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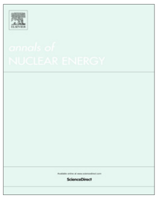

Tungsten Carbide compact primary shielding for Small Medium Reactor

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ABSTRACT

In order to improve the Small Medium Reactor's radiation protection system, a new design for primary radiation shielding based on Tungsten Carbide and Lead is presented. The application of Tungsten Carbide is considered, so that a compromise between low weight and high absorption is found, to achieve allowed radiation dose rate after reactor shutdown. Its high density and the presence of Carbon nuclei, makes this material an interesting shielding against photons and fast neutrons as well, leading to an original design. Tungsten Carbide is arranged in absorbing rods of 17.05 mm inner diameter with a pitch of 20 mm, voids between absorbing rods are filled with Lead in order to increase the self-shielding of the structure. Design process is illustrated with an application example for a hypothetical 200 MW Small Medium Reactor. Radiation source was quantified with ORIGEN code and radiation transport throughout shielding was calculated with MCNP5 code. The result was a shielding of 31 cm thickness and 150 MT of weight. The maximum dose rate was 3 μSv/h, after 83 min since reactor shutdown.

1. Introduction

1.1. Motivation and scope

During the last two decades, Small Medium Reactors (SMRs) have become a major player for future nuclear power generation (Bragg-Sitton, 2015). There are several projects dedicated to the design and construction of these reactors, for example: NuScale (U.S.A), mPower (B&W, U.S.A), KLT-40S (Russian Federation), SMART (South Korea) and CAREM (Argentina). SMRs are able to provide more than electricity, including seawater desalinization among its applications as well as cogeneration power. Therefore, new projects on its complementary facilities are under development. Protection against radiation is a main concern to obtain a reliable design.

In a general concept, shielding is divided into a primary and secondary shield (Bunemann and Enginol, 1970). The primary shield provides sufficient attenuation of neutron flux to prevent inducted activity on surrounding structures by neutron capture. It also provides attenuation of photon flux generated in the reactor core by radioactive decay of fission products as well as neutron activation. Primary shield must provide an acceptable radiation dose rate during reactor shutdown, so that maintenance of reactor components could be accomplished. The secondary shield allows an acceptable dose rate for reactor works and general public during normal reactor operation at full power.

Conventional materials for primary shield are steel, concrete and Lead. Their high density makes them effective materials against gamma radiation. In the special case of concrete and steel, it is possible to incorporate special additives with high neutron absorption cross-section. In steel, the inelastic scattering on Iron allows an efficient removal of fast neutrons. In the case of concrete, the weight fraction of Hydrogen could be increased by addition of water. Then, fast neutron moderation is possible. Although these materials are widely validated in various applications, their use leads to thick and very heavy structures. Borated water is also used in combination with steel, so that moderation of fast neutrons and thermal absorption reduces the total amount of neutrons dose rates.

Considering a mobile SMR for floating power generation plants (e.g.: icebreaker "Lenin", cargo ship N.S. Savannah, cargo ship Otto Hahn (Bunemann and Enginol, 1970) and icebreaker Marine Reactor X (Yamaji and Sako, 1994), a compromise between low weight and high density is required, to achieve allowed radiation dose rate. Therefore, dose rate shall be optimized as a function of weight and volume. In order to improve the design of SMR's radiation protection system, the application of Tungsten (W) and Tungsten Carbide (WC) is considered. In this work, a new design for primary radiation shielding based on WC and Lead is presented. Several pellets of WC are introduced inside stainless steel tubes which

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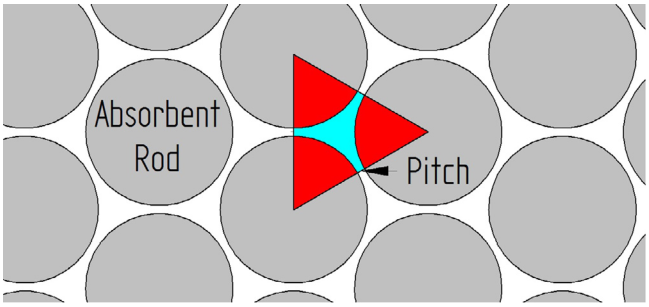

Fig. 1.1. Schematically model of triangular pitch rods arrangement for shielding.

are placed in a triangular pitch as shown in Fig. 1.1. Space between rods is filled with Lead to avoid radiation streaming.

Tungsten and Tungsten Carbide are very effective shielding against gamma and neutron radiation, because of their high density, fast neutron removal cross section and fast neutron capture cross section. Tungsten Carbide is of particular interest since the presence of carbon nuclei contributes to the moderation of fast neutrons flux, reducing their contribution to total dose rate. However, they are not widely used as a shielding material except for small high-energy source applications where space is restrictive or as specific parts where additional shielding is required in the same space allocation (Hamer and McArthy, 1970). Tungsten should be considered for applications on high temperature environment. The primary restrictions on the use of Tungsten are high cost, difficulty in fabrication and the limitation of availability in large size.

In order to qualify its performance, a full design process is illustrated with an application example for a hypothetical 200 MW SMR. Reactor parameters are shown on Table 1.1, and a schematically view of its design can be seen on Figs. 1.2 and 1.3. This design is based on a desalinization reactor proposed by Gimenez and Chocron (Giménez et al., 2016).

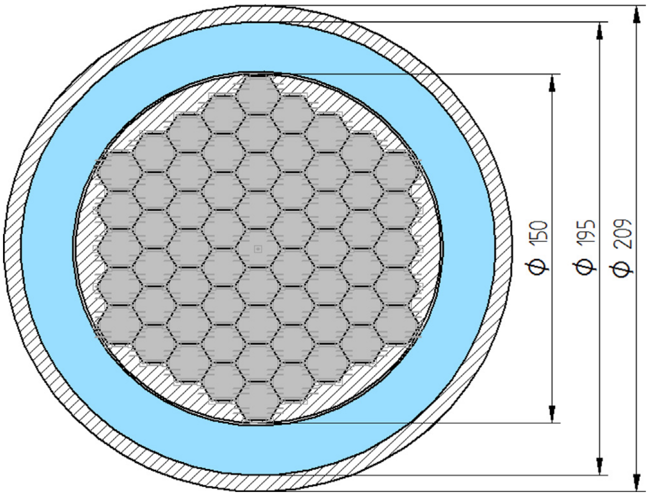

Fig. 1.2. Reactor core configuration and size. Units in cm.

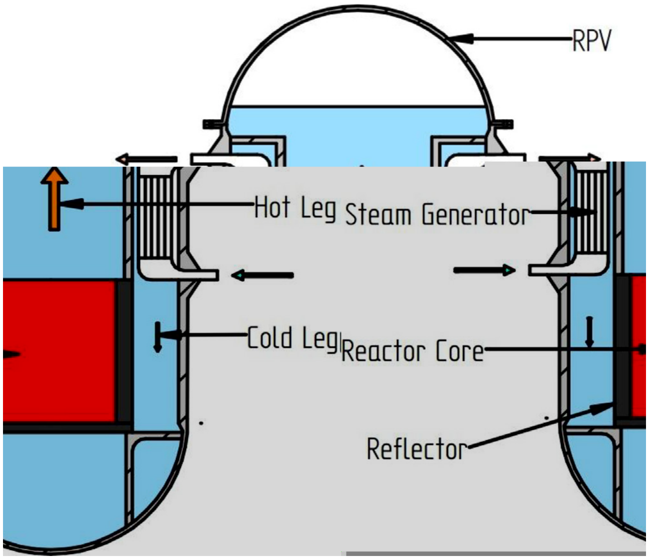

Fig. 1.3. Main components of the reactor under study. The design was proposed by Giménez et al. (2016).

1.2. Design requirements and procedure

The proposed reactor employs integrated primary loop configurations, and then primary shield design becomes simple, since the reactor pressure vessel (RPV) confines all radiation sources. Primary shield shall be designed so that radiation dose rate at the periphery of the shield is equal or lower 3 μSv/h 1 h after reactor shutdown. This ensures a safe working environment for operators during reactor maintenance. The dose rate corresponds to the criteria of the Argentinean Nuclear Regulatory Authority; established in Autoridad Regulatoria Argentina (2002). Additional requirements imply a weight limitation of 200 MT and a maximum thickness of 500 cm. For full power operation, a secondary shield must be designed and goes beyond the scope of this work.

Table 1.1
Main reactor design specifications.

General Design	
Reactor Design	PWR-Hexagonal Fuel Cell
Thermal Power	200 MW
Design Pressure	120 bar
Core inlet temperature	285 °C
Core outlet temperature	310 °C
Cooling mass flow rate	1509 kg/s
Cooling velocity	2.27 m/s
Core	
Equivalent diameter	134 cm
Active length	114 cm
Number Fuel Elements	61
Fuel rod/Fuel Element	108
Fuel rod diameter	9.1 mm
Rod Pitch	12.2 mm
Enrichment	4.35%
Uranium Inventory	2.90 MT
Power Density	124 kW/L
Discharge Burn Up	50,265 MW day/MTHM

Flow diagram of design process is shown on Fig. 1.4. Process begins with a source term calculation in order to quantify neutron and gamma radiation. To quantify their intensity and spectrum, ORIGEN code (Wieselquist et al., 2016) is used. These results breed a 1D analytical code based on point-kernel calculations programmed by the authors. The code calculates the thickness of material necessary to achieve a certain transmission of photons. Those results are a first estimation to compare the performance of different materials.

Once the materials are selected, structural design process begins, which concerns volume, weight and geometry. Finally, all parameters are integrated in a Monte Carlo simulation with MCNP5 code (X-5 Monte Carlo Team, 2003).