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Radiological considerations on multi-MW targets. Part II: After-heat and temperature distribution in packed tantalum spheres

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Abstract

CERN is designing a Superconducting Proton Linac (SPL) to provide a 2.2 GeV, 4 MW proton beam to feed facilities like, for example, a future Neutrino Factory or a Neutrino SuperBeam. One of the most promising target candidates is a stationary consisting of a Ti container filled with small Ta pellets. The power deposited as heat by the radioactive nuclides (the so-called after-heat) can considerably increase the target temperature after ceasing operation, if no active cooling is provided. An estimate of the induced radioactivity and after-heat was performed with the FLUKA Monte Carlo code. To estimate the highest temperature reached inside the target, the effective thermal conductivity of packed spheres was evaluated using the basic cell method. A method for estimating the contribution to heat transmission from radiation is also discussed.

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1. Introduction

CERN is designing a Superconducting Proton Linac (SPL) to provide a 2.2 GeV, 4 MW proton beam to feed facilities like, for example, a future Neutrino Factory [1] or a Neutrino SuperBeam [2]. The essential elements of such facilities are a target, a magnetic horn, a decay tunnel and a beam dump. At the present stage, the two most promising targets are a free-surface jet of mercury [3] and a solid stationary target made of tantalum [4]. The production of residual nuclei in the target and in its surroundings is discussed elsewhere for both targets [5]. This paper further investigates the induced radioactivity and the after-heat in the stationary target.

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The stationary target is made up of tantalum pellets with diameter in the millimetre range. These spheres are confined inside a 0.25 cm thick titanium container (2.25 cm radius, 18 cm length) and cooled by water or He gas. The lifetime of the Ta target is not known yet and will depend on the beam intensity and the irradiation cycle. The present calculations were made assuming that the target will be replaced together with the horn every 6 weeks of operation. The power deposited as heat by the radioactive nuclides (the so-called after-heat) can considerably increase the Ta target after ceasing operation, if no active cooling is provided. An estimate of the induced radioactivity and after-heat was performed with the FLUKA Monte Carlo code. To estimate the highest temperature reached inside the target, the effective thermal conductivity of packed spheres was evaluated using the basic cell method. A method for estimating the contribution to heat transmission from radiation is also discussed.

2. FLUKA simulations

The material activation and the fluence of secondary particles in the target were estimated with FLUKA [6,7]. The 4 MW, 2.2 GeV proton beam had a Gaussian profile ($\sigma = 0.3$ cm) and no momentum spread or divergence. All particles were transported with an energy threshold of 10 MeV except pions (energy threshold 10 keV), protons (1 MeV) and neutrons (down to thermal energies). The magnetic field in the horn was taken into account and biasing techniques were employed to reduce the statistical uncertainty, in particular inside the concrete wall. The results were normalized per proton incident on target (rather than per pion produced).

The stationary target filled with small tantalum spheres (16.6 g cm^{-3} density) was approximated as a homogeneous cylinder made of tantalum, with an effective density $\rho_{\text{eff}} = 10$ g cm^{-3} [4]. The volume (286 cm^3), the external shape and the weight (2.861 kg) of the target were respected. The tantalum target was thus defined as a cylinder 18 cm long and 2.25 cm in radius surrounded by a 0.25 cm thick layer of titanium representing the container enclosing the pellets.

Because of the high specific activity of Ta, the power deposited as heat by the radioactive decays (the so-called after-heat) can considerably increase the target temperature after ceasing operation. Although facilities like a Neutrino Factory may use the SPL beam for some 10 years, the target is likely to be exchanged every few months. For completeness, this paper first analyses the case of 10-year irradiation, after which the expected activity in Ta is 3.26×10^{16} Bq.

A first estimate of the heat generated in the target was obtained with the software package MicroShield [8]. For a given source of radioactivity and a defined geometry, MicroShield calculates the heat deposited by α- and β-particles and γ-rays. The power deposited in the target after 10-year operation and generated by the 20 most radioactive nuclides is 1424 W. Major contributors are ^{146}Eu, ^{170}Lu and ^{276}Ta.

Because long-lived radioactive nuclides do not play an important role in heat generation, the after-heat approaches a saturation value within a few weeks of irradiation and increases only slightly with longer irradiation times. At the end of the operation, the heat generated in the target increases during the first minutes and reaches a maximum about 30 min after ceasing irradiation. The after-heat after 1-month irradiation is shown in Fig. 1, as a function of the waiting time.

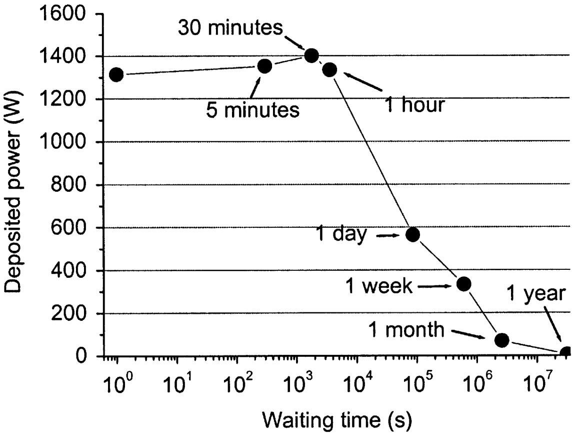

Fig. 1. After-heat in a Ta target after 1-month irradiation, as a function of the waiting time.