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Advances in neutronics and radiological protection of HiPER 4a

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ABSTRACT

The HiPER project, phase 4a, is evolving. In this study we present the progress made in the field of neutronics and radiological protection for an integrated design of the facility. In the current model, we take into account the optical systems inside the target bay, as well as the remote handling requirements and related infrastructure, together with different shields. The last reference irradiation scenario, consisting of 20 MJ of neutron yields, 5 yields per burst, one burst every week and 30 years of expected lifetime is considered for this study. We have performed a characterization of the dose rates behavior in the facility, both during operation and between bursts. The dose rates are computed for workers, regarding to maintenance and handling, and also for optical systems, regarding to damage. Furthermore, we have performed a waste management assessment of all the components inside the target bay. Results indicate that remote maintenance is mandatory in some areas. The small beam penetrations in the shields are responsible for some high doses in some specific locations. With regards to optics, the residual doses are as high as prompt doses. It is found that the whole target bay may be fully managed as a waste in 30 years by recycling and/or clearance, with no need for burial.

1. Introduction

It is foreseen that High Power laser Energy Research (HiPER) phase 4a will be an experimental facility for testing the integration of high repetition rate technologies related to Inertial Fusion Energy (IFE). During the last several years, the different groups inside the HiPER project have proposed alternative solutions for the systems they are in charge of (optical assembly, lasers, target injection. . .). A preliminary integrated design, coupling optical systems together with shields against neutrons and gammas, was evaluated from the standpoint of radiological assessment [1]. A deep study was also accomplished on the materials selection for the reaction chamber [2]. Linking the conclusions of those studies [1,2] to some changes in the baseline design, a new and advanced design of HiPER 4a target bay is ready. In this advanced design three systems are integrated: optical systems, remote maintenance systems and shielding requirements. The arrangement of the systems is described in the subsection 1.1. It has been decided to set the reference irradiation scenario of HiPER 4a as follows: It will operate in 100 shots bursts. In every burst there will be only 5 ignitions, with 20 MJ neutron yields each one. The other 95 shots, non-yield shots, will not ignite, but they will be oriented to other aspects of illumination. However, aspects such as debris or shrapnel are not addressed in this study. One burst will take place every week, what represents 5200 MJ/year of neutron yield. It is assumed a 30 years lifetime for the facility.

We present a dose rates and waste management assessment for the advanced design of HiPER 4a target bay, considering the new reference irradiation scenario. Taking into account the obtained results, we offer an evaluation of the shielding proposal regarding to protection to workers and to optical systems during the operation of the facility. In the time between bursts, we characterize the different areas from the standpoint of residual dose rates for workers. We offer a waste management assessment of all the components inside the target bay.

1.1. Baseline design

The advanced design of HiPER 4a, integrates the main systems of the target bay: optical systems, remote handling infrastructure, and shielding requirements. The different systems and their configuration are briefly explained in this section. Figs. 1 and 2 are devoted to explain this design.

Centered in the origin, there is the reaction chamber. It has an inner radius of 5 m, and 10 cm of thickness. It is built of T91 commercial steel [3]. The chamber presents 48 penetrations for the laser beams. The beams are brought to the chamber through 48 beam tubes which keep the vacuum inside. These tubes are also made of T91 steel. They have a squared section of 1 m per 1 m. The wall thickness of the beam tubes is 1 cm. At 8 m from the origin and

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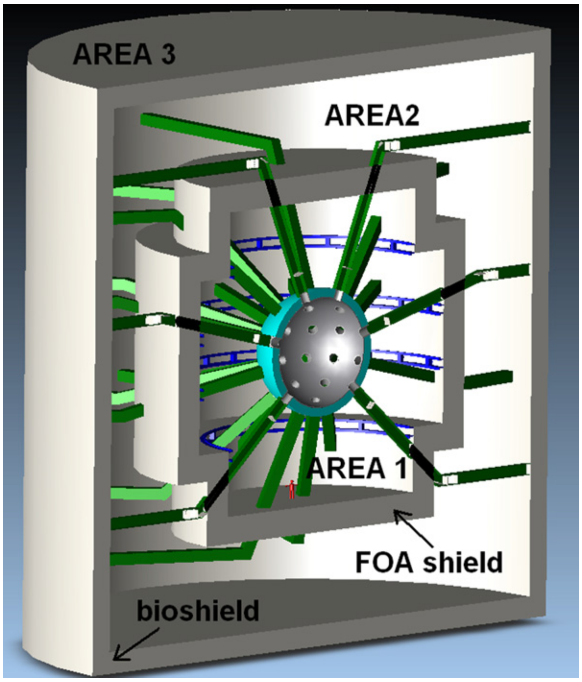

Fig. 1. General view of the advanced design of HiPER 4a.

inside the beam tubes, there are 48 focusing lenses. They are called the “renewable optics”, and they are placed in front of the explosions with no shield to protect them against the resulting radiation. The renewable optics are squared lenses of 75 cm side and 5 cm of thickness. At 19 m from the origin, also inside beam tubes, there are 48 groups of optical elements, named the Final Optics Assembly (FOA). These groups consist of 6 optical elements with different functions (mirrors, focusing lenses and frequency converters). All the elements are squares of 75 cm side, with thicknesses varying from 1 to 5 cm. They are also made of pure silica.

We have proposed four shields in the target bay to protect both the workers and the optics. The first one is placed against the reaction chamber and it is called the chamber shield. It consists of a spherical shell of 80 cm of thickness, made of borated concrete. This material choice is motivated by NIF [4] choice of chamber shield. Given the efficiency of shielding close to the source, its thickness has doubled from the previous design. We pursue a general reduction of neutron spreading with this decision. At 16 m from the origin, and outside the beam tubes, there is the FOA shield. It is a 2.5 m thick shield made of standard concrete. To improve the previous situation between bursts in some areas regarding waiting time for workers entrance, its size has increased from 2 to 2.5 m from the previous design, and its shape has changed from spherical to a double cylinder, because of remote handling systems requirements. At the same position, but inside the beam tubes, there are the pinhole shields. They are 48 concrete cylinders, with 50 cm of radius and 2.5 m long, placed inside the beam tubes, presenting a conical perforation to allow the beam go through. Finally, there is a cylindrical shell shape bioshield of 25 m of inner radius and 2 m of thickness. This shield has not been optimized, as beam penetrations sizes have not been defined and a lot of machinery has still to be defined. However, it is expected that this bioshield will be the final barrier against radiation during the operation of the facility. This distribution of shields defines 4 areas which need a radiological classification with regards to workers access both during operation and during the maintenance. The interior of the chamber is well defined, and requires no special name. The space between the chamber shield and the FOA shield is called area 1. The space between the FOA shield and the bioshield is called the area 2; the space outside the bioshield is called area 3. We assume only workers in the facility, thus no reference is made to public.

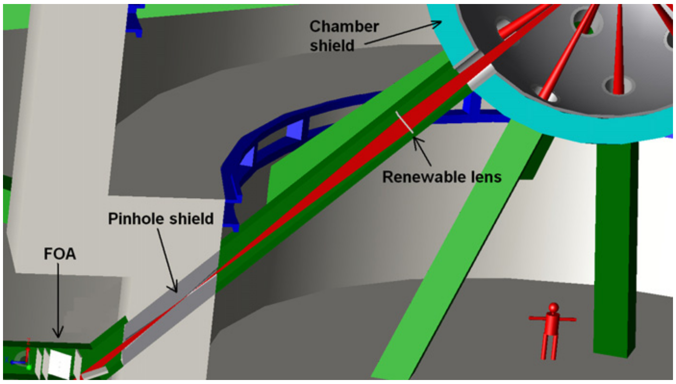

Fig. 2. Detailed view of the main optical systems: renewable lenses, final optics assembly, pinhole shield and beam tubes.

The remote handling systems requirements have forced the FOA shield to change its shape from spherical to double cylinder. Attached to this shield, there are four rails, from which the robots will access to the beam tubes, renewable optics and to outer part of the reaction chamber. The rails are made of steel alloy BS970-817M40 [5]. The remote maintenance in the interior of the reaction chamber does not impose restrictions on the shields, but on the chamber material. As it will be necessary for the chamber to exert some structural functions, aluminum alloys are definitively abandoned as candidate materials for the reaction chamber in benefit of steel alloys. Commercial T91 steel has been selected from a previous study [2] for waste management considerations.

1.2. Objectives

We present a dose rate and waste management assessment of the advanced design of HiPER 4a target bay, integrating optical systems, remote handling infrastructure and shielding requirements. We pursue to characterize the radiological performance and justify the materials choice for this design. We divide the study in three stages of the lifetime of the facility: burst operation, period between bursts, and decommissioning. This study is interesting to make decisions on many aspects, such as materials choice, placement of equipments, systems configurations or remote maintenance design.

2. Study scope

The radiation presence offers a natural division in three stages in the time of interest for this study: the burst operation of the facility, where important neutron and gamma dose rates levels are reached during short periods of time; the time between bursts, where gamma dose rates resulting from the activation of the facility can be high enough to preclude the access of worker to certain areas; and the decommissioning, the period after the definitive shutdown of the facility when cooling times are spent for different waste management strategies for the activated components. All the materials have been studied considering a real or reasonable impurities concentrations, and their effect on the activation behavior has been taken into account.

2.1. Burst operation

While explosions happen, there is a neutron spreading. A lot of these neutrons interact and generates gamma rays, which also spread through the target bay. The combination of neutron and