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NON DESTRUCTIVE CONTROLS OF RADIOACTIVE WASTE AT CEA

7th International Summer School on Nuclear Decomissionning and Waste Management

14-18 SEPTEMBER 2015, ISPRA

SUMMARY

- French context for waste management
- Objectives of waste characterization
- Non-Destructive analysis
  - Gamma spectrometry
  - Neutron measurement
  - X Ray Radiography and Tomography
- Conclusion

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FRENCH CONTEXT

French Nuclear laws

- No free release
- The nuclear transparency and safety law 13 June 2006 :
  - Define a policy for the management of nuclear matters and radioactive wastes : interim storage and final geological repository
  - Increase transparency,
  - Adresses Economical aspects for waste management and decomissioning of installations
- National Plan for the Matters and Radioactive Waste Management (PNGMDR : 28th June 2006 law)
  - Four activity levels
  - Three half life levels

PNGMDR aims :

- To improve the existing ways of matter and nuclear wastes management,
- To develop new ways of nuclear waste management and associated R&D : HLW and MA-LL for geological disposal
- Updated every 3 years (last update : 2013).

NUCLEAR WASTE CLASSIFICATION

CONTROLS by CEA under ANDRA Spécification

Massic Activity (Bq/g)	lower than 100	100 to 10^5	10^5 to 10^9	Higher than 10^9
Activity level and repository	**(1) VLLW** *Very low level wastes* **(Storage at Centre de l'Aube -CIRES)**	**(2) LIL-SL $t_{1/2}$<31 y (Storage at Centre de l'Aube-CSA)** *low-level and intermediate-level, short life*		**(5) HA** *High Activity* Producer intermediate storage *-> CIGEO (project)*
		(3) LA-LL *low-level and intermediate-level, long life* Intermediate storage *final storage (project)*	**(4) IL-LL** *CIGEO (project)*	
Type of solid wastes	Debris, scrap iron, plastics,… mainly from the dismantling	Gloves, coats, glasses, scrap iron, …	Cladding, hulls and end caps from spent fuel, Wastes coming from glove boxes and hot cells, filters, …	Vitrified Fission Products coming from the fuel reprocessing
% of volume of French radioactive waste	20,1%	LIL-SL : 68,8 % LA-LL : 7,2 % IL-LL : 3,6%		0,2 %
% of activity	0,000003%	LIL-SL < 0,03% LA-LL < 0,009% IL-LL : 4,98%		94,98 %

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OBJECTIVES OF WASTE CHARACTERIZATION IN THE MANAGEMENT OF RADIOACTIVE WASTE

Several levels of characterization and controls :

1. Nuclear waste generation (AREVA, EDF, CEA, …)
   - Process control,
   - Quality control and characterization of produced nuclear waste

2. Nuclear waste storage in repository (ANDRA)
   - Second level nuclear waste control in and out of site

3. Supercontrols : for LIL-SL WP : Specified by Andra (sampling), performed by CEA (Several laboratories involved)
   - Blind non-destructive and destructive controls
   - Waste conformity check versus process control, transportation, interim storage and definitive storage specifications

ROLE OF WASTE CHARACTERIZATION IN THE MANAGEMENT OF RADIOACTIVE WASTE

Conformity checks to ANDRA agreement

- Radiological specifications
  - α, $\beta\gamma$ activities
  - α after 300 years
  - Fissile matter amounts
- Geometrical specifications
  - Sizes
  - Envelope thickness
  - Outside containers
  - Waste centering
- Physical specifications
  - Free space remaining
  - Homogeneity
  - Local defects
- Chemical specifications
  - Amount of limited materials
  - Forbidden materials (wood,…) , items (batteries, …)

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NON-DESTRUCTIVE ANALYSIS

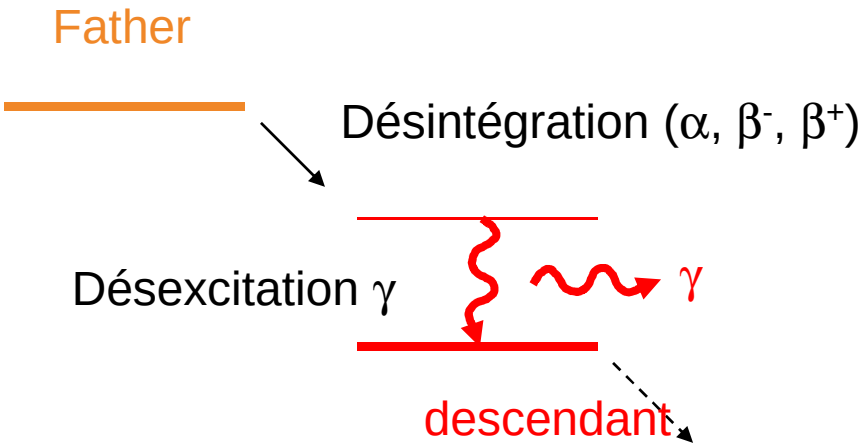
Non-destructive nuclear measurements for …

- Radiological characterization (by gamma spectrometry active & passive neutron measurements, passive imagery, etc.)
- Physical characterization (by active imagery : radiography and tomography)
- Elemental characterization (by neutron interrogation or activation)

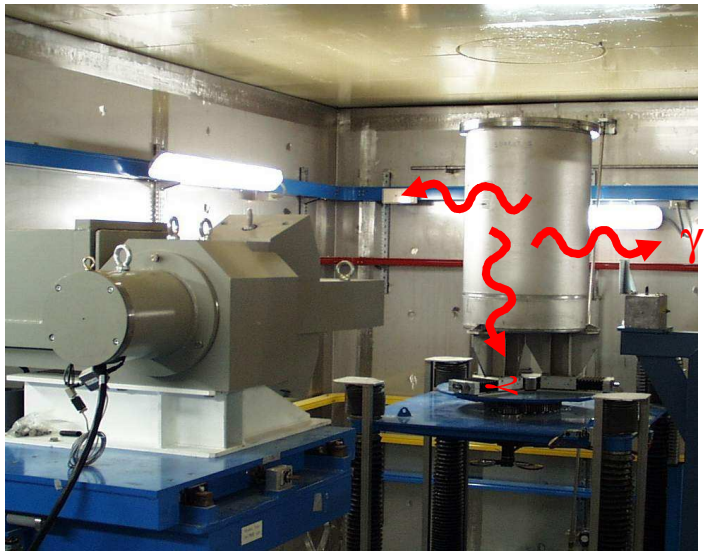
Characterization of …

- Waste packages (contaminants, matrices)
- Historical waste, "exotic" waste, etc.

NON-DESTRUCTIVE ANALYSIS : GAMMA SPECTROMETRY



Identification and quantification of radionuclides through his descendants



- Global Measurement
- Segmented Measurement

Germanium Detectors

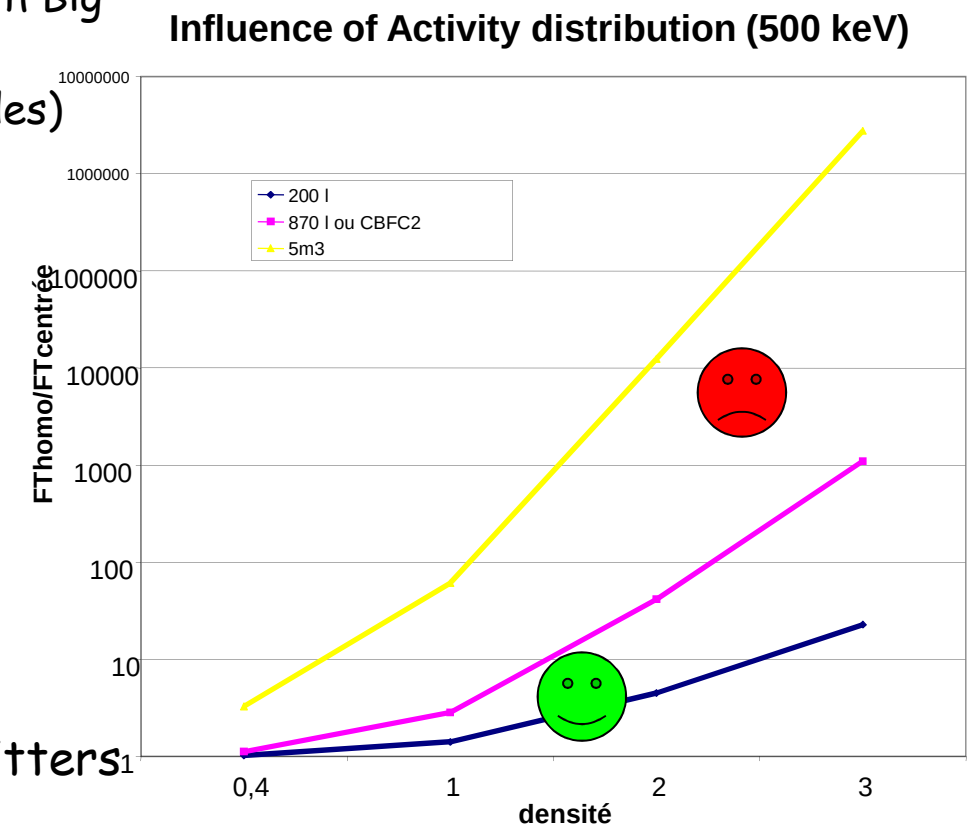
THE AND OF GAMMA SPECTROMETRY

- Impact of activity distribution with Big volumes and/or high densities
- Difficult for Low energies (actinides)
- Interpretation of measurement for heterogeneous WP needs :
  - Density distribution
  - Activity distribution

$$A_{\text{inside WP}} = A_{\text{measured}} / FT(E_\gamma, WP)$$

Uncertainties

- Easy to implement
- Useful for Activity of β/γ emitters
- WP < 1m³, d < 1,5



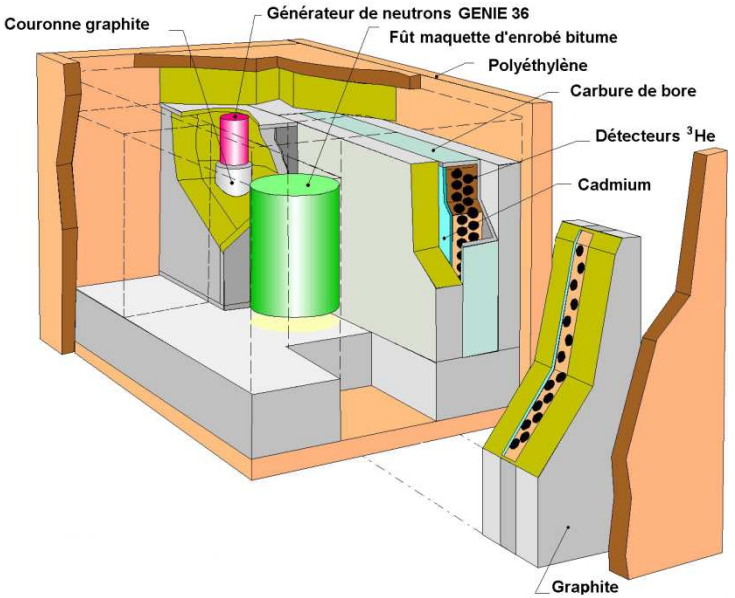
NON-DESTRUCTIVE ANALYSIS : NEUTRON MEASUREMENT

Passive Measurement

Global measurement of neutron emission
(spontaneous fission + (α, n) reaction)

E_n ~ 2MeV => **slowing down-thermalisation-detection**

Prométhée cell



Indirect Measurement :

- ^{238}Pu + ^{240}Pu + ^{242}Pu + !(^{244}Cm, ^{241}Am …)!
  - E_n (^{240}Pu)= 1020 n.s^{-1}.g^{-1}
  - E_n (^{238}Pu)= 2590 n.s^{-1}.g^{-1}
  - E_n (^{244}Cm)= 1,08 10^7 n.s^{-1}.g^{-1}

- Needs Isotopic Composition (CI)

-> coupling with gamma spectrometry

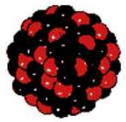
- Global counting and coincidence ((α, n) rate)

Active Measurement

Global measurement of neutron emission after activation
(induced fission by thermal neutrons)

Symetric cell

E_n=14MeV (2.10^9 s^{-1})

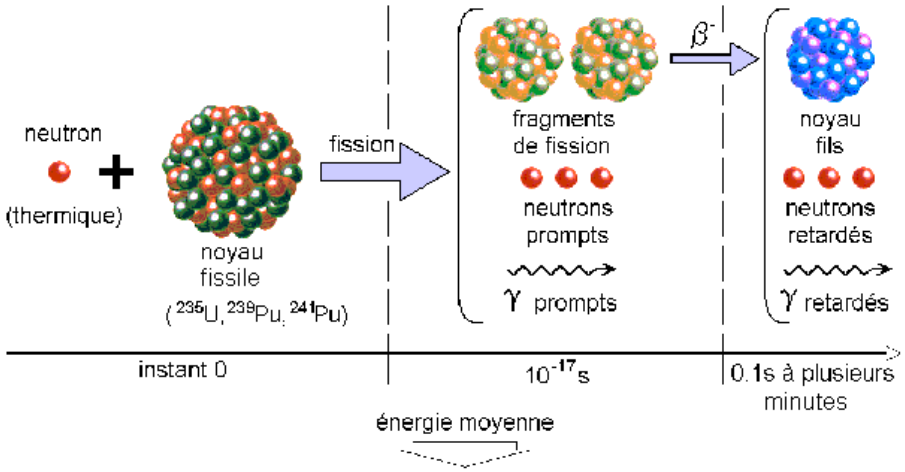


Indirecte Measurement :

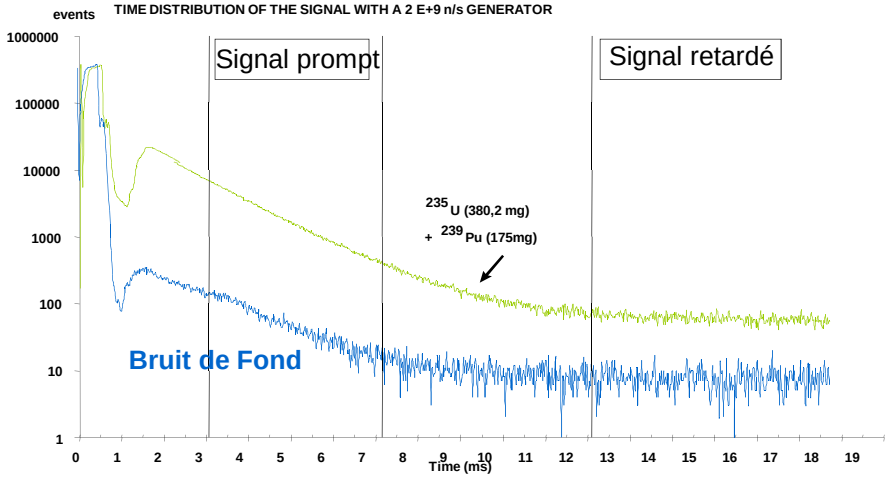
- ^{235}U + ^{239}Pu + ^{241}Pu
  (No more problem with Cm!)
- Needs Isotopic Composition

NON-DESTRUCTIVE ANALYSIS : NEUTRON MEASUREMENT

PRINCIPE DE LA MESURE NEUTRONIQUE ACTIVE



- neutrons prompts : 2 MeV 2 à 3 par fission
- neutrons retardés : 500 KeV $0,6\ 10^{-2}$ à $1,6\ 10^{-2}$ par fission
- γ retardés : 1 MeV 5 à 7 par fission



NON-DESTRUCTIVE ANALYSIS : NEUTRON MEASUREMENT

Passive Measurement (Source at the center of a 118 liter drum - 30 minutes)

Matrice	Fût vide	Cellulose d=0,14	PVC d=0,18	PVC d=0,25	Metal d=0,26
ε (%)	22,9	19,1	19,0	17,2	18,9
CE ^{240}Pu (c/s/g)	39,6	27,5	27,2	22,3	27,0
Detection limit (g ^{240}Pu)	$1{,}7.10^{-3}$	$2{,}5.10^{-3}$	$2{,}5.10^{-3}$	$3{,}1.10^{-3}$	$2{,}6.10^{-3}$

Active Measurement (Source at the center of a 118 liter drum - 15 minutes)

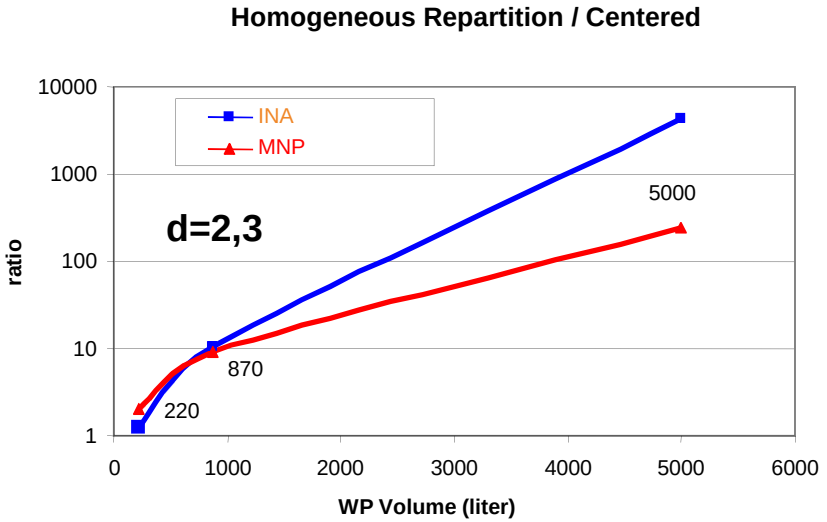
Matrice	Cellulose d=0,14	PVC d=0,25	Metal d=0,26
Ket ^{239}Pu (c/s/mg)	12	0,3	4,2
Detection limit (mg ^{239}Pu)	0,09	3,4	0,3

NON-DESTRUCTIVE ANALYSIS : NEUTRON MEASUREMENT

THE AND OF PASSIVE AND ACTIVE NEUTRON MESUREMENT

- Needs Isotopic Composition
- Chemical Composition dependant (α,n)
- Impact of contamination (Passive - Cm)
- Impact of background (Active measurement)
- Impact of Hydrogen (light materials, concrete)
- Impact of absorbers (B, Cl)

- Useful for Measurement of (U, Pu)
- Works with high density (metallic)
- Irradiating WP
- Can provide Activity distribution
- Up to 870 liters drum
- Localisation (IPA)



NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

Methods for non destructive examination of the WP to check :

- Geometrical criterias
  thickness, position, shielding, …
  Spatial Resolution from 2 mm (cylind.) to 1 cm (caisson)

- Homogeneity, défaults
  Homogeneity, void (cm^3), cracks (2mm*qq cms)
  Resolution for density : from sev. %(cylind.) to 10%(caisson)

- Absence of Forbidden Wastes (form recognition, density) :
  wood, batteries, liquids, ….

- Provides Information on the whole Waste Package

- Allows reduction of uncertainties on activity measurements

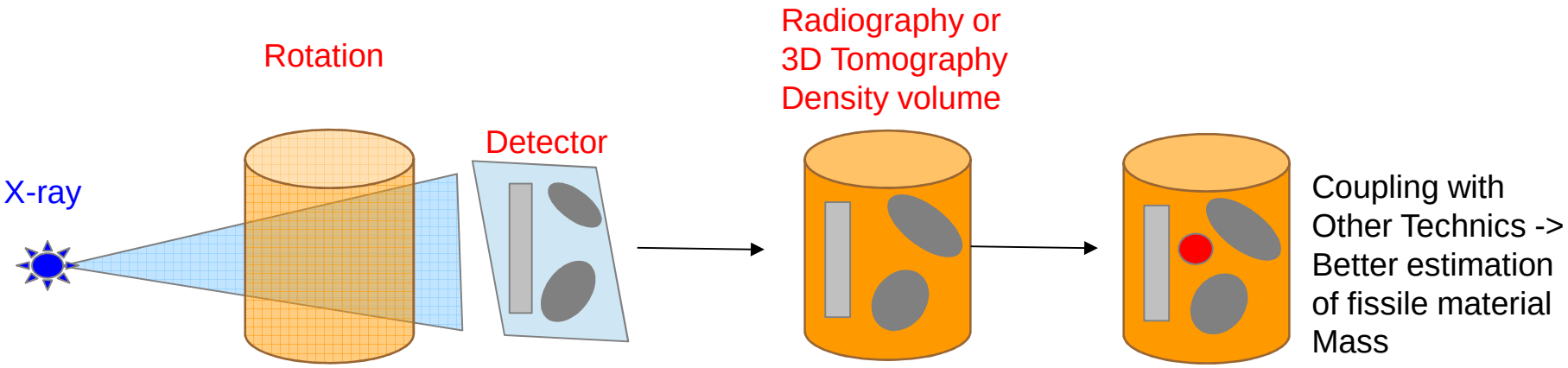
- Provides Information for destructive analysis : cutting, coring

X Radiography/Tomography : prior to other measurements

NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

PRINCIPLE

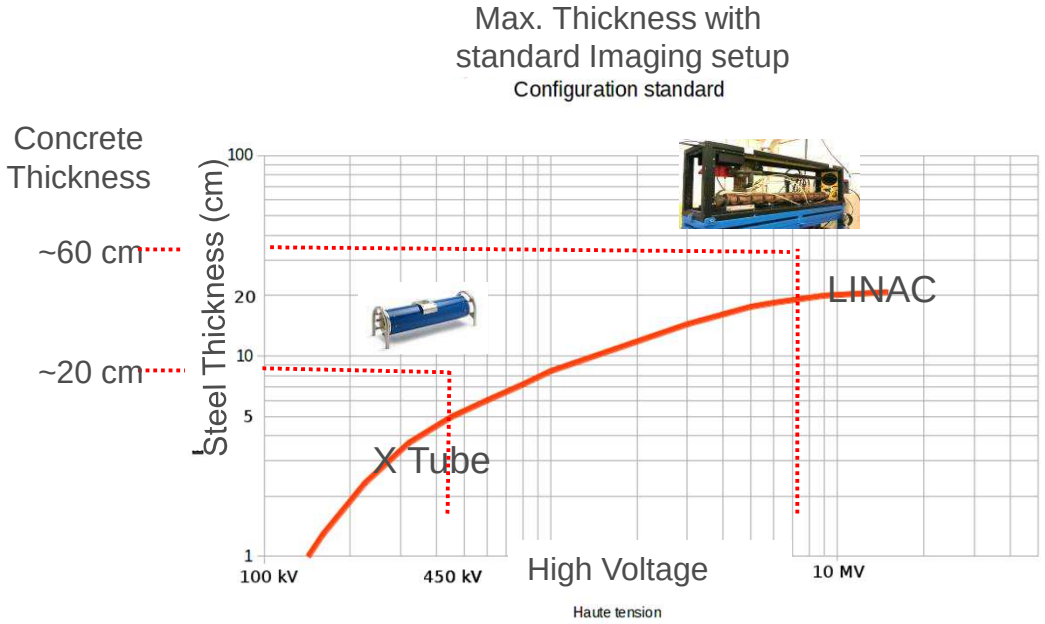
- Measurement of the exponential attenuation of X Ray inside the Waste Package : attenuation factor μ linked to density



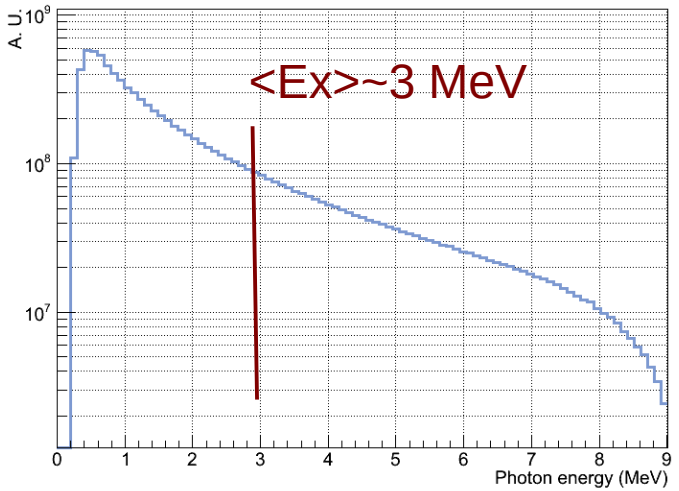
NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

IMAGING SOURCE: LINEAR ACCELERATOR (LINAC)

- For medium (60 cm diam.) and large (> 1m diam.) waste drums, MegaVoltage source mandatory



Varian MiniLinatron 9 MeV
Eq. Dose rate: **20 Gy/min**
Pulse Freq : 300 Hz
Bremsstrahlung Spectrum:



- Radiological Safety : imaging setup placed in irradiation cell CINPHONIE

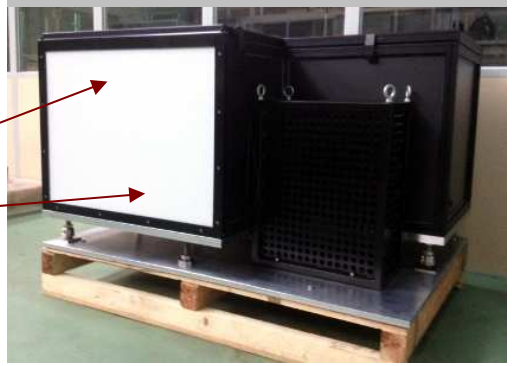
NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

IRRADIATION CELL: CINPHONIE

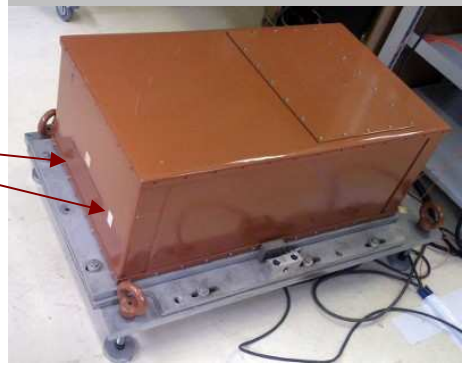
- Cell view

- 2 Detectors used (prototypes)

Phosphor screen



CdTe Detectors



NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

Phosphor Screen Detector

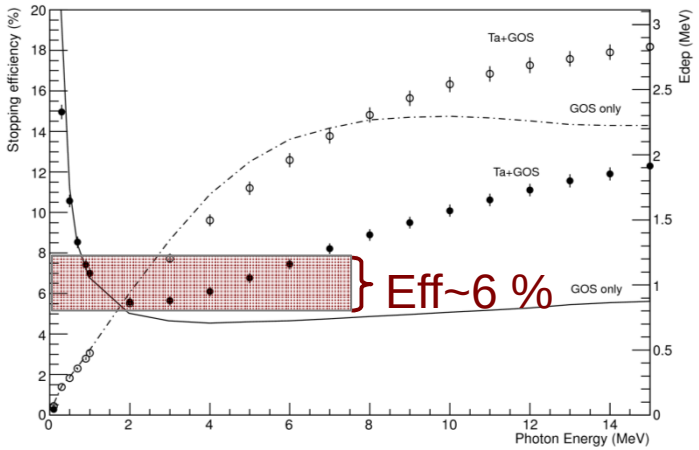
Measurements on medium size objects (<80 cm)

Radiography
3D Tomography (Cone-Beam CT)

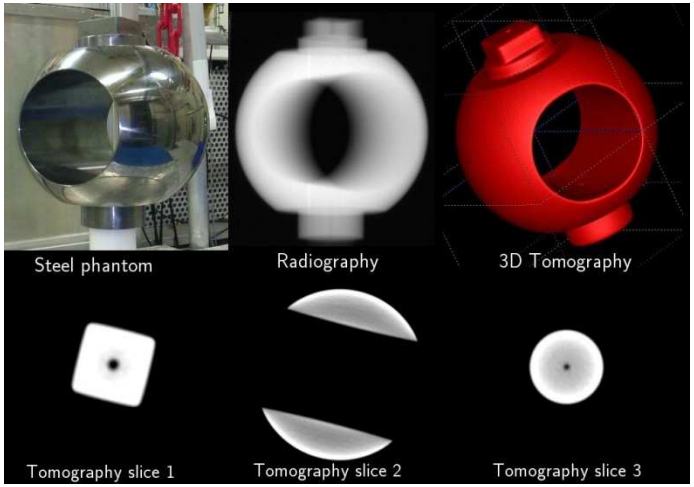
Phosphor screen | Mirror | Low-noise Camera



Phosphor Screen efficiency (GEANT4 Simulation)



Validation on steel phantom
EQ. 60-cm concrete



	CEA Prototype	Commercial flat-panels
Size (cm^2)	80x60	40x40
Efficiency (%) @ 2MeV	6	<0.1

Pros: easy to use and fast

Cons: Spatiale resolution : 2 mm
Max attenuation : 2 decades

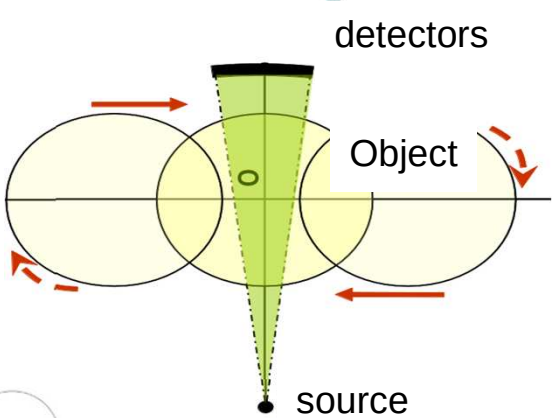
NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

CDTE DETECTORS

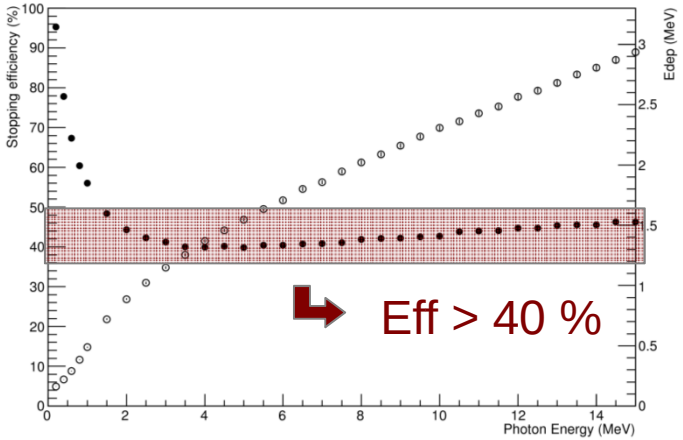
Measurements on large size objects (>100 cm)

Radiography
2D Tomography
3D Tomography (Helical CT)

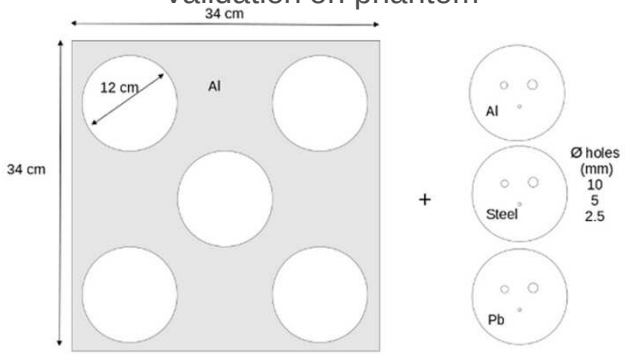
25 CdTe sensors



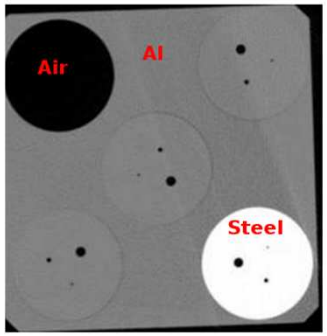
CdTe sensor efficiency (GEANT4 Simulation)



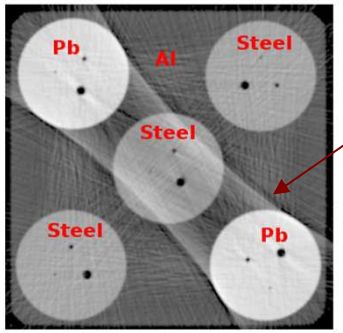
Validation on phantom



2 decade attenuation



6 decade attenuation



Reconstruction artefact (total attenuation)

Pros: Spatial resolution ~ 1mm
Max attenuation 5 decades

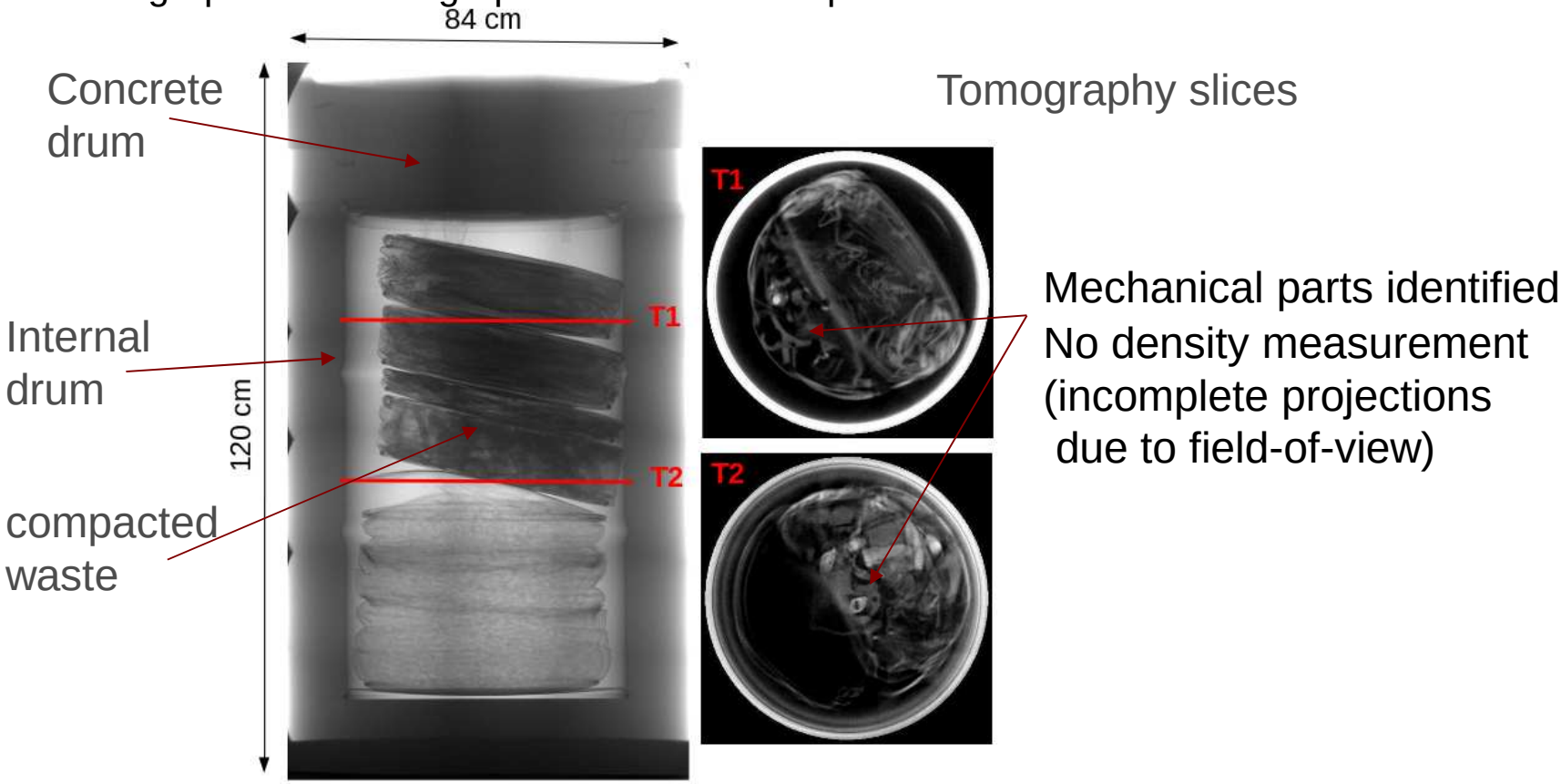
Cons: NOT easy to use
Meas. Duration 45 min/slice

2.5 mm holes detected with 6 decade attenuation !
eq. 2 m concrete

NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

MEDIUM-SIZE WASTE DRUM IMAGING

- Radiographies & Tomographies with 2D Phosphor screen



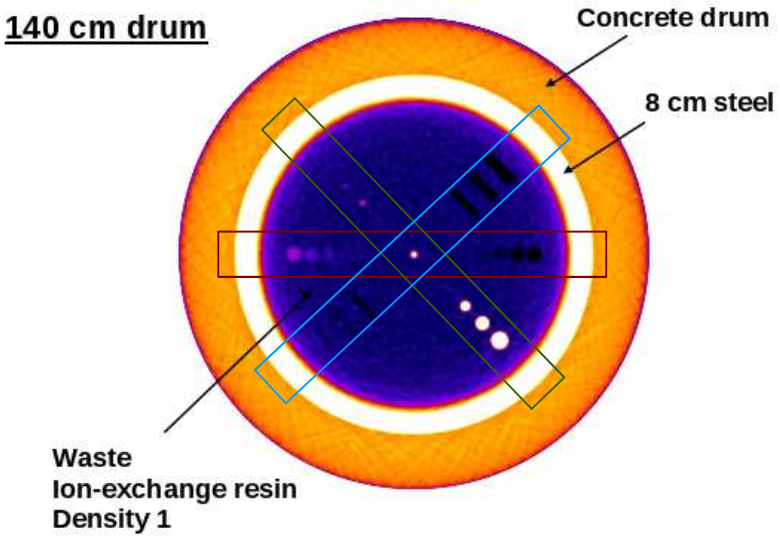
- Waste drum imaging with CdTe sensors should start this year

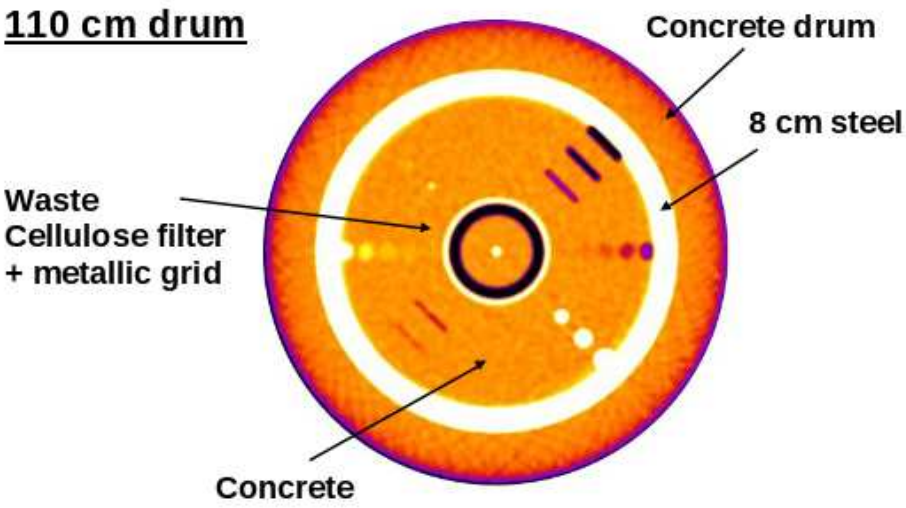
NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

Expected results on large size drum (CdTe sensors)

- Tomography simulation with MODHERATO (internal dev)

Model without scattering (collimated geometry) and without beam hardening correction





- Density patterns: ± 40 % to ± 5 %
- Steel patterns: Ø 40 to 1.25 mm
- Void patterns: thick. 20 to 0.6 mm

Expected Results

Heterogeneity detection: ± 5 % matrix density
Steel object detection: 5 mm
Void crack detection: 1.25 mm

NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

Future upgrades & Prospects

- Current setup limitations:
  - Single electron energy 9 MeV
  - X-ray Focal size ~ 3 mm
  - Object mass < 2 tons

- Upgrades under investigation:
  - High power linac: energy up to 25 MeV, 250 Gy/min
    - Small focal size (0.5 - 2 mm)
    - Tunable e^- energy
  - Mechanical bench with load capacity 5 tons

New modality
Multi-energy tomography
→ Atomic Number and Density map

- Upgrades starts in 2015

NON-DESTRUCTIVE ANALYSIS : RADIOGRAPHY AND TOMOGRAPHY

Conclusion

- 2013: At Cadarache, comissionning of underground irradiation cell CINPHONIE
  - High Energy Imaging on medium size nuclear waste drum
  - Handled object < 2 tons
  - Imaging setup unique in France
- 2015-2017: global upgrade
  - High Power Linac
  - Handled object < 5 tons
  - Imaging setup unique in World !
- Tomography setup could be used for non-nuclear applications (examination of equipments for aircraft manufacturing, …)

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NON-DESTRUCTIVE ANALYSIS : CONCLUSION

A large number of non-destructive analysis techniques
but with limited capacities…

✓Incomplete Information but also
✓Complementary information

Coupling of measurement -> reduction of uncertainties

X Ray Radiography / Tomography allows matrice characterization
and reduction of uncertainites on activity measurement

Commissariat à l’énergie atomique et aux énergies alternatives

Etablissement public à caractère industriel et commercial | RCS Paris B 775 685 019