SIMULTANEOUS USE OF NEUTRON AND GAMMA RADIATIONS IN IMAGING APPLICATIONS

RATEN ICN PITEŞTI
INSTITUTUL DE CERCETĂRI NUCLEARE

M. DINCA

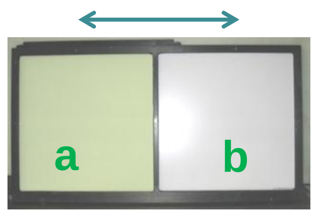
Institute for Nuclear Research (INR), Pitesti, Romania

marin.dinca@nuclear.ro

Imaging facility

- Imaging facility, INUS, uses thermal neutrons and γ radiations separately or together by transmission method. It is placed at the tangential channel of the TRIGA Annular Core Pulsing Reactor (**ACPR**) from INR, operable in steady state (up to 500 kW) and in pulsing mode (up to 20000 MW). For imaging experiments ACPR was operated only at 100 kW in steady state mode.

- Hanged and forward-back movable detector over object holder contains:
  - Two remote controlled interchangeable scintillators:
    (1) 300 mm x 300 mm, ^{6}LiF-ZnS:Cu (0.3 mm) on 1.5 mm aluminum holder (a);
    (2) Gd_2O_2S:Tb (0.12 mm) on 0.19 mm plastic holder, LANEX type (b).



  - Two remote controlled interchangeable cameras that captures scintillations 90º reflected by a mirror:
    (1) EM-CCD HAMAMATSU C9100-02 camera (1000 pixels x 1000 pixels on 8.0 mm (H) - 8.0 mm (V)) with Xenon 0.95/25 mm lens and exposure time (**ET**) on sensor from100 µs to10 s (a);
    (2) CCD camera STARLIGHT XPRESS SXV-H9 (1392 pixels x 1040 pixels and 8,98 mm (H) x 6,7 mm (V)) + XD-4 type image intensifier + custom made lenses, ET on sensor from µs to minutes (b).

  Geometrical resolution of the detector is about 0.2 - 0.3 mm and geometrical resolution of the INUS is about 0.3 - 0.5 mm (assembly collimator-object-scintillator – CCD camera) for field of view (**FOV**) = 300 mm.

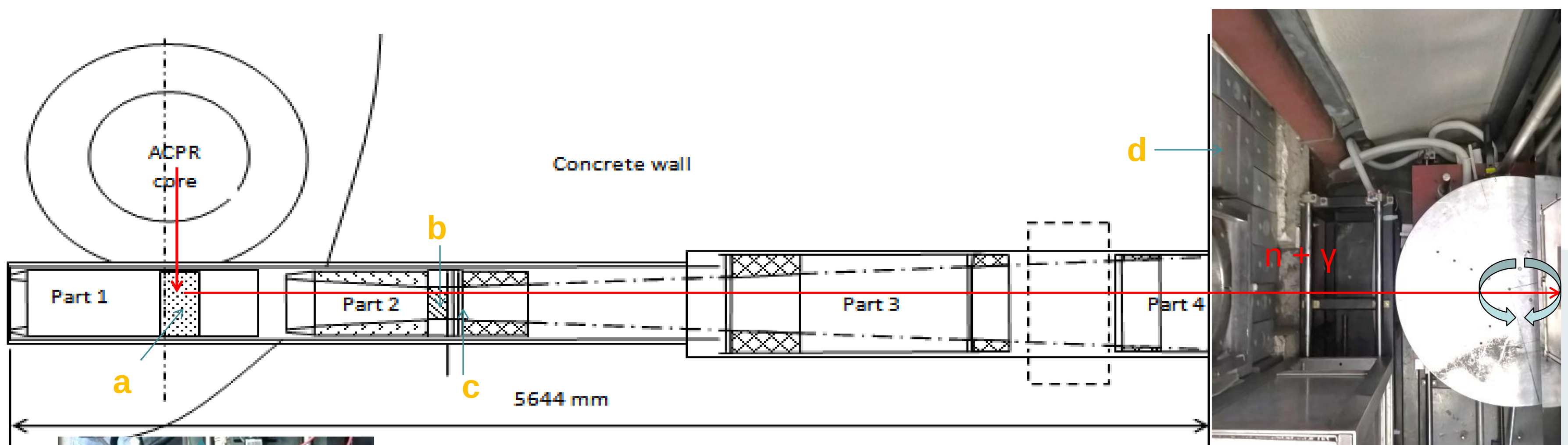


*Fig. 1– Sketch with ACPR source of radiations and four collimator parts in beam tube plus a photo from INUS premises with rotary object's holder. Graphite diameter = 180 mm (a), bismuth mono-crystal filter (**Bi**) = 30 mm thickness (b), pin-hole aperture (D) = 45 mm (c), removable cadmium (**Cd**, 2 mm thickness) and **Boral** (6.5 mm thickness) plates (d), L/D = 92.8 and beam diameter = 288.3 mm at rotary table's axis.*

- With dedicated software, developed in INR in LabView, it is remote controlled a rotary table that holds investigated object. A TTL signal from a step by step motor triggers Hamamatsu camera. It is changed the position of the rotary table with 0.45º, 0.9º, 1.45º or 1.8º for a new 2D image projection of the investigated object, used at tomography reconstruction. It is assured a complete automatic operation mode for predetermined 200, 400, 600 or 800 projections/360º. Quasi-dynamic inspection it is possible to be performed also.

Experiments

- An electrical kettle for water was investigated by non destructive imaging using thermal neutrons and gamma radiations, statically and dynamically, including boiling phase. Kettle has the lateral wall made in plastic (2 mm thickness) covered with a stainless steel thin sheet. The volume of water has from 14 cm to 12 cm in diameter.

- The purpose was to establish the quality level for images obtained for such a device and to show differences on images by registering gamma radiations not only neutrons.

- Only EM-CCD HAMAMATSU C9100-02 camera was used with various electron multiplications (**EM**) factors and ET, FOV=280 mm x 280 mm. ET was established in auto exposure mode (**AET**) by Hamamatsu camera or manually fixed in software's window.

- From both scintillators, 6LiF-ZnS and Lanex, were captured static and dynamic images. ^{6}LiF-ZnS scintillator registers only neutrons but Lanex scintillator registers both γ radiations and neutrons.

- Thermal neutron intensity: 1.22 x 10^5 n/cm^2/s, R_{Cd}=5.51, measured by gold foils activation method; debit dose of 740 mSv/h for γ radiations measured with a Teleprobe FH 40TG detector.

Fig. 2 – An electrical water kettle put in front of the scintillator's aluminum holder on rotary table.

Results

- Fig. 3 - Fig. 5 present the static images obtained at first series of experiments on ^{6}LiF-ZnS and Lanex scintillators for kettle before water boiling for EM=200, specific AET for captured image, with bismuth filter (Bi), Boral and Cd plates out of the radiations beam. All images are presented without any processing for noise and contrast.
  - In Fig. 3, at left, it is seen the image of a device (real size and 5X), fixed on the aluminum holder of the ^{6}LiF-ZnS scintillator, made in gadolinium (0.1 mm thickness) for geometrical resolution assessment and image focalization.
  - In Fig. 4, at right, it is seen the image of a dysprosium stripe (0.1 mm thickness), fixed on aluminum holder, produced by neutrons on Lanex scintillator. Image from Fig. 4 is similar to one obtained adding two separate images, with proper software, as ImageJ, one obtained with neutrons and the other one obtained with gamma radiations.
  - Fig. 5 presents the image obtained simultaneously on both scintillators, Lanex scintillator being faster than 6LiF-ZnS scintillator.
  - Table 1 presents four values of the AET obtained for both scintillators for two values of the EM, 200 and 255. Four ratios for these AET are presented also. The AET ratios for every scintillator are very close, 4.576 and 4.593 respectively, indicating a reproducible dependency between chosen EM by operator and established AET by Hamamatsu software, indifferently of scintillator type (empirically, about a double AET for 25 units diminution of the EM). The AET ratios between scintillators at every EM are very close also, 1.445 and 1.450, respectively. This indicates that Lanex scintillator emits roughly 45% more light than ^{6}LiF-ZnS scintillator in mixed beam of radiations, neutrons and gammas. Other experiment revealed that contribution of neutrons on Lanex is about 36.4% at image formation, so that only gammas on Lanex produce more luminance that neutrons on ^{6}LiF-ZnS scintillator.
- Fig. 7- Fig. 12 present static images and captures from videos made in boiling process in a second series of experiments.
  - Images from Fig. 7 and Fig. 8 were obtained as the best static images. Image from Fig. 7, taken from ^{6}LiF-ZnS, is similar with image from Fig. 3 but with improved quality; lower EM and longer AET for a better statistic of the photons not of the multiplied electrons. The same fact for images from Fig. 4 and Fig. 8 taken from Lanex scintillator. For these images was taken minimum EM that conducts to AET close to 10 s, maximum integration time on sensor. Better clarity for images from Fig. 7 and Fig. 8, than images from Fig. 3 and Fig. 4, can be seen in the magnified image of the gadolinium device in Fig. 3 and Fig.4 where smaller gap is 0.1 mm.
  - To determine the neutron transmission through Bi filter were captured two images from ^{6}LiF-ZnS scintillator without/ with Bi filter in beam obtaining images from Fig. 9 and Fig. 10 for the same EM=200 with AET=5.53 s, respectively 9.94 s. The ratio for the two AET=1.8. This means a diminution of the neutron intensity through mono-crystal Bi filter of 44,37%, in good agreement with theoretical supposition of 41% diminution at facility design.
  - From a video registration were captured two images presented in Fig. 11 and Fig. 12. To have a quasi real time imaging must use EM=255 because of the small neutron and gamma intensity of radiations at INUS facility. Tests with smaller EM failed to offer recognizable images at ET<1s. To observe details of the kettle was made a compromise between time resolution and geometrical resolution with AET=0.9 s for EM=255. In Fig. 12 it is seen how the level of the water rises but no any bubbles can be observed in the thick layer of water. Image on Lanex scintillator has a better contrast between water layer and air from kettle. On ^{6}LiF-ZnS scintillator this boundary between water and air is not very clear because of the plastic layer in the kettle's wall that removes neutrons from beam.

Fig. 3–Image for kettle captured from ^{6}LiF-ZnS, produced by neutrons, EM=200, AET = 6.04 s, Bi, Cd and Boral out of beam.

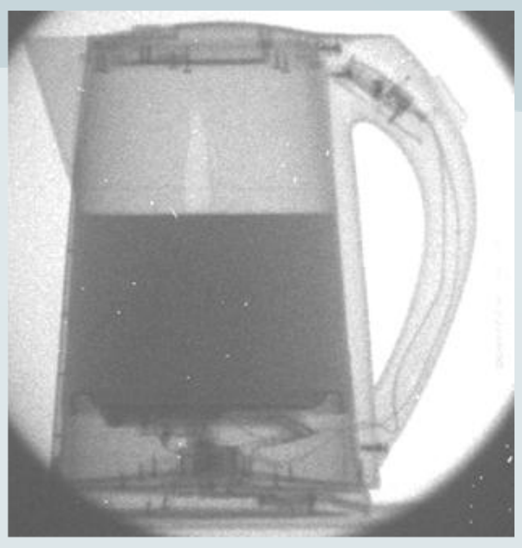


Fig. 4–Image for kettle captured on Lanex, produced by neutrons and gammas, EM=200, AET = 4.18 s, Bi, Cd and Boral out of beam.

Fig. 5–Image for kettle captured simultaneously on Lanex (left part, with neutrons and gammas) and ^{6}LiF-ZnS (right part, with neutrons), EM=200, AET = 6.07 s, Bi, Cd and Boral out of beam.

Table 1 – Values for AET at image capturing from scintillators and their ratios obtained for two values of the EM at first series of experiments

EM (relative units)	200	255	TI_{200}/ TI_{255}
AET_n (from ^{6}LiF/ZnS:Cu) (s)	6.04	1.32	4.576
AET_g (from Lanex) (s)	4.18	0.91	4.593
AET_n/ AET_g	1.445	1.450	-----

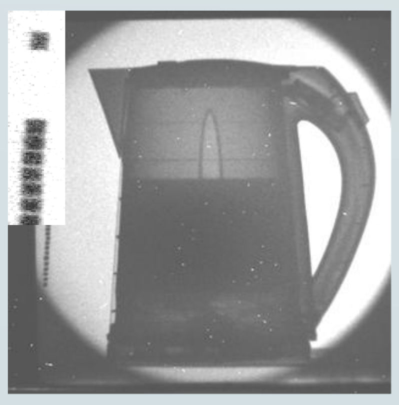


Fig. 7–Image for kettle captured from ^{6}LiF-ZnS, produced by neutrons, EM=180, AET = 9.76 s, Bi, Cd and Boral out of beam.

Fig. 8–Image for kettle captured on Lanex, produced by neutrons and gammas, EM=150, AET = 10 s, Bi, Cd and Boral out of beam.

Fig. 9–Image for kettle captured from ^{6}LiF-ZnS, produced by neutrons, EM=200, AET = 5.53 s, Bi, Cd and Boral out of beam.

Fig. 10–Image for kettle captured from ^{6}LiF-ZnS, produced by neutrons, EM=200, AET = 9.94 s, Bi in beam, Cd and Boral out of beam.

Conclusions

- INUS, from INR Pitesti has a beneficial possibility to use two types of penetrant radiations at non destructive investigations by imaging methods. Imaging facilities placed at neutron guides or those where γ radiations are stopped by non removable filters (bismuth, sapphire, silicon) do not benefit from this advantage. This deficiency is resolved with X-ray generators at some facilities but γ radiations have bigger energies and so more penetrant in thick structures than X rays, even on a tangential channel like at INUS facility. No gamma energy spectrum was assessed till now.
- Using Lanex scintillator, that registers thermal neutrons and gamma radiations simultaneously, it is obtained an instant sum image produced by two types of radiations without other image processing operations by registering images separately with neutrons and gamma radiations.
- For the presented experiment it is obtained a clear image through plastic structures, for screws and electrical wires. Gamma radiations create a base image on Lanex scintillator for materials discriminated by electromagnetic radiations but penetrating strong neutron absorbing or scatterings materials. Over this image, which would be with very small contrast only with neutrons, because of the plastic layer, comes the image created by neutrons with the shadow of plastic and water sensitive to neutrons, improving image created only by gammas.
- An easy operation of the facility with two types of radiations is facilitated by use of two scintillators, changed in 5 s with a stepper motor. A unique feature for INUS facility is the detector that hangs over object's holder and can be moved in close contact with the object to increase geometrical resolution despite low L/D of 92.8.

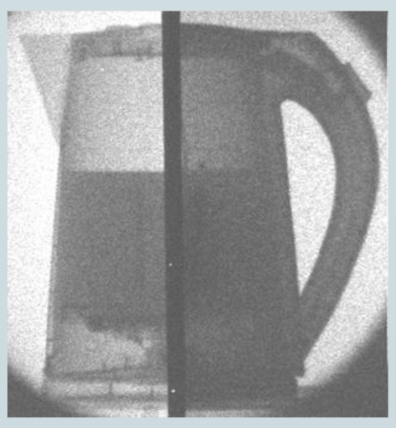


Fig. 11–Image for kettle captured simultaneously on Lanex (left part, with neutrons and gammas) and ^{6}LiF-ZnS (right part, with neutrons) from a video, EM=255, AET = 0.9 s, Bi, Cd and Boral out of beam, before water boiling.

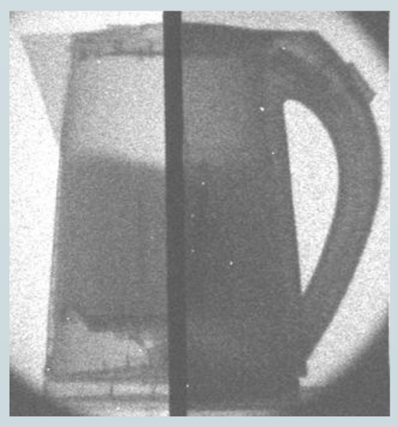


Fig. 12–Image for kettle captured simultaneously on Lanex (left part, with neutrons and gammas) and ^{6}LiF-ZnS (right part, with neutrons) from a video, EM=255, AET = 0.9 s, Bi, Cd and Boral out of beam, when water is boiling.

Acknowledgements

The development of the INUS imaging facility was assisted invaluable through a research contract with IAEA (2003-2006 CRP - Neutron Imaging: A Non-Destructive Tool for Materials Testing) and further, to commence the operation of the INUS facility and to put in practice the neutron and gamma imaging applications, was a new opportunity with a new research contract between IAEA and INR (2012-2016 CRP - The Neutron and Gamma Imaging Method Combined with Neutron-Based Analytical Methods for Cultural Heritage Research).