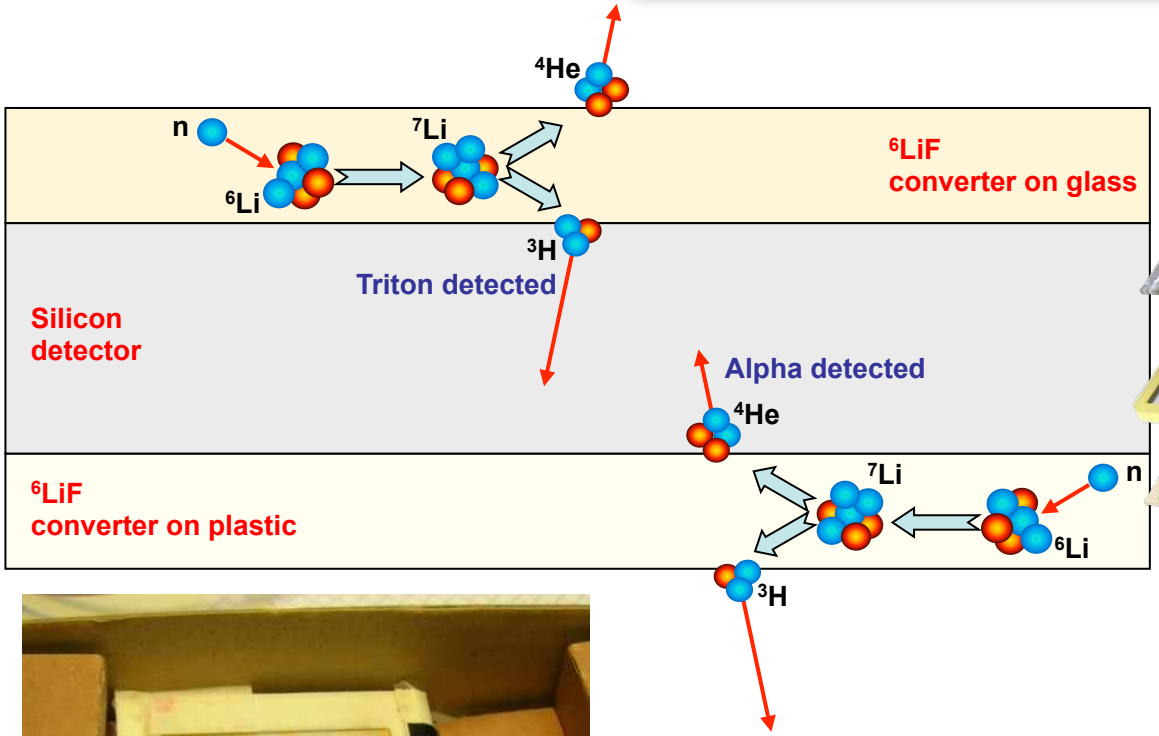
thickness: 1.8μm vs 1.5μm
20% more efficient

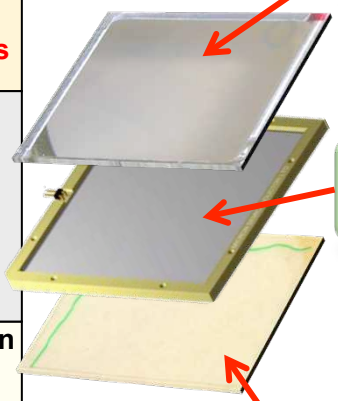
ΔE calculated: 195 keV
ΔE measured: 200 keV

optimal ^{6}LiF thickness 1.8μm

added 2 gamma sources
to test rejection (740 MBq)

Si detector + ^{6}LiF





^{6}LiF on glass

double sided silicon
3cm x 3cm x 300μm

^{6}LiF on plastic

2 converters: double efficiency

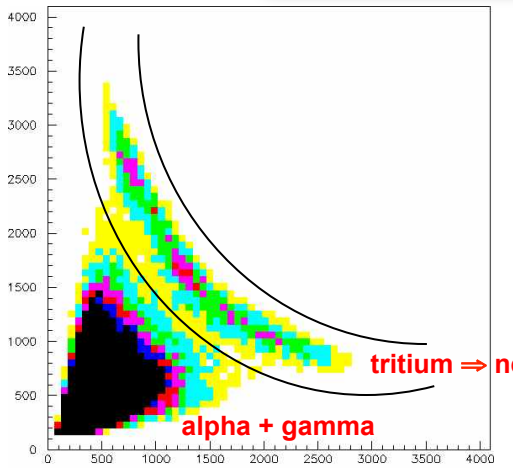
features

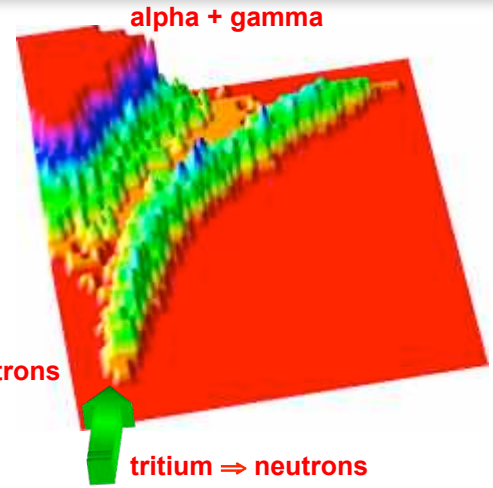
- mechanically simple and robust
- reasonably cheap
- commercial solid state detectors
- strips for position measurements
- simple use (no spectrum analysis or subtraction for gamma rejection)

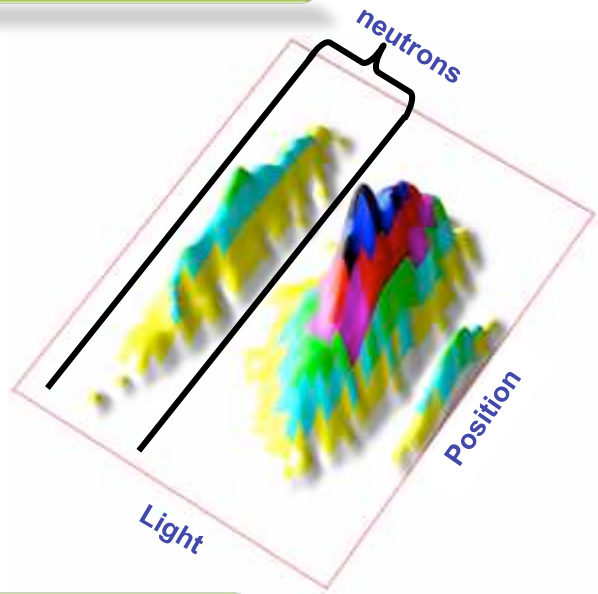
next steps

- ^{6}Li deposits over large area (A4?)
- better efficiency (up to 50%?)
- scintillators... → patent? YES

test with AmBe source: Scintillators + ^{6}LiF

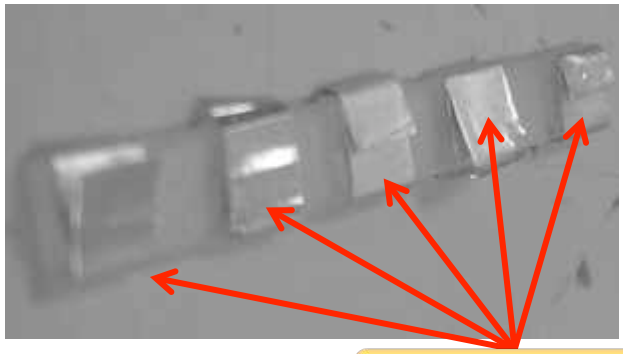




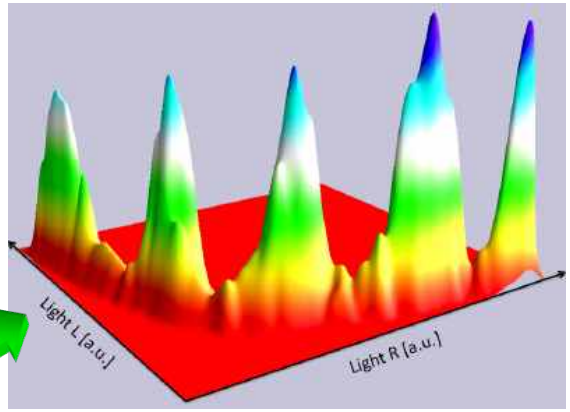


- good intrinsic efficiency
- position sensitive (Δx ≈ 1-2 mm)
- low cost
- many possible geometries and schemes

...and more to come



^{6}LiF converter

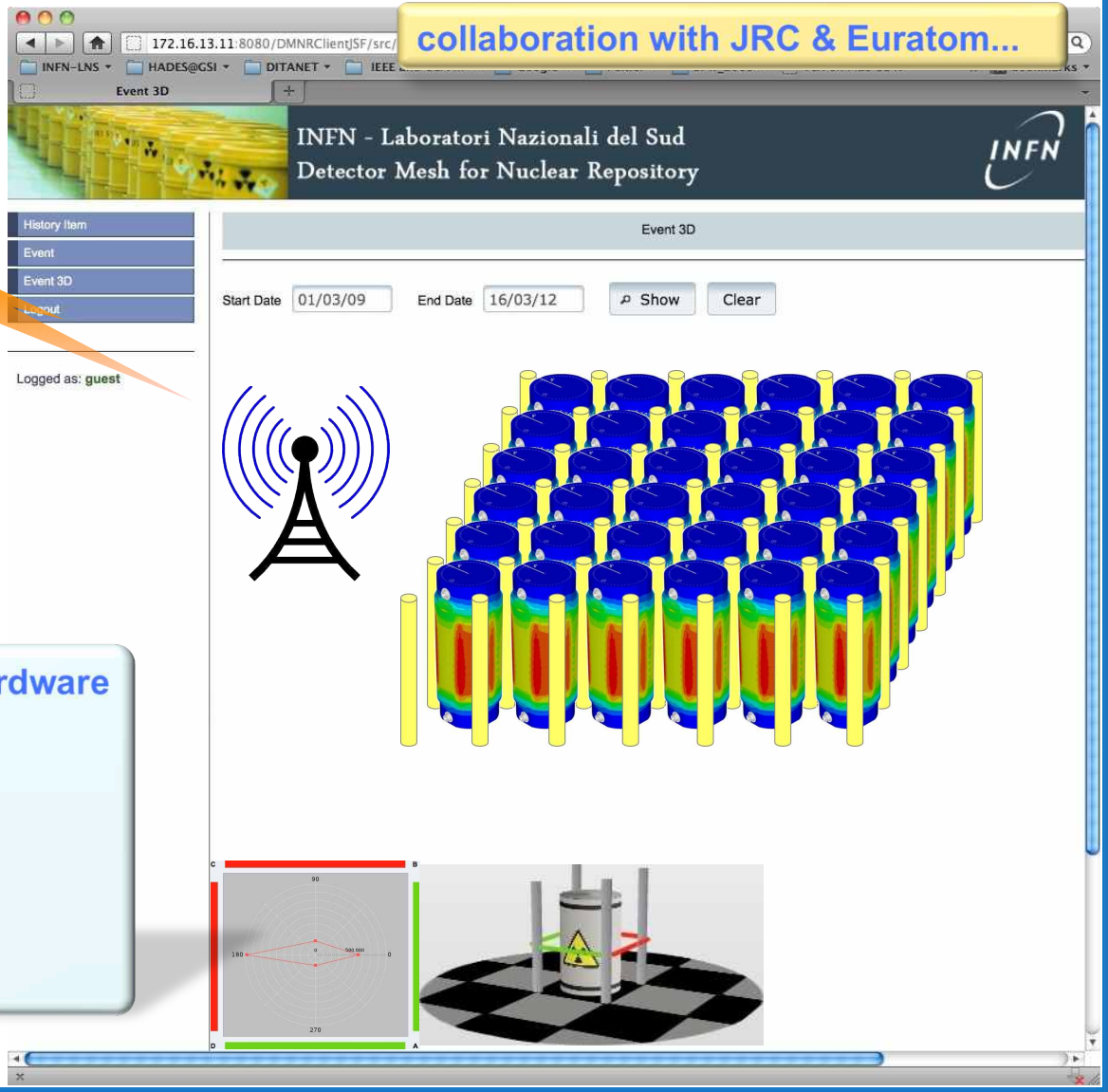


RM2013A000254

real-time castor storage monitoring

collaboration with JRC & Euratom...

wireless transmission



easily integrated into the existing hardware and software architecture of DMNR:

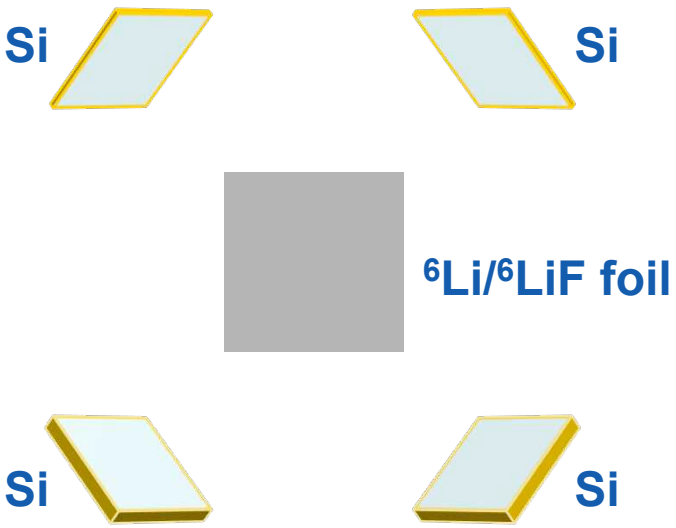
- electronics
- data acquisition
- system control
- data logging
- database handling
- Graphical User Interface

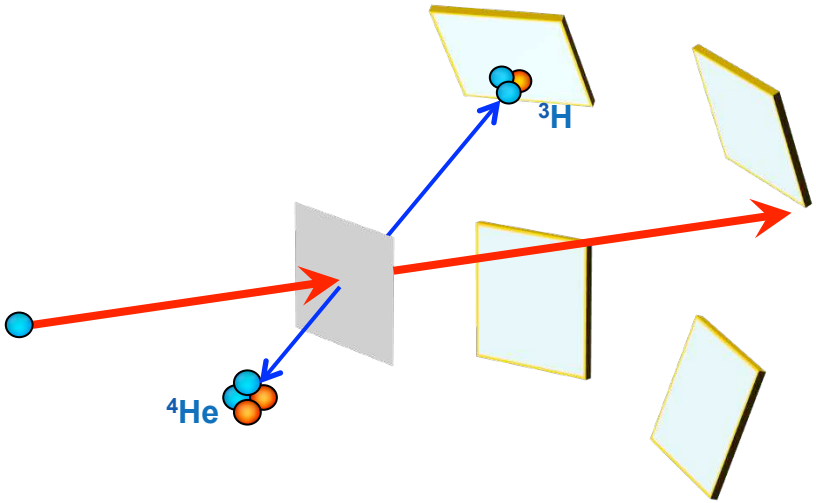
possible applications

- Nuclear physics research
- Homeland security (nuclear material smuggling)
- Dosimetry
- Radwaste monitoring
- Spent fuel handling and storage monitoring
- Search for nuclear material accidentally lost among scrap metal
- Material structure (with neutron beams)
- other...

SiMon2: neutron beam monitor for flux normalization

Si detector + $^{6}Li/^{6}LiF$

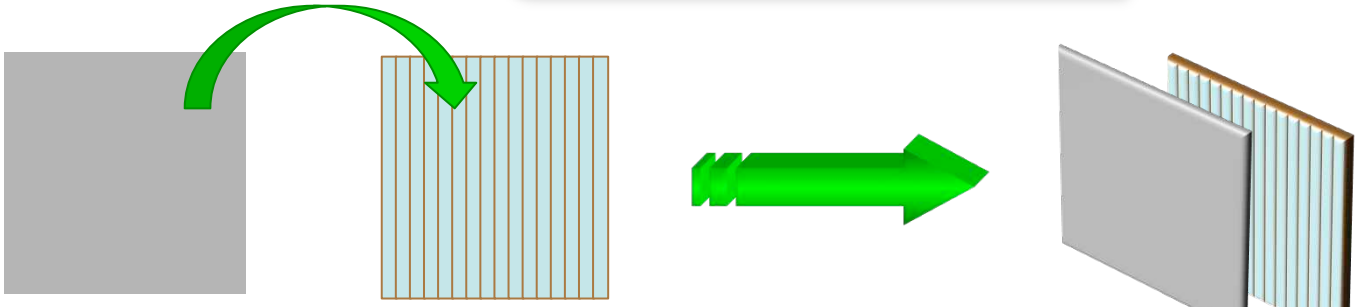




n-TOF collaboration @ CERN

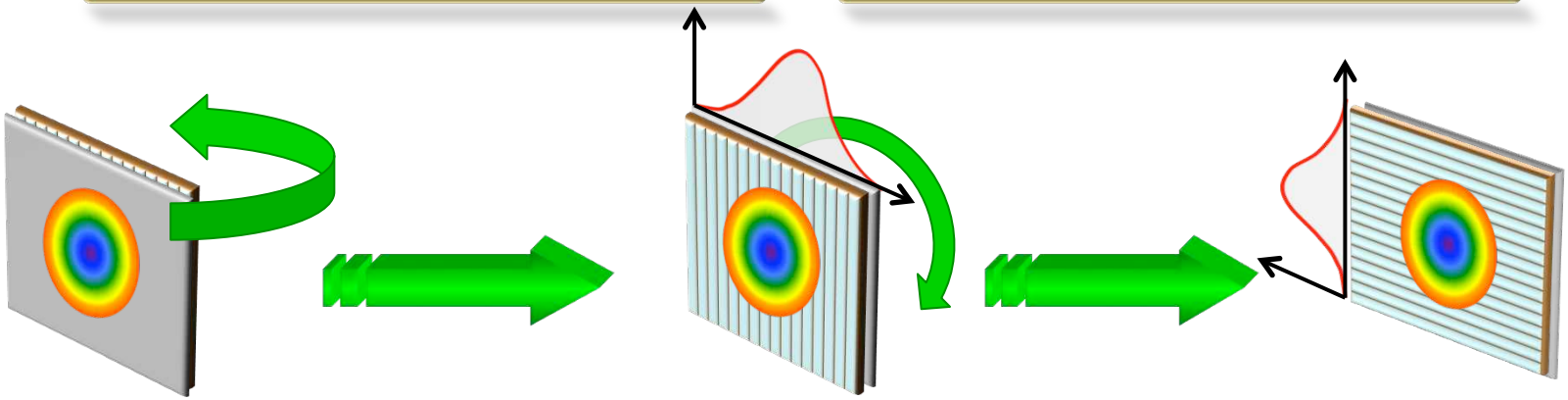
BeaMon: neutron beam characterization

Si detector + ^{6}Li/^{6}LiF



α-t forward-backward asymmetry

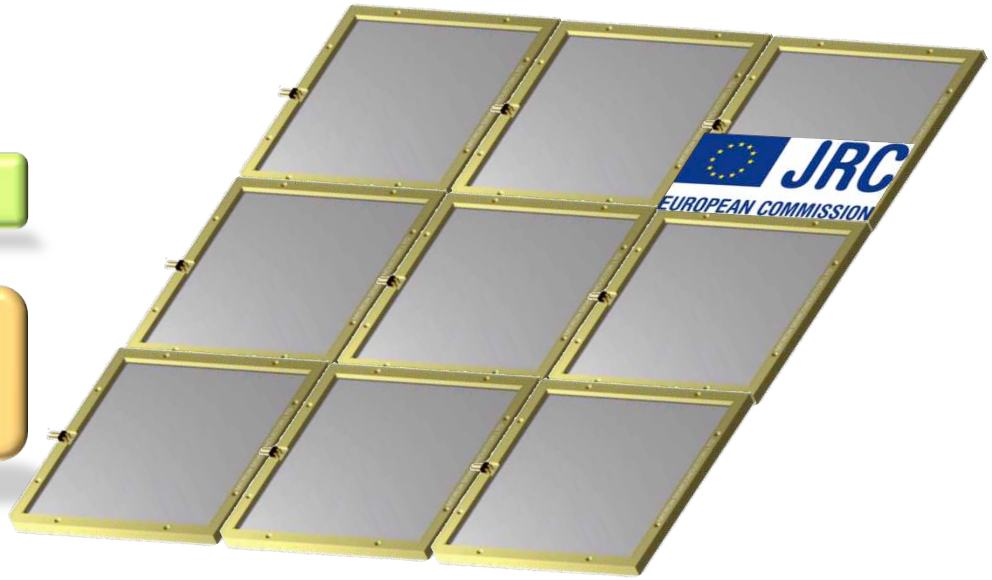
XY distribution



n-TOF collaboration @ CERN

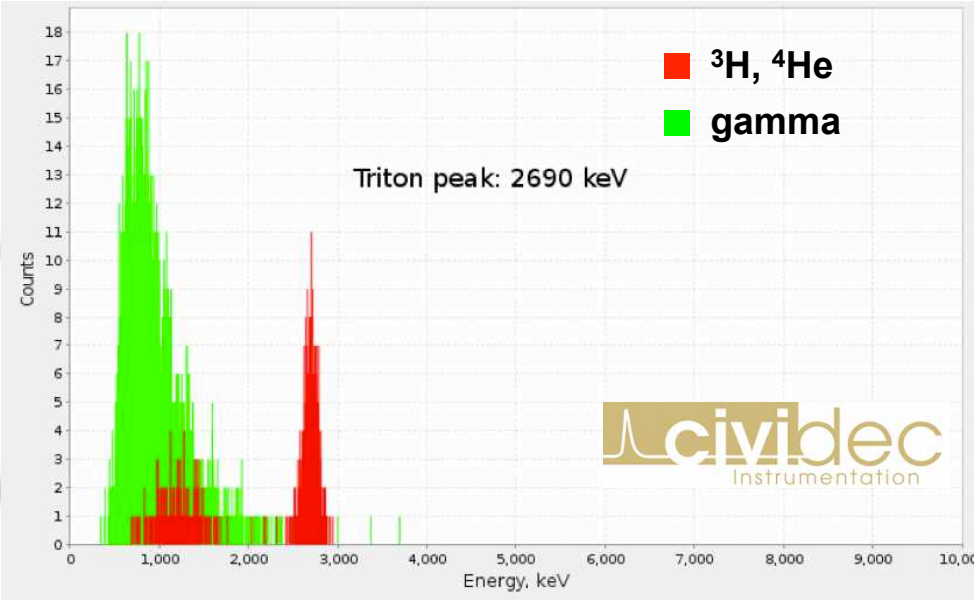
Ongoing ollaboration with JRC & Euratom:

large panels for neutron coincidence measurements as possible ^{3}He panels replacement



Last week's result from collaboration with CIVIDEC (Austria):

diamond detectors for thermal neutrons outstanding results with the first test at a reactor



compact neutron monitors?

RadSieve

Sorting table for hot spots detection in decommissioning

patent in preparation

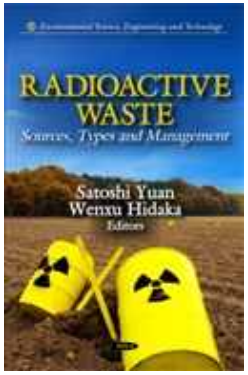
RadSieve

Radwaste drum rough characterization

Radwaste drum fill level optimization

scientific production

- P.Finocchiaro, talk given at the Helium-3 Replacement in Italy meeting, 2-3 december 2013
- A.Pappalardo, talk given at the 3rd European Energy Conference, Budapest, 27-30 October 2013
- P.Finocchiaro, talk given at the 3rd European Energy Conference, Budapest, 27-30 October 2013
- L.Russo, presented at the 3rd European Energy Conference, Budapest, 27-30 October 2013
- S.Scirè, talk given at the 6th International Workshop on the Application of FPGAs in NPPs, Kirovograd, 10-Oct-2013
- P.Finocchiaro, invited talk to be given at XCIX Congress of Italian Physics Society, 2013, Trieste
- P.Finocchiaro et al., presented at the 1st SCINTILLA public workshop, Budapest, 12-Sep-2013
- P.Finocchiaro, et al., Invited seminar at University of Milan 2013
- M.Barbagallo et al., Rev. Sci. Instrum 84 (2013) 033503
- G.Vecchio et al., International Journal of Nuclear Energy Science and Engineering, 10089, vol.3, issue 3, (2013)64
- G.Vecchio, P.Finocchiaro, Global Journal of Computer Science and Technology Graphics & Vision, v12, n12 (2012) 1-5
- P.Finocchiaro et al., IEEE Trans. Nucl. Sci., v59, n4 (2012) 1426-1431
- P.Finocchiaro, in “Radioactive Waste: Sources, Types and Management”, Nova Science Publishers, 2012
- A.Pappalardo et al., Nucl. Phys. B 215 (2011) 41-43
- P.Finocchiaro, invited talk given at the Low Carbon Earth Summit (LCES) 2011, Dalian
- L.Cosentino, talk given at the XXXV International Symposium "Scientific Basis for Nuclear Waste Management", 2011, Buenos Aires
- P.Finocchiaro, invited talk at XCVII Congress of Italian Physics Society, 2011, L'Aquila
- P.Finocchiaro et al., talk given at the 3rd International Nuclear Chemistry Congress, Terrasini 2011
- P.Finocchiaro et al., talk given at ANIMMA 2011, Ghent
- A.Pappalardo, presented at the 49th International Winter Meeting on Nuclear Physics, Bormio 2011
- P.Finocchiaro, invited talk at the Round Table on "Science and Technology for the solution of the Energy Supply Problems", Ekaterinburg 2010
- P.Finocchiaro, invited talk at SSEM 2010, Royal Society of Chemistry, London
- P.Finocchiaro et al., talk given at SSD16 2010, Sydney
- M.Barbagallo et al., Rev. Sci. Instr. 81 (2010) 093503
- P.Finocchiaro et al., NIM A652 (2011) 143-145
- M.Barbagallo et al., NIM A652 (2011) 355-358
- P.Finocchiaro, invited seminar at University of California Los Angeles 2010
- A.Pappalardo et al., presented at IPRD 2010
- P.Finocchiaro et al., presented at SORMA 2010
- P.Finocchiaro et al., presented at DNDO workshop 2010
- A.Pappalardo et al., presented at E2C European Energy Conference 2010
- V.Bellini, M.Capogni, V.Febbraro, and P.Finocchiaro, Appl. Rad. and Isot. 68 (2010) 1320
- P.Finocchiaro et al., Nucl. Phys. B197 (2009) 35 Proc. Supp.
- M.Capogni, presented at ICRM 2009, Bratislava, Slovak Republic, September 2009
- A.Pappalardo et al., presented at ANIMMA 2009
- L.Cosentino et al., presented at ICENES 2009
- L.Cosentino et al., presented at IPRD 2008



www.lns.infn.it/link/DMNR

theses

- L.Russo, upper level (master) Thesis (2013)
- F.Oliveri, first level Thesis (2013)
- L.Curcuruto, upper level (master) Thesis (2012)
- M.Campione, upper level (master) Thesis (2012)
- S.Scirè, upper level (master) Thesis (2012)
- C.Greco, first level Thesis (2011)
- S.Grillo, first level Thesis (2011)
- C.Scirè, upper level (master) Thesis (2011)
- V.Finocchiaro, first level Thesis (2011)
- G.Guardo, upper level (master) Thesis (2011)
- V.Febbraro, upper level (master) Thesis (2009)
- S.Scirè, LNS Stage final report (2009)
- G.Greco, upper level (master) Thesis (2009)
- M.Barbagallo, upper level (master) Thesis (2009)

etna walk
www.etnawalk.it

Thank you