ANALYSIS OF GAMMA-RAY FIELDS EMITTED AROUND NUCLEAR REACTOR IN OPERATION

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In the area of NPP, one must discriminate between two various modes of gamma analysis of the gamma-ray fields. First is used in scheduled down time reactor phase and second is in full power reactor phase. Spectra of gamma-ray fields are different during both phases. Gamma-ray sources at the down time phase are with energy up to 2 MeV and at the full power phase are up to 10 MeV. Spectrometry measurements by NaI(Tl) scintillation detector have been performed in both operation phases at several chosen points of the NPP. Real dose rate spectra have been calculated from the acquired physical spectra employing Whole Spectrum Processing (WSP) technique [1].

A) INSTRUMENTS

The measurements have been performed using the conventional 2" x 2" NaI(Tl) scintillation detector. Pulses from the detector have been fed into a portable spectrometry system with connection to a PC compatible computer system in following configuration:

- INSPECTOR 2000 DSP PORTABLE MCA – portable multi-channel analyzer with digital signal processing, HVPS, 16k MCA memory, USB or RS-232C connection to host Genie 2000 computer, integral cable
- UNISPEC – the universal multi-channel analyzer for scintillation spectrometry, USB connection to host Genie 2000 computer
- GENIE 2000 BASIC SPECSTROSCOPY SOFTWARE – for control, displaying and calibration of measurements, parameters setup, PNA calculation
- BOB SPECTRUM DISCOVERY SOFTWARE - for control, displaying and evaluation of measurements using the whole spectrum processing, WSP calculation
- SCINTILLATION DETECTOR 802 – dimension of 2" x 2", resolution of 7.5 %, including photomultiplier and preamplifier
- COMPUTER – portable Notebook

B) METHODS

For calculation of the real incident gamma ray spectra, the response operator method based on Scaling Confirmatory Factor Analysis (SCFA) technique has been employed. This is presented in detail in Ref. [1].

The photon fluence rate $\phi\,[s^{-1}.cm^{-2}]$ from a point isotropic source characterized by an intensity $Q\,[s^{-1}]$ may be expressed in a distance $R\,[cm]$ from the source as

$$\phi = \frac{Q}{4\pi R^2} \text{ and } \phi(E) = \frac{Q(E)}{4\pi R^2}, \tag{1}$$

respectively, where $Q\,(E)$ characterizes a spectral distribution of source intensity according to photon energy.

In regard to the matrix approximation of spectra used in the mathematical formulation of the spectrum measurement, we have analogously introduced a matrix equation for *in situ* measurement using definition (1) as follows

$$\mathbf{D} = \mathbf{KQ} = 4\pi R^2 \mathbf{K\Phi} = \mathbf{K_F \Phi}\,, \tag{2}$$

where $\mathbf{K}_F$ (c x c) is the fluence rate response matrix and $\mathbf{\Phi}$ is the c x r matrix with c-vectors of the spectral fluence rate as columns corresponding to experimental quantification of the function $\phi(E)$ by c points and R is the distance of calibration point from detector.

Now the results obtained for the spectral photon fluence rates make it possible to evaluate fundamental quantities used in the gamma-ray dosimetry. Exposure rate, X, and dose rate, D, from mono-energetic photon source can by expressed as follows

$$X = \phi \left[\frac{\mu_{en}}{\rho} \right]_{air} E_0\,, \tag{3}$$

$$D = \phi \left[\frac{\mu_{en}}{\rho} \right]_{water} E_0\,, \tag{4}$$

where ϕ is the photon fluence rate, μ_{en} is the linear energy absorption coefficient for air and water, respectively, ρ is the specific mass of air and water, respectively, and E_0 is a photon energy.

A photon fluence rate spectrum put as column in **Φ,** which may be obtained as solution of equation (2), can be used for determination of the spectral exposure and photon dose rate using equations (3) and (4). Energies corresponding to the middles of spectrometric channels should be used for appropriate energies of E_0 associated with the values of fluence rate spectra.

C) EXPERIMENTAL

Real gamma-ray fields are different for a down time phase and a full power phase. Contributions of the contaminants within primary circuit are dominating during down time phase, but they are strongly overlapped with higher energy contributions which are coming from neutron interactions, especially capture of thermal neutrons on iron atoms, inelastic scattering on iron atoms and interaction of fast neutrons on oxygen atoms. Gamma-ray energies of the contaminants is usually less than 2 MeV and gamma-ray energies of neutron interactions are up to 10 MeV.

1. Measurement during scheduled down time phase

The response operator matrix $\mathbf{K}_F$ has been calibrated by experimental measurements and interpolated by SCFA technique within energy range 2 MeV. An example of spectra measured in NPP area are physical gamma-ray spectra depicted in Fig. 1. Decomposition of an integral dose rate according to primary sources is hardly achievable by traditional dosimetry tools. However, incident spectra being obtained by WSP analysis already represent spectral fluence rate, and/or dose rate energy distribution. Single contaminants were recognized using scintillation spectrometer with resolution close to semiconductor spectrometry (cca 5keV). Fig. 2 shows fluence rate spectra and Fig. 3 represents dose rate spectra. Both have been computed from physical spectra displayed in Fig 1.

Figure 1. Physical gamma-ray spectra

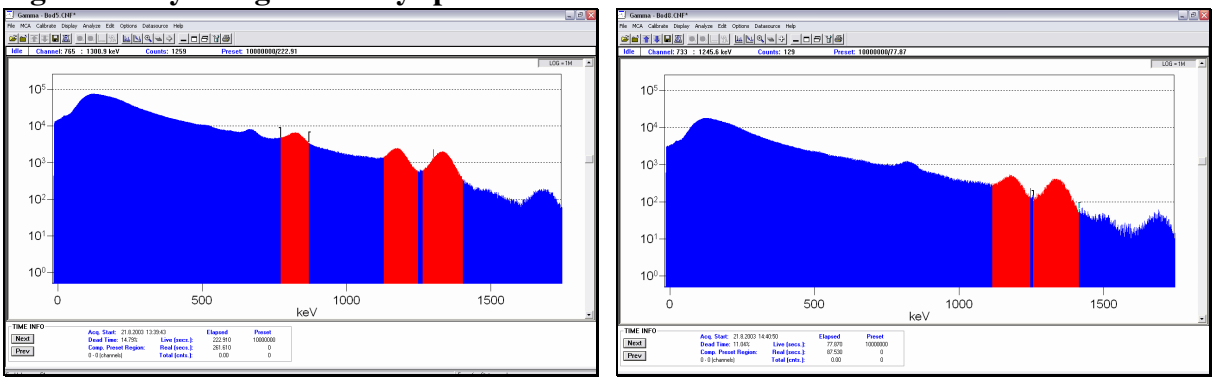


Figure 2. Computed fluence rate spectra

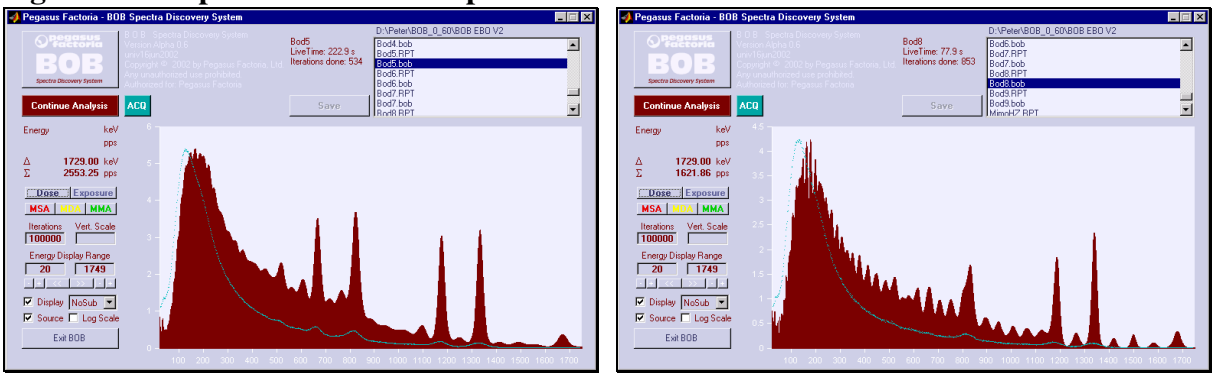
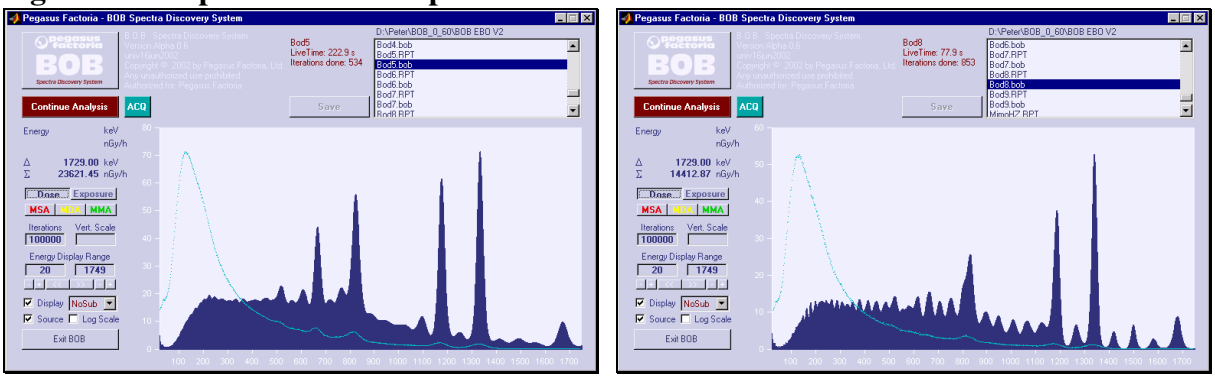


Figure 2. Computed dose rate spectra



Analysis identified especially following contaminants: ^{134}Cs, ^{137}Cs, ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co, ^{110}Ag, and ^{40}K. The obtained dose rate contributions from particular contaminants were from values close to background 10 nG/h (^{134}Cs) up to 2 μG/h (^{60}Co).

2. Measurement with full power reactor

The response operator matrix $\mathbf{K}_F$ has to be calibrated by combination of experimental measurements and mathematical simulation [4]. Physical gamma-ray spectra depicted in Fig. 3 are an example of spectra being measured in NPP area during the full power phase. These scintillation spectra are hardly to put under dosimetry analysis. For similar analysis, it is conveniently used rather semiconductor than scintillation detector. However as one can see in Fig. 5 and 6, respectively, high energy spectra is possible to analyze by WSP with sensitivity higher then by semiconductor detector.

Figure 4. Physical gamma-ray spectra

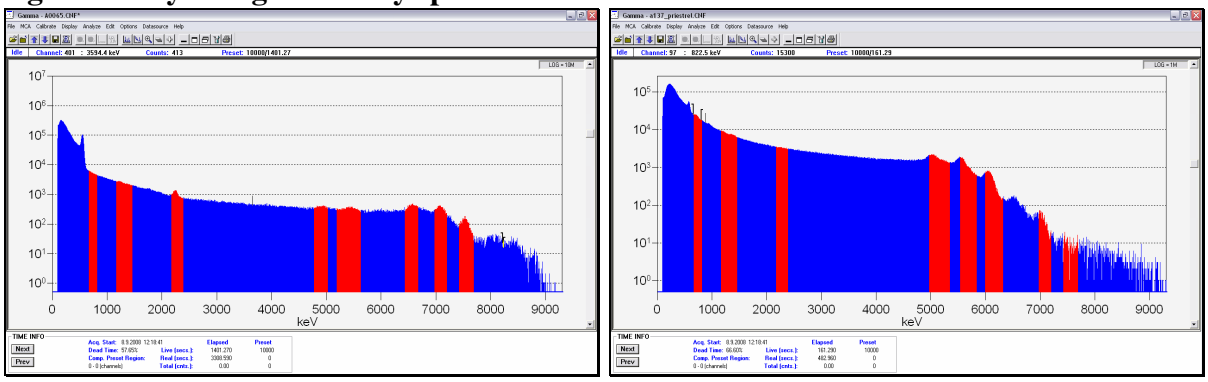


Figure 5. Computed fluence rate spectra

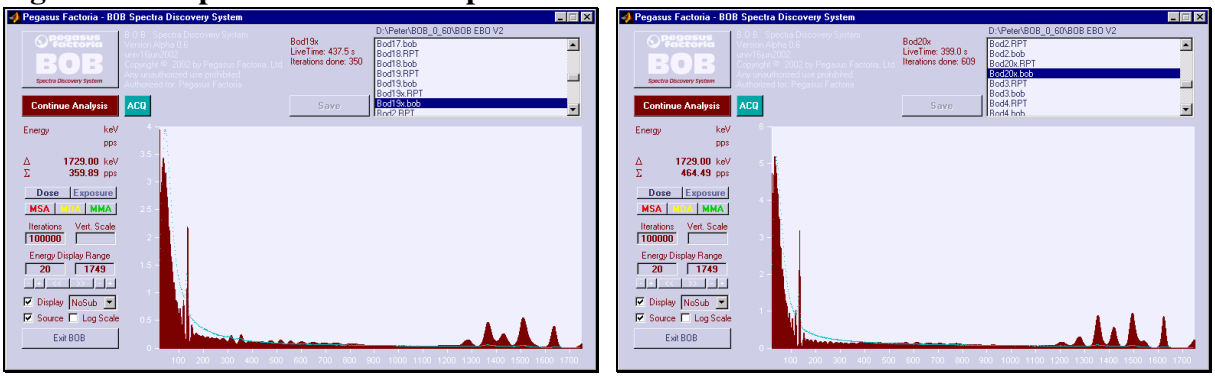
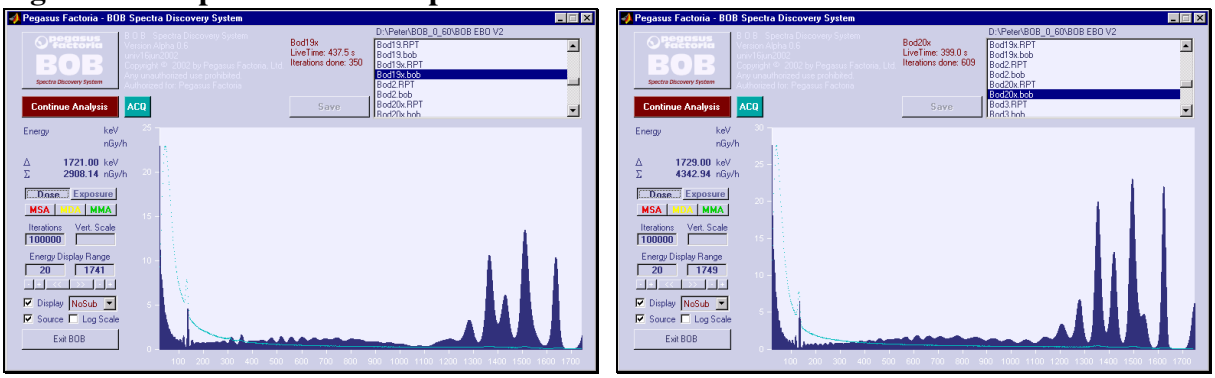


Figure 6. Computed dose rate spectra



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