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Citation: AIP Conference Proceedings **1612**, 149 (2014); doi: 10.1063/1.4894043
View online: http://dx.doi.org/10.1063/1.4894043
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1612?ver=pdfcov
Published by the AIP Publishing

Gamma Ray Spectrometer for ITER

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Abstract. Gamma diagnostics is considered to be primary for the confined α- particles and runaway electrons measurements on ITER. The gamma spectrometer will be embedded into a neutron dump of the ITER Neutral Particle Analyzer diagnostic complex. It will supplement NPA measurements on the fuel isotope ratio and confined alphas/fast ions. In this paper an update on ITER gamma spectrometer developments is given. A new geometry of the system is described and detailed analysis of expected signals for the spectrometer is presented.

Keywords: tokamak, DT plasma, alpha- particles, diagnostics, gamma- spectrometry, ITER, fast ions, runaway electrons, knock-on ions.
PACS: 52.55.Fa, 52.59.Px, 52.65.-y, 52.55.Pi, 52.70.-m, 52.70.La, 07.85.Nc

INTRODUCTION

Gamma diagnostic is unique in its abilities of fast ions and runaway electron (RE) diagnosing. Indeed, it allows tracking runaway electrons even before they leave the plasma and hit the wall. Preventing wall damage is the matter of highest importance – issue of machine protection. Diagnostic of fast ions, their control and behavior studying is important for many key processes in the tokamaks: burning, additional heating, plasma components confinement, instabilities development etc. Runaway electrons interact with plasma species producing bremsstrahlung emission (hard X-Ray, HXR), fast ions give rise to γ-rays in nuclear reactions with fuel and main plasma impurities. Emission spectral analysis gives information on quantity and energy distribution of the particles under study. Table 1 gives some overview on essential parameters of the ITER plasma that can be provided by gamma ray spectrometer (GRS) within the neutron particle analyzer (NPA) complex (equatorial port 11), see also [1].

TABLE 1. Preliminary estimation of the diagnostic abilities according to ITER diagnostic requirements [2].

	SRD Contribution	Parameter Operational Role	Original measurements	Specification Parameter
1.	Backup	1b.AC	07. Neutron flux and emissivity	014: Neutron- and α- source profile
2.	Supplementary	1a.2BC	11. Fuel ratio in plasma core	020: n_t/n_d, core
3.	Supplementary	1a.2BC	12. Impurity species monitoring	022: Be, C, O rel. conc.
4.	Primary	2.PHY	15. Runaway electrons	034: E_{max}
5.	Primary	2.PHY	15. Runaway electrons	035: I runaway
6.	Backup	1b.AC	29. Core He density	067: Profile of ^{3}He concentration
7.	Primary	2.PHY	30. Confined alphas and fast ions	068: Alpha Density profile
8.	Supplementary	2.PHY	30. Confined alphas and fast ions	069 Alpha Energy Spectrum
9.	Supplementary	2.PHY	30. Confined alphas and fast ions	070: p, D, T, ^{3}He energy spectrum
10.	Supplementary	1b.AC	32. Impurity density profile	074: Fractional content, Z≤10

Continuous HXR spectra can be deconvoluted to derive RE distribution function (DF) [3]. Gamma spectra produced by fast ions contain peaks related to different reactions. Amplitudes of the peaks depend on the DF of the reactants. Analysis of the spectra allows identifying all fast ion species at the same time [4]. Using 2-D detector arrays, information on the time-dependent spatial distribution of fast particles can be obtained.

Gamma/HXR diagnostics have been used on some tokamaks. The most developed system on JET demonstrated abilities of the technique [5]. For the first time it was demonstrated there benefits of the high purity germanium (HPGe) spectrometers [6, 7]. High resolution detectors allow not only to register γ- lines magnitudes, but also

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to analyze their shapes. The measured line shape reflects velocity DFs of its reactants [7]. A detector array positioned toroidally can be used for studying 3-D effects related to plasma instabilities and magnetic perturbations. This approach was tested on Globus-M tokamak [8] and can be employed in ITER.

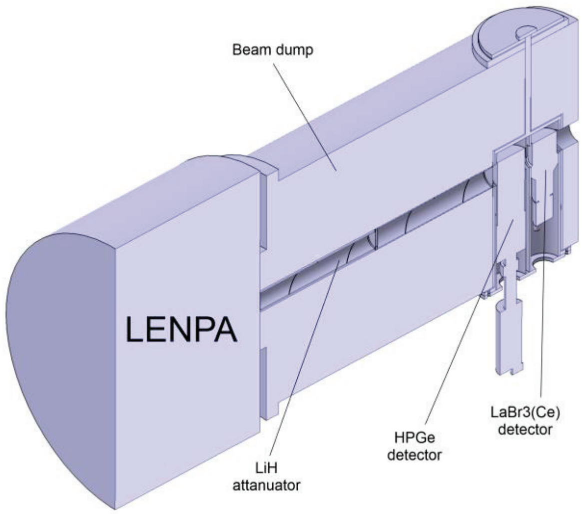

FIGURE 1. Gamma spectrometer in the NPA beam dump.

PROPOSED SOLUTION

Full NPA diagnostic complex layout with integrated gamma ray spectrometer was given in the reference [9]. In this paper a new concept of the gamma diagnostic integration is proposed (Fig. 1). Regarding to the initial proposal, the orientation of HPGe detector has been changed and $LaBr_3$ detector is included in the GRS complex. To provide optimal gamma-ray measurements for a particular plasma scenario, the detectors are placed into the revolving chamber. In this case the detectors can be remotely interchanged before experiments. In the suggested scheme $LaBr_3$ will be used in the discharges with high count rates. Modelling of the experiments shows that the $LaBr_3$ detector can provide spectrometry at count rates higher than 10^7 events per second. The HPGe-detector is needed for high energy resolution spectrometry providing the Doppler broadening analysis. The same line of sight for all the diagnostics of the NPA complex will be beneficial for the validation and interpretation of data.

SPECTRA CALCULATIONS

Preliminary assessments of the expected parameters of γ- spectra that could be recorded by GRS were reported in [9]. In this paper, using the same model as in [9], more detailed results are presented The ITER inductive scenario was used in the previous and the current calculations. A preliminary analysis shows that γ- ray spectrum features will be qualitatively the same in the case of the steady state scenario. d- and t- thermal and knock-on components distribution functions were taken into account. For these ion species list of possible reactions with ^{9}Be, which is main impurity, and corresponding excitation levels were determined and their cross sections parameterized (EXFOR data used). All these information were used to derive partial reaction rate coefficient for the final nuclei produced due to interaction of knock-on d- and t- ions with ^{9}Be (data summarized in table 2).

TABLE 2. Reactions with ^{9}Be in ITER plasma. Incoming particles are in the table header; particles of the exit channel grouped together Q-values (underlined), excitation levels and their reaction rate coefficient (in brackets) are in the table cells. Excitation levels and Q values are given in MeV, reaction rate coefficient – in cm^3s^{-1}.

p	d	t	^{3}He	α
0.718, ^{10}B	$\underline{4.3613}$: 0.718 (2.27•10^{-17}),	$\underline{9.56}$: 2.125 (2.02•10^{-18}),	$\underline{10.3228}$: 2.125,	4.44,
	1.740 (3.00•10^{-18}), 2.154 (1.14•10^{-17}),	4.445 (1.23•10^{-18}),	4.444, ^{11}B+p	^{12}C+n
^{6}Li+α	3.587 (1.54 •10^{-17}), ^{10}B+n	7.286 (3.16•10^{-18}), ^{11}B+n		
			2.0, 4.318, ^{11}C+n	
2.43, ^{9}Be+p	$\underline{4.5877}$: 3.368 (7.59•10^{-18}), ^{10}Be+p	$\underline{2.9257}$: 0.9808 (9.56•10^{-18}),		
		^{8}Li+α	0.718, 1.022, ^{10}B+d	
	$\underline{7.1507}$: 0.478 (9.05•10^{-18}), ^{7}Li+α			

Reaction rate coefficient multiplied by reactant densities has given spatial profiles of the γ- emission produced by knock-on and thermal d- and t- ions (see fig. 2). In order to complete that task branching tables were built for some reactions to recalculate levels excitation into particular γ- lines emission profiles taking into account actual nuclear levels de-excitation schemes. Finally, MCNP calculations in ITER geometry, including NPA diagnostic complex geometry were performed to derive expected spectra (also shown on fig. 2). HPGe detector with active zone of Ø11.4x8 cm was used in the calculations.

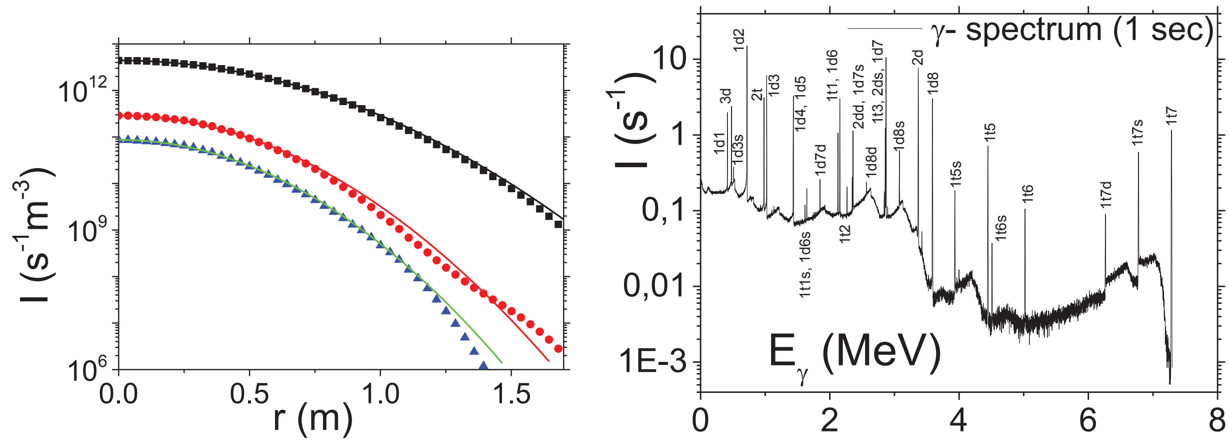

FIGURE 2. Modelling results for γ- measurements. (a) Spatial profiles of emission from ^{9}Be(d, αγ)^{7}Li reaction. Upper symbols (squares) – knock-on emission component, middle (circles) – reaction between thermal ions, lower (triangles) – thermal deuterons and neglecting ^{9}Be speed. Lines on the figure give Gaussian approximation of the profiles. (b) Expected spectrum to be measured by ITER HPGe detector during 1 s inductive scenario discharge; histogram step 1 keV, also lines identified accordingly to the scheme given in table 3.

Peaks on the spectrum were analyzed: background subtracted, fitting undertaken and lines areas calculated (see table 3). Time resolution of the measurements for given accuracy values 10% and 20% are also derived. Two total areas – for all the peaks from reactions with deuterons and tritons correspondingly – were found in order to have estimation of the time resolution in d/t isotope ratio monitoring with the spectrometer.

TABLE 3. Gamma lines intensities expectation; table divided into three parts. First column (for each part) - lines designations: reaction number for given reactant, d for deuterium or t for tritium, line number for given reaction where present, s for single escape or d for double escape gamma where present. The following column are: E_γ – energy of the line, keV; I – count rate, s^{-1}; time resolution (given in seconds) for 10% and 20% accuracy demand accordingly.

line	E_γ	I	Δt 10%	Δt 20%
Data for deuterons				
^{9}Be(d, nγ)^{10}B				
1d1	414,3	5,34	18,7	4,68
1d2	718	58,6	1,71	0,43
1d3	1022	28,3	3,53	0,88
1d3s	511	0,55	182	45,5
1d4	1432	9,9	10	2,53
1d5	1436	17,8	5,62	1,4
1d6	2154	19,9	5,03	1,26
1d6s	1644	0,72	139	34,7
1d7	2869	82,5	1,21	0,3
1d7s	2359	7,32	13,7	3,42
1d7d	1847	1,01	99	24,8
1d8	3587	26,4	3,79	0,95
1d8s	3077	4,05	24,7	6,17
1d8d	2567	0,62	163	40,7

line	E_γ	I	Δt 10%	Δt 20%
Data for deuterons				
^{9}Be(d, pγ)^{10}Be				
2d	3368	65,2	1,53	0,38
2ds	2857	8,98	11,1	2,78
2dd	2347	1,25	80	20
^{9}Be(d, αγ)^{7}Li				
3d	478	6,99	14,3	3,58
Total area for deuterons				
		345,4	0,29	0,07
Data for tritons				
^{9}Be(t, nγ)^{11}B				
1t1	2125	6,63	15,1	3,77
1t1s	1614	0,272	368	91,9
1t2	2266	0,81	123	30,9

line	E_γ	I	Δt 10%	Δt 20%
Data for tritons				
^{9}Be(t, nγ)^{11}B				
1t3	2841	0,78	128	32,1
1t4	2895	0,235	425	106
1t5	4445	6,95	14,4	3,6
1t5s	3935	1,6	62,5	15,6
1t6	5020	1,06	94,3	23,6
1t6s	4509	0,33	303	75,8
1t7	7286	14,3	7,01	1,75
1t7s	6778	6,99	14,3	3,58
1t7d	6267	0,91	110	27,5
^{9}Be(t, nγ)^{11}B				
2t	980,8	13,7	7,3	1,82
Total area for tritons				
		54,54	1,83	0,458

As it can be seen on the figure 2, Gaussian function can well interpret spatial distribution of the emission: the discrepancies became noticeable only when intensity drops in about two orders. It can be also noticed, that knock-on ions role in γ- emission from ^{9}Be+d and ^{9}Be+t is dominant (particularly comparing to the thermal components interaction). Finally, we can see, that for thermal ions beryllium motion cannot be neglected.

Also it were analyzed reactions ^{9}Be(α, nγ)^{12}C (E_γ=4.44 MeV, $I_{4.44}$=3•10^3 s^{-1}) and d(t, γ)^{5}He (17 MeV, 4•10^4 s^{-1}). These are the key reactions for α- particles production and confinement diagnostics correspondingly.

SUMMARY

GRS project for ITER, described here was proposed for the first time just couple years ago [9]. In this paper a new concept was presented. Preliminary calculations of the expected spectrum are shown. The code used for the calculations allows assessing diagnostic capabilities of the GRS. Particularly, time resolution for the isotope ratio measurement was estimated to be of order of 1 s. Some other measured plasma parameters can be deduced from the given data. A comprehensive geometry of GRS was taken into account in the reported calculations, which includes NPA complex, ^{6}LiH attenuator used for neutron induced background suppression etc. An estimation of the neutron induced background is need for full GRS performance assessment. The calculation of γ- ray spectra induced by neutrons is in progress.

ACKNOWLEDGEMENTS

The work was supported by contract No.05-12 between “Technoexan, Ltd” and Institution “Project Center ITER” and No. 02-12 between Ioffe Institute and Institution “Project Center ITER”. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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