NEUTRONIC CALCULATIONS FOR THE SUNS ULTRA COLD NEUTRON SOURCE

F. Atchison

INTRODUCTION

The SUNS facility is an ultra-cold neutron (UCN) source based on the spallation source principle presently under construction; the main purpose will be to provide UCNs for experiments to measure the electric dipole moment and the lifetime of the neutron. UCN are neutrons at the extreme low energy end of the spectrum; their chief special property is that they can be totally internally reflected at material boundaries which means they can be stored in a “neutron” bottle. They also have a kinetic energy that is low enough that the influence of gravity is of great significance.

The notable differences between SUNS and a more conventional spallation neutron source are that it is switched on for only 2 to 8 seconds every 10 to 15 minutes or so and a very cold moderator is required. This pulsed structure reduces background (the experimental measurements are made after the few second filling period over a time limited by the UCN lifetime in the spectrometer) and simultaneously reduces the power load on the cryogenic system for the solid D_2 moderator by a factor of 100 or more.

The single most important item in the SUNS system is the cold moderator which consists of about 5½ kg of solid Deuterium at $\approx$ 8 K mounted about 20 cm from the 1 MW proton beam. The main aim of these calculations was to confirm the values for the two critical parameters, the beam-dependent heat load on the moderator and the UCN production, which have been calculated by the PNPI team [1]. A full description of this calculation is given in reference 2. The main components of the SUNS source are indicated in Fig. 1.

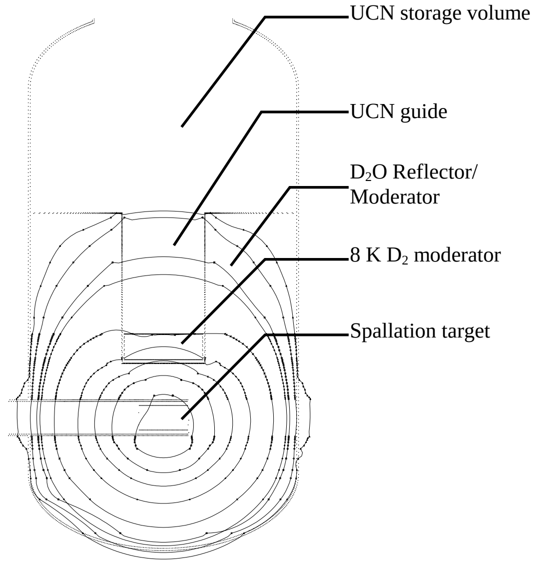

Fig. 1: Neutron flux contours superimposed onto an outline of the SUNS source. Contours are shown for flux levels of 10, 8, 6, 4, 2, 1, 0.8, 0.4 and 0.2×10^{13}/cm^2/sec for 1 mA proton current are shown.

NEUTRON LIFETIME

The mean lifetime of the “normal” neutrons (i.e. not the UCN) in SUNS is 4.4 msec which is comparable with that for SINQ and means that SUNS is, from a neutronics standpoint, a continuous source and that a main concern has to be neutron economy (e.g. avoiding neutron loss through using materials with high neutron absorption cross-section). The time constant is consistent with the neutron population as deduced from the flux density and with the neutron production rate.

NEUTRON FLUX DISTRIBUTIONS

The fast neutrons produced by the 590 MeV protons in the target are moderated to thermal energies by heavy water and further moderation is made with the 8 K solid Deuterium. The thermal neutron flux distribution is shown as a contour plot superposed onto a sketch of the SUNS system in Fig. 1.

The heavy water between target and moderator is there to remove some of the heat load from the cold moderator (mainly the contribution from the fast neutrons).

The variation of the cold flux across the D_2 moderator is shown in Fig. 2 in terms of the intensities for the three Maxwell spectra that approximate the calculated spectrum. Because there is only an outgoing “cold” neutron current, there is a gradient in the 14 K spectrum towards the escape faces of the moderator. Similarly, the 327 K (thermal) neutron component dips towards the middle of the moderator as it is depleted to produce the “cold” component.

POWER DENSITIES

A critical aspect of the SUNS design is maintaining the D_2 moderator at 8 K throughout the duration of the proton beam pulse. The power density distribution across the moderating system from this calculation is shown in Fig. 3; the values are in good agreement with those from the PNPI team.

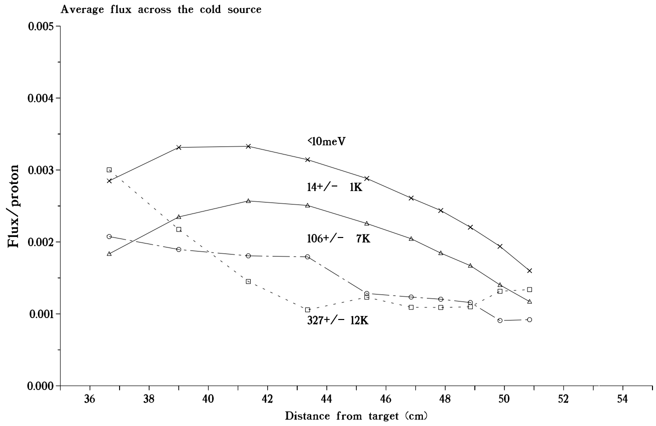

Fig. 2: Variation of the neutron flux across the cold moderator modelled as 8K D_2 gas. The four curves shown are the contributions of the three Maxwell functions and the total intensity below 10 meV.

UCN INTENSITY

The UCN collected in the storage volume will be the neutrons in the solid D_2 moderator escape-spectrum with velocities in the range 4.5 (the cut-off velocity for Deuterium) to 7.95 m/sec. The upper limit is set by the gravitational deceleration over the height difference of the UCN guide (0.68 m) that brings the velocity to below 6.8 m/sec (the upper limit for total reflection).

The calculations with the full system were more conveniently carried out using cross-sections for scattering from an 8 K gas. For a solid, the lattice vibrations will have a Debye spectrum [2] giving a lower mean temperature for the Deuterons (6 K cf. 14 K) and hence of the cold neutron spectrum (7.5 K cf. 16.6 K). The spectrum for neutrons escaping the upper open face of the moderator is shown in Fig. 4.

The UCN density in the storage volume assuming a lifetime of 2 seconds during the filling period[1] and a proton pulse of 2 mA for 4 seconds is estimated to be 2000/cm^3 and also in good agreement with the results of the PNPI calculations [1].

REFERENCES

[1] A. Fomin et al., *An ultra cold neutron facility at PSI*, PSI internal report TM-14-01-01 (2001).

[2] F. Atchison, *Calculated values for heating, particle fluxes and activation in components of the UCN source*, SUNS, PSI internal report TM-14-02-02 (2002).

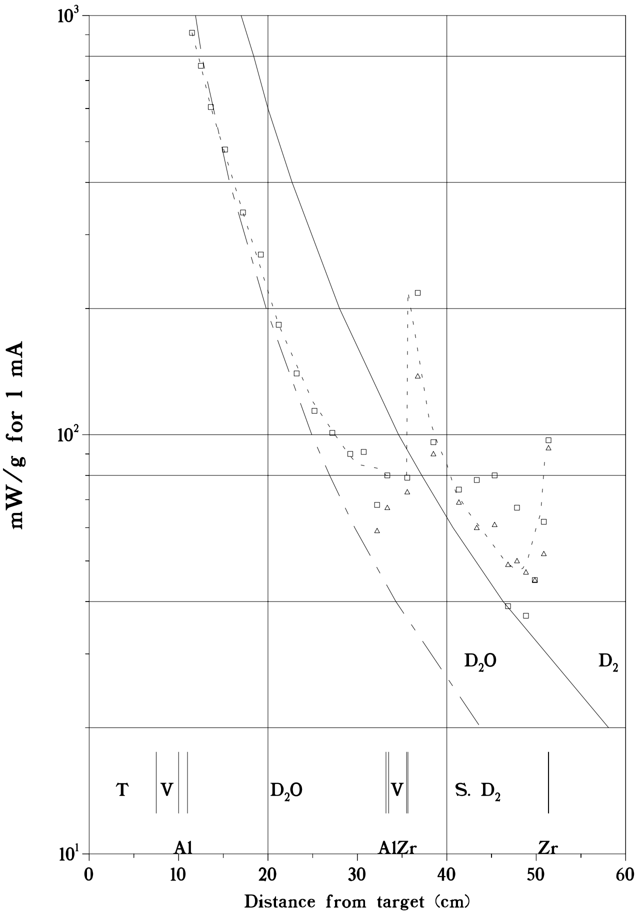

Fig. 3: Calculated power densities along the vertical axis of the SUNS system (dashed line with squares and triangles). The other two lines are the results from the PNPI calculation (solid for the D_2 and double-dashed for the D_2O). The actual media in the various regions are indicated by the symbols along the bottom (T = target, V = vacuum).

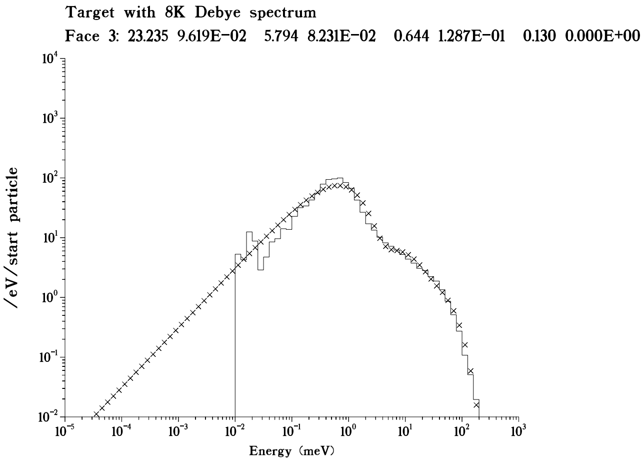

Fig. 4: The spectrum of neutrons escaping the upper open face of the moderator (histogram) with the result from fitting the data to the sum of three Maxwell flux spectra (shown by crosses). The target Deuterons in the scattering have a Debye spectrum at a temperature of 8 K.

[1] This is limited by UCN returning to the moderator. At the end of the filling period the top end of the guide will be closed-off to produce an intermediate storage bottle.