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Replacing, refurbishing irradiated fuel rods X ray equipment

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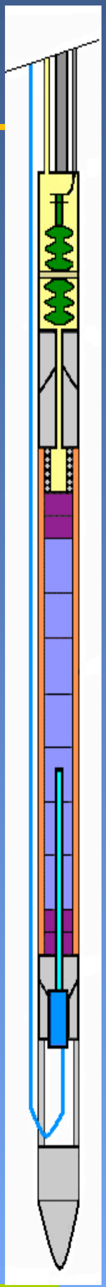
The Gas Extraction and Non-Destructive Examinations Laboratory in LECA Facility

Outline

- Objectives
- Identified Technology
- Results
- Conclusion



Objectives

- Refurbishing X-rays equipement for fuel rod inspection
- New applications for the futur device :
  - Core inspection instrumented fuel rod
  - Enhance resolution, image contrast
  - Tomography
- Integrate the components in the actual X-rays cabine :
  - Limit civil engineering operations.

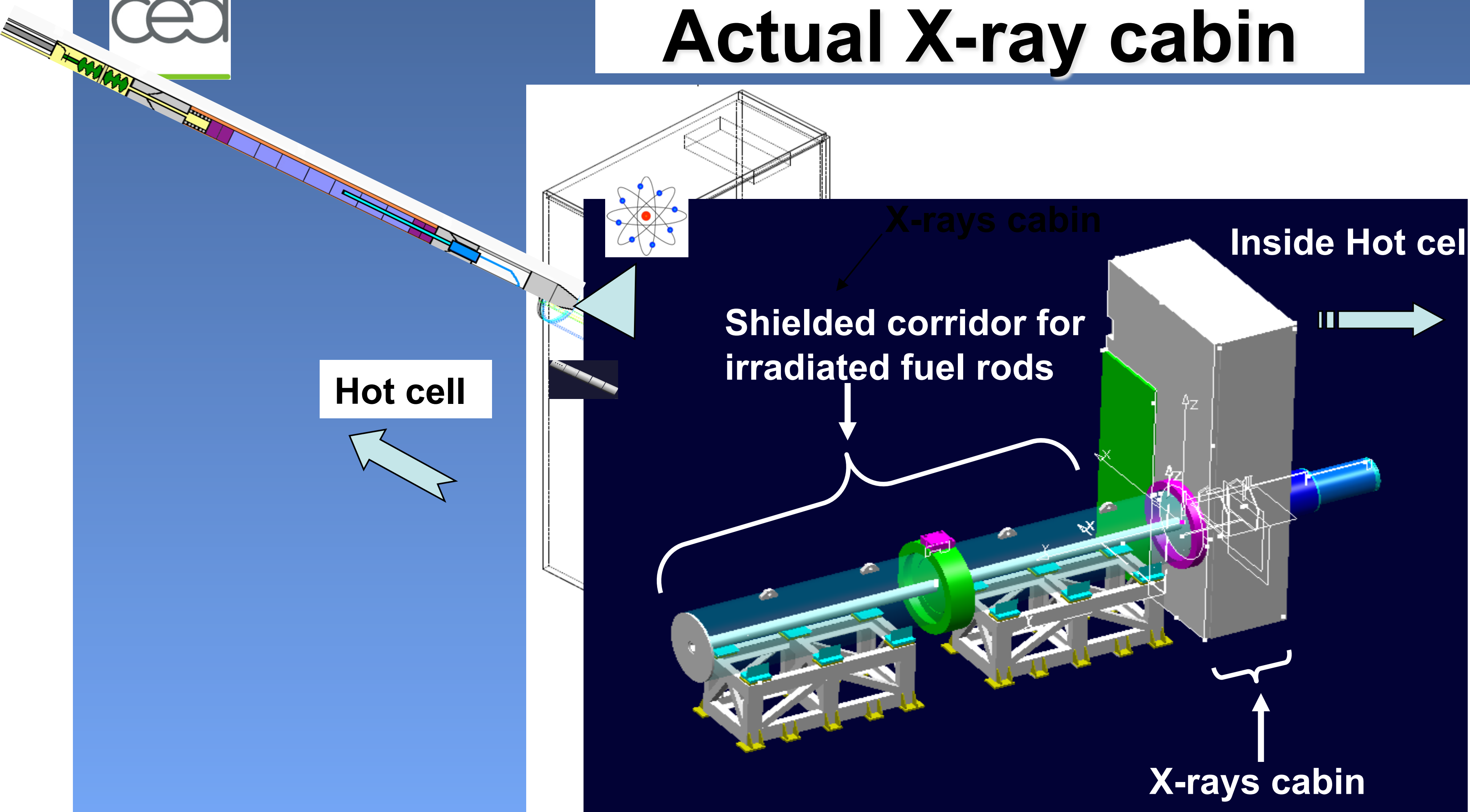
Motivations

- Refurbishing X-ray equipment for fuel rod inspection in LECA Facility in Cadarache center :
  - 15 years of age Technology
  - Source mini-spot 160 kvolt 2 mA – mini-spot 0,2 mm
  - Image Intensifier as X-ray detector
  - Low image contrast
  - Low resolution
- New X-rays equipment :
  - High-tech components
  - Computer tomography
- Further applications :
  - Inspection in core instrumented fuel rods
  - Enhance image contrast, resolution less than 100 µm
  - Computer tomography
- Mock-up testing on standard sample
- Results
- Hot cell Implementation in 2011

Applications actual X rays equipment

- Fuel column length and diameter measurement
- Length and diameter pellet measurement
- Dishing
- Gap between pellets
- Gap between cladding and pellets
- End plug, spring… rod components

Actual X-ray cabin



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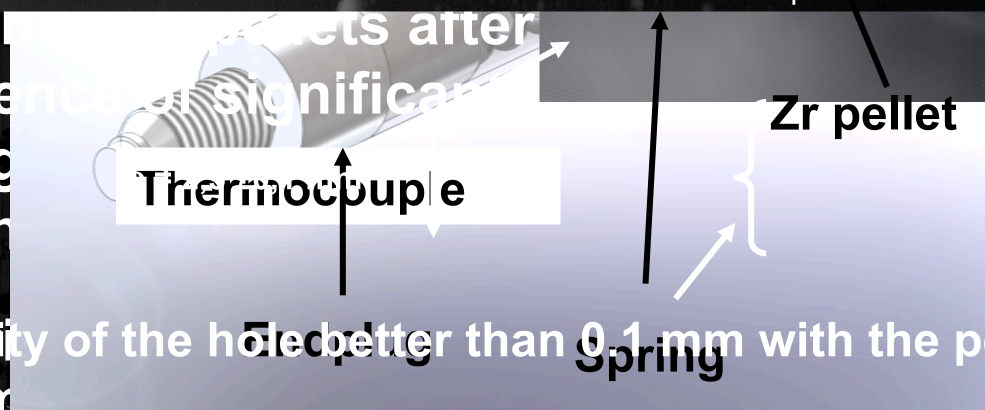
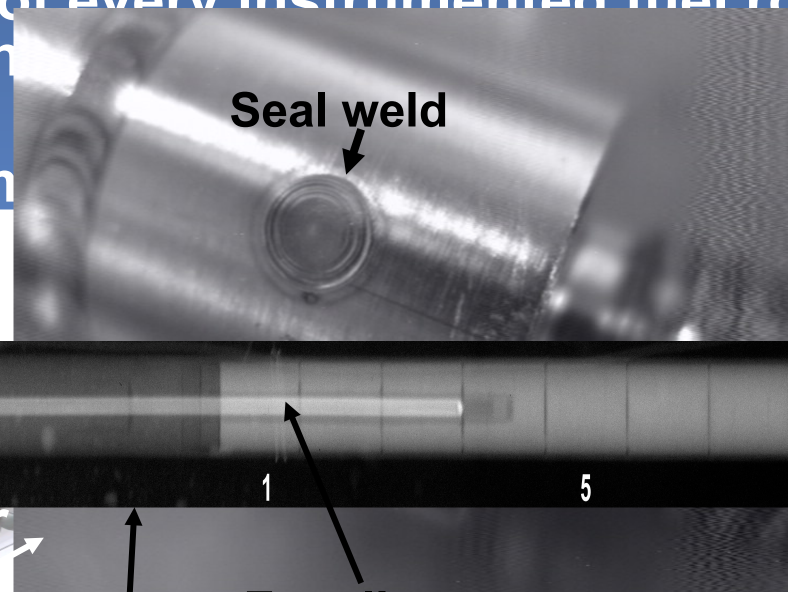
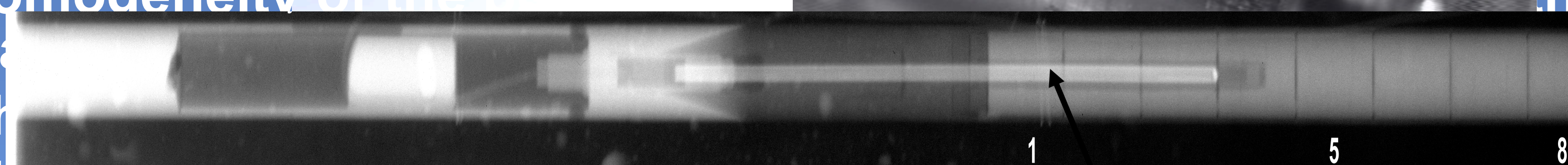
New x-rays equipment applications

- Full length x-rays will be taken of every instrumented fuel rods manufactured in LECA Facility. Th… in…
- the presence of the correct com…
- the absence of gaps in…
- homogeneity of the b… …h the shea…
- th…
- flatness of t… …ets after and the absence of significan…
- The x-radiog… …enum length
- Additional h… …op girth and seal weld zones … …re-fabricated fuel rod - this will… …sound and meet specified lim…





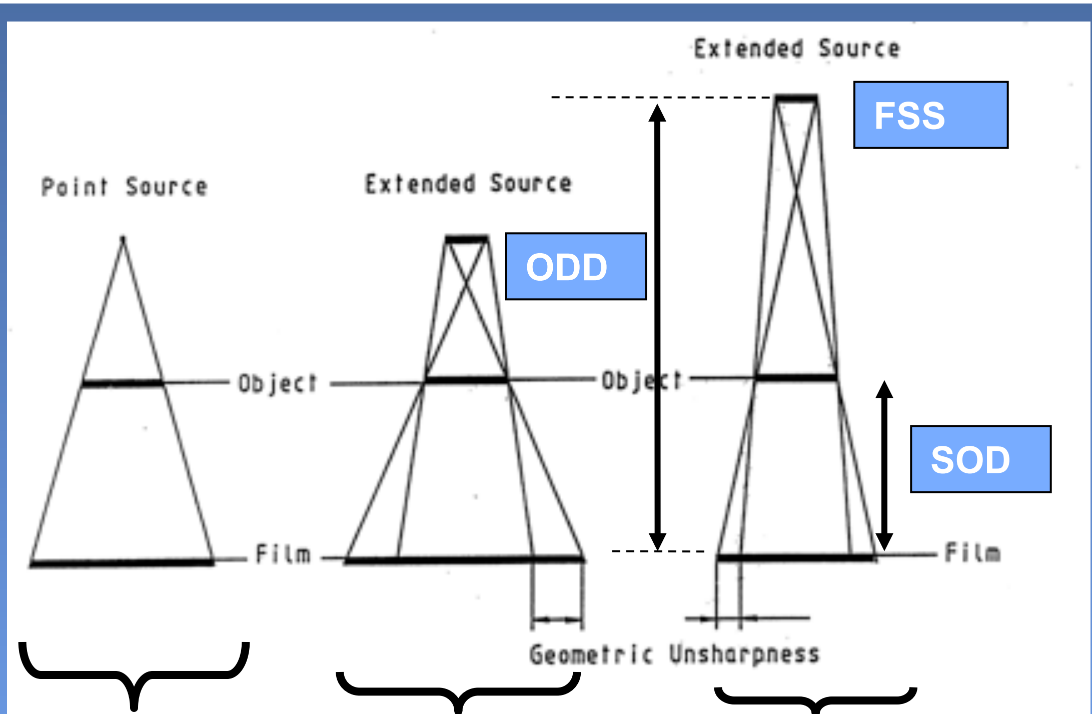


X ray source : Microfocus X-rays tube

Our x-ray examinations need very high-resolution images and do therefore require x-ray tubes that can generate very small focal spot sizes. In our case, typically **100 µm** in diameter for **450 kvolt.**

Radiographic unsharpness (Ug)

Comparaison of geometric unsharpness of 3 configurations



(A) Point source **(B) Extended source** **(C) Extended source Further away from the Image plane**

- If the focal spot is infinitesimally small, the blur is minimized because of minimal geometric bluntness
- As the focal spot increases, the blur in the image increases

Radiographic unsharpness (Ug)

Radiographic unsharpness (Ug) is related to the geometry of the radiographic technique and simply put, is the amount of 'blur' present in a radiography image.

The primary factors contributing to Ug in the radiographic technique are:

1. A large focal spot :

(point from which the usable radiation beam emanates). In X-ray tubes, this is the area where high speed electrons are focused onto the target, resulting in the generation of photons.

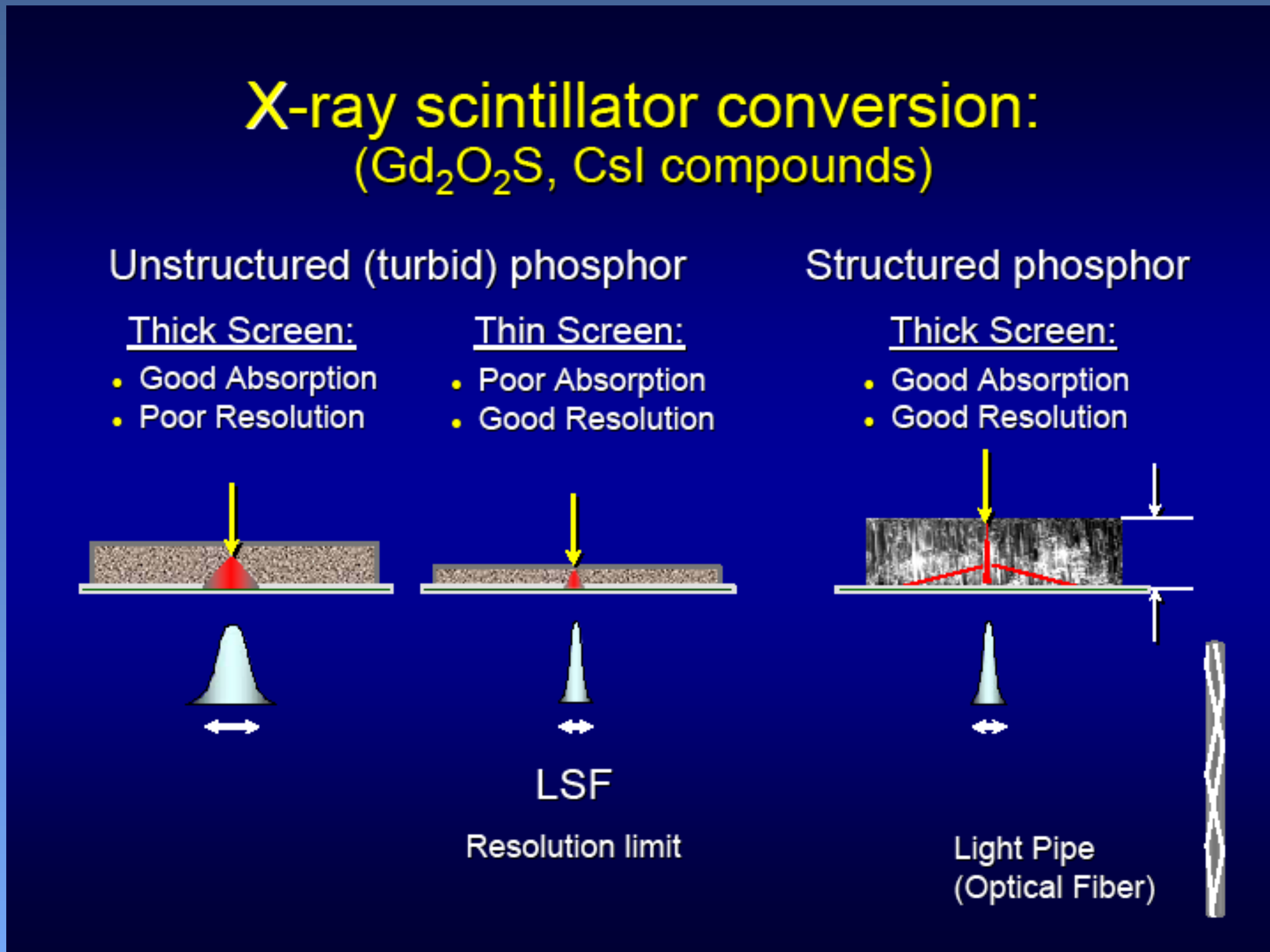
1. Excessive object to detector distance, as related to focal spot size (FSS).

Ug for any radiographic technique can be easily calculated using the following formula:

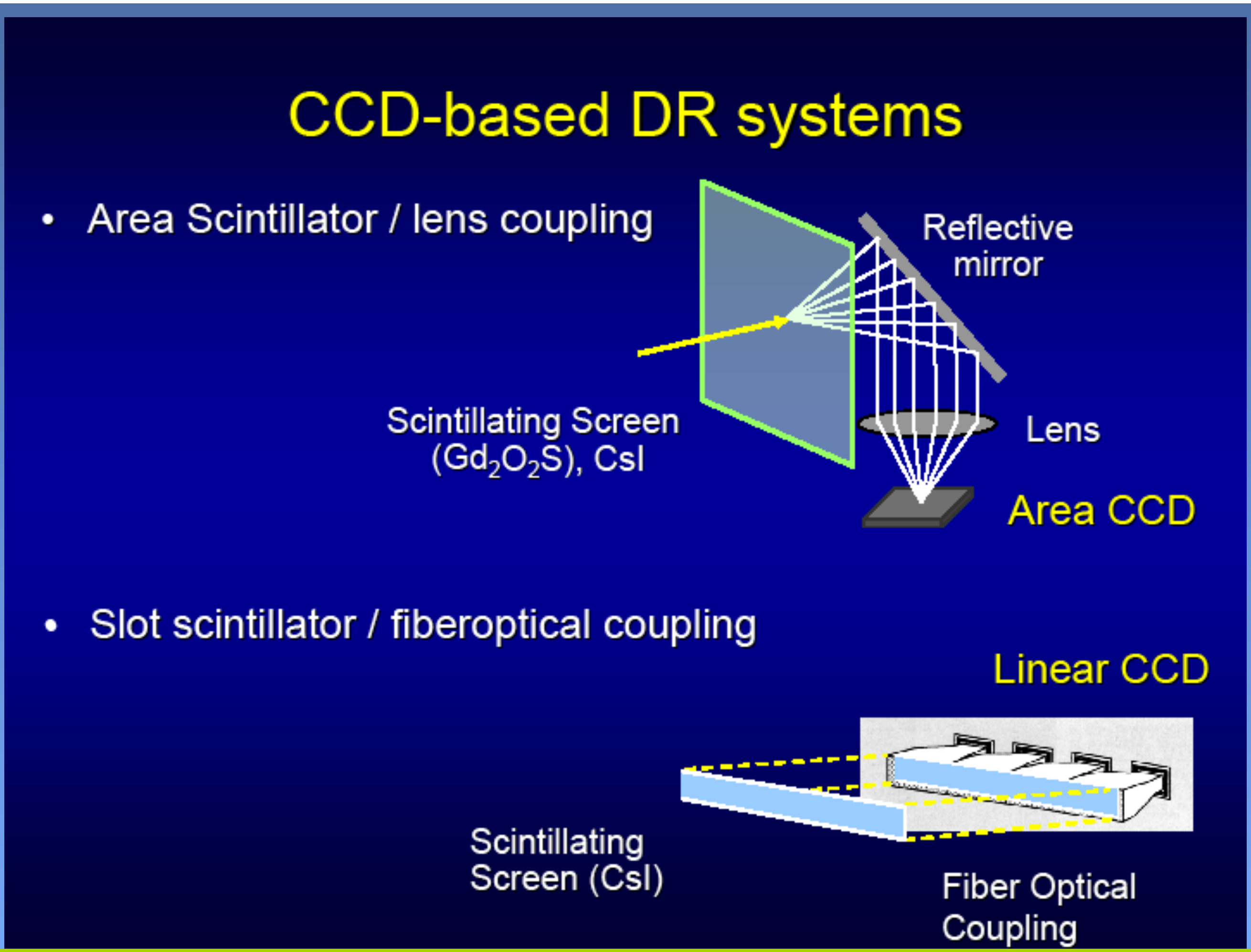
$$Ug = \frac{FSS \times ODD}{SOD}$$

FSS = Focal spot size
ODD = Object to detector distance
SOD = Source to object distance

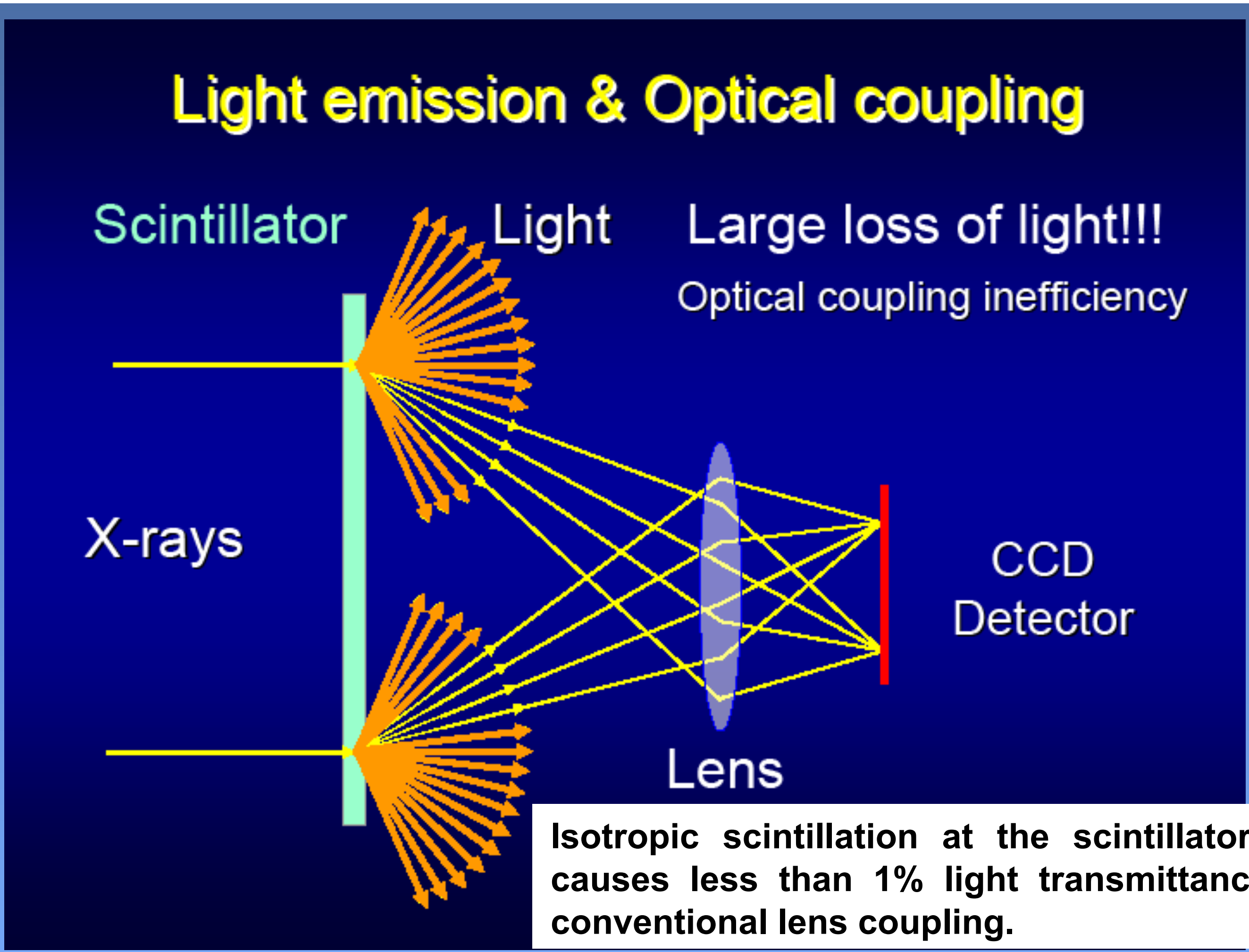
For our X-ray cabin, Ug will be minimized by using a micro spot, keeping the fuel rod as close to the digital detector as possible. In our case this distance is limited by biologic protection around the specimen.


X-ray scintillator conversion:
(Gd_2O_2S, CsI compounds)
Unstructured (turbid) phosphor
Thick Screen:
• Good Absorption
• Poor Resolution
Thin Screen:
• Poor Absorption
• Good Resolution
Structured phosphor
Thick Screen:
• Good Absorption
• Good Resolution
LSF
Resolution limit
Light Pipe
(Optical Fiber)

"Indirect" x-Indirect detector: a conversion of x rays into light by a scintillator, *and* light into electrons for signal capture



Schematic illustration of the lens coupling between a scintillator and a CCD detector.



Isotropic scintillation at the scintillator surface causes less than 1% light transmittance with a conventional lens coupling.

Collection efficiency for lenses

Collection efficiency for lenses

$$\eta_L = \frac{T_L}{1 + 4 \bullet f_{\#}^2 \bullet (1+m)^2}$$

- Assuming Lambertian source of light

T_L = transmission factor of lens

$f_{\#}$ = f-number of lens

m = demagnification factor

- Note $f_{\#}$ and m appear as squared terms

Example

$f_{\#} = 1.2$, $T_L = 0.8$, and $m = 2$

$\eta_L = 1.5\%$

Collection efficiency – fiber optic

$$\eta_{TFO} = \left(\frac{1}{m}\right)^2 \bullet \left(\frac{\left(n_2^2 - n_3^2\right)^{1/2}}{n_1}\right)^2 \bullet T_F \bullet (1 - L_R) \bullet F_C$$

Asuming Lambertian source as before

m = demagnification factor

n_1, n_2, n_3 = refraction indices of sources medium, fiber core and cladding

T_F = loss due to Fresnel reflection

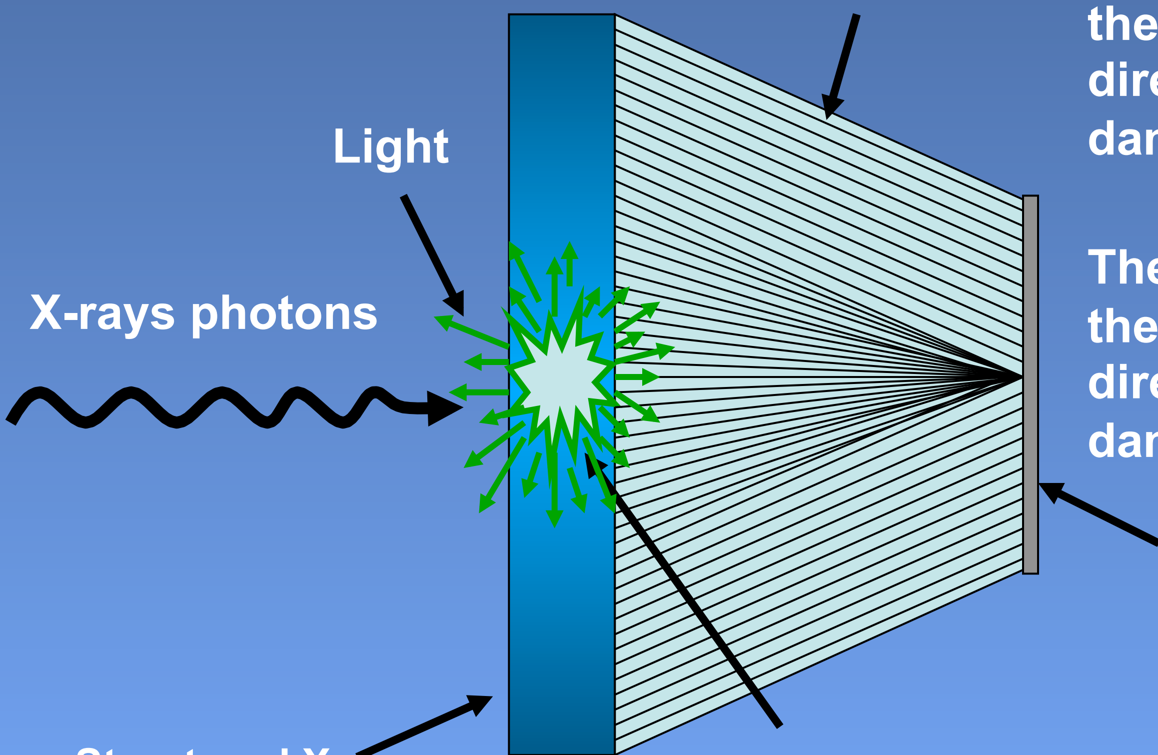
Fc = fill factor of core

Examples : m = 2; n_1 = 1; n_2 = 1,8; n_3 = 1,5; T_F = 0,8

F_c = 0,85 and L_R = 0

η= 15%

Indirect detection principle



The CCD is sensitive to radiation, therefore, the bundle can not be directly coupled to it to avoid damage to CCD.

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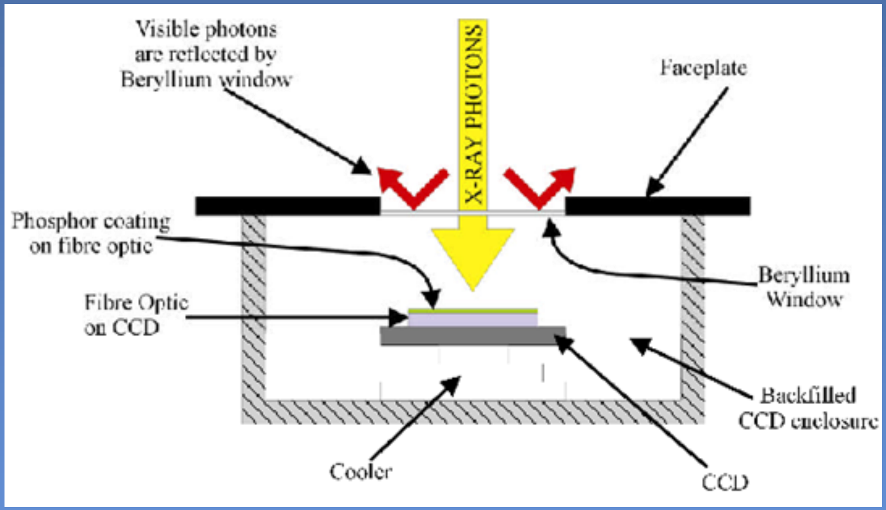
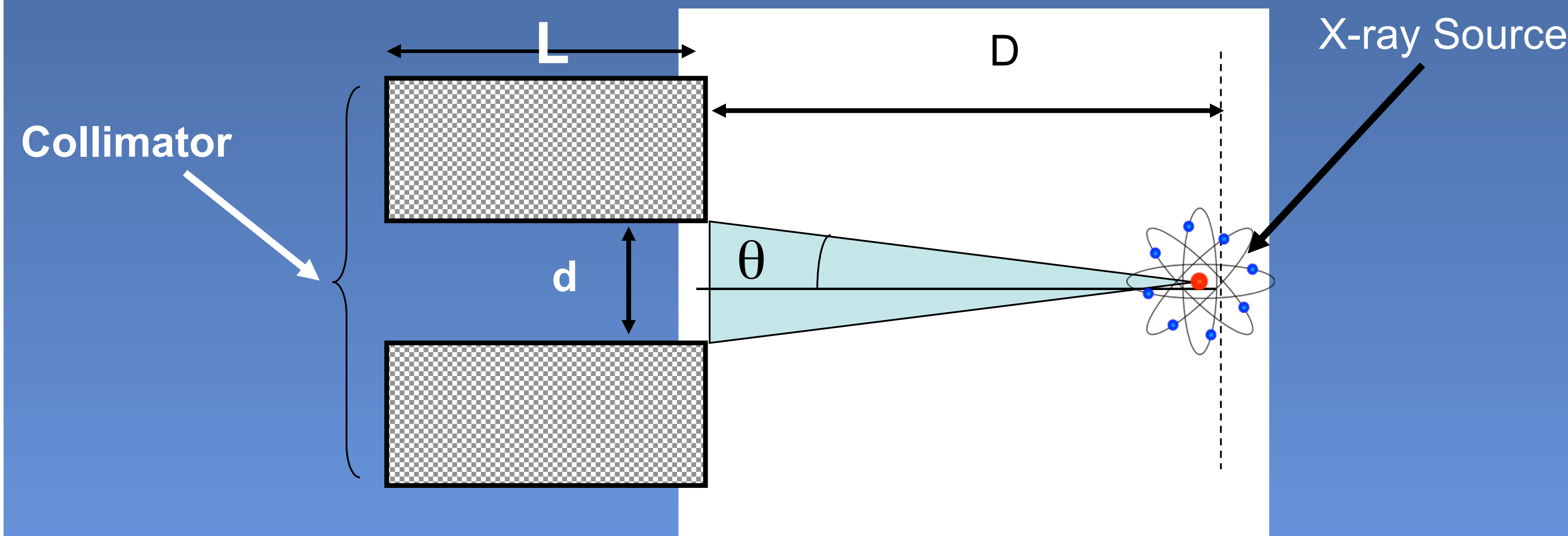
Indirect X-rays sensor



Indirect detection is used for hard X-ray detection and when you need:

- **Single photon sensitivity even with highly demagnifying**
- **tapers (EMCCD technology available)**
- **QE (Quantum Efficiency) coverage that stretches well into the hard x-ray region**
- **Large area coverage (via magnifying taper)**
- **High dynamic range at high energy levels**
- **Protection of the CCD sensor**

X Rays source general characterizations



D distance from collimator, d diameter slot, L collimator length

- **Resolution proportional to θ**
- **Resolution proportional to Distance from Source**

Spatial Resolution

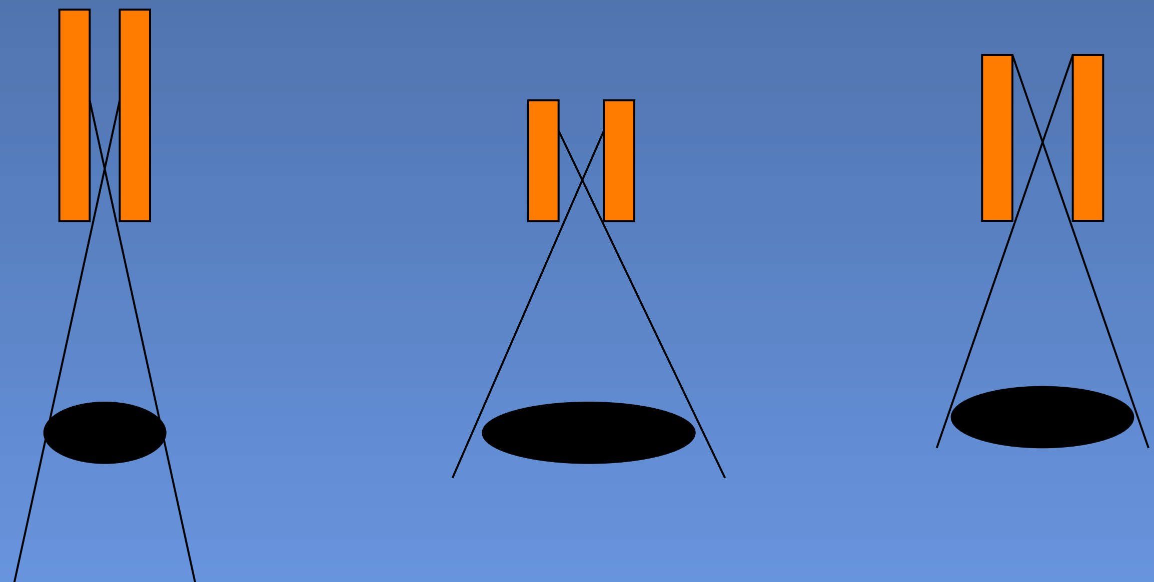
- R is an indicator of spatial resolution
- Spatial resolution degrades rapidly with increasing collimator-to-object distance D
- Size of the image produced by parallel-hole collimator not affected by distance of object from collimator

Spatial Resolution

Geometrical resolution Rg ~ $\frac{d \times (L + D)}{L}$

- As d increases, Rg increases (resolution is worse)
- As L increases, Rg decreases (resolution is better)
- As D increases, Rg increases (resolution is worse)

Sensitivity



From geometrical considerations, sensitivity is dependent on area seen by hole

Sensitivity ~ $(Rg)^2$

Sensitivity

- Sensitivity = efficiency of the collimator
- Sensitivity = the ratio of the number of photons that pass through the collimator to the number emitted
- Resolution is better as Rg decreases but sensitivity is much worse as Rg decreases (influence is squared)
- Thus efforts to improve resolution and sensitivity go in opposite directions
- So choice of collimator is a tradeoff between spatial resolution and sensitivity

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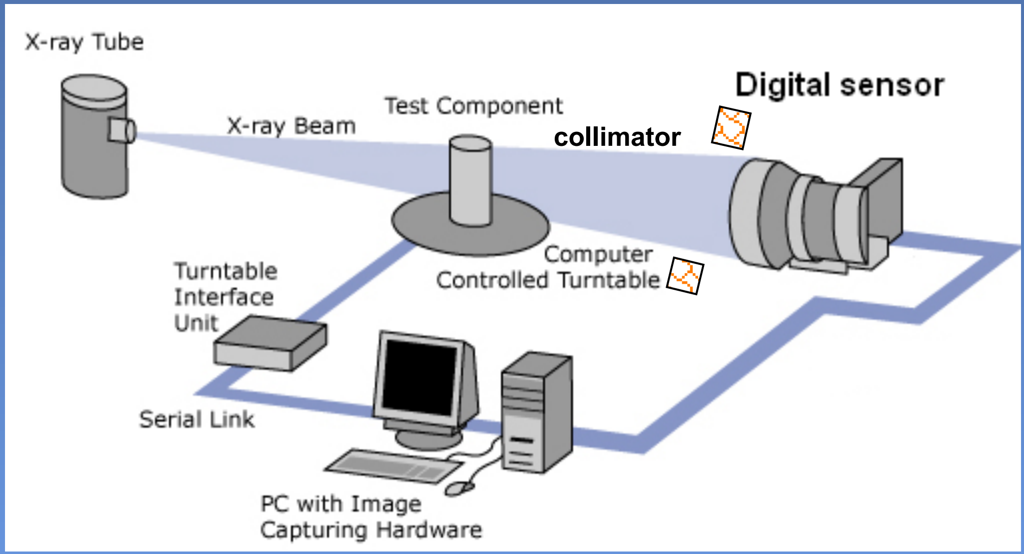
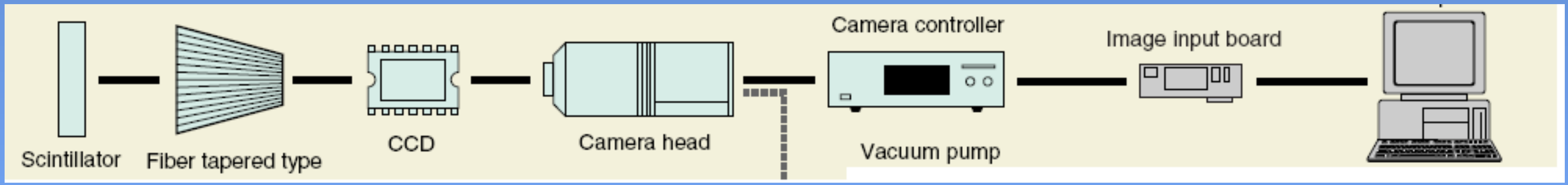
X-ray equipment



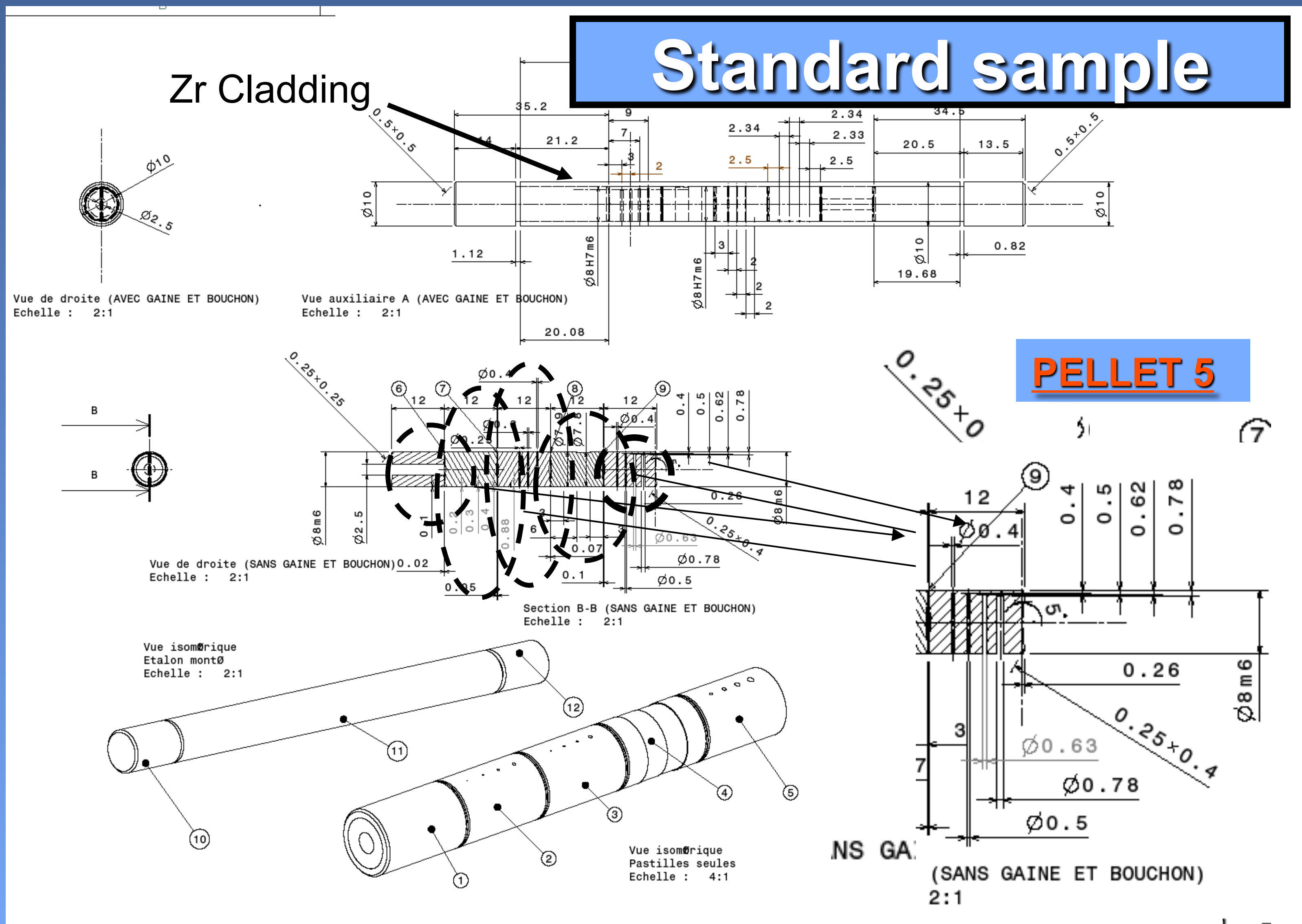


Digital X-ray detector : scintillator coupled with ccd sensor by fiber optics

Main Test Parameters

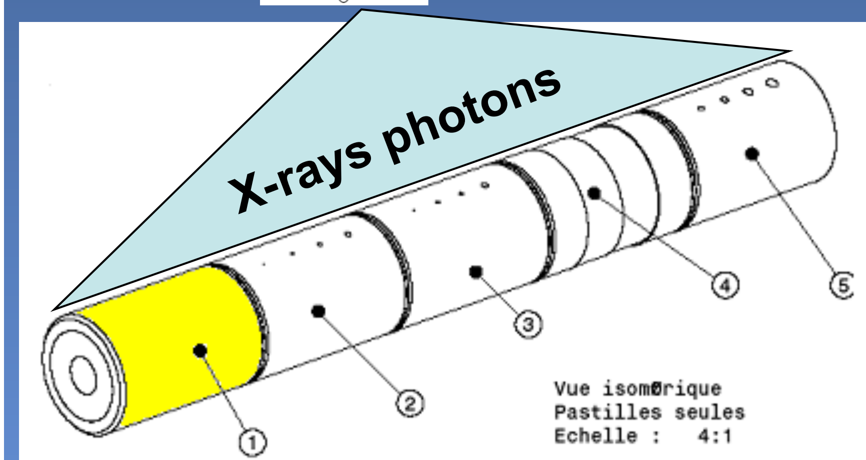
- X-ray high voltage 450kV
- X-ray tube current 1.55mA
- Geometrical magnification 2.7
- Focal spot size 0.1 mm
- 100 µm slot lead collimator
- Indirect sensor 25 µm pixel size
- Integration time 1 - 64 seconds19

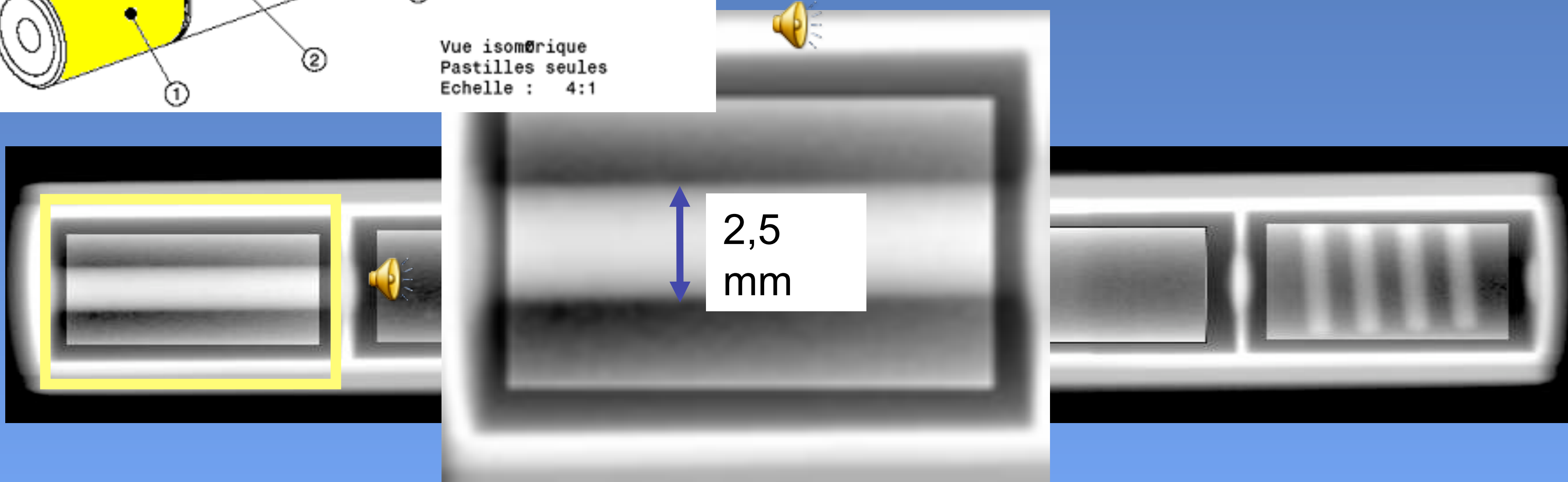
The French Energy Commission CEA
Fuel Studies Department DEC



The French Energy Commission CEA
Fuel Studies Department DEC

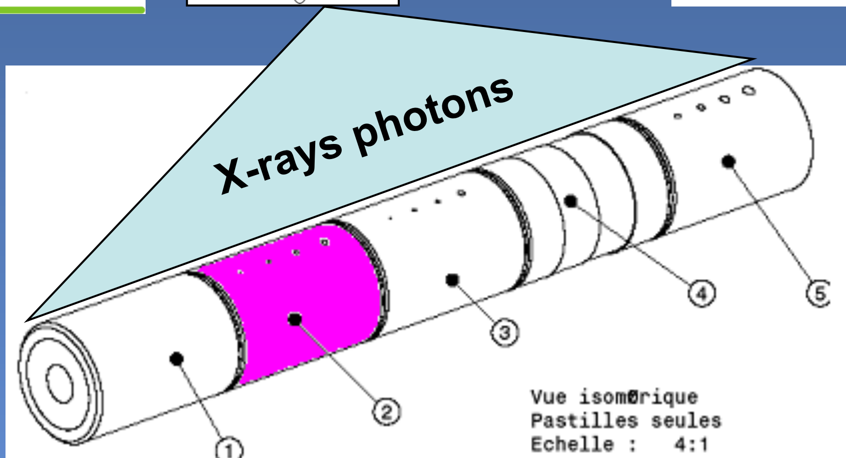
Pellet 1 digital radiography

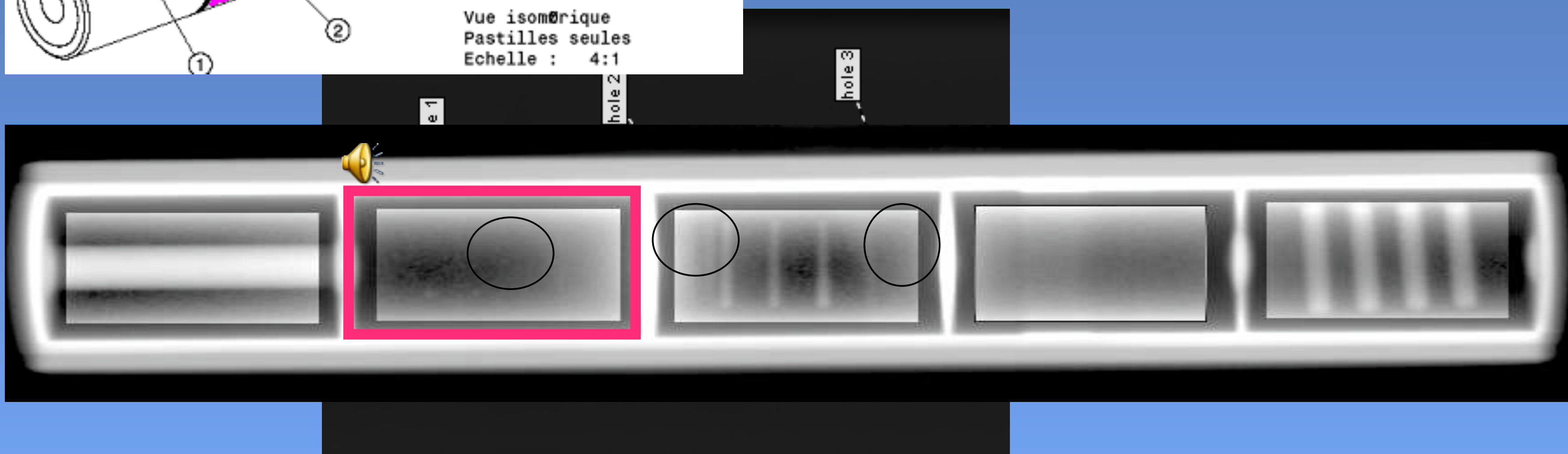




Orientation 0°, 450kV, 1.55mA, 64s integration time, original x-ray image without digital filtering.

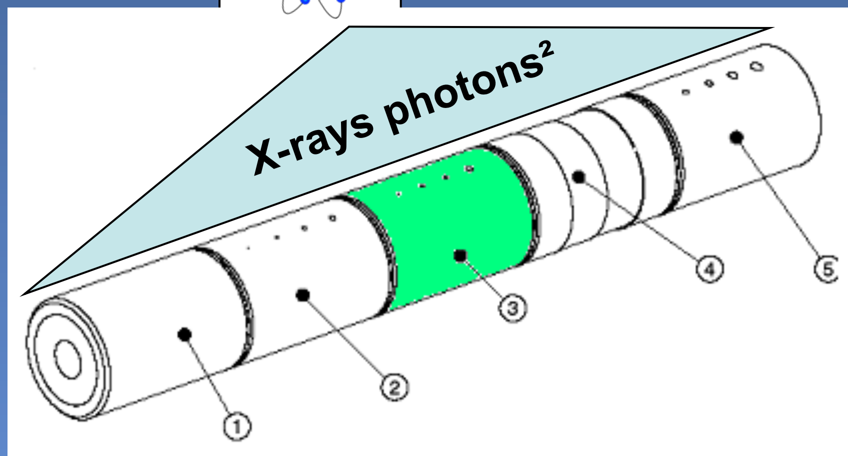
Pellet 2 digital radiography

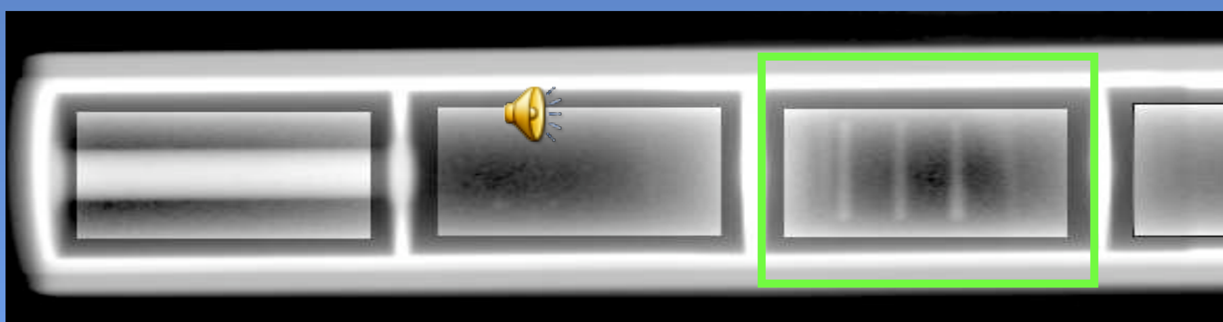


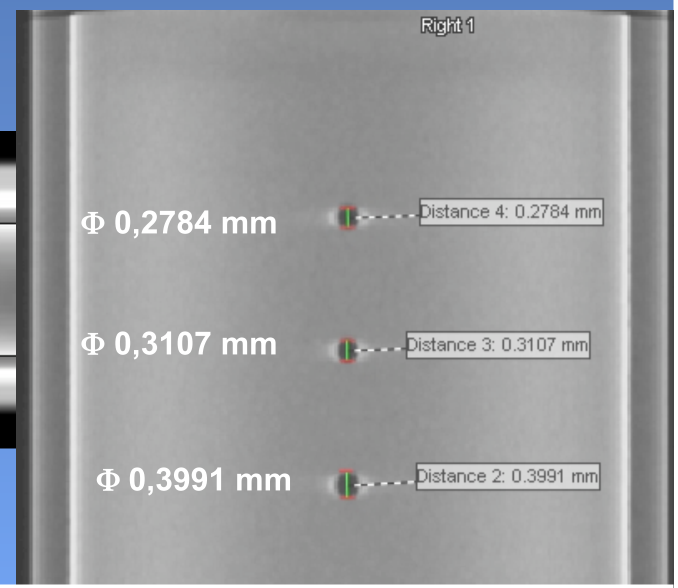


Orientation 0°, 450kV, 1.55mA, 64s integration time, original x-ray image without digital filtering.

Pellet 3 digital radiography

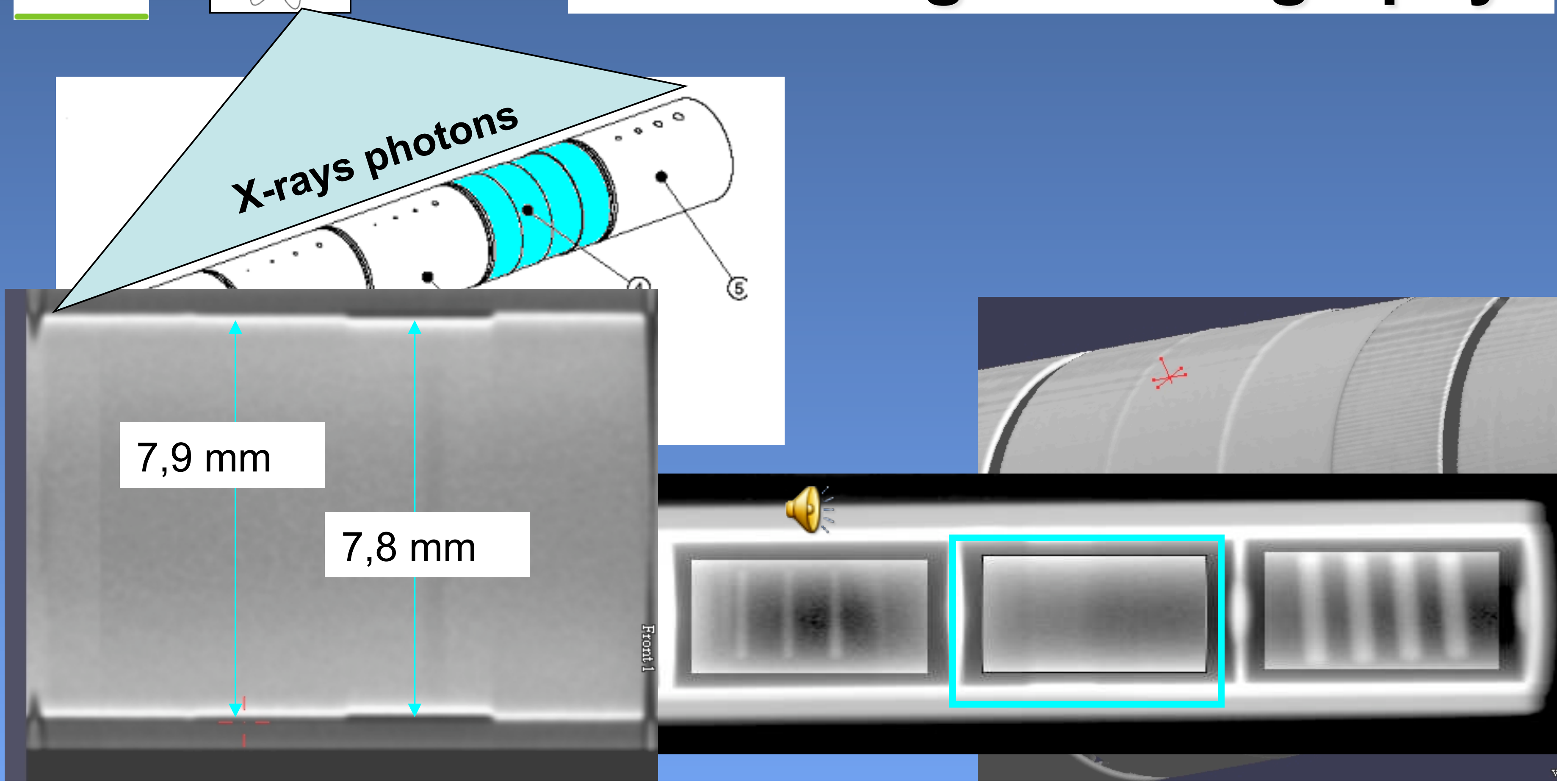






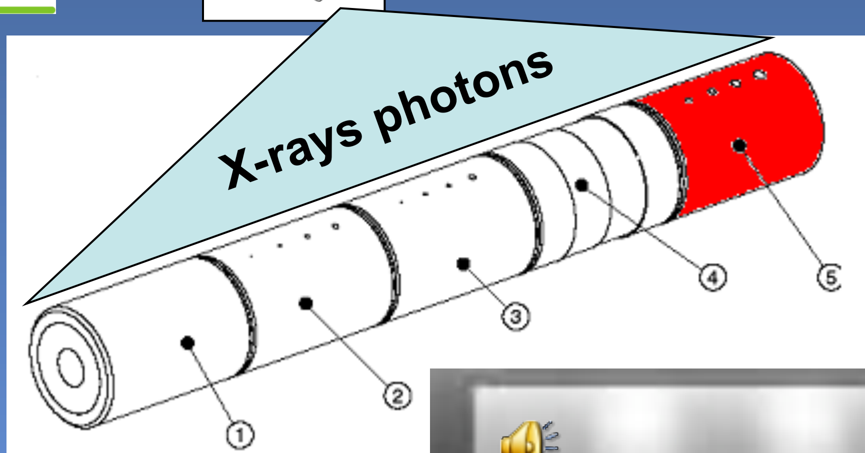
Orientation 0°, 450kV, 1.55mA, 64s integration time, original x-ray image without digital filtering.

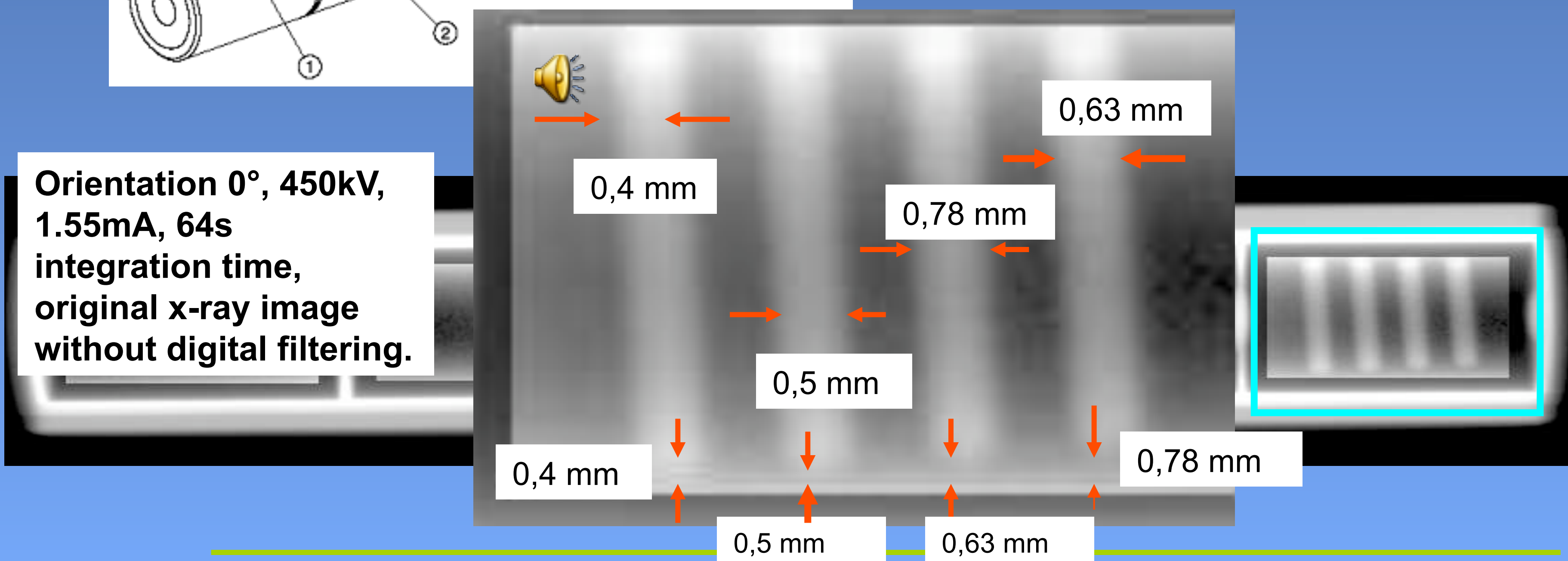
Pellet 4 digital radiography



Orientation 0°, 450kV, 1.55mA, 64s integration time, original x-ray image without digital filtering.

Pellet 5 digital radiography





Orientation 0°, 450kV, 1.55mA, 64s integration time, original x-ray image without digital filtering.

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Conclusion

- X rays tests in a mock-up
- Identification suitable X-rays cabin components
- Simulation confirms our components and predict the future device
- performance. One of the strong points of this tool is to integrate gamma background
- Actual X-rays cabin is dismantling
- New X-ray equipment emplementation is planned for 2011
- This X ray equipment will be a complement to fast neutron radiography

Thank You for Your Attention !

Any questions ?