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** See annex of F. Romanelli et al, "Overview of JET Results",*
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1. INTRODUCTION

The activation technique, based on the irradiation of suitable materials placed close to the plasma, is used in large magnetic confinement devices for the measurement of the neutron yield and is being developed to provide the neutron spectra for both DD and DT operation [1]. In previous experiments at JET, stacks of separate elemental foils were used [2]. Nowadays High Purity Germanium (HPGe) detectors, with high efficiency and resolution, can be numerically characterized very well in terms of efficiency and energy calibration. This allows the application of samples with mixed elemental compositions and shapes. The technique presented in this paper was implemented on the JET neutron activation diagnostic.

2. SYSTEM FOR GAMMA RAY DETECTION AND ACCURACY OF NUMERICAL EFFICIENCY CALIBRATION

The main components of system to detect the emission of the samples and discussed in this paper are: a HPGe coaxial detector, a Numerical Characteristic (NCh) of the detector and Laboratory Sourceless Object Calibration Software (LabSOCS). NCh allows estimating a sample activity without having to perform an *in-situ* calibration. For the aim of this paper the efficiency of photon registration always means Absolute Full Energy Peak Efficiency (AFEPE) [3]. The complete geometry of the particular detector used, including its mounting and housing hardware, is included in a dedicated MCNP model of LabSOCS. This software provides a calibration which comprises a set of energy-efficiency curves for the relevant geometries. The calculated standard deviation is typically in the interval 3%-7.1% [4],[5]. The efficiency calibration calculated by the LabSOCS and obtained as the result of measurements with a real calibration source is presented on the Fig.1. It shows that in this particular case, when the main characteristics of the real sample, i.e. its shape (geometry), density and elemental composition, are precisely defined, the accuracy of LabSOC is very high.

3. THREE DIMENSIONS EFFICIENCY CALIBRATIONS FOR IDEAL AND REAL SAMPLES

The efficiency calibration is the function of AFEPE versus photon energy. Usually it is a logarithmic polynomial of order fifth or less. By plotting the calibration functions for different sample sizes, the Three Dimensions (3D) curves of efficiency have been obtained. Figure 3 represents 3D AFEPE as the function of energy and distance from the detector end cap for an ideal point source and as function of the indium sample diameter. In case of a real sample, the self attenuation dominates, whereas the geometrical factor represented by the inverse square low plays the main role for an ideal sample.

3.1 OPTIMIZATION OF THE GEOMETRY FOR REAL ACTIVATION SAMPLES

The following relation (1) represents the dependence of AFEPE on the diameter of the used indium sample as a result of Gaussian fitting of each particular cross section of the efficiency surface.

$$D\,(x,\,E = const) = y0 + \sqrt{\frac{\pi}{2}} \cdot \frac{A \cdot \exp\left(-\frac{2(x-xc)^2}{w^2}\right)}{w} \qquad (1)$$

X- diameter of the sample; xc, A, y0, and w are the parameters of the Gaussian fitting.

The AFEPE curve changes its shape below a particular inflection point, as shown in Fig.3 (left). The sequence of inflection points represents the interval of optimal sample diameters and it is presented in Fig. 3 (right). The sample optimization plays an important role particularly when the number of neutrons activating the sample is very limited.

3.2 ABSOLUTE FULL ENERGY PEAK EFFICIENCY FOR A STACK OF SEPARATE FOILS ACTIVATED DURING RECENT JET CAMPAIGNS, AND FOR A SAMPLE MADE OF MIXTURE OF ELEMENTS

During recent JET campaigns a stack of different metal foils with constant diameter and different thicknesses have been used. The processing of the sample efficiency calibration is expensive and time consuming. This limits the number of metals which can be used during the activation experiments. Actually the NCh of the HPGe detector practically gives unlimited access to a wide number of activation materials with different geometry and density. The detector NCh allows estimating the efficiency calibration for the mixture of nuclides as well as coping with a range of sample geometries. Finally a set of samples consisting of up to five elements have been designed for JET activation diagnostic. During 2008-2009 JET campaigns eleven mixed samples of Al, Se, Y, Au, Fe powder with different composition have been used. This technique allows measurements of a higher number of nuclear reactions in a single activation than previously.

CONCLUSIONS

- The performed analysis shows the applicability of the proposed mixed sample technique to characterize the neutron yield in large fusion devices like JET and ITER [6].
- The relatively high AFEPE for mixed activation samples is the result of optimizing their composition. In case of a stack of foils the lower sample density the higher its AFEPE.
- Optimization of sample size allows using the above technique in place with low neutron yields.
- The optimal sample diameter depends only slightly on photons energy.

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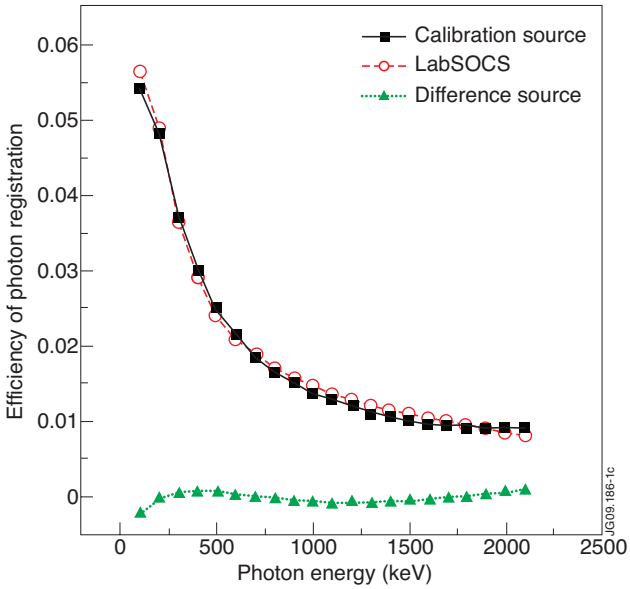

Figure 1: Efficiency calibration obtained with certificated calibration source (black squares) and LabSOCS (red dotes) and differences between those data (green triangles).

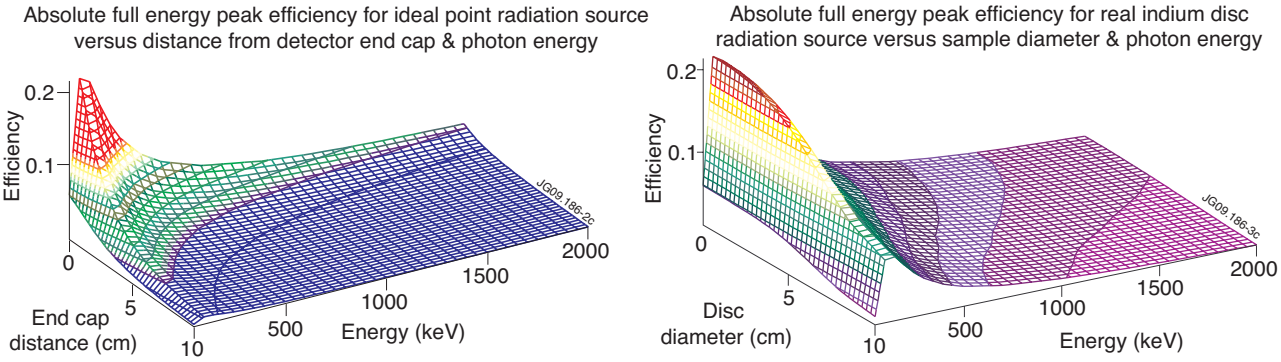

Figure 2: The AFEPE of an ideal point radiation source (left figure) is the function of photon energy and sample distance from detector end cup meanwhile the AFEPE of a thin real indium disk (right figure) is presented as the function of photons energy and sample diameter.

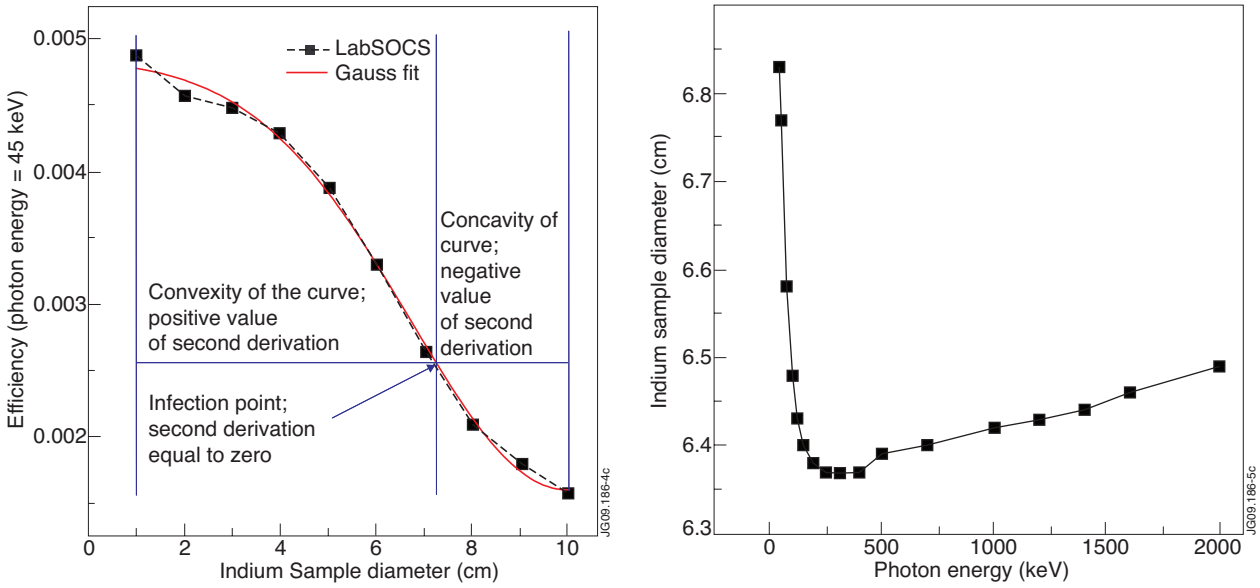

Figure 3: Typical cross section of the AFEPE for E=const (left figure) presents dependence of efficiency of a real indium sample. Sequence of the inflection points (right figure) represents the interval of optimal diameters.

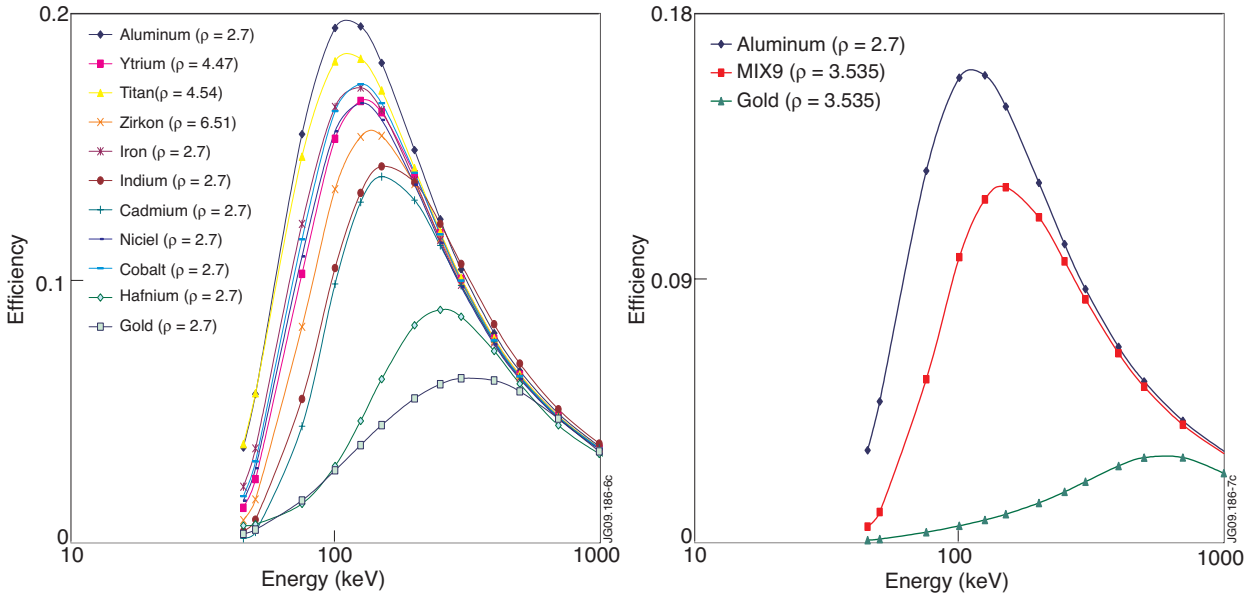

Figure 4: AFEPE for different activation samples (left figure) with diameter 18mm and thick 1mm and AFEPE for real samples with 18mm diameter and 5,6mm thick (right figure). The efficiency of mixed sample is relatively high nevertheless it consists of Al, Se, Y, Au, Fe. It is the result of careful choosing the sample composition.