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Study of the neutron field around ENSA-DPT spent fuel transport and storage casks

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HIGHLIGHTS

- Evaluation of neutron spectra and dose around spent fuel casks.
- Experimental neutron field characterization of DPT type spent fuel casks.
- Monte Carlo simulation with actual and detailed specifications of fuel and cask.
- Neutron work-field correction for neutron monitors.

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ABSTRACT

Neutron field measurements around individual DPT type spent fuel transport and storage casks were performed at the storage installation of Trillo Nuclear Power Plant. Neutron spectra were determined at five different positions using a Bonner sphere system. These measurements were used to validate the dosimetry measurements of two neutron monitors. Axial and angular measurements were used to determine the ambient dose equivalent. The results are consistent with the cask design and no field correction is needed when using these monitors.

1. Introduction

The Trillo Nuclear Power Plant (NPP), located in Guadalajara (Spain), had a spent fuel storage installation (ATI for its acronym in Spanish) since 2001. At the end of 2016, 30 DPT casks were stored in a rectangular grid inside the ATI. The ATI is a large concrete warehouse (83 m long, 44 m wide and 22 m high) with a licensed capacity for 80 casks. It is divided in two areas separated by a concrete wall, one for cask storage and the other for cask maintenance. The DPT (Dual Purpose Trillo) cask is a dual purpose metal container built by ENSA and licensed for the dry transport and storage of 21 KWU (Kraftwerk Union) spent fuel assemblies with maximum burn up of 49 MWd/kgU and minimum cooling time of 9 years. Each cask is 5 m high and 2 m in diameter. It is a double steel cylinder with a 104 mm gamma-shield lead in between, and a 120 mm outside neutron shield layer. The neutron shielding material employed in the casks is a hydrogenated polymer with boron and alumina, known as NS4FR. The cask has a double lid made of steel and an external neutron shield lid of 25.4 mm. Inside the bottom of the cask there is 50 mm neutron shield layer. Each cask has four lifting trunnions at the upper part, two rotation trunnion holders at the lower part and a steel ring section between two of the lifting trunnions, to avoid cask rotation during transport. These further reduce the lateral neutron shielding.

Radiation exposure around spent fuel casks is mainly due to neutrons, and neutron dose is strongly dependent on the neutron spectrum. In addition, a measured neutron dose depends on the response of the monitor used to record it. Neutron monitors are usually calibrated with standard neutron sources, as recommended by ISO 8529-1 (ISO, 2001), but workplace neutron fields, such as those found around spent fuel casks, are different from calibration fields. For this reason ISO 12789-1

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(ISO, 2008) recommends calibration in simulated workplace fields or the use of spectrometry to check the performance of the monitors and evaluate the necessity of field corrections.

Therefore, it is fundamental to evaluate the effect of the cask design on the neutron spectrum outside the cask, as well as the effect of this spectrum in the performance of neutron monitor employed for area dosimetry surveillance. The aim of this study is to characterize the neutron fields around DPT casks stored at the ATI of the Trillo NPP in terms of neutron spectrum and ambient dose equivalent rate. Measurements were performed around two DPT casks, using a Bonner sphere system spectrometer (BSS) to determine neutron spectra. These measurements were also used to validate the measurements of two neutron monitors (Berthold LB6411 and Studsvik Digipig 2222A) in the neutron field around the casks. These neutron monitors were then used to perform extensive ambient dose equivalent rate measurements around the cask.

This is the first experimental evaluation of the neutron field around this type of cask. Previously published studies concerning similar measurements considered different types of casks, such as CASTOR type casks (Buchillier et al., 2007; Rimpler, 2002), TN type casks (Buchillier et al., 2007; Mayer et al., 2012; Rimpler et al., 2010) or TNL type casks (Lacoste et al., 2007). The main difference in the methodology employed in this study is the combination of extensive measurements, both of neutron spectrometry and dosimetry, with detailed Monte Carlo simulations, and the advantages derived from this combination.

It is not usual to have detailed data for the cask model from the manufacturer, and it is even less usual to have detailed and up to date information of the spent fuel characteristics as burn up, enrichment or cooling time in order to obtain a realistic source term for the model. In this case this information was provided by the power plant and allowed to perform detailed Monte Carlo simulation of the measurements. On one hand, such simulations allows to provide for each spectrometry measurement an initial spectrum for the unfolding process which is very close to the real measurement conditions and detailed by the use of a large number of energy bins, instead of a more general spectrum. This realistic initial spectrum along with the use of a large 12 Bonner sphere set and a spherical 3He detector allows enhancing the results of the Bonner sphere spectrometry. The resolution of the unfolded spectrum is improved with the use of 206 energy groups and detailed structures can be observed. On the other hand, the agreement between simulations and measurements allows validating the Monte Carlo model, providing an excellent tool to analyze in detail the effect of the different materials of the cask in neutron spectrum and ambient dose equivalent. When analyzing the results of the measurements, Monte Carlo results are very helpful to evaluate the different shielding configurations of the cask or to identify the structures of the measured neutron spectrum and their origin.

The extensive spectrometry measurements performed and their agreement with dosimetry measurements with neutron monitors proofs the suitability of using these monitors to extend the points of measurements around the cask despite the significantly different effect of the cask design in each measurement location. In this way, angular dose rates profiles measured ant different heights around the casks allows evaluating the anisotropy in the distribution of the spent fuel assemblies inside the casks as well as the effect of structural elements of the cask as the trunnions and the contribution of the rest of stored casks in the facility. Also longitudinal measurements along the axis of the cask allows evaluating the effect of the burn-up profile of the spent fuel and the effect of the trunnions.

2. Materials and methods

The BSS spectrometer used by the Neutron Standards Laboratory (LPN for its acronym in Spanish) consisted of 12 polyethylene spheres, from 76.2 to 304.8 mm (3–12 in.) in diameter, with a spherical ^{3}He proportional counter with a gas pressure of 228.5 ± 2.0 kPa (Gallego et al., 2012; Lagares et al., 2016; Méndez-Villafañe et al., 2010). It is used with a Canberra DSA1000 compact electronic chain. The BSS was calibrated in monoenergetic neutron beams at PTB (Germany). The GRAVEL and MAXED unfolding codes, from the UMG 3.3 code package developed by PTB (Reginatto, 2002) were used to obtain neutron spectrum, φ_E, from BSS measurements. The integral quantities neutron fluence rate, φ, and ambient dose equivalent rate, $H^*(10)$, and their associated uncertainties were determined by the same code package, which uses the ICRP74 fluence-to-dose conversion factors (ICRP, 1996).

In order to obtain appropriate initial spectra for the unfolding code, detailed Monte Carlo models of the DPT cask and the ATI of Trillo NPP were developed (Campo et al., 2017) for the MAVRIC module of SCALE 6.1 code package (Bowman, 2007), (Monaco with Automated Variance Reduction Using Importance Calculations), which is a 3D continuous energy and multigroup fixed-source Monte Carlo code with automated variance reduction. Detailed geometry and materials of the cask and building are included in the models. Each spent fuel assembly was modelled individually considering its own neutron source and homogenized materials. The neutron source for the model (emission rate, neutron emission spectrum and isotopic composition) was provided by Trillo NPP, calculated for each spent fuel assembly considering their actual specifications (enrichment, cooling time, specific power and burn up profile) using the ORIGEN module of SCALE 6.1 (Bowman, 2007).

Trillo NPP uses a Studsvik 2222 A Digipig neutron monitor for routine neutron area dosimetry surveillance during the transport and storage of the casks. This neutron monitor consists of a cylindrical BF_3 proportional counter (~ 106 kPa) surrounded by a cylindrical polyethylene moderator (Tanner et al., 2007). It is verified periodically using an ^{241}Am-Be source at the site. The Berthold LB6411 neutron monitor used by the LPN consists of a cylindrical ^{3}He proportional counter (~ 345 kPa) surrounded by spherical polyethylene moderator (Burgkhardt et al., 1997). It is calibrated with ^{252}Cf and ^{241}Am-Be sources at CMI (Czech Republic).

Two individual casks (DPT27 and DPT28) were measured during their transfer to a provisional position to minimize the influence of the casks already stored inside the ATI. A total of 7 spectrometry measurements and more than 100 dosimetry measurements were made. The first group of measurements were made with the two casks in the vertical position inside the ATI storage area. DPT27 was measured at 0.6 m height in contact with the lateral surface and at 1 and 2.5 m height at 1 m distance. DPT28 was measured at 1, 2.5 and 4.4 m height at 1 m from the lateral surface. For each height, measurements were made at one location with the BSS, and at 12 different locations around the cask with the LB6411 monitor, in order to obtain angular profiles of ambient dose equivalent rate. One of these angular profiles was also measured with the Digipig monitor. A second group of measurements were made with the cask DPT28 in the horizontal position inside the ATI manipulation area. Two measurements were made at 1 m from the centre of the lid and the bottom of the cask with the BSS and also with the LB6411 monitor. The longitudinal axis of the cask was also measured with the LB6411 monitor at 1 m from the surface and every 0.2 m, in order to obtain a longitudinal profile of ambient dose equivalent rate.

The uncertainties considered in the BSS measurements were the statistical uncertainties in BSS count rates, the uncertainty of the BSS response matrix and the uncertainty introduced by the unfolding numeric algorithm. Statistical uncertainties were related to the total BSS count rates obtained with each sphere. The integrated measurement time varied approximately from 30 s for the smallest sphere to 2000 s for the biggest. These conditions allowed statistical uncertainties below 1% for BSS counts. The uncertainty of the BSS response matrix was estimated at 2% on the basis of calculations and measurements reported in the BSS calibration report. The uncertainty introduced by the unfolding numeric algorithm was calculated by the IQU code, also included in the UMG 3.3 unfolding code package (Reginatto, 2002). These uncertainties were combined by the same IQU code to obtain the