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Lost alpha particle monitor for JET. A conceptual design

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ABSTRACT

The Lost Alpha Monitor (LAM) diagnostics technique is based on the detection of the gamma radiation induced by the escaping particles on a target external to the plasma. For a beryllium target the nuclear reaction is ^{9}Be (a, nγ)^{12}C. The main components of the LAM diagnostics include a radiation collimator and shield which houses two gamma-ray detectors located behind lithium hydride neutron attenuators. Several solutions have been considered for the LAM beryllium target. The chosen conceptual solution is presented here.

1. Introduction. Diagnostics principle

Future deuterium-tritium experiments on JET are expected to produce significant population of alpha particles at plasma parameters approaching as closely as possible the ITER values. The confinement of fast particles produced in fusion reactions is of crucial importance for future fusion devices like ITER and DEMO.

Fast particles (including alpha particles) have been studied on JET by a set of diagnostics that provided information both on confined and escaping particles. The JET diagnostics dedicated at the moment to lost alpha particle studies are the thin foil Faraday cup array [1] and a scintillator probe [2]. The Faraday Cup array (KA2 JET diagnostics) detects the current of escaped fast ions at multiple poloidal locations, the detectable energy range for alpha particles being about 1–5 MeV. The Scintillator Probe (KA3 JET diagnostics) detects lost fast ions and provides information on the lost ion pitch angle and gyro-radius.

A new method to monitor escaped alpha particles has been recently proposed for JET [3]. Its working principle is presented schematically in Figure 1. Alpha particles escaping the JET plasma would bombard a dedicated beryllium target having suitable geometry placed at a specific location close to the plasma boundary. Gamma-rays from the 9Be(α, nγ)12C reaction would be detected by a detector placed within a radiation structure that should provide adequate collimation for the target emitted gamma-rays. At the same time the radiation system should also provide adequate shielding for the gamma-ray detector from both the neutrons and the background gamma radiation. Escaped alpha particles with energies in excess of 1.7 MeV interacting with a bulk beryllium target will produce 4.44-MeV gamma-radiation. Measurements of the gamma radiation will provide information on the rate of fast alpha particle losses.

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Eventually the alpha particle monitor could provide a local value of the lost fast particle flux (number of lost particles per unit surface and time).

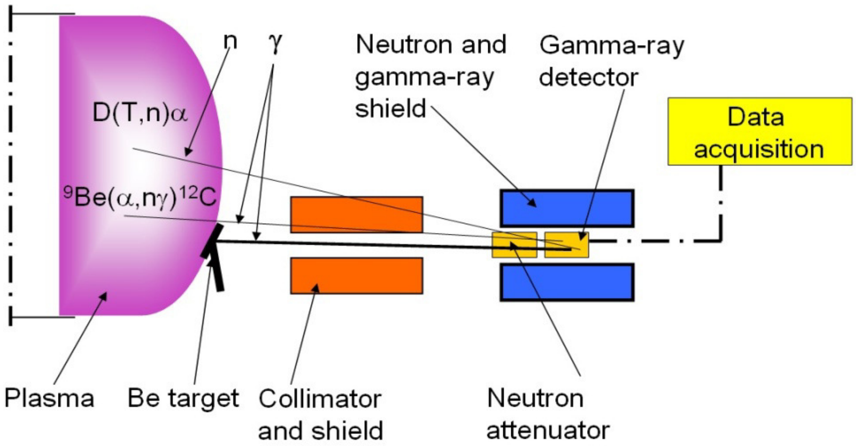

Figure 1: Schematic diagram for the LAM/KA4 principle

2. Design options for the LAM/KA4 diagnostics

The selected location of LAM ex-vessel components has the advantage of using the massive structure of KJ5 soft x-rays camera. From the eight channels of the upper KJ5 camera channel no. 1 has a dead soft X-ray detector, channels no. 2 and 3 were rendered useless as a result of the installation of TAE (Toroidal Alfven Eigenmode) antenna. The fields of view of the soft X-ray detectors in two channels are being blocked by components of TAE antenna.

The main hardware for the LAM diagnostics (KA4 in the JET diagnostics nomenclature) is to be located behind the JET KJ5 upper soft X-ray camera in octant 4 (Figure 2). The soft X-ray camera is made up of an array of soft X-ray detectors placed inside a radiation shield whose inner stainless steel core acts as a collimator. Several lower channels of the KJ5 collimator provide a satisfactory Field-of-View to potential targets (Figure 3). At the same time the KJ5 collimator is to be used as a pre-collimator for the LAM/KA4 diagnostics.

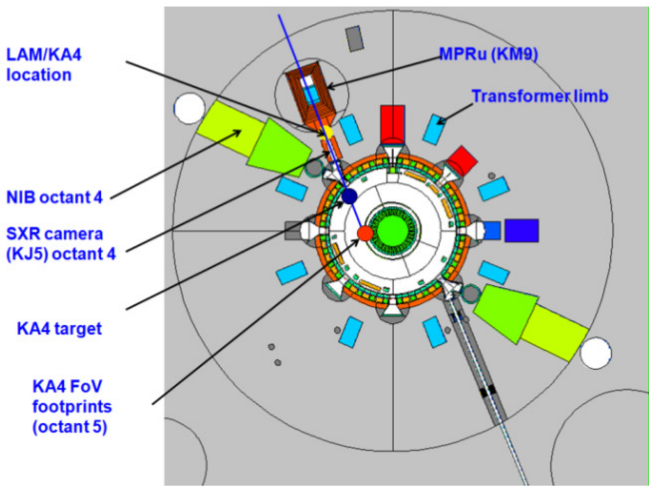

Figure 2: Location of the LAM/KA4 diagnostics: radiation shield (yellow dot), behind the KJ5 soft X-ray camera; target (blue dot). (MPRu: Upgraded Magnetic Proton Recoil neutron spectrometer, KM9 JET diagnostic)

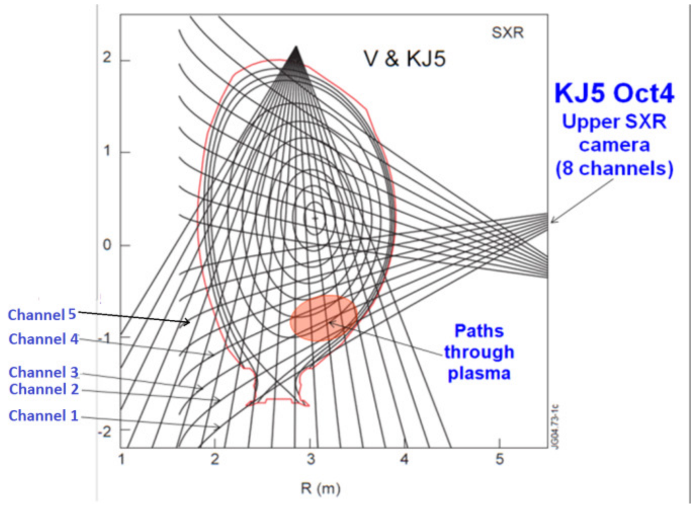

Figure 3: Cross-section of the JET plasma showing the KJ5 soft X-ray camera channels. Channels 1-5 have been considered to be used for the LAM/KA4 diagnostics

For this location (KJ5 SXR) various design options have been considered and evaluated. Figure 4 shows a schematic diagram for two options:

- Option 1: In this option channels 2 and 3 are used for reference and for the target, respectively. The channel 3 Line-of-Sight intersects one of the beryllium protection tiles of the TAE (Toroidal Alfven Eigenmode) antenna. This TAE protection tile is proposed to be used as the LAM/KA4 target. This option presents the advantage that the diagnostics could be designed using exiting components inside the vacuum vessel. One downside of this option is that both channels have divertor carbon fiber composite tiles in their field of view.

- Option 2: For this option the LAM/KA4 target is an extension of one of the TAE antenna protection tiles. The beryllium target falls into the field of view of channel 4 while channel 5 is used as the reference channel. This design option would avoid the effects of the parasitic gamma-radiation from the carbon fiber composite divertor tiles. However the extension of the TAE antenna protection tile represents a very challenging technical task according to an internal JET report. At the same time this design option has a high impact on the KJ5 soft X-ray camera as it uses two out of its five remaining working channels.

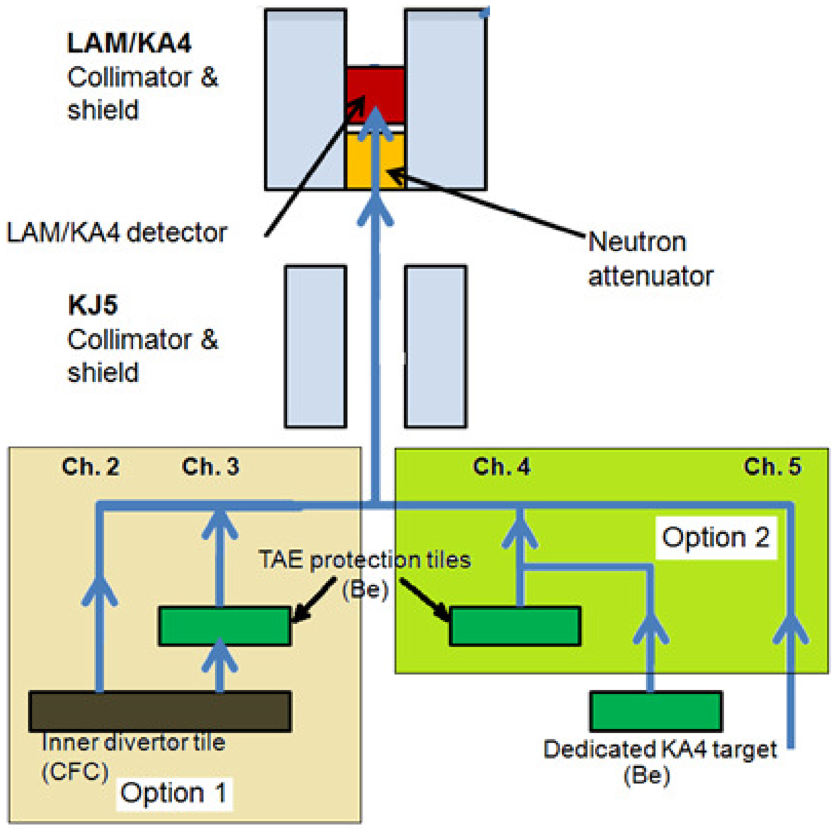

Figure 4: LAM/KA4 design solutions on the KJ5 location

3. Conceptual design.

Option 1 has been developed within a conceptual design study. This design option is presented schematically in Figure 5. Besides the components already described in the previous chapter (KJ5 SXR, fields-of-view of channels 2 and 3) it contains two KA4 gamma-ray detectors (based on the CeBr3 scintillator [4]) placed within a new radiation collimator and shield, behind Lithium hydride (LiH) neutron attenuators.

In this design option, both gamma-ray detectors have divertor carbon fibre composite tiles in their field of view.

A vertical section of the LAM/KA4 diagnostics containing all its hardware components is shown in Figures 5A and 5B.

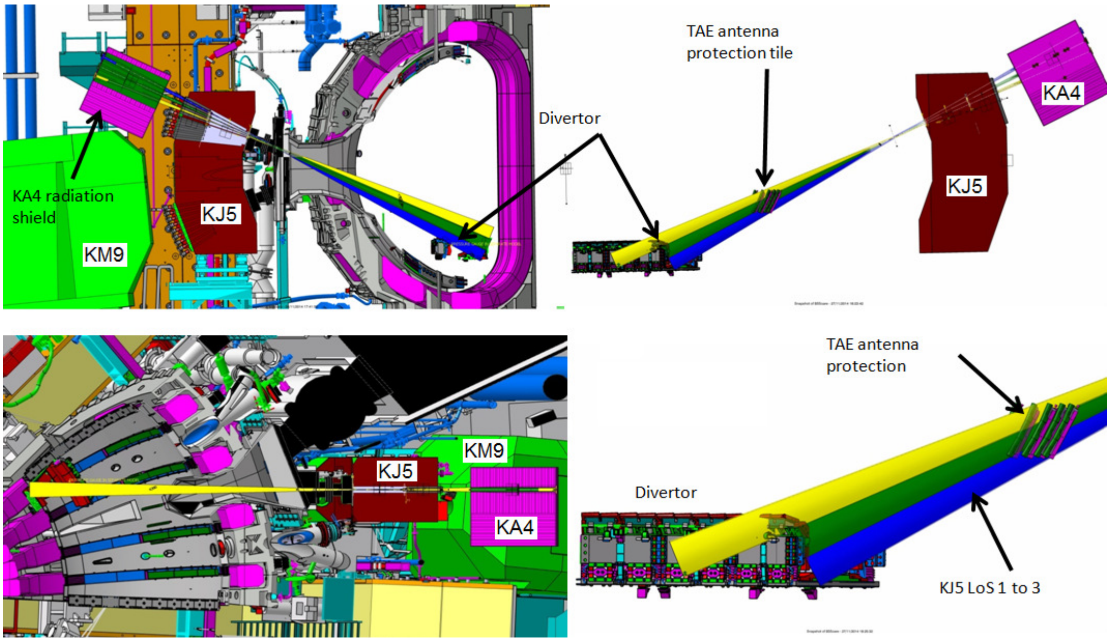

Figure 5A: KA4 radiation collimator and shield showing its position with respect to the adjacent JET diagnostics: KJ5 soft X-ray camera and KM9 magnetic proton recoil spectrometer. The fields of view for channels #1, 2, and 3 are also shown crossing the TEA antenna protection tiles and ending on the inner divertor tiles

The radiation collimator and shield is located behind the KJ5 radiation shield which is used as a pre-collimator for the KA4 diagnostics. The dimensions of the KJ5 collimator determine the dimension (solid angle) of the field of view for the KA4 detectors. The KA4 radiation collimator and shield houses the two KA4 gamma-ray detectors (see details in Figure 4B). A LiH neutron attenuator is placed in front of each gamma-ray detector. The detector in channel #3 views the LAM target through the KJ5 stainless steel collimator. The detector field of view at the target (the TAE protection tile) is shown in Figure 5.

The LAM/KA4 radiation (neutron and gamma-rays) shield is made up of alternating plates of high density polyethylene and lead. The radiation collimator is made of a slab of stainless steel into which the channels for the detectors and neutron attenuators are drilled. The LAM/KA4 target is one of the TAE antenna protection tiles. The upper part of the beryllium tile (about 2/3) falls into the field of view of the detector in channel #3 (Figure 6). The KA4/LAM neutron attenuators are based on LiH with natural isotopic composition.

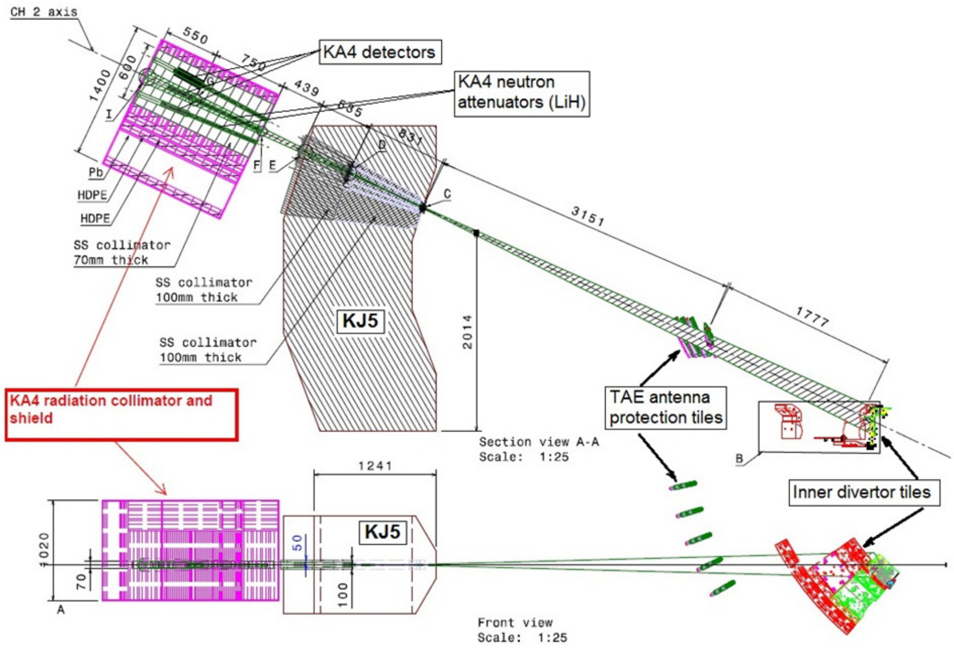

Figure 5B: drawing (section & top view) of the main components

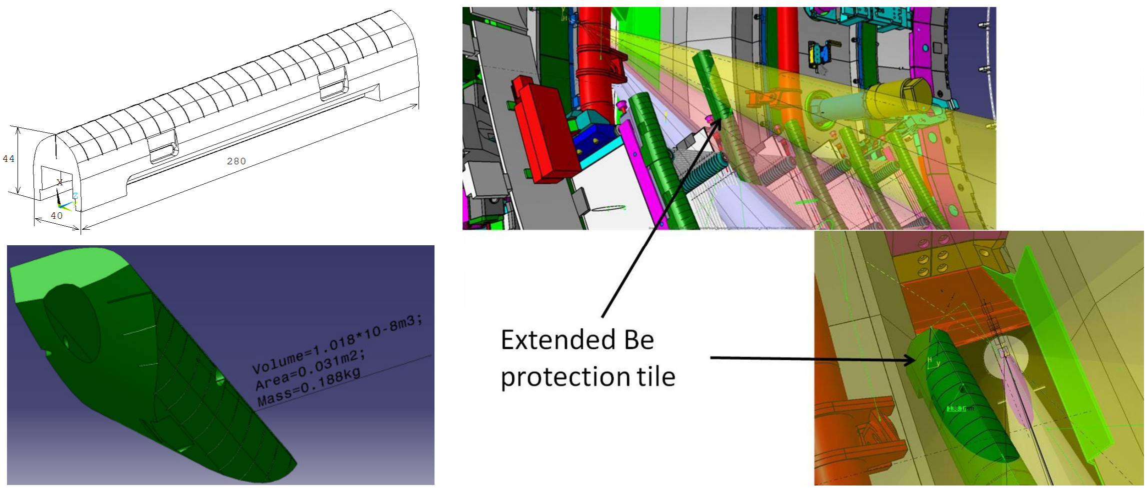

Figure 6 Beryllium tile protection / target; field of view (Ch 1 to 3); beryllium protection tile dimensions; beryllium tile inside Ch3 field of view; extended beryllium protection tile (drawing)

4. Radiation transport calculations

In order to assess the operational features of the Lost Alpha Monitor (LAM/KA4) radiation system an evaluation of its collimation and shielding characteristics was performed for Option 1. The evaluation has been performed by means of Monte Carlo numerical simulations using the MCNP-6.1 code [5] using point gamma-ray sources emitting within a defined narrow solid angle which ensures the coverage of the structures of interest. The point gamma-ray sources are placed at positions equivalent to KA4 target, the TAE antenna protection tile. The MCNP model takes into account both the existing KJ5 radiation shield and the newly designed LAM/KA4 radiation collimator and shield.

The MCNP numerical results (Figure 7) show that the combination of the two radiation shields (KJ5 and KA4) provides adequate shielding and collimation for the KA4 detector, and that shielding factors of about 10^3 can be obtained. On the other hand, the designed LAM/KA4 configuration has to be improved in order to allow a larger area of the beryllium target to be seen by the LAM/KA4 detector.

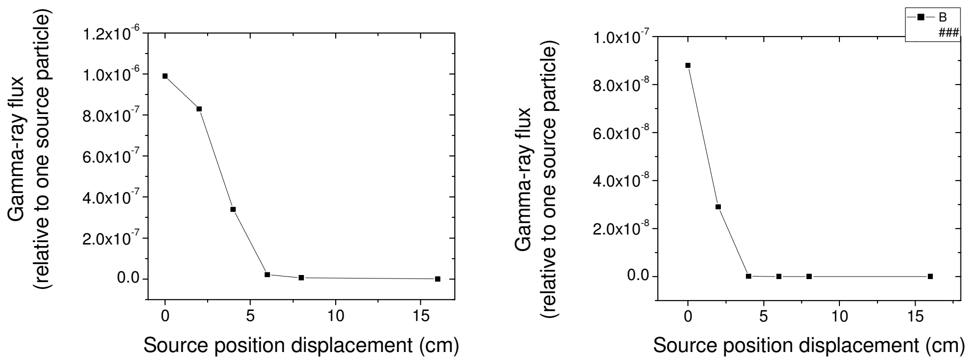

Figure 7: The dependence of the photon flux on the source position for the detectors located on the KA4 diagnostics axis of symmetry in case of KJ5 (left) and KJ+KA4 (right) radiation shields

5. Conclusions.

A new method to monitor escaped alpha particles has been recently proposed for JET. Several design options were investigated based on the initial requests and available locations and arrangements. The selected design was further refined and used for MCNP photon-neutron transport calculations, for either the beryllium target gamma-ray radiation / carbon fiber composite gamma-ray radiation or for the beryllium target MCNP calculation for the Line of Sight. The MCNP numerical results show that the combination of the two radiation shields (KJ5 and KA4) provides adequate shielding and collimation for the KA4 detector, and that shielding factors of about 10^3 can be obtained.

Acknowledgement

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