

# Mechanical design of the upgraded JET gamma-ray cameras

S. SOARE<sup>a\*</sup>, M. CURUIA<sup>a</sup>, V. KIPTILY<sup>b</sup>, A. MURARI<sup>c</sup>, P. PRIOR<sup>b</sup>, V. ZOITA<sup>d</sup>, M. ANGHEL<sup>a</sup>, G. BONHEURE<sup>e</sup>, M. CONSTANTIN<sup>a</sup>, E. DAVID<sup>a</sup>, T. EDLINGTON<sup>b</sup>, S. GRIPH<sup>b</sup>, F. LE GUERN<sup>f</sup>, Y. KRIVCHENKOV<sup>b</sup>, S. POPOVICHEV<sup>b</sup>, V. RICCARDO<sup>b</sup>, B. SYME<sup>b</sup>, V. THOMPSON<sup>b</sup>, JET EFDA CONTRIBUTORS<sup>\*</sup>

<sup>a</sup>Association EURATOM-MeDc, National Institute for Cryogenics and Isotopic Technologies, Rm. Valcea, Romania

<sup>b</sup>Association EURATOM-UKAEA/JOC, Culham Science Centre, Abingdon, UK

<sup>c</sup>Association EURATOM-ENEA, RFX, Padova, Italy

<sup>d</sup>Association EURATOM-MeDc, National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania

<sup>e</sup>Association EURATOM-Belgian State, LPP-ERM/KMS, B 1000 Brussels, Belgium

<sup>f</sup>JET-CSU, Culham Science Centre, Abingdon, UK

The JET gamma-ray camera diagnostics have already provided valuable information on the gamma-ray imaging of fast ion in JET plasmas /1, 2/. The JET Gamma-Ray Cameras (GRC) upgrade project deals with the design of appropriate neutron/gamma-ray filters ("neutron attenuators"). The main design parameter was the neutron attenuation factor /3/. The two design solutions, that have been finally chosen and developed at the level of scheme design, consist of: **a)** one quasi-crescent shaped neutron attenuator (for the horizontal camera) and **b)** two quasi-trapezoid shaped neutron attenuators (for the vertical one). Pure light water was chosen as the attenuating material for the JET gamma-ray cameras. Finite Element Analysis (FEA) methods used to evaluate the behaviour of the filter casings under the loadings (internal hydrostatic pressure torques) have proven the stability of the structure.

(Received March 1, 2008; accepted June 30, 2008)

**Keywords:** Tokamak, Diagnostics, Gamma-rays

## 1. Introduction

The JET gamma-ray camera diagnostics system (KN3 neutron/gamma-ray profile monitor) has already provided valuable information on the fast ion evolution in JET plasmas /1, 2/. The applicability of gamma-ray imaging diagnostics to high power deuterium and deuterium-tritium discharges is strongly dependent on the fulfilment of rather strict requirements for the control of the neutron and gamma-ray radiation fields. These requirements were augmented by the very hard design restrictions on JET (e.g., the requirement of minimum effects on the co-existing neutron camera diagnostics).

The main objective of the JET Enhancements (EP2) gamma-ray camera diagnostics upgrade is the design, construction and testing of neutrons attenuators for the two sub-systems of the KN3 gamma-ray imaging diagnostics: a) KN3 gamma-ray horizontal camera (KN3 HC) and b) KN3 gamma-ray vertical camera (KN3 VC). This diagnostics upgrade should make possible gamma-ray imaging measurements in high power deuterium JET pulses, and eventually in deuterium-tritium discharges.

Another objective of this upgrade project is to develop and test design solutions of relevance to ITER. Eventually the JET KN3 gamma-ray cameras diagnostics upgrade should validate design solutions of interest for ITER.

## 2. JET Gamma-ray camera neutron attenuators

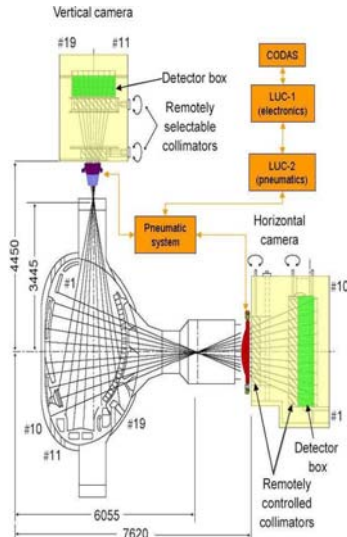
Several design versions were developed and evaluated for the JET gamma-ray camera neutron attenuators at the conceptual design level. The main design parameter was the neutron attenuation factor /3/. The following design solutions were chosen and developed at the level of scheme design:

- One quasi-crescent shaped neutron attenuator for the horizontal camera
- Two quasi-trapezoid shaped neutron attenuators for the vertical camera, with different attenuation lengths: a short version, to be used together with the horizontal attenuator for deuterium discharges and a long version to be used for high performance deuterium and DT discharges.

The horizontal camera neutron attenuator is designed to function as a neutron filter when in working position (in the plane determined by the gamma-ray detectors lines of sight).

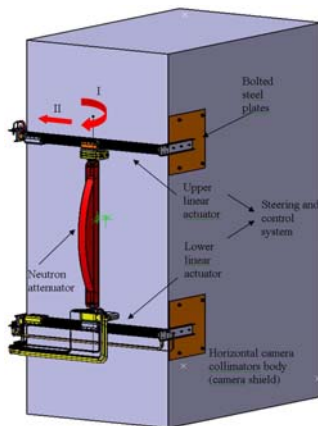
To move the neutron attenuator to and from the working position two movements are required: first a 90° rotation (to the right when looking to plasma) and second a 630 mm translation as shown in Fig. 2. The locations of the neutron attenuators are shown schematically in Figure 1 together with the detector lines of sight of each of the two KN3 cameras. The attenuators are placed within the

KN3 diagnostics system in Octant 1 between the vacuum port and the collimator body (also called “radiation shield”), both in the case of the horizontal camera (HC) and vertical camera (VC) (Fig. 1).



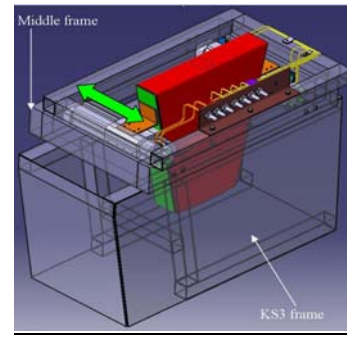
**Fig. 1.** Horizontal and Vertical Camera Neutron Attenuator

The horizontal camera neutron attenuator (HC\_NA) is steered and controlled by a commercially available electro-pneumatic system and several additional custom-tailored parts. The neutron attenuator consists of a metal casing filled with the pure light water (as attenuating material) and a U-shaped profile that provides the structure with mechanical strength and connects with the steering and control system (Fig. 2).



**Fig. 2.** Horizontal Camera Neutron Attenuator in working position

The vertical camera neutron attenuator (VC\_NA) is positioned on Octant 1, inside the KS3 optical diagnostics box (Fig. 3).



**Fig. 3.** Vertical Camera Neutron Attenuator in working position

To move in and out of the working location the attenuator is translated 100 mm by the steering and control electro-pneumatic system. Both vertical camera attenuator casings (short and long version) have a quasi-trapezoidal shape with internal reinforcements parallel to and between the lines of sight.

Both attenuators, of horizontal and vertical cameras, are situated in strong poloidal magnetic fields generated by the nearby poloidal and shaping coils. The vertical camera neutron attenuator is in a worse situation than that of the horizontal camera, due to larger torques from different directions. Finite Element Analysis was used to evaluate the casings deformation and stresses when subjected to torques larger than those thought to exist. Results suggest there is no cause of concern from this point of view.

#### 4. Finite Element Analysis Method

The attenuator casings models were constructed in CATIA and then prepared to be exported to a commercially available finite element package, ANSYS. The loads, material properties and boundary conditions are those assumed by literature or provided by the Engineering Analysis Group (EAG) from JET. The model was then imported, loaded and analysed. Several assumptions were done and they are mentioned below:

- Even though the real structure consists of two parts, the model was handled as just one body. The reason was the existence of a large contact area between the two parts as well as a long weld.

- The material properties are those of an aluminium alloy (imported from the ANSYS material library). However they can be changed.

- Ends are considered to have fixed support

##### 4.1 Simulation model of HC-NA

A moment of 200 Nm was applied on the lateral faces along the longitudinal axis, an internal hydrostatic pressure of 5 bar was applied and the ends were fixed, Fig. 4. Earth standard gravity was also applied. The work environment was set to static analysis.

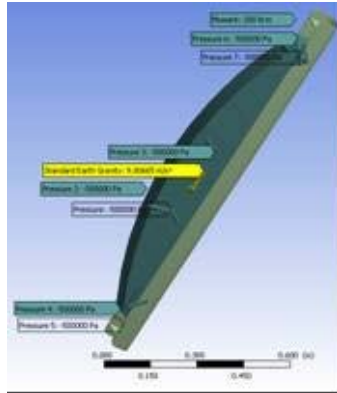


Fig. 4. Loaded model: applied moment, internal hydrostatic pressure and earth gravity.

The model was solved in one step, static solution. The maximum deformation is less than 2 mm on X-axis, Figure 5a.

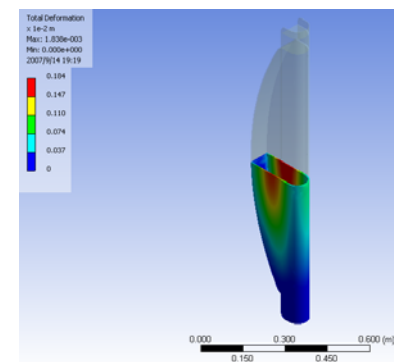


Fig. 5.a Half-model showing the maximum deformation

The equivalent von Mises stress is less than  $250 \times 10^6$  Pa, Figure 5.b

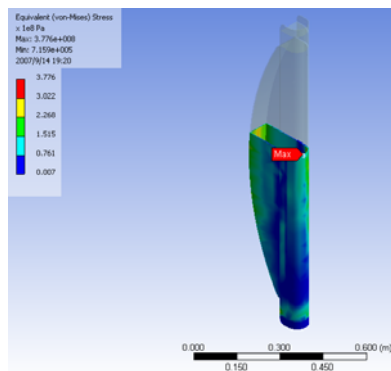


Fig. 5.b Half-model showing the equivalent von Mises stress

#### 4.2 Simulation model of VC-NA

The boundary conditions and model loads are shown in Figure 6. The holes surfaces of the connecting elements were set fixed and a 200 Nm torque was applied, about Y-axis, on all the casing parts. Internal hydrostatic pressure was applied as well as the earth gravity. A downward force of 200 N was applied to simulate the weight of water. The work environment was set to static analysis.

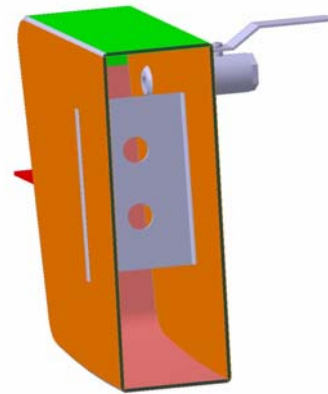
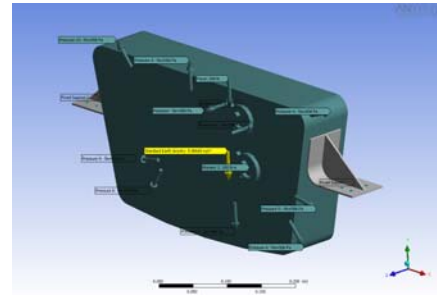


Fig. 6. Model of the Vertical Camera Neutron Attenuator: a) cross-section and b) model loaded and constrained

Shown in figure 6a are the internal reinforcements; their purpose is to prevent an excessive deformation due to the water pressure (5 bar).

The model was solved in one step, static solution. The maximum deformation is shown in figure 7 and is 0.4 mm on Z-axis.

The equivalent (von Mises) stress has the distribution seen on Fig. 8 and does not exceeds  $1.7 \times 10^8$  Pa.

#### 5. Conclusions

The design of the upgraded JET KN3 gamma-ray camera diagnostics was developed up to the scheme design level. All issues regarding the impacts on adjacent systems ("interfaces") were addressed and adequate design solutions were developed. The analysis of the mechanical behaviour showed that the deformations were insignificant and will not present any causes of concern. The severe

design constraints limited the attainable parameters of the upgraded gamma-ray cameras. The upgraded GRC diagnostics will work as a two-camera system for low power JET pulses and as a single (vertical) camera for high power deuterium and deuterium-tritium pulses. The addition of the neutron attenuators for the KN3 gamma-ray cameras has no significant impact on the co-existing neutron camera diagnostics. The finite element analysis has shown that there is no cause of concern regarding the mechanical stability of the neutron attenuator casing.

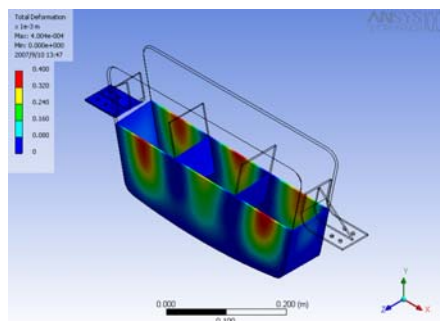


Fig. 7. Half model of the Neutron Attenuator deformed casing

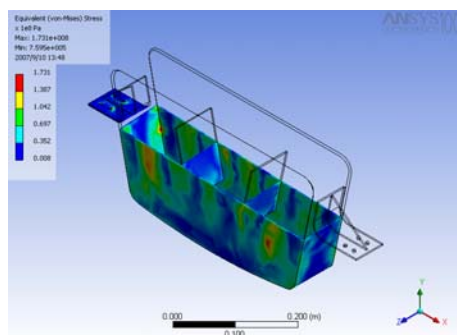


Fig. 8. Half model of the Neutron Attenuator casing: equivalent von Mises stress

## References

- [1] V. Kiptily, D. Borba, F. E. Cecil, M. Cecconello, D. Darrow, V. Goloborodko, K. Hill, T. Johnson, A. Murari, F. Nabais, S. D. Pinches, M. Reich, S. E. Sharapov, V. Yavorskij, I. N. Chugunov, D. B. Gin, G. Gorini, A. E. Shevelev, D. B. Syme, V. Zoita, "Fast ion JET diagnostics: confinement and losses", AIP Conference Proceedings, Volume **988**, 283 (2008)
- [2] V. Kiptily, F. E. Cecil and S. S. Medley, "Gamma ray diagnostics of high temperature magnetically confined fusion plasmas", Plasma Phys. Control. Fusion, **48**, R59 (2006).
- [3] S. Soare V. Zoita, T. Craciunescu, M. Curuia, V. Kiptily, I. Lengar, A. Murari, P. Prior, M. Anghel, G. Bonheure, M. Constantin, E. David, T. Edlington, D. Falie, S. Griph, F. LeGuern, Y. Krivchenkov, M. Loughlin, A. Pantea, S. Popovichev, V. Riccardo, B. Syme, V. Thompson, I. Tiseanu and JET EFDA contributors, "Upgrade of the JET Gamma-Ray Cameras", AIP Conference Proceedings, Volume **988**, 299 (2008).

\*Corresponding author: soare@icsi.ro