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Upgrade of the tangential gamma-ray spectrometer beam-line for JET DT experiments

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The JET tangential gamma-ray spectrometer (KM6T) is undergoing an extensive upgrade in order to make it compatible with the forthcoming deuterium-tritium (DT) experiments. The paper presents the design of the main components for the upgrade of the spectrometer beam-line: tandem collimators, gamma-ray shields, and neutron attenuators. All these form the Radiation Field Components Assembly (RFCA). The existing KM6T tandem collimators will be upgraded by installing two additional collimator modules. Two gamma-ray shields will define the gamma-ray Field-of-View at the detector end of the spectrometer Line-of-Sight. A set of three lithium hydride neutron attenuators will be used to control the level of the fast neutron flux on the gamma-ray detectors. The design of a combined movable gamma-ray shield and neutron attenuator will provide a choice of three operational conditions for deuterium and DT experiments, including that of a gamma-ray shutter. The design of the upgraded spectrometer beam-line has been supported by extensive radiation (neutron and photon) transport calculations using both large volume and point radiation sources.

Keywords: tokamak, diagnostics, neutron attenuators, gamma-rays, gamma-ray spectrometer.

1. Introduction

The upgrade of the tangential gamma–ray spectrometer beam–line consists of the design, manufacturing and installation of a complex system of shields and attenuators for both neutron and gamma radiations in order to maximize the signal-to-background ratio at the spectrometer detector (this ratio is defined in terms of the plasma-emitted gamma radiation and the gamma-ray background). The resulting RFCA, will contribute also to the improvement of the definition of the spectrometer Field-of-View [1]. This major KM6T upgrade will comprise the following activities:

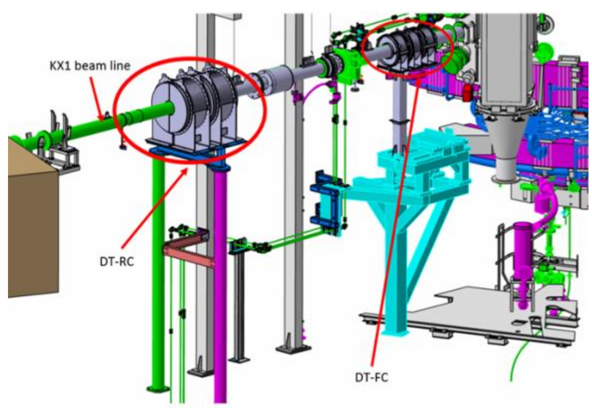

Fig. 1. Upgraded KM6T tandem collimators
DT-FC: Front Collimator for DT pulses.
DT-RC: Rear Collimator for DT pulses.

- Manufacture and installation of additional modules for KM6T Tandem Collimators [2] in order to fulfill the requirements for DT operation, Fig. 1;

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- Design, manufacture and installation of gamma-ray shields for minimizing the flux of parasitic gamma radiation reaching the detector (produced by the interaction of the fast neutron flux with components inside the KX1 bunker);

- Design, manufacture and installation of a set of LiH neutron attenuators (NA) with the aim of reducing the fast neutron flux at the gamma-ray detector position

2. Design of the gamma-ray shields

The gamma-ray shields are positioned inside KX1 X-ray crystal spectrometer bunker, behind the KX1 spectrometer chamber, with the axis coincident with the KX1 beam-line axis. The RFCA has two gamma-ray shields: one is vertically movable (Movable Gamma-Ray Shield, MGRS) with three working positions (top, middle, and bottom) and the other one is bolted onto the metal sheet placed on the vertical wall (Fixed Gamma-Ray Shield, FGRS). For MGRS the materials of choice were SS metal sheet (5mm thick) for the casings and slabs of Pb nuclear grade for the shielding material (11 plates with outer diameter of 348 mm, inner diameter 103 mm and thickness of 25 mm). The two lids which close the assembly are made of SS metal sheet 5 mm thick with the outer diameter of 410 mm and inner diameters of 101.6 mm and 90 mm respectively. The casing structure is reinforced by two rings welded to it towards both ends and are made of SS sheet 10mm thick. The casing elements are bolted with either M5 or M8 bolts. The collimator is securely fixed to its cradle which is bolted to a U-channel that transfers the load to the jack system. The vertical movement is done by a jack system powered by an electric motor, Fig. 2.

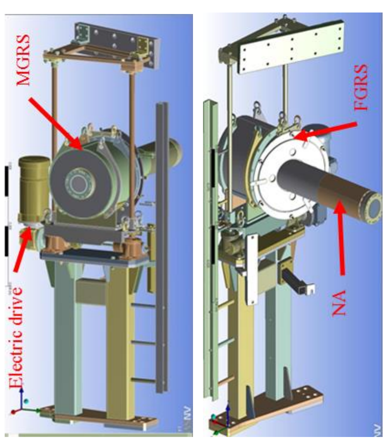

Fig. 2 RFCA components inside the KX1 bunker

The electrical motor and movable shield assembly is supported by a frame fixed onto the bunker wall and floor. MGRS has the following functions and corresponding working positions:

-DT discharges, maximum neutron attenuation thickness, bottom working position, Fig. 3;

-Gamma-ray shutter, middle working position;

-DD discharges, minimum attenuation thickness, top working position.

MGRS has to be moved to the top or to the bottom positions as required by experiments. MGRS in its middle position is to be used as a gamma-ray shutter (replacing the existing gamma-ray shutter).

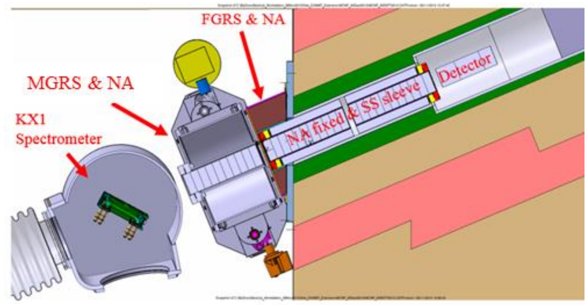

Fig. 3 RFCA inside the KX1 bunker for DT discharges

2.1 Movable Gamma Ray Shield (MGRS) assembly

The MGRS assembly is an all-welded casing the only detachable part being the lid which is bolted (eight M8 bolts equally spaced). The casing is made of SS304 stainless steel while the active materials are discs of nuclear grade lead, Fig. 4.

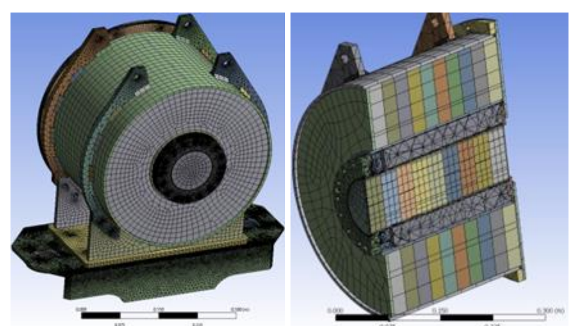

Fig. 4 Complete assembly (for installation);
Section of operating assembly (MGRS, sleeve and NA)

This CAD model (CATIA) was transferred into a commercially available finite element analysis software (ANSYS) to evaluate the behavior during installation procedure and long-time operation. This model includes to supporting structures such as cradle and U-channel connecting to the jacks system, left, and just the casing, right.

In terms of FEA the boundary conditions change from the installation (when the assembly is hoisted;

four points) to operation (supports at the ends of the U-channel). Further details are given in the operation situation analysis.

During operation the assembly shows no signs of excessive deformation nor did it experience high levels of stress (distributed or concentrated) compared to the tensile yield of SS304, Fig. 5.

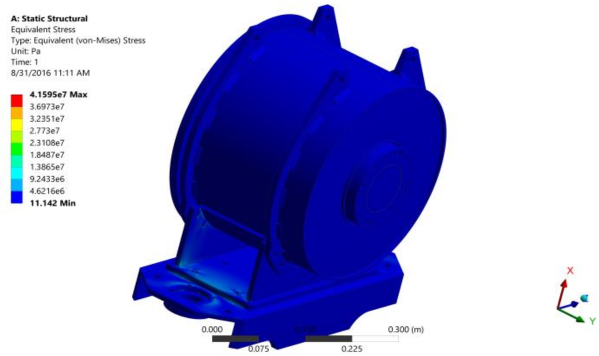

Fig. 5 Stress levels for 42 MPa operation

2.2 Control of the MGRS

The MGRS can be locally controlled and monitored by CODAS through the dedicated PLC, Fig. 6.

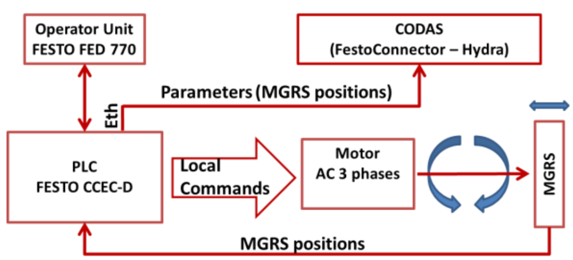

Fig. 6 MGRS command and control

This is to be done in accordance with requirements of the JET KM6T diagnostics Responsible Officer. Moreover, in order to avoid unauthorized commands, the PLC chassis is fitted with a lockable switch disconnector. An operator unit interface connected to PLC provides an easy way to initiate the movements. The MGRS movements are initiated by using this operator unit interface, the position of the shield is being monitored by CODAS. Nevertheless the PLC can be controlled remotely by means of the Ethernet connection, and this feature was tested also. The position of the MGRS is detected with three photoelectric sensors. Based on the signal provided by these sensors the PLC commands the electric motor that drives the jacks system. The electric motor is equipped with a brake that is activated when the motor is not energized and thus keep the shield in position.

2.3 Fixed Gamma-Ray Shield

The fixed shield is bolted onto a steel sheet (10mm thick) by six M10 bolts equally spaced; the steel plate is attached to the KX1 bunker wall by eight studs. The fixed shield is an all welded structure made of SS304 5mm thick sheet housing a nuclear grade lead slab cut at an angle of 22.5deg to match the local configuration. The central bore is designed to accommodate the protruding end of the neutron attenuator (flange side) and its sleeve.
A similar finite element analysis was also done for FGRS. The FEA model shows neither excessive deformation nor high levels of equivalent stress compared with the tensile yield of SS304. The stress map shows obviously a concentration on the thicker lead slab side due to the asymmetry of the model, Fig. 7.

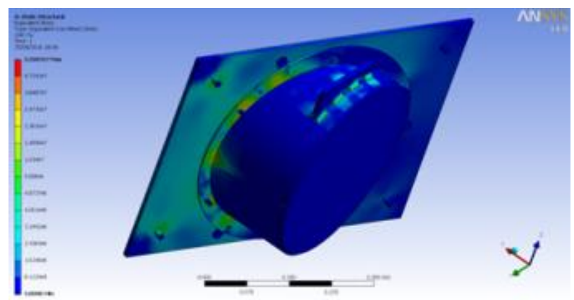

Fig. 7 Equivalent stress, 5,6e7Pa

3. Design of neutron attenuators

The 14 MeV neutron flux at the KM6T detector location should be significantly reduced in order to perform proper gamma-ray measurements. Within the GSU project this will be achieved by the manufacturing and installation of a set of lithium hydride (LiH) neutron attenuators. The choice of LiH material has the advantage of avoiding carbon-containing materials which lead to the production of inelastic scattering neutrons with energies E>5 MeV from 12C (n,n'γ)12C reactions and, consequently, to a high background of 4.44 MeV gamma-rays. LiH with a natural Li composition is compact, effective and well transparent to MeV gamma-rays. It does not produce interfering gamma-rays in the high-energy range.
The KM6T LiH attenuators, Fig. 8, are made of a stack of LiH discs placed inside a ultra-high vacuum stainless-steel enclosure. These attenuators were designed to provide in their full length configuration a reduction of the neutron flux at the KM6T detector by a factor of 10^4 for 2.45 MeV neutrons and by a factor of 10^2 for 14.1 MeV neutrons, respectively.

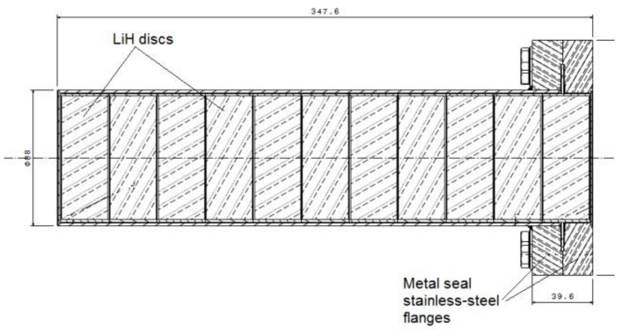

Fig.8 Cross-section showing the structure of a neutron attenuator

4. Monte Carlo calculations for the RFCA design

The performance of the upgraded KM6T beam-line has been evaluated by radiation transport calculations using the MCNP numerical code. The full structure of the RFCA from the plasma end of the beam-line to the detector and beyond have been taken into account. These calculations cannot be performed in a straightforward manner due to the extreme degradation of the flux from the plasma to the KM6T detector position (the degradation amounts to several orders of magnitude). Therefore the problem has been split in two parts. First, the neutron field throughout the KM6T beam-line and on a circular surface located at the entrance into the JET Torus Hall south wall penetration was estimated.

This estimation based on a large volume radiation source (part of a JET DT plasma) is used afterwards in a second stage of transport calculations to construct circular planar neutron and gamma-ray sources, emitting particles perpendicular to the south wall penetration, in a cone characterized by an angle of 10^{o}. These point sources have been used to restart the MCNP simulation and to evaluate the radiation field at the detector position. Several variance reduction techniques were used in order to obtain satisfactory results.

One of the results of the first stage of computation was a clear illustration of the radiation emitting regions defined by the upgraded KM6T beam-line inside a DT JET plasma, Fig. 9. This confirms previous estimations [1] for the KM6T field-of-view inside the JET plasma. Eventually the MCNP calculations provided an estimation for the neutron attenuation factor for the LiH attenuators: ~125 for the whole energetic range, and ~275 for the energetic region [13.9 – 15] MeV.

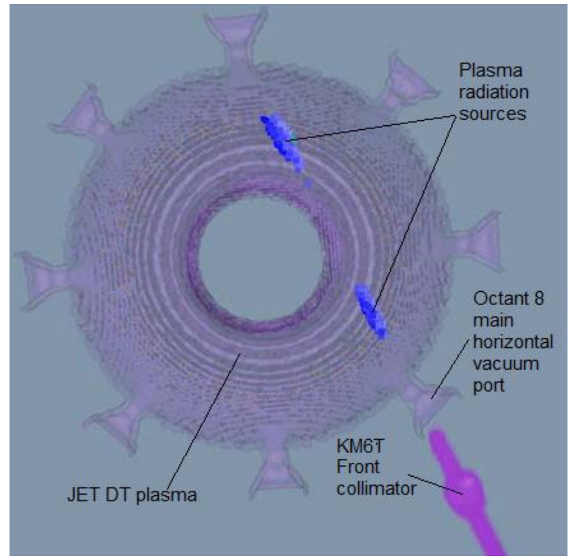

Fig. 9 JET plasma radiation sources for the KM6T tangential gamma-ray spectrometer

5. Conclusions

The upgraded beam-line for the JET tangential gamma-ray spectrometer (KM6T) will provide a clear definition of the spectrometer field-of-view inside a DT plasma. The components of the RFCA will also define and control the neutron and gamma-ray fields at the KM6T detector. The fast neutron flux at the detector location can be attenuated by a factor of more than 102 for high power DT pulses. Lower attenuation factors can be set for deuterium pulses and low power DT ones. This is made possible by a set of three LiH neutron attenuators and a remotely controlled movable gamma-ray shield comprising one of the three attenuators. The same movable gamma-ray shield can be used as a gamma-ray shutter in front of the KM6T detector.

Acknowledgments

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