Calculation of ultracold neutron production at the TRIGA Mainz Reactor

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Ultracold neutrons (UCN) are, by definition, neutrons with energies below the reflecting potential of most materials. This means, the kinetic energy of UCN is below ~250 neV. Therefore, UCN can be stored in traps enabling experiments at very low energies. The most significant experiments in this field are searches for a static electric dipole moment of the neutron (EDM) and measurements of the free neutron lifetime [1,2].

UCN can be produced by inelastic down-scattering of higher energy neutrons creating excitations in a moderator material. In thermal equilibrium, the rates of up- and down-scattering are equal and the temperature of the neutrons becomes that of the moderator. However, up-scattering depends strongly on the moderator temperature. Below a certain temperature, up-scattering is negligible. A moderator where no thermal equilibrium can be reached is called a converter. One possible converter material is solid deuterium at 5 K.

The expected UCN production and the energy release for solid deuterium as a converter was calculated for the TRIGA Mainz reactor. A UCN source of this type was recently installed at the beam tube C [3]. The neutron fluxes averaged over the converter volume were calculated by Monte Carlo N- Particle simulations with the program MCNP [4]. As input to MCNP, a detailed model of the reactor core was used including exact positions of all fuel elements, regulation rods and their claddings. Based on these fluxes, the UCN production was calculated in the one phonon incoherent approximation for the scattering cross section and with a dynamic Debye model of the moderator material [5]. In this model, the down-scattering cross section of a room temperature thermal neutron flux down to the energy range 50 neV to 250 neV in very low temperature deuterium is 10^{-8} b. The most optimal neutron temperature was found to be ~30 K. In this case, the cross section is 14 times larger.

The thermal neutron flux in the tangential beam tube C averaged over a 5 cm thick deuterium cell is 1.1×10^{11} n/cm$^2 \cdot$s at a reactor power of 100 kW. Neglecting multi-phonon down-scattering which increases the UCN production, the calculation results in a UCN production rate of 60 UCN/cm$^3 \cdot$s. During a 6 MJ pulse the total UCN production will be 3.5×10^3 UCN/cm^3.

As mentioned above, premoderation of the incident neutron flux will increase the UCN production. A premoderator of 1.0 – 1.2 cm thickness of solid or liquid methane at the temperature of 10 K to 20 K decreases the neutron temperature down to 30 K to 40 K. In this case, the cold neutron flux at 100 kW reactor power will be 7×10^{10} n/cm$^2 \cdot$s. With this, the predicted UCN production rate at beam tube C is 4.5×10^2 UCN/cm$^3 \cdot$s, the total UCN production during a reactor pulse of 6 MJ is 2.7×10^4 UCN/cm^3.

At the radial beam channel D, a graphite shield of 10 cm – 12 cm thickness was found to be necessary to reduce the heating of the converter. In this case, the thermal neutron flux is 5.4×10^{11} n/cm$^2 \cdot$s at 100 kW. With this shield and a methane premoderator, the predicted UCN production rate at beam tube D is 3.5×10^3 UCN/cm$^3 \cdot$s at 100 kW and 2×10^5 UCN/cm^3 per 6 MJ pulse.

As experimental check of the MCNP calculations, heating of different substances in the central thimble of the TRIGA Mainz during a 6 MJ pulse was measured and compared with the calculations (Table 1). For all materials, a constant ratio of ~1.5 was found between measured and calculated values, indicating that the used model of the reactor was still not exact, but it shows also that the calculated values of the UCN production rates are close to reality.

Material	ΔT_{exp} [K] (measured)	ΔT_{calc} [K] (calculated)	$\Delta T_{exp} / \Delta T_{calc}$
Al	3.5	2.27	1.54
PE	6.0	3.55	1.69
Graphite	5.4	3.55	1.52
PMMA	5.4	3.53	1.53

Table 1: Comparison of calculated and measured heating of different materials in the central thimble of the TRIGA Mainz

References

[1] P.G.Harris et al., PRL 82 (1999) 904.
[2] S. Arzumanov et al., NIM A 440 (2000) 511 .
[3] S. Paul et al., this report.
[4] J. F. Briesmeister, Ed., LA-13709-M (April 2000)
[5] V. Turchin, "Slow Neutrons", Atomizdat, Moscow,1963.