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ADS LBE Spallation Target Design: A Review on Geometrical Influences on Neutronic and Thermal Behavior

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1. Introduction

Accelerator Driven System (ADS) are reactors that combine a sub-critical core with a spallation-induced neutron source. In most ADS projects, a linear particle accelerator produces high energy proton beams (>100 MeV per nucleon, [1]) that collide in a heavy nuclei target, usually Tungsten, Lead and Lead-Bismuth Eutectic (LBE). As a result of the spallation reaction, an average of 30 neutrons are released per incident proton [2].
In the recent context of searching for viable spent fuel handling and storage solutions, ADS projects are emerging as one of the most promising technologies for transmuting long-lived minor actinides (MA) from spent fuel (SF), decreasing considerably their radioactivity and environmental long-term impacts.
One of the most important design parameters within an ADS is its spallation target, as it constitutes the interface between the particle accelerator and the reactor core. In the design process for an ADS spallation target, neutron production and leakage (from the target region) per proton should be maximized [1], in order to optimize the energy efficiency, as a significant part of the energy generated by the reactor core is consumed by the proton accelerator. As for thermal aspects, the target should be subject to temperatures physically endurable by available engineering materials, as well as allow for an efficient heat transfer to the coolant. These, among many other reasons, are strong justifications for why an ADS' spallation target should be carefully designed and optimized.
The Nuclear Engineering Department (DEN) of the Universidade Federal de Minas Gerais has recently resumed its LBE-cooled, sub-critical ADS design [3], with the initial purposes of electricity generation and SF transmutation research. Thus, this work's main goal is to present recent studies on window spallation targets, with a focus on developing a design methodology that considers geometry and its influences on neutronic and thermal behaviors. With this study ensemble, it is expected to achieve an optimized spallation target design, according to the specific needs of DEN's ADS project.

2. Methodology

Following the latest design updates from MYRRHA (Multipurpose Hybrid Research Reactor for High-Tech Applications) [5], a window spallation target will be initially chosen instead of a windowless design, given the already-faced technical issues with mechanical assembly, core space utilization, material heat resistance and an undesirable additional coolant loop, presented by [4], in which the transition from windowless to a window spallation target (Figure 1) in the

MYRRHA project is explained. With the defined type of spallation target, the methods for evaluating its thermal and neutronic performance are to be presented.

For the sake of first evaluation simplicity, the spallation material of choice will be the coolant itself, liquid LBE. Thanks to MEGAPIE (Megawatt Pilot Target Experiment) project achievements on successfully sustaining spallation reactions on heavy liquid metal target [6], confidence can be gained regarding this design choice.

The proton beam definition (current [mA] and energy per nucleon [MeV]) and the target dimensions are the next step in the design process. It must be noted that the priority lies in optimizing the production of high energy neutrons per proton (n/p). Considering DEN's ADS neutronic needs for SF transmutation and fission sustaining, and also core space limitations, this design step will follow the methodology presented in the work of [8], that correlates proton beam intensities with LBE targets different geometries using Monte Carlo simulations.

As presented in the work of [7], in the beam window (BW) target design, several engineering issues should be taken into account, including: Thermal stresses; irradiation damage; erosion/corrosion damage and fatigue damage. Aside from physical damage issues, [7] also raises the question on coolant flow stagnation on the BW's tip, which worsens heat concentration. To avoid aggravating these issues when the proton beam hits the BW in a single central spot, a beam profile shaping optimization will be employed, as presented by [4], in which the beam is swept along the target's axis, forming an annular incident region, as shown in Figure 2.

Following the definition of the beam profile, it is possible to obtain the power distribution and the neutron source linear density, as in Figure 3. After defining the neutron linear density distribution, the target's BW axial position can be accurately defined, according to the core's neutronic needs. This stage is important as it serves as main input for the following thermal analyses for cooling capacity and material stress. These thermal evaluations can be performed using general-purpose CFD codes, as per [4] and [7]. Lastly, the materials employed in the target design will be evaluated regarding their maximum temperature, in order to verify if they applicability and the possible need for substitution.

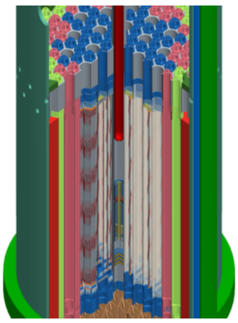

Figure 1: MYRRHA window target, red tube in central assembly. Adapted from [4].

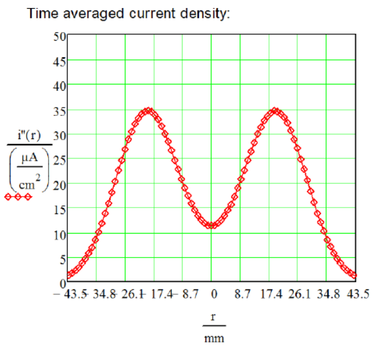

Figure 2: Time-averaged current density of a sweeping beam, [4].

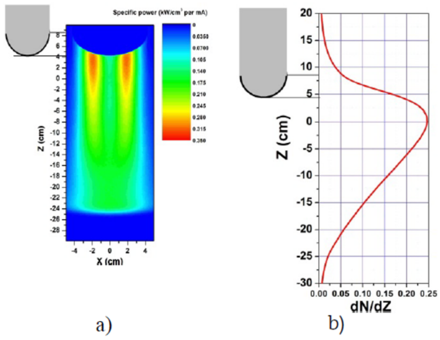

Figure 3: a) Power density distribution, b) Neutron source linear density, [4].

3. Expected Results

Upon the presented methodology for designing a spallation target and beam window, DEN's ADS project is expected to reach a considerable level of technical description of its own spallation target. Parameters such as detailed geometrical dimensions, neutron production and distribution and local thermal characteristics are among the expected results for this study.

4. Conclusions

As the spallation target consists of one most crucial parts of an ADS core, much attention should be directed its design. Although the development of DEN's ADS project is still rather incipient, this study is expected to provide a solid basis for its technical maturing.

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