UPGRADE OF GAMMA-RAY CAMERAS – NEUTRON ATTENUATORS

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1. Introduction

The main purpose of the EP2 diagnostics project "Upgrade of Gamma-Ray Cameras –Neutron Attenuators (GRC)" is to provide conditions for gamma-ray measurements on JET during high-power DD and DT discharges. The work carried out during the last quarter of 2005 was focused on finding suitable materials, various design solutions and techniques which would fulfill the physics requirements for such experiments. Also, it had to take into account the possible effects on the existing equipment already in place as well as all the aspects concerning the manufacture and installation of the new parts.

The mechanical component of the project consists of three neutron attenuators (NA) which will be installed the lines of sight (LoS) of the gamma-ray detectors:

1 KN3-HC-NA (KN3 horizontal camera)
2 KN3-VC-NA (KN3 vertical camera)
3 KX1-TS-NA (KX1 LoS gamma-ray spectrometer) - horizontal/tangential gamma-ray spectrometer (KX1)

The required values of the neutron attenuation factors depend on the type of the JET discharges:

- for DD discharges (2.45 MeV neutrons) required attenuation factor 10^4

- for DT discharges (14 MeV neutrons) required attenuation factor 10^2

Each of the two types of discharges is associated with a set of designs consisting of three solutions:

- attenuation factor 10^4
  – KN3-HC-NA movable, slab-shaped container filled with liquid (possible pure water)

  - KN3-VC-NA movable container with natural Li, near (or as near as possible) to the neutron collimator body

  - KX1-TS-NA consisting of sealed containers filled with water

- attenuation factor 10^2
  - KN3-HC-NA segmented container (three segments) filled with water, filled/drained remotely in a time span

of 20 minutes, mounted on a new, modified re-entrant vacuum door

- KN3-VC-NA movable container with natural Li, near (or as near as possible) to the collimator

- KX1-TS-NA consisting of sealed containers filled with water

2. Neutron Attenuator Assembly: KN3-HC- NA

2.1 Background

Various design solutions have been developed and evaluated for the neutron attenuators. The ones based on a solid lithium hydride (LiH) attenuator seem to fulfill most of the design requirements.

A LiH attenuator is proposed to be used inside the vacuum chamber. This structure will be moved in and out of line of sight by an electric motor placed outside the vacuum vessel. The attenuator and its supporting structure will be fixed on the vacuum door inside by welding or by screws depending on the results of further technical evaluations. There have been several options for the attenuating material to be used such as: 92% ^{6}Li enriched LiH, 60% ^{6}Li enriched LiH, or natural isotopic composition LiH (natural LiH). Depending on the cost and availability as well as on the position of the attenuator several structures were proposed: closer to the focus (a smaller quantity of material needed) or further away (more material necessary).

Initially 92% enriched ^{6}LiH was considered. An attenuator based on this material was to be placed as near to the focus as possible in order to reduce the amount of material. Physics has to be taken into account meaning that an object close to the focus will act as a neutron scatterer. This issue was correlated with the price (about 45$/g) and availability (strategic material). Beside this, further technical difficulties ruled out this solution.

The second solution proposed was a segmented liquid attenuator placed inside the vacuum chamber. This structure was designed with four compartments to allow variable attenuation factors, with pipes for filling/draining the attenuating material and pump. This required a safe solution for the thermal insulation of the liquid attenuator, implied a new vacuum door to accommodate the attenuator and raised major safety concerns. This option was considered to be a back-up solution for the main solution – a natural LiH (or 60% enriched ^{6}Li) attenuator.

The natural LiH attenuator is considered to fulfill most of the design requirements for the KN3 horizontal camera. This option will be detailed in the following section.

2.2 Horizontal Camera Attenuator Design

Taking into account the future operating conditions of the attenuator, the structure imposed geometry is presented in Figure 1.

Inside the attenuator 100 x 50 x 20 mm bricks will be placed. This is due to the overall attenuator dimensions which are too large to allow for the manufacture of a single slab compacted to a density close to about 0.8 g/cm^3.

The attenuator will be placed inside the vacuum vessel as seen in Figure 2. Although the exact distances and dimension have to be accurately determined, this option remains the best candidate for the final design solution.

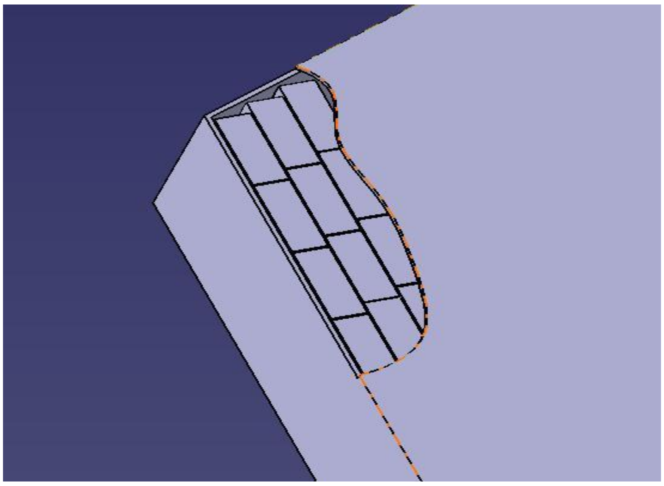

Figure 1. Horizontal Attenuator – LiH bricks can be seen in the attenuator structure

To obtain the required attenuation factor a thickness of the attenuating material (92% ^{6}LiH) of 400mm is to be used. To optimize the attenuator shape the upper and lower edges are parallel to the lines of sight. The thickness of the attenuator will be 100 mm, slightly larger than the collimator diameters. A detailed representation is shown in Figures 3 & 4.

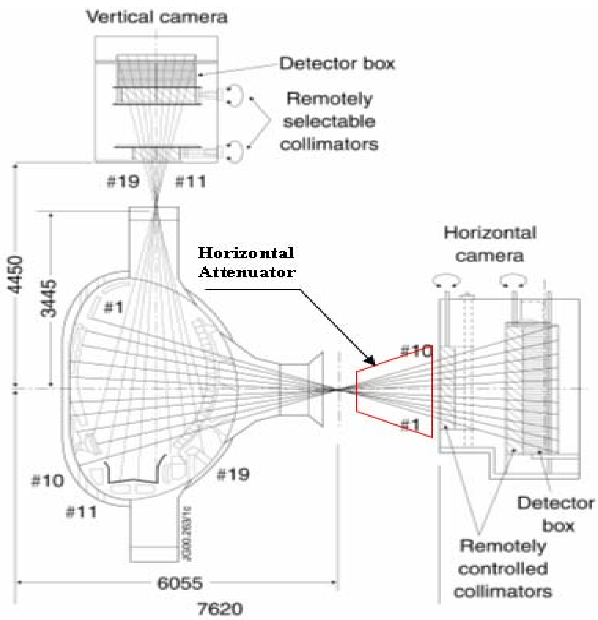

Figure 2. Horizontal Attenuator (marked by red lines) positioned in front of KN3 horizontal camera

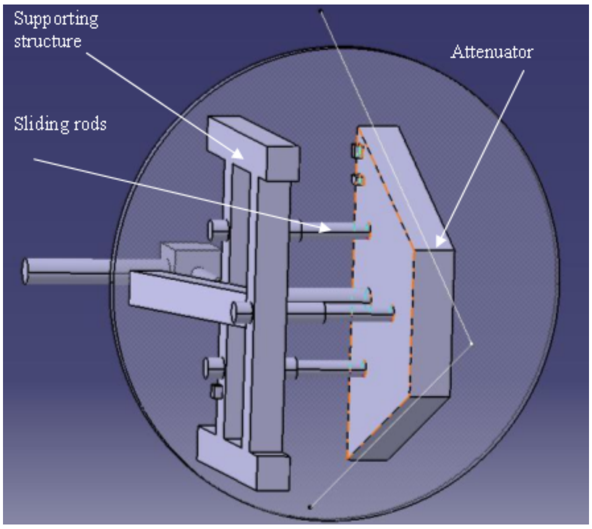

Figure 3. Horizontal Attenuator fixed on the vacuum door – front isometric view

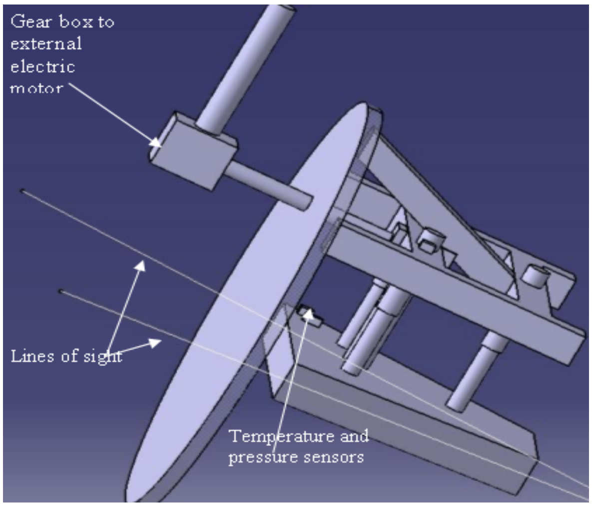

Figure 4. Horizontal Attenuator fixed on the vacuum door – side-on isometric view

On the above structure the following components can be observed: the sliding rods, the supporting structure, the drive and the electric motor. The sliding rods will be connected on the attenuator face determining a virtual equilateral triangle while the driving rod will be placed in the middle of this triangle. The attenuator will be moved a maximum 150 mm in order to take it out from the line of sight. This distance is determined by the available space existent inside the vacuum vessel (as seen later 1100 mm diameter), Figure 5.

For safety reasons the electric motor was taken out of the vacuum chamber; the inside attenuator will be linked to the motor through a UHV rotation feed-through. A system able to handle a possible structure jamming inside vacuum has to be designed bearing in mind the exceptional environment in which the device has to operate: up to 10^{-10} bar vacuum, a constant operating temperature of 220°C and 320°C during the vacuum baking stage. Also the additional energy resulted from the neutron-attenuating material interaction has to be taken into account; the structure is placed in vacuum with no chance of transferring the resulted heat other than the supporting structure. For this reason it was proposed to cool the attenuator with GALDEN, a synthetic fluid already used at JET. This issue further complicates the design by adding compartments for this fluid as well as pipes in a confined space inside the vacuum chamber.

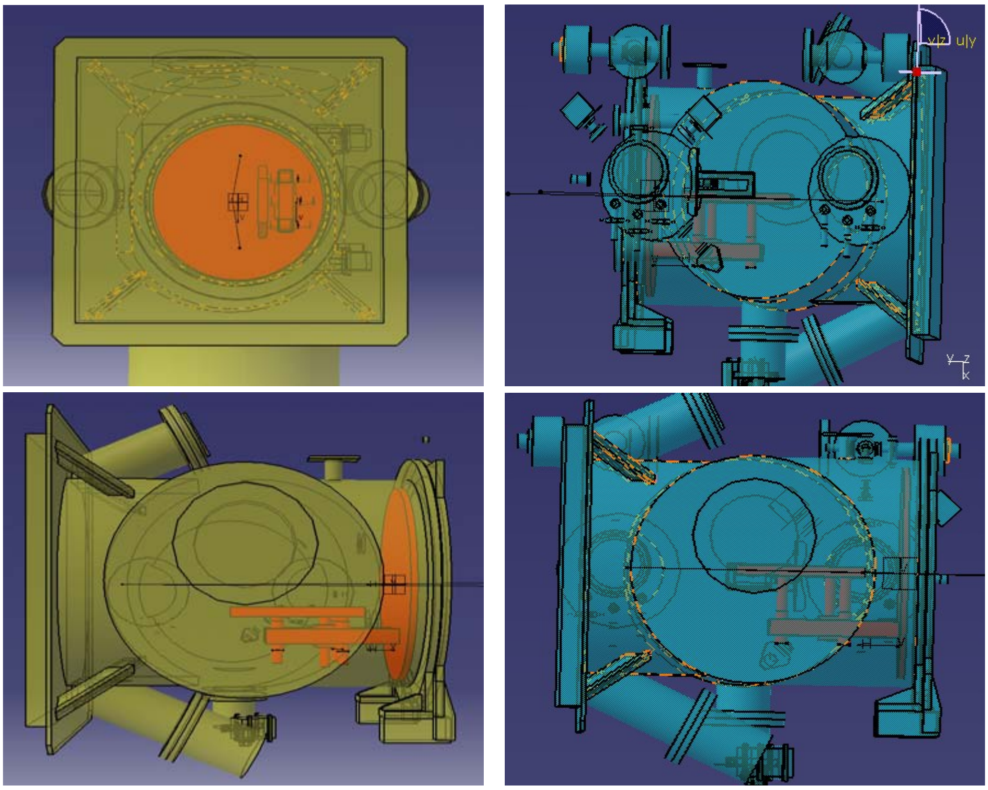

Figure 5. Horizontal Attenuator placed in position: left: out of line of sight; right: in the line of sight (Top: front view; bottom: side view)

A third design solution for the KN3-HC-NA was developed: an Out-of-Vessel liquid attenuator. The main constraint resulting form this design solution (see Figure 6) involves changing the vacuum door and the use of a re-entrant vacuum door.

This solution presents its own set of difficulties such as manufacturing a new vacuum door (very expensive and technically demanding job), reduced thermal insulation in the region of interest, very close to the lines of sight limits.

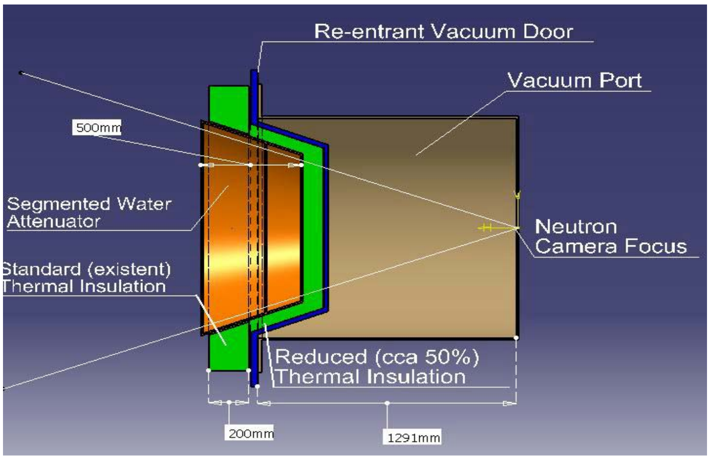

Figure 6. KN3-HC liquid attenuator with re-entrant vacuum door

3. Neutron Attenuator Assembly: KN3-VC-NA

3.1 Background

For the vertical attenuator three solutions have been developed: solid attenuating material (natural LiH and ^{6}Li enriched LiH) and liquid attenuating material (pure water or boronated water). The liquid option was developed preferentially due to a supposed lower price compared to that of the solid version.

The shape of the attenuator will be similar to that of the horizontal one. The only difference is that it will consist of four compartments to allow a variable attenuation factor by filling/draining each compartment independent of each other. The maximum attenuation factor is achieved with a water layer 600 mm thick.

Again the entire attenuator structure has to be movable so that it can be taken out from the line of sight. An electric motor will do this job. The structure will be supported by the adjacent transformer limbs.

3.2 Design of the Vertical Attenuator

Figure 7 shows the environment in which the attenuator will be placed. It is situated above the vacuum flange, close to the focus. The first compartment to be filled is the closest one to the collimator (to minimise the neutron in-scattering). The structure will be placed in an already existent frame that, at the moment, hosts some diagnostics hardware that could be moved.

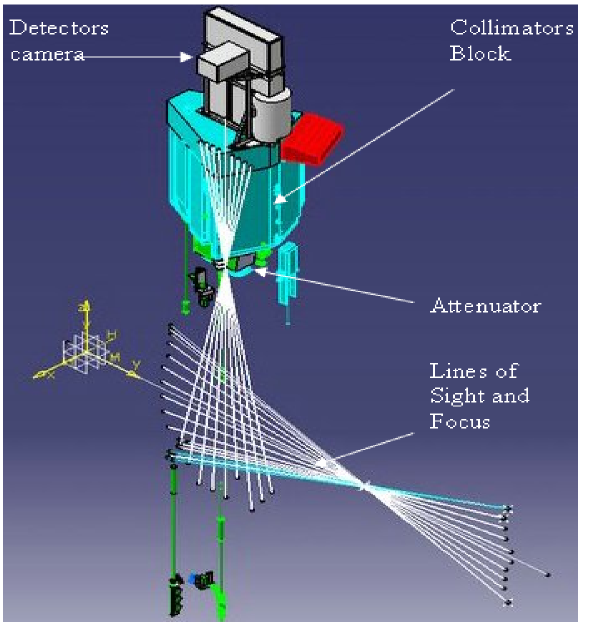

Figure 7. Position of the Vertical Attenuator

In Figures 8 & 9 is shown the attenuator in working position (in the detector line-of-sight). As it can be seen the attenuator tip is close to other components as well as to the focus.

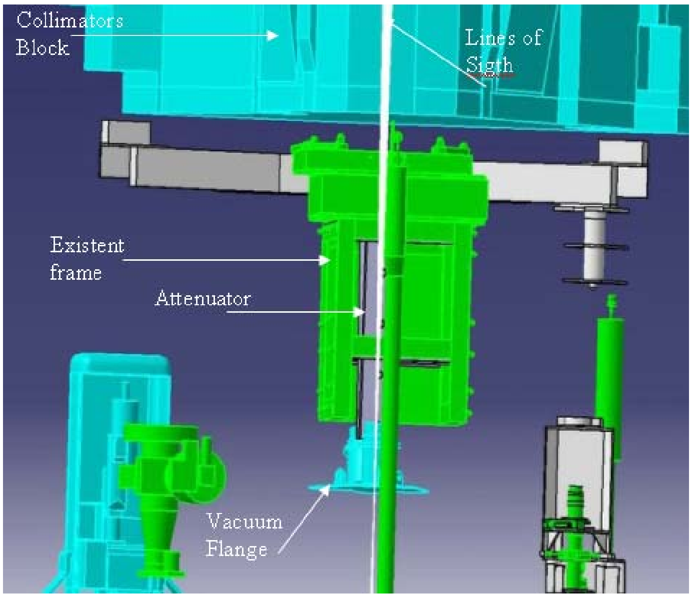

Figure 8. Attenuator in working position – front view

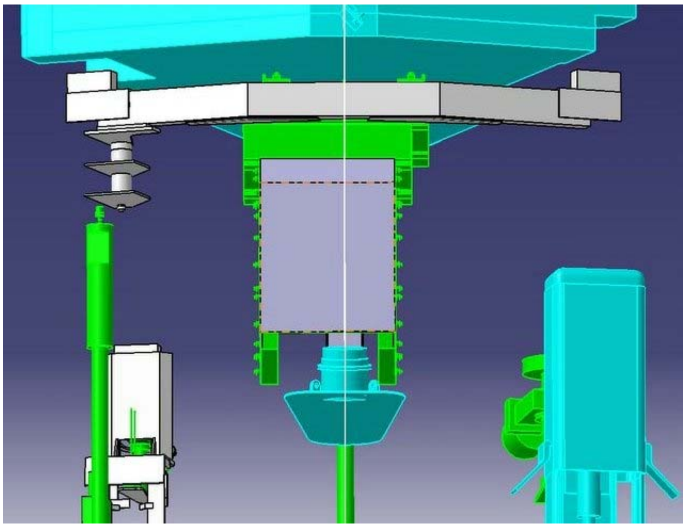

Figure 9. Attenuator in working position – back view

The attenuator will be moved sidewise in the line of sight for gamma measurements and out of line of sight when performing neutron experiments.

Figures 10 & 11 show the existent frame, which was re-designed, the attenuator placed inside and the detector lines-of-sight. Also can be seen the rigid connection to the electric motor. The pipes will be linked with flexible joints (hoses).

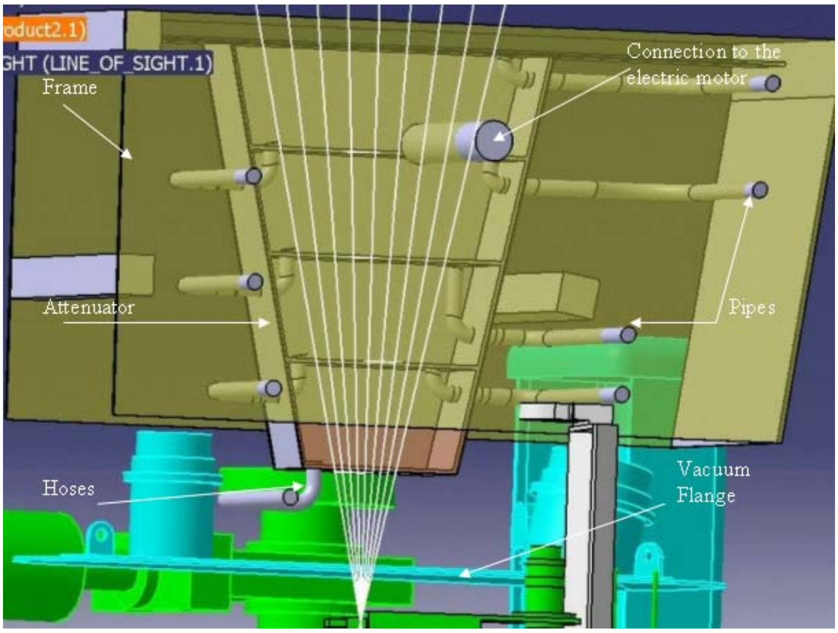

Figure 10. Side view of the attenuator; for clarity the frame ("diagnostics box") is transparent

However, as it can be seen the available space is quite limited and any unforeseen piece of equipment can strongly affect the attenuator design.

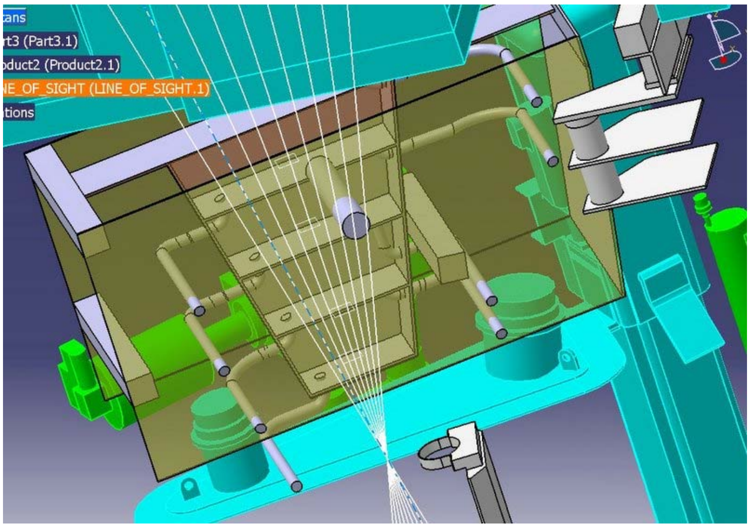

Figure 11. Isometric view of the attenuator; for clarity the frame ("diagnostics box") is transparent

The proposed filling/draining circuit is shown schematically in Figure 12. The liquid circuit is labeled with red color as the air circuit is marked with black color. This scheme consists of the following:

- two pumps – it is required to have an active control rather than passive (draining under gravity effect): one pump for filling, the second one for draining
- twelve valves – six for water circuit, six for air circuit
- two switches – for each pump one switch
- two flow meter – one for each pump; necessary to determine when one or all the compartments are full

- max/min indicator – necessary for the initial filling of the circuit
- reservoir

The water segments will be filled in the following sequence: the closest to the collimator block compartment first, then the second from the collimator block and so on till the last one (situated to the far end of the attenuator).

Each segment can be filled/drained independently according to the following procedure:

- all valves are closed except those corresponding to the segment to be filled (liquid/air) and to the filling pump
- the same method can be applied for each of the compartments until all of them are either full or empty according to the requirements

The reservoir must not be completely filled with liquid in order to allow the air from the circuit to enter the tank.

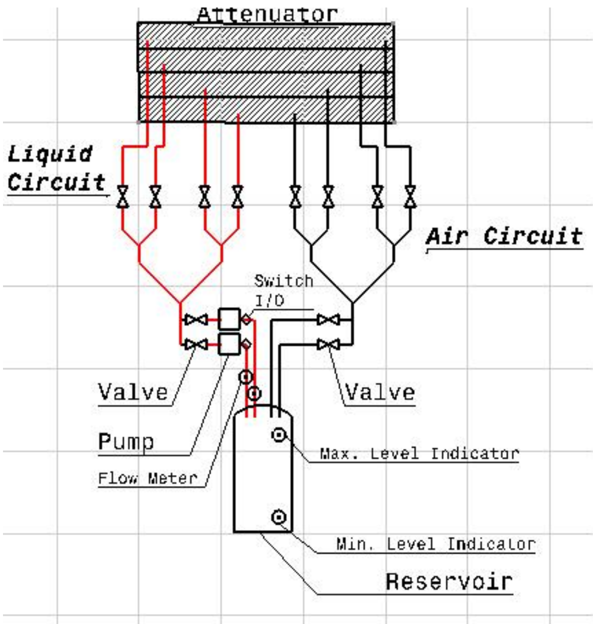

Figure 12. The filling/draining circuit

4. Neutron Attenuator Assembly: KX1-TS-NA

4.1 Background

Schematically, the tangential neutron attenuator will be placed within the KX1 X-ray spectrometer bunker, between the X-ray crystal chamber and the gamma-ray spectrometer diagnostic assembly (Figure 13). The KX1 bunker is linked with pipes to the tokamak machine vacuum chamber (by the pink pipe), gamma-ray diagnostics (by the yellow pipe) and to the X-ray detector (by the red pipe). The approximate dimensions of the bunker are 2 m (L) X 1.5 m (W) X 1.5 m (H); the wall thickness is reduced for clarity.

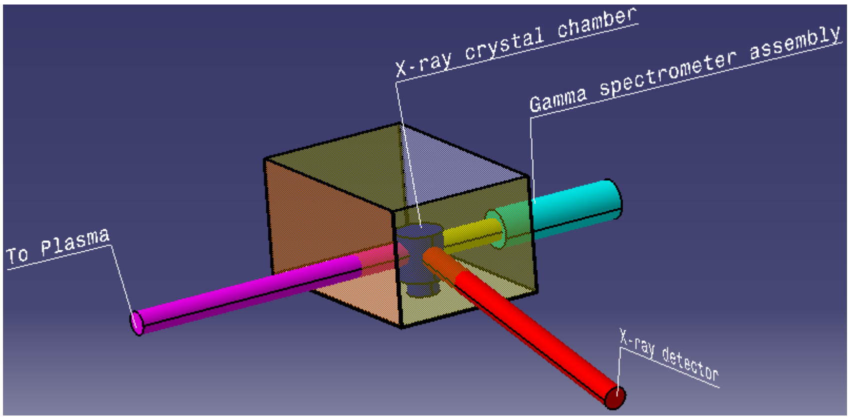

Figure 13. KX1 bunker with connections and the X-ray crystal spectrometer

The actual bunker wall is a thickness 2650.5 mm, Figure 14; in that wall are placed, from inside to outside, the following parts: the first polyethylene attenuator, gamma-ray spectrometer diagnostics, the second polyethylene attenuator, and a steel plug. Outside the bunker is placed a boronated concrete plug. The wall is made also of boronated bricks (brickwork no mortar joints except external faces). All of these components mentioned previously were installed from outside (right hand side) removing the concrete plug; they are placed in a steel tube and surrounded by silica grout.

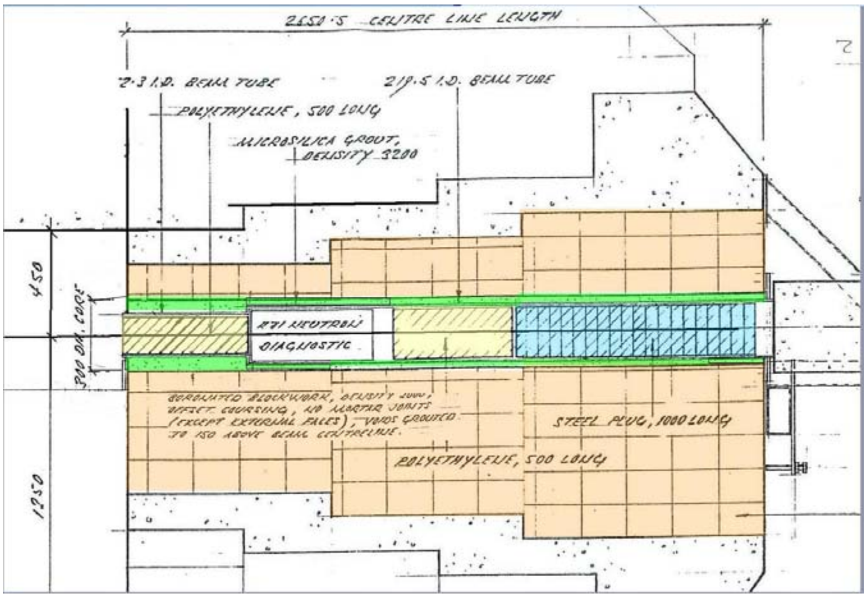

Figure 14. Drawing of the bunker wall and neutron attenuators, gamma-ray ("neutron") diagnostics (X-section)

Within the GRC project diagnostics upgrade, the first polyethylene neutron attenuator only will be replaced. Depending on the available space in the bunker (determined after inspection), the installation of the new attenuator is intended to be done from the inside bunker provided there is enough space between the X-ray crystal chamber and the bunker wall. Alternatively, the installation of the KX1-TS neutron attenuator could be done during an envisaged upgrade of the KX1 X-ray spectrometer.

4.2 Design of the attenuator assembly

One of the reasons of replacing the existent attenuator is the neutron streaming along the steel tube. Another reason is the removal of the organic-based material (polyethylene) from line of sight and replacing it with pure water. The geometry of the attenuator has to be changed (a stepped geometry) in order to provide a better protection as seen in Figure 15. According to experiment requirements, the neutron attenuator has to provide a variable attenuation factor; this can be achieved by several attenuator material layers, four in this case.

The proposed attenuator consists of four cylindrical containers filled with water, independent of each other, so that one or more of them can be used simultaneously. On the below drawing (Figure 15), the structure (yellow) is divided into four discs with different diameters, the last two (the smaller ones) being fitted into another structure (the blue one). The attenuator parts will be put in place and removed at shutdowns (or even during week-ends) using suction cups as handling tools.

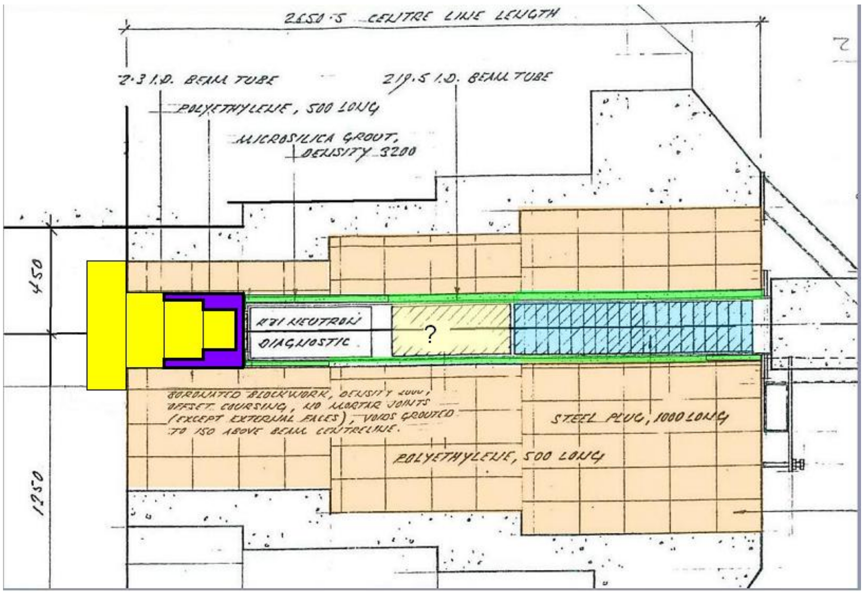

Figure 15. Drawing of the proposed neutron attenuator and its environment – section

The material used for manufacturing the attenuator is stainless steel 304, formed in 2 mm thick sheets. A more detailed drawing is presented in the following figures, 16, 17, 18 and 19.

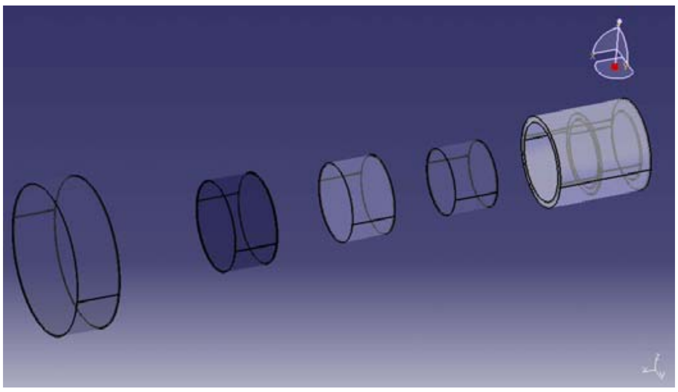

Figure 16. All parts of the neutron attenuators before assembly

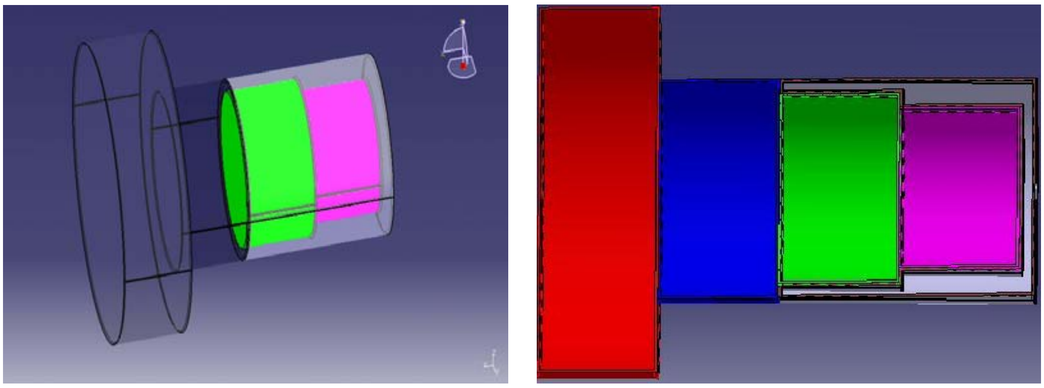

Figure 17. Assembled neutron attenuator

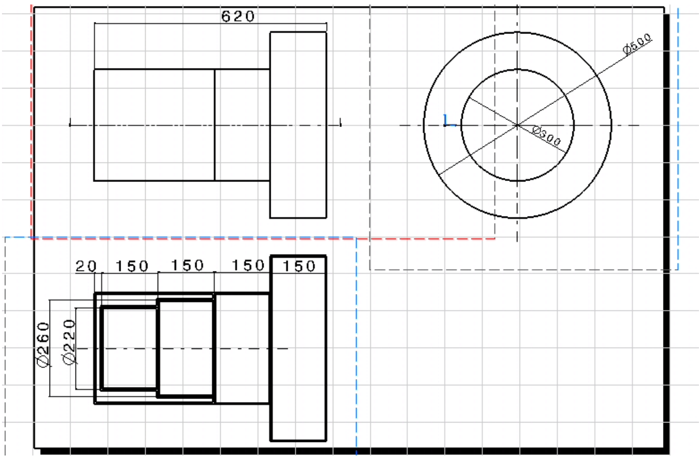

Figure 18. Overall dimensions of the assembled attenuator, front and left view above; Cross – section along the central axis below

As mentioned before, the last two sections will be fitted into a structure as shown in Figure 19. The point of placing this structure is to have a protective layer of water, 300 mm diameter and independent of the diameter discs, preventing neutron leakage and thus protecting the detectors. This structure has a role in supporting those two smaller discs when placed in the neutron beam.

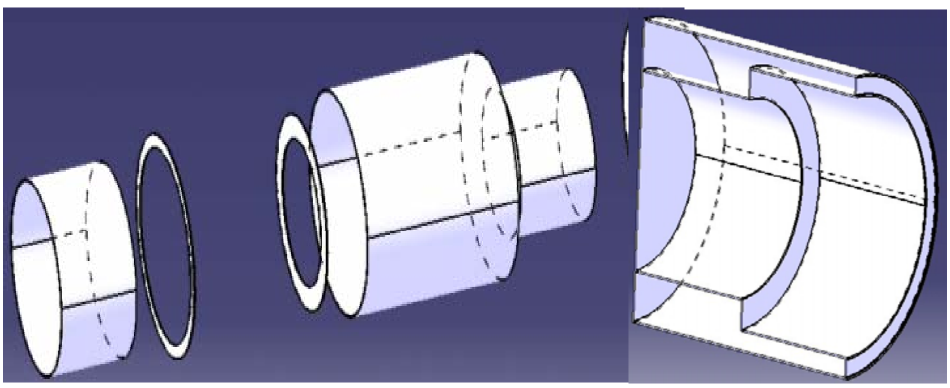

Figure 19. The "supporting structure" shown as components & cross-section

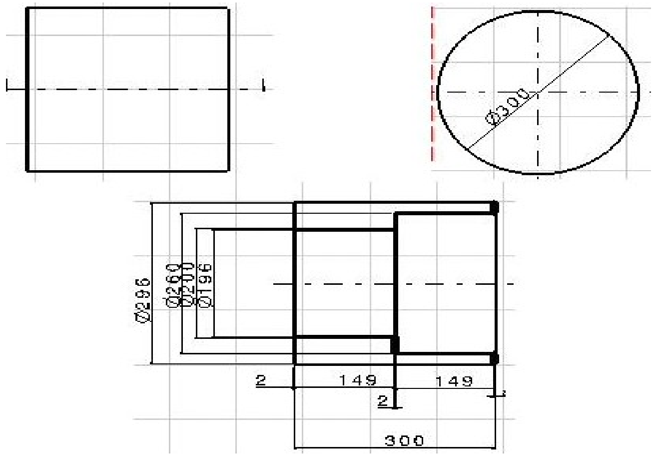

Figure 20. Cross-section and drawing (with dimensions)

The whole tangential neutron attenuator will be manufactured from stainless steel 304L 2 mm thick. All the segments are fitted with special openings for filling/draining of liquid as well as for taking samples for chemical analyses.

5. Conclusions

A range of design solutions for the neutron attenuators have been developed and a number of attenuating materials have been evaluated.

The evaluated attenuating materials were:

-lithium hydride (LiH) in the following forms: 92% ^{6}Li enriched LiH, 60% ^{6}Li enriched LiH, or natural isotopic composition LiH (natural LiH).

-water (both pure water and water with additional elements – boron and lead)

The design solutions (especially the attenuator configurations) have to be optimised with respect to the available space and attainable neutron attenuation factors.

The impacts on the interfaces have to be addressed also (albeit at a very preliminary level, due to the complexity of the problem).

Further work should lead to decisions between the following attenuator options:

- KN3, vertical camera:

- natural LiH, in-vessel components

- out-of-vessel liquid attenuator

- KN3, vertical camera

- H_2O segmented container, remote filling/draining

- Natural LiH: minimisation of attenuating material

- KX1 tangential gamma spectrometer

- H_2O, sealed containers installed/removed at shutdowns

- H_2O, segmented container with remote filling/draining

The main objectives for year 2006 are:

-Finalise the Conceptual Design

-Develop the Scheme Design

-Develop the Detailed (Engineering) Design

Acknowledgements

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