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MCNPX modelling of the NPL manganese bath facility based on a converted CAD model

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ABSTRACT

A detailed CAD model of the new manganese bath facility of the UK National Physical Laboratory has been converted into MCNPX format using the conversion program MCAM. The model has been used to evaluate a number of important parameters of the new facility such as the fraction of neutrons that escape from the manganese sulphate solution but subsequently return and are captured by it, and the degree of irradiation of the solution when a source is being transferred to and from the bath. It has also been used to recalculate the correction factors for the fraction of neutrons captured by nuclei other than manganese, the fraction captured by the source and the source mounting assembly and the fraction escaping from the bath itself, and compare these with values from an earlier simplified model.

1. Introduction

The NPL manganese bath facility is used to measure the emission rates of radionuclide neutron sources for use within NPL and by fee-paying customers. The system consists of two spherical baths, one large (⌀ 98 cm) and one small (⌀ 50 cm), filled with manganese sulphate solution ($MnSO_4$(aq)), the pumping system, and two counting reservoirs (a large one and a small one) each with a pair of NaI scintillator detectors. Most measurements are performed with the large bath although the small bath has advantages for low energy sources.

The basic principle of the measurement is that a neutron source positioned at the centre of a bath activates the manganese via the ^{55}Mn(n, γ)^{56}Mn reaction. The activity induced depends on the emission rate of the source, and by measuring it the neutron emission rate can be determined. A more detailed description of the method can be found in the work by Axton et al. (1965). A moderator assembly is also available for measuring source emission rates by a simple comparison technique using a source of similar construction and type with accurately known emission rate.

In 2007 the facility was relocated into a new purpose-built laboratory (Roberts and Jones, 2008, 2010). During the design phase of the new laboratory a detailed CAD model was created (see Fig. 1). Using the CAD conversion program MCAM (Wu, 2009) the model could be converted into the cell and surface cards required for the Monte Carlo code MCNPX (Pelowitz, 2008). It was then possible to evaluate a number of important parameters of the new facility. These include the "room return", i.e. fraction of neutrons escaping from the bath that scatter in the room and are subsequently recaptured by the bath, and the degree of pre- and post-irradiation of the bath when sources travel between the source cell and the bath at the start and end of a measurement. The correction factors for the fraction of neutrons captured by nuclei other than manganese, the fraction captured by the source and the source mounting assembly and the fraction escaping from the bath itself have also been calculated using the model.

2. Converting the CAD model

The CAD model was first simplified by removing unnecessary components, including anything beyond the blockhouse which surrounds the bath room, and approximating components with highly irregular shapes. The simplified model was then exported in the form of a STEP file (STandard for the Exchange of Product model data) and imported into the conversion program MCAM beta version 4.7, FDS Team, China. As the STEP file did not include any information on the materials of the components in the model, it was necessary to use the graphical interface of MCAM to identify and assign materials to each component.

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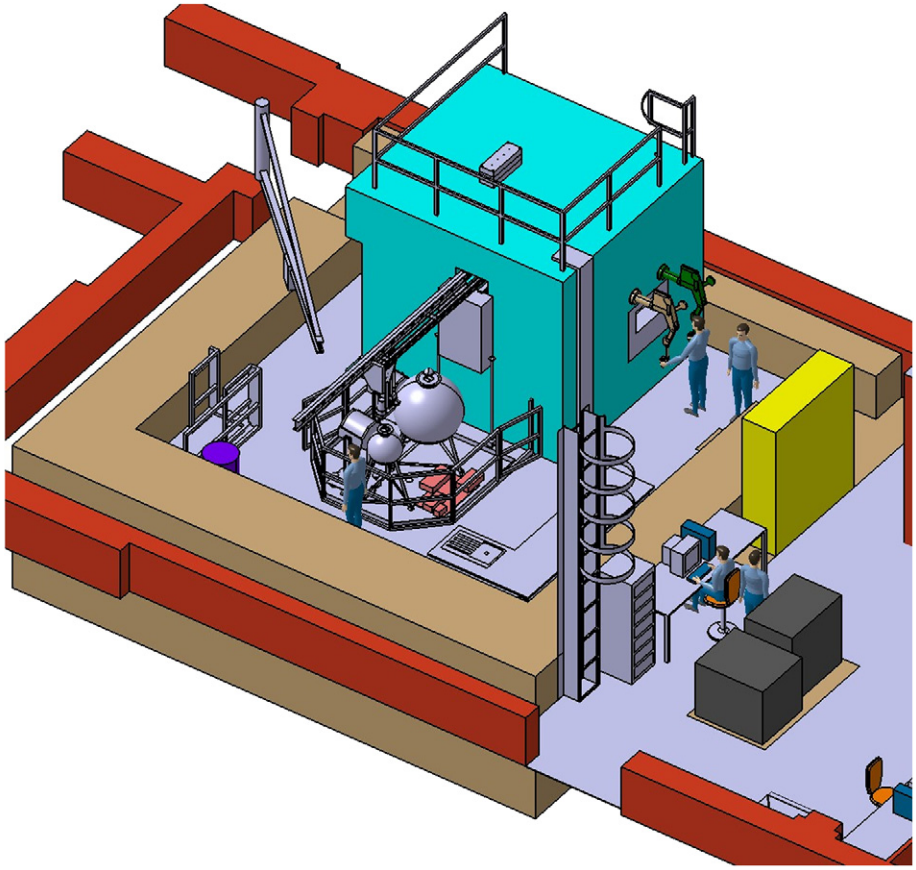

Fig. 1. CAD image of the new manganese bath suite. The concrete blockhouse and brick walls surrounding the bath room have been cut-away.

The pre-processing tools "Heal" and "Check" were used to resolve any issues where the surfaces of adjacent components either interfered with each other or did not completely touch. The option to generate void space was selected when converting to MCNP format and, in order for the conversion to work, the option to use the complement operator "#" had to be enabled to exclude whole cells when defining the void space as opposed to defining the void solely in terms of surface numbers. The code authors advise against indiscriminate use of the complement operator as it can add significantly to the required computer time. However, as a consequence of using the complement operator the definitions of the void cells contained more words of storage than the 1000 allowed for each cell in MCNP5, so MCNPX had to be used which allows up to 2000 words. The converted model has 581 cells constructed from 2192 surfaces, including 93 cells to define the air in the room.

3. Calculation of correction factors

The three neutron loss correction factors are defined by Axton and Bardell (1985) as follows:

- *O* is the fraction of neutrons lost due to capture in fast neutron reactions in oxygen and sulphur i.e. O(n, α), S(n, α), S(n, p)
- *S* is the fraction of neutrons which are captured by the source and its mounting assembly,
- *L* is the fraction of neutrons which escape from the boundaries of the bath.

Tallies were added to the model to allow each of these to be determined.

The two most common source types were modelled, ^{252}Cf and ^{241}Am–Be, using spherical surface distributions that enclose the source capsule. Hence, neutrons start from outside the boundaries of the capsule and initially move away from the capsule. This ensures that the energy spectrum and the emission rate of neutrons leaving the source are not modified by interactions within the source material and the encapsulation. This approach also allows the source capture correction to be easily determined in the model as all neutron events that occur within the capsule and source material are due to neutrons which have previously interacted in the solution and/or source mounting assembly. The source mounting geometry used at NPL lends itself to this approach as the sphere surrounding the source does not conflict with the source cavity or the manganese sulphate solution.

The results were compared with those from a previous MCNP model by Roberts (2001), shown in Table 1, which was re-run for a solution concentration corresponding to a hydrogen to manganese number density ratio (N_H/N_{Mn}) of 34.1922 and with sulphur

Table 1
Comparison of CAD model results with those from previous MCNP model.

	^{252}Cf, X1 capsule			^{241}Am–Be, X14 capsule		
	CAD	Previous	CAD/Previous − 1	CAD	Previous	CAD/Previous − 1
O	0.84%	0.83%	+0.3%	3.41%	3.41%	−0.05%
S	1.85%	1.89%	−2.5%	2.16%	2.17%	−0.25%
L	0.37%[a]	0.35%	+7.7%	1.43%[a]	1.35%	+6.0%
1/(1-*O*-*S*-*L*)	1.03155	1.03175	−0.02%	1.07521	1.07436	+0.08%

[a] corrected for room return as described in Section 4.