UPGRADE OF GAMMA-RAY CAMERAS – NEUTRON ATTENUATORS

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1. Introduction

The JET KN3 gamma-ray camera diagnostics system 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 pulses and to deuterium-tritium discharges is however strongly dependent on the fulfilment of rather strict requirements for the control of the neutron and gamma-ray radiation fields. The upgraded diagnostics should fulfill these requirements and it should, at the same time, observe 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 EP2 diagnostics upgrade project “Gamma-Ray Cameras – Neutron Attenuators” (GRC) is the design, construction and testing of neutrons attenuators for the two sub-systems of the KN3 gamma-ray imaging diagnostics [3-5]:

- KN3 gamma-ray horizontal camera (KN3 HC)
- 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.

A second objective of the GRC project is the design (scheme design level) of the KM6T tangential gamma-ray spectrometer upgraded diagnostics.

An important objective of the GRC project is to develop and test design solutions of relevance to ITER. Eventually the GRC diagnostics upgrade should validate design solutions of interest for ITER.

2. KN3 Gamma-ray cameras neutron attenuators

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) (Figure 1).

The KN3 neutron attenuators consist of metal casings filled with pure light water. Two materials were considered for the attenuators casings: INCONEL 600 and aluminium alloy 6061. The final choice was for INCONEL 600 (3mm thick sheet) and it was determined both by considerations related to the interaction with pure water and by considerations related to the manufacturing process flow (effects of welding, bending, mechanical and electrical behaviour).

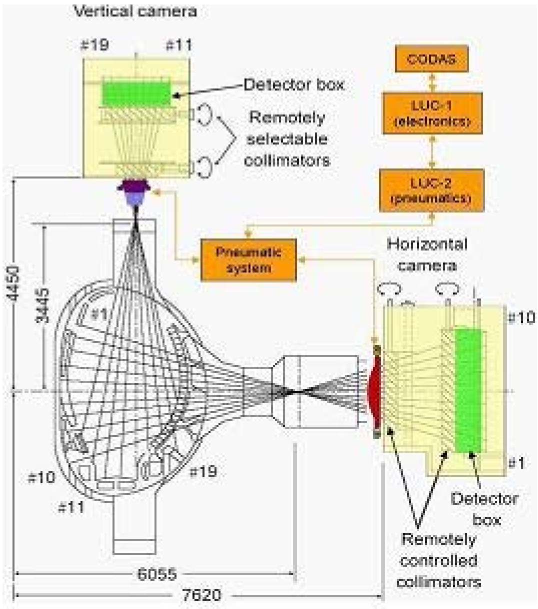


Figure 1. Horizontal and Vertical Camera Neutron Attenuator (HC-NA, VC-NA)

2.1 Horizontal Camera Neutron Attenuator

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 remove the neutron attenuator from the working position two movements are required: first a 90^{o} rotation (to the right when looking to plasma) and second a 630 mm translation as shown in Figure 2.

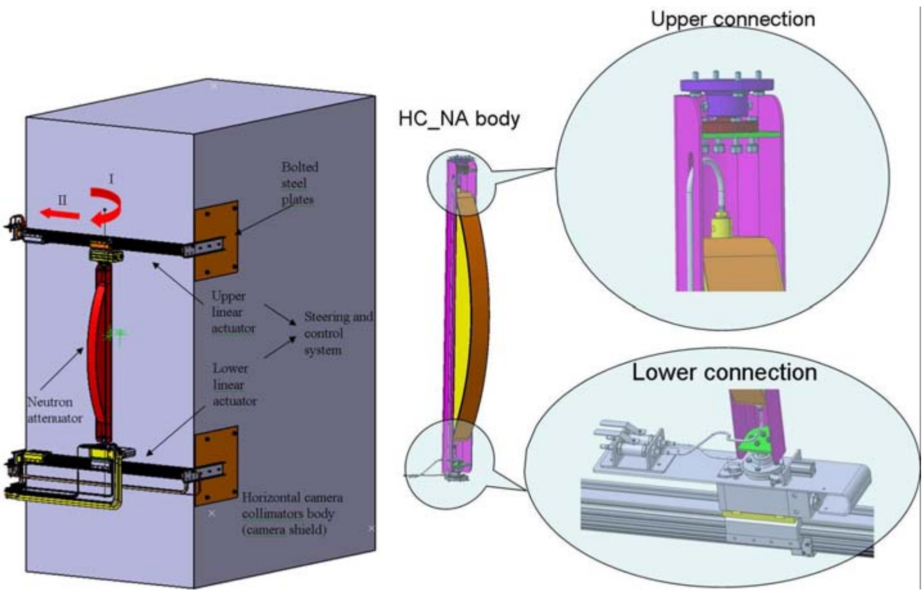


Figure 2. a) Horizontal Camera Neutron Attenuator in working position; b) HC-NA system

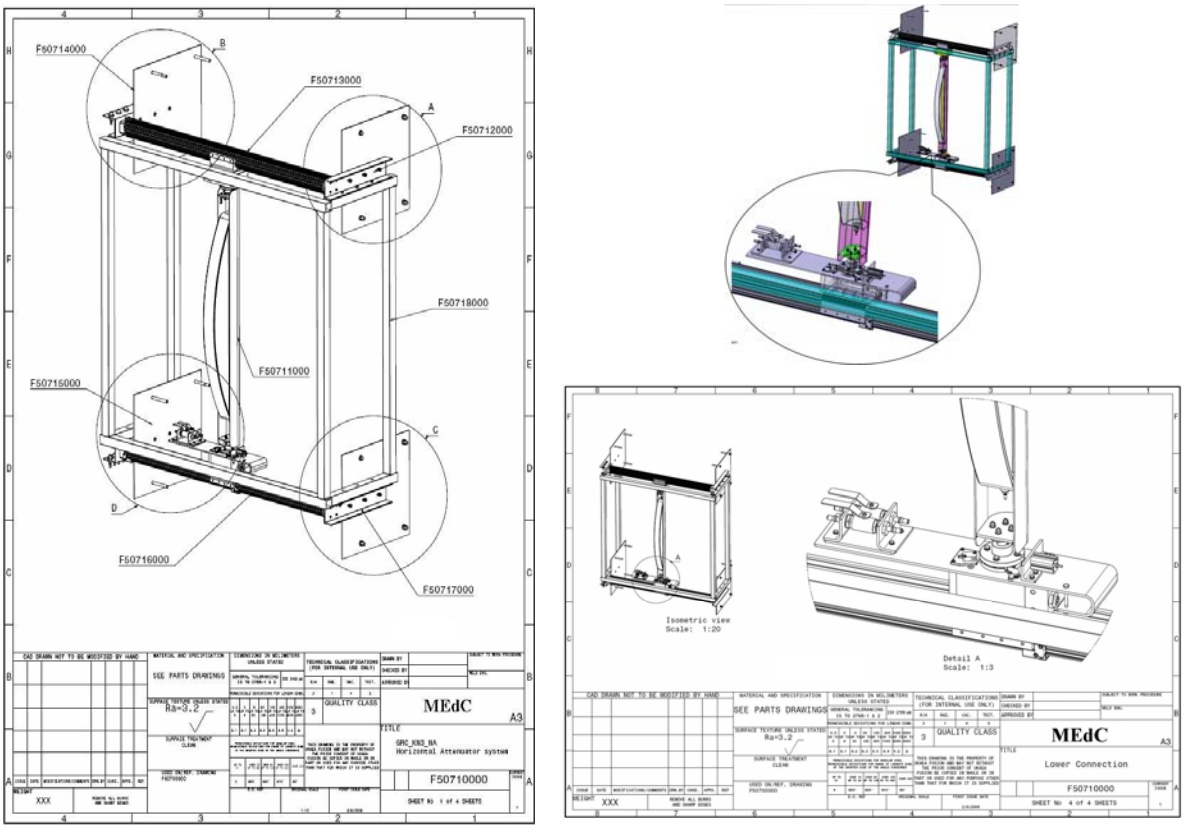


Figure 3. Horizontal Camera Neutron Attenuator system – drawing and 3D model

To place the attenuator into the working position the same actions are to be taken in reverse order. The attenuator is steered and controlled by a commercially available electro-pneumatic system that includes additional several custom-tailored parts.

The neutron attenuator consists of the pure light water (used as attenuating material) casing and a U-shaped profile that provides the structure with mechanical strength and connects with the steering and control system.

The Horizontal Camera Neutron Attenuator system was developed to the detailed design level. The components of the system are: attenuator casing, mounting frame, pneumatic linear/rotating drives, filling/draining assembly, connecting parts, and fittings. All of them are assembled into the functional system shown as drawings (drawing no. F50710000 sheet 1 and sheet 2) and 3D model in Figure 3.

2.2 Vertical Camera Neutron Attenuator

The vertical camera neutron attenuator is positioned on Octant 1, inside the KS3 optical (H alpha) diagnostics box, mounted on the diagnostics metal frame. The vertical camera neutron attenuator casing was developed into two versions: long (assembly drawing no. F50721000, Figure 5) and short (assembly drawing no. F50720000, Figure 4).

To move in and out of the working/parking location the attenuator is translated 100 mm by a steering and control electro-pneumatic system (not as complex as that from the horizontal camera neutron attenuator), Figure 4.

Both vertical camera attenuator casings (short and long version) have a quasi-trapezoidal shape with internal reinforcements parallel and between the lines of sight.

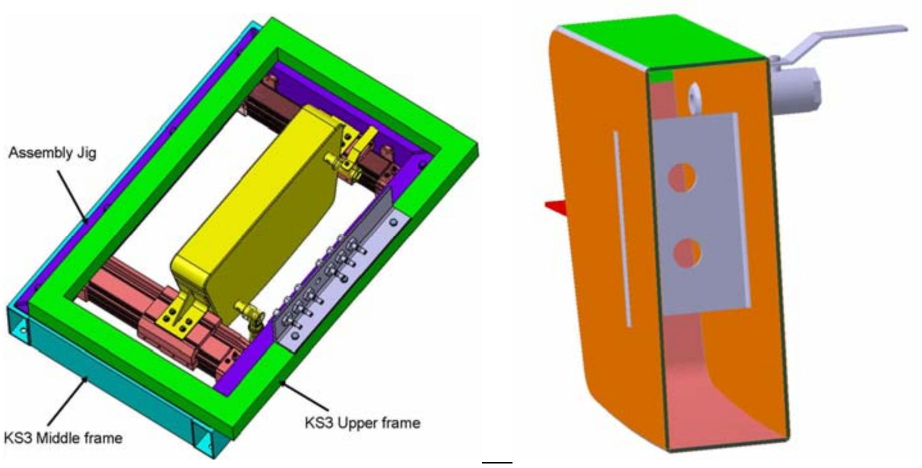


Figure 4. a) Vertical Camera Neutron Attenuator in working position; b) Cross-section of the attenuator casing

The vertical camera neutron attenuator system was developed to the detailed design level. The assembly drawing shows the middle and upper frames (parts F50722000 and F50723000 respectively from Figure 5) of KS3 diagnostics box; these parts are required to be prepared for the attenuator system subsequent installation. The pneumatic steering and control devices will be mounted onto an assembly jig (part F50724000 from Figure 5). The assembly jig will then be fixed onto the KS3 diagnostics box with bolts.

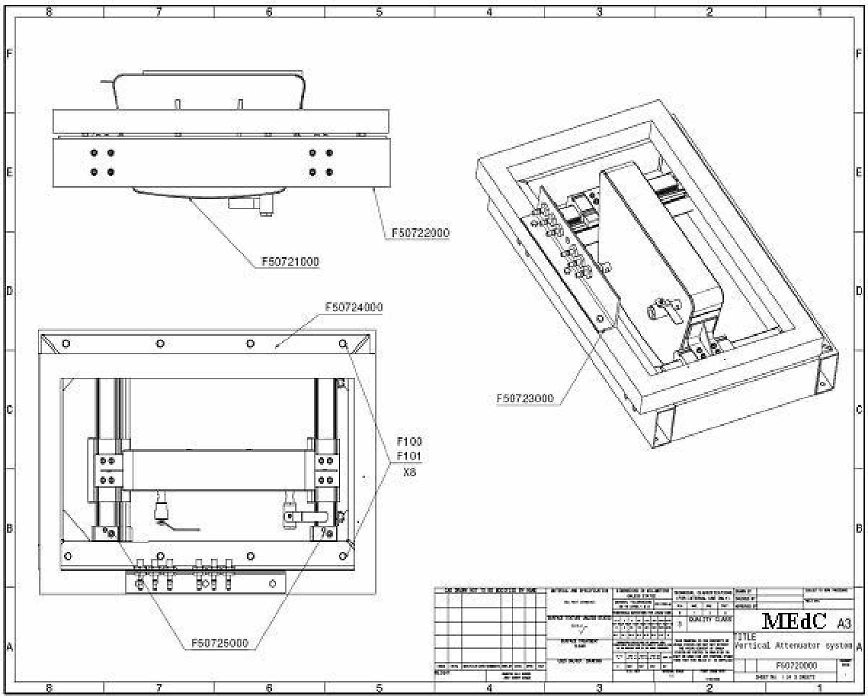


Figure 5. Assembly drawing of the Vertical Camera Neutron Attenuator

The vertical camera neutron attenuator casing long version (assembly drawing no. F50721000) is shown in Figure 6. It consists of the same components, the only difference being its height of 600 mm (compared with 240 mm for the short version casing).

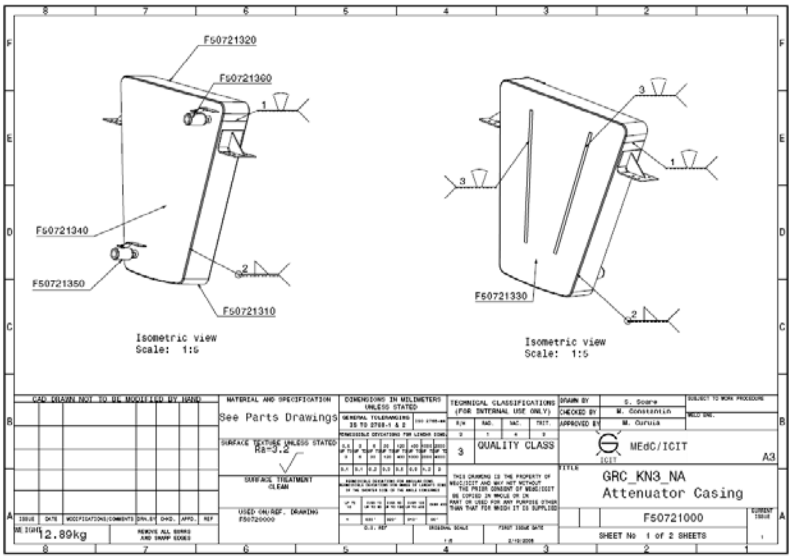


Figure 6. Assembly drawing of the long version of the vertical camera neutron attenuator casing

2.3. Steering and control system for KN3 gamma ray camera neutron attenuators

The KN3 gamma-ray camera neutron attenuators will operate in a very harsh electromagnetic environment. It was thus recommended to avoid as much as possible the use of electrical and electronic components for the attenuator steering and control. Therefore a design solution based on pneumatic components was developed for attenuator steering.

A block-diagram of the KN3 neutron attenuator steering and control system is presented in Figure 7. The components are grouped into three sub-systems:

- **LUC-1** (Local Unit Cubicle 1) contains a programmable logic controller, an operator unit and a power supply. The programmable logic controller that is permanently connected to CODAS receives electrical signals from the pneumatic-electric converter from Local Unit Cubicle-2, (LUC 2) and sends electrical signals to the directional control valves from LUC-2.

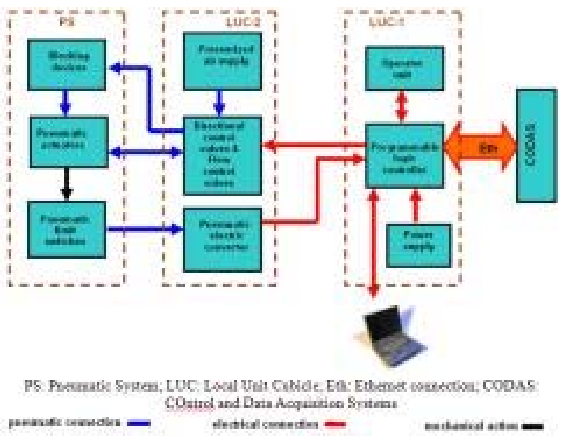


Figure 7. Block-diagram of the KN3 neutron attenuator steering and control system

- **LUC-2** (Local Unit Cubicle 2) contains the directional control valves, the flow control valves, the pressurized air supply and the pneumatic-electrical converter.

There are two pressurized air circuits for each actuator. The pneumatic-electric converter (PEC) receives pneumatic signals (air pressure changes) from the pneumatic limit switches and converts them into electrical signals that will be sent to the Local Unit Cubicle 1 (LUC-1). The pressurized air supply will be connected to the JET pressurized system that will provide 5-7 bar air pressure.

-PS (Pneumatic System) consists of pneumatic actuators, pneumatic limit switches and blocking devices. The pneumatic actuators perform the translation and/or rotation movements necessary to place the attenuators either in the working or in the parking positions. The role of the pneumatic limit switches is to indicate whether the attenuators have reached their pre-set positions (either the working or the parking position, with no intermediate position indications). The blocking devices will hold firmly the attenuators into their pre-set positions.

3. Vertical Camera Neutron Attenuator prototype

A fully functional prototype based on the vertical camera neutron attenuator was developed, manufactured and electro-mechanically tested. It is similar in size, shape and used materials as the KN3 vertical camera neutron attenuator; additionally a support frame was manufactured to mimic part of the KS3 optical diagnostic box. Shown in Figure 8 are the 3D model and a drawing (isometric view) of the prototype system.

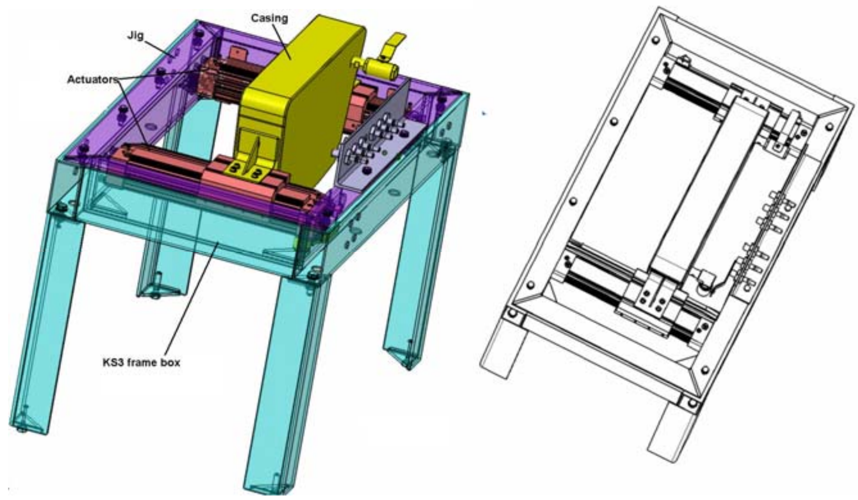


Figure 8. Prototype casing, support and pneumatic linear actuators

Figure 9 shows the manufactured prototype system (the mechanical part) and the casing.

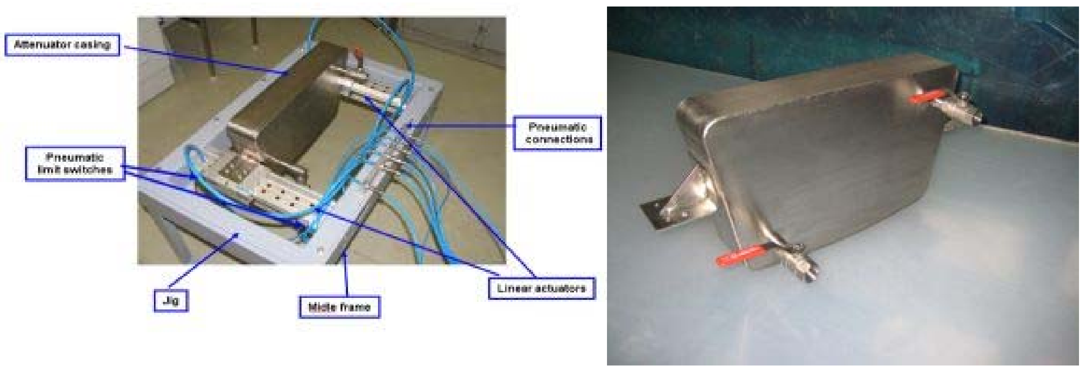
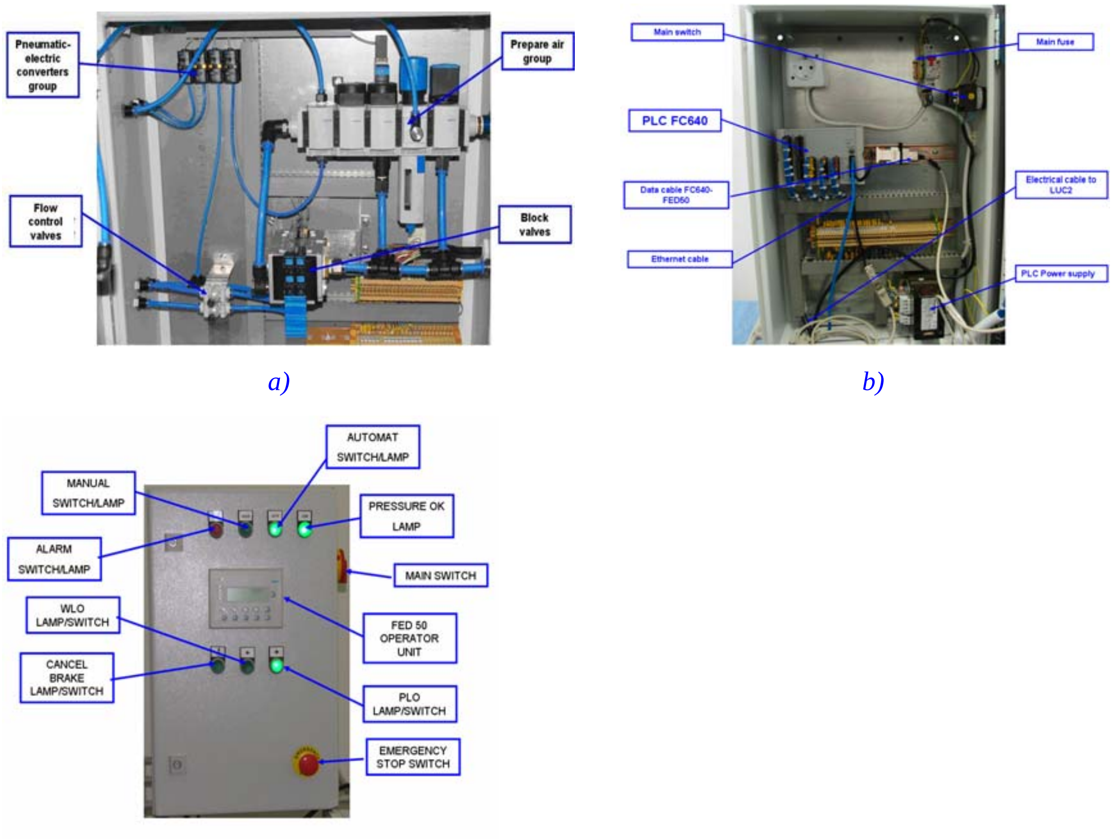


Figure 9. a) Manufactured neutron attenuator prototype; b) manufactured attenuator casing

The steering and command system is similar to that of the KN3_NA in terms of components. The differences lay with the software that commands and controls the translations and end-stroke positions. All the three main blocks (LUC 1, LUC 2 and PS) are shown in figure 10 a), b), and c) – see Chapter 2.3.



a) *b)*

c)

Figure 10. Main block of the prototype steering and command system (FESTO components); a) Local Unit Cubicle 1 (LUC 1) b) Local Unit Cubicle 2 (LUC 2) c) Pneumatic System (PS)

The casing was designed and manufactured according to the legal requirements currently in-force: ISCIR, (Romanian) Office for the Assessment of Lifting and High Pressure Equipment and CNCAN, (Romanian) National Commission for the Control of Nuclear Activities. Subsequently the casing was subjected to several integrity tests: helium leak test, pressure test, and penetrating liquid. The casing passed all tests it was subjected to.

4. Profile reconstruction techniques for the JET neutron camera diagnostics (KN3)

The JET neutron profile monitor ensures coverage of the neutron emissive region that enables tomographic reconstruction. However, due to the availability of only two projection angles and to the coarse sampling in each projection, tomography is a limited data set problem. In consequence, appropriate reconstruction methods must be developed in order to ensure good reconstructions.

This work on profile reconstruction techniques for the JET neutron camera diagnostics (KN3) started in 2007 with the development and implementation of a method based on the maximum entropy principle (ME). It continued during the last quarter of 2007 with work on the implementation of a Monte Carlo Back-Projection (MCBP) algorithm. The algorithm starts with an empty image and tries to allocate a small quantity “d0” in a randomly chosen pixel: $f_i^{(iter+1)} = f_i^{(iter)} + do$. If the allocation is compatible with the existent projections, i.e., $p_k - f_i^{(iter+1)} w_{i,k} \geq 0$ the allocation remains permanent, and $f_i^{(iter+1)} = f_i^{(iter)}$; otherwise it is discarded: $p_k \rightarrow p_k - f_i w_{i,k}$.

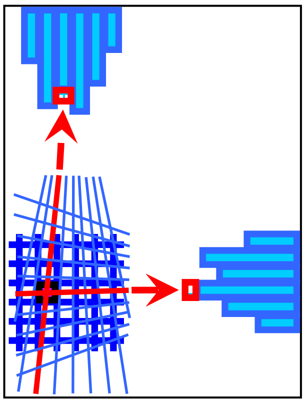


Figure 1 – Illustration of the Monte Carlo algorithm principle

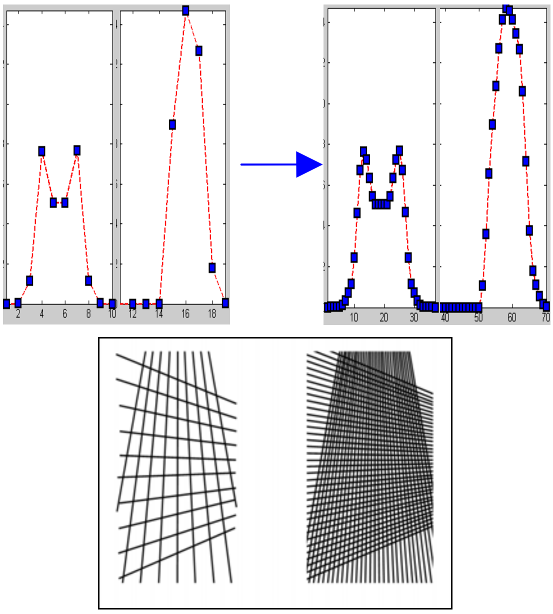


Figure 2 – Projection resampling implies improved domain coverage

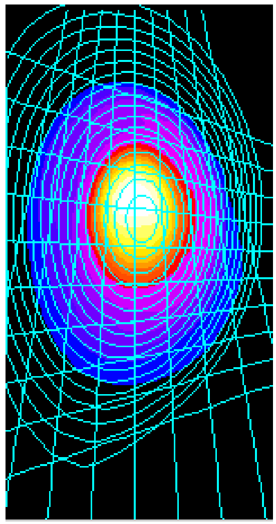


Figure 3 - Reconstruction of the neutron emissivity for shot 61161 at 51.52 s

The same smoothing principle as in the case of the ME method was used. It assumes smoothness on magnetic flux surfaces. We implemented the smoothing operator as a one-dimensional median filtering, using a sliding window which moves on the magnetic flux contours. This operator works on the tomographic projection/back-projection weighting matrix. In order to introduce some additional degree of smoothing the experimental projections were transformed by resampling, using spline interpolation (Fig. 2). Projection resampling implies the introducing of virtual lines of sight (Fig. 2) which ensures an improved coverage of the reconstruction domain. The work was continued with the evaluation of the performances of this method. This evaluation is performed using numerically generated phantoms and experimental data. Encouraging results were obtained (Fig. 3).

5. KM6T tangential gamma-ray spectrometer

Regarding the upgrade of the JET tangential gamma-ray spectrometer (KM6T) a long series of scientific and technical evaluations carried out over a period of about two years lead to the conclusion that the full diagnostics system should be upgraded in order to fulfil the requirements of high power DD and DT JET discharges (i.e. not only the replacement of the neutron attenuators).

A Conceptual Design phase for the KM6T diagnostics upgrade is under way and it is to be completed by end of January 2008, with a conceptual design review meeting at JET planned for February 2008.

The structure proposed for the KM6T diagnostics upgrade contains:

-a neutron and gamma-ray collimating system

-neutron and gamma-ray shielding components

-a system of three neutron attenuators using lithium hydride as the attenuating material

The KM6T field of view was defined by the new diagnostics configuration. A preliminary evaluation of the radiation (neutron and photon) performance was done by means of the MCNP transport code. The effect of the parasitic gamma-ray sources falling within the new KM6T field of view was also evaluated.

A high performance data acquisition system for the existing BGO gamma-ray detector was also considered as a necessary upgrade, but this is no longer realistic under the present financial difficulties in the lead Association, MEdC.

In order to provide the necessary information for a realistic evaluation of the upgrade of the KM6T tangential gamma-ray spectrometer it was proposed (at the Project Board no. 4, 16.07.2007) to carry out a Scheme Design phase until June 2008.

In order to test the new technology for the manufacture of the LiH attenuators for the KM6T upgrade an attenuator prototype was proposed to be developed. For this propose our experimental device for the manufacturing of the LiH discs from LiH powder was constructed. The discs will be produced by a technology based on ultrasonically assisted hot sintering.

6. Conclusions

The neutron attenuator system for the JET KN3 Gamma-Ray Cameras (KN3 GRC) diagnostics has the following main components (sub-systems): horizontal camera neutron attenuator (HC-NA), vertical camera neutron attenuator (VC-NA), and neutron attenuators steering and control. Work during 2007 progressed with the detailed design phase where the drawing of assemblies and parts were produced.

A fully functional neutron attenuator prototype was manufactured and tested. The system, as a whole, performed according to the specifications. Integrity tests proved the neutron attenuator casing is suitable (from the mechanical point of view) for use.

Techniques for the reconstruction of the radiation profiles provided by the JET KN3 neutron/gamma-ray cameras have been successfully developed and tested.

The work on the KM6T tangential gamma-ray spectrometer upgrade continued with a conceptual design of the full diagnostics system.

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