

Thermal neutron flux measurements using lithium carbonate and liquid scintillation counting system

Lithium carbonate in pellet form is frequently used for estimation of tritium production rate in irradiated samples in fusion blanket neutronics experiment and the activity is measured by liquid scintillation counting technique¹⁻³. In the present work, lithium carbonate powder was used for measurements of low and high thermal neutron fluxes by counting the samples in liquid scintillation counting system.

Thermal neutron flux measurement using gold foil is the standard method for estimation of thermal flux. This method has the following advantages: (i) 100% abundance of Au-197; (ii) convenient half-life of 2.697 days; (iii) high activation cross-section of 98 barns. Thermal neutron measurements were done using lithium carbonate powder. The powder when exposed to thermal neutrons undergoes (n, α) reaction to produce tritium. This was counted at ultra-low level liquid scintillation counter. The advantages of this technique are: (i) tritium produced has considerable half-life of 12.3 years which does not require immediate counting of tritium after irradiation; (ii) cross-section of Li-6 (n, α) reaction is one order of magnitude higher (980 barns) than gold activation cross-section. The only disadvantage is the abundance of lithium-6 in natural lithium to the extent of 7.5%. This can be

improved using enriched lithium carbonate powder. Hence by using enriched lithium carbonate powder, the limit for detection of thermal flux can be lowered by one order of magnitude compared to gold foil method. In the present work, natural lithium carbonate powder in different amounts was irradiated in the thermal neutron irradiation facility and in zero power at the Advanced Heavy Water Reactor (AHWR) critical facility at BARC.

Lithium carbonate powder (AR grade) in mg quantity was packed in gelatin

capsules and sealed with PVC as shown in Figure 1. The sealed packets of Li_2CO_3 powder were irradiated in the thermal neutron irradiation facility having flux of $6.4 \text{ E}3 \text{ n/cm}^2/\text{sec}$ for fluence of $2.10 \text{ E}10 \text{ n/cm}^2$. In another experiment, the sealed capsules of various masses of Li_2CO_3 powder were irradiated in zero power at the AHWR critical facility at BARC having a flux of $3.38 \text{ E}7 \text{ n/cm}^2/\text{sec}$ for a fluence of $1.22 \text{ E}11 \text{ n/cm}^2$.

The Li_2CO_3 powder was dissolved in 0.5 ml acid solvent having nitric acid and acetic acid in the ratio of 1 : 3 (ref. 4).

Table 1. Comparison of thermal flux values estimated by Li_2CO_3 powder and standard gold foil methods

Irradiation facility	Mass (mg) Li_2CO_3	Flux estimated	Average flux estimated using Li_2CO_3 powder	Flux estimated using gold foil
Critical facility (100 W)	20.4	3.85E7	$3.50 \text{ E}7 \pm 8.2\%$	3.38E7
	41.3	3.62E7		
	62.1	3.31E7		
	71.1	3.23E7		
Thermal irradiation facility	10.4	5.50E3	$5.91 \text{ E}3 \pm 6.10\%$	6.4E3
	20.0	5.74E3		
	41.0	6.35E3		
	60.0	6.03E3		
	Enriched powder			
	10.0	7.02E3		
	20.0	6.59E3		
	40.0	6.34E3		
	60.0	6.68E3		



Figure 1. Li_2CO_3 powder packed in gelatin capsules and sealed in PVC.

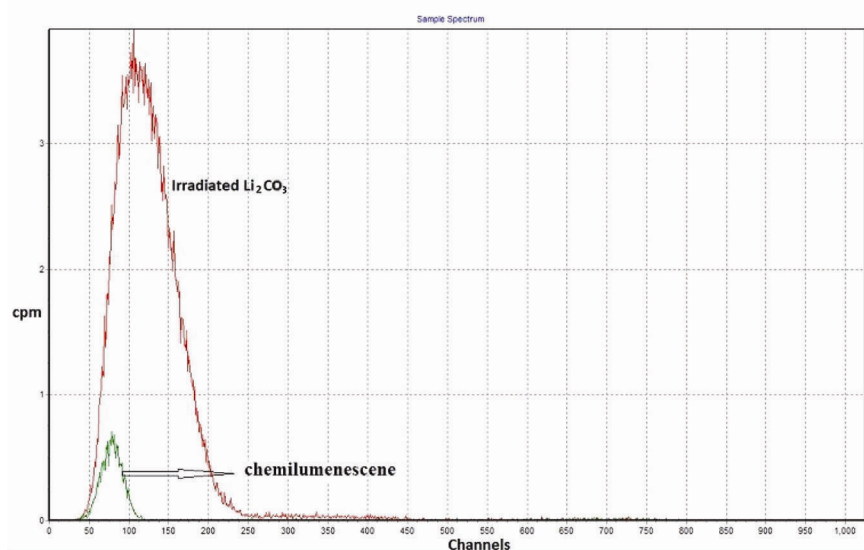


Figure 2. Interference of chemiluminescence in tritium counting region (channels 50–100).

and 10 ml of Quicksafe 400 (Zinsser Analytic) scintillation cocktail was added in high density polyethylene (HDPE) vials.

Tritium counting was done in Quantulus 1220 (Perkin Elmer) liquid scintillation counter with minimum detectable activity (MDA) of 10 mBq for 250 min counting time. Quenching in the sample was denoted by spectral quench parameter of external standard (SQP(E)). Nitromethane (Merck) was used as a chemical quencher to simulate various quench levels. A series of increasingly quenched tritium standards were prepared and used to calibrate the system.

Chemiluminescence in liquid scintillation counting is caused by chemical reaction that results in generation of excited molecules within sample⁴. Chemiluminescence due to Li₂CO₃ powder adds additional counts in the tritium window of 50–200 channels. But the majority of counts due to chemiluminescence was observed in 50–100 channels of counting window (Figure 2). The calibration curve for different values of spectral quench parameter SQP(E) is shown in Figure 3, for both counting windows.

Figure 4 shows that minimum detectable activity (MDA) in tritium window of 50–200 channels increases with the increase in the mass of the Li₂CO₃ powder for both neutron fluences. The MDA is calculated as

$$MDA(Bq) = \frac{3 * (bkgcpm * 250)^{1/2}}{(250 * 60 * \text{Counting efficiency})} \quad (1)$$

where bkgcpm is background counts per minute. MDA remains almost constant with increase in mass of the Li₂CO₃ powder in counting window of 100–200 channels. This is because chemiluminescence adds additional counts in the lower counting window of 50–100 channels and these counts increase with increase in mass of the Li₂CO₃ powder. There is no interference of chemiluminescence in the window of 100–200 channels, which results in constant value of MDA. Henceforth all calculations for thermal neutron flux are taken by considering the tritium activity in counting window of 100–200 channels.

Figure 5 shows tritium activity in the sample with increase in mass of the Li₂CO₃ powder (natural and enriched) for two different fluences which were

estimated by standard gold foil method. The thermal neutron flux calculated using Li₂CO₃ powder is shown in eq. (2).

$$\phi = \frac{(T * M)}{(A * W * \sigma * I * t * \lambda)} \quad (2)$$

where ϕ is the thermal flux, T the tritium activity in Bq, M the mol. weight of Li₂CO₃ (74), A the Avogadro number (6.023E23), W the weight of Li₂CO₃ powder in g, σ the thermal neutron cross section of Li-6 (980 barns), I the abundance of Li-6 (7.5% for natural and 32% for enriched), t the irradiation time in sec, and λ is the decay constant (sec⁻¹).

The thermal fluxes estimated for various masses of Li₂CO₃ powder are given

in Table 1. It is observed that thermal flux estimation using Li₂CO₃ powder varied by 4.2–8.2% compared to gold foil methods. Hence this method can also be used as a substitute for thermal flux estimation.

The MDA of liquid scintillation counting set-up was estimated to be 10 mBq in 100–200 tritium window range for 250 counting time (Figure 4). Using this MDA, the minimum thermal fluence that can be estimated using this methodology with different amounts of Li₂CO₃ powder (natural and enriched) is shown in Figure 6. As negligible decay takes place in tritium, minimum fluence can be achieved for very low fluxes and long irradiation time. In case of gold foil method, the

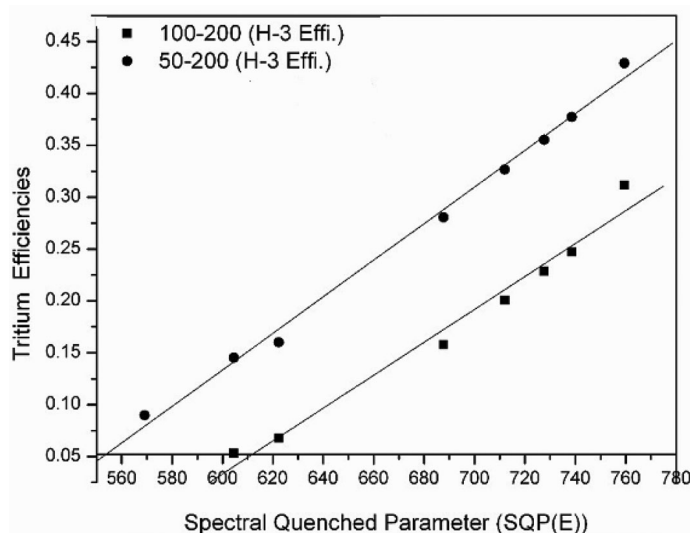


Figure 3. Calibration graph for various SQP values.

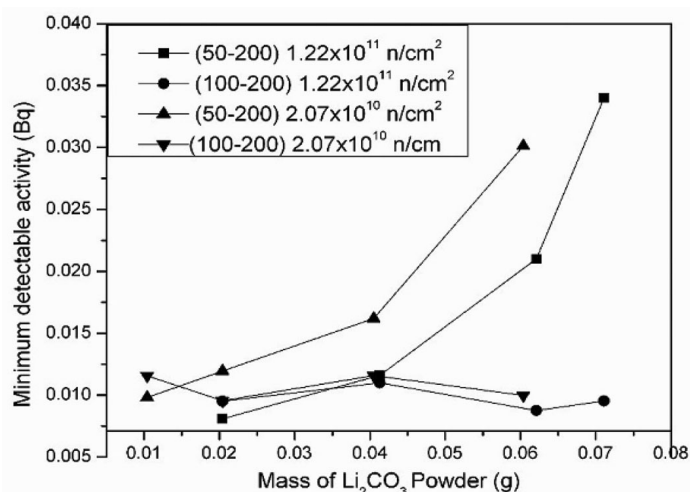


Figure 4. Minimum detectable activity with mass of Li₂CO₃ powder for the same counting time.

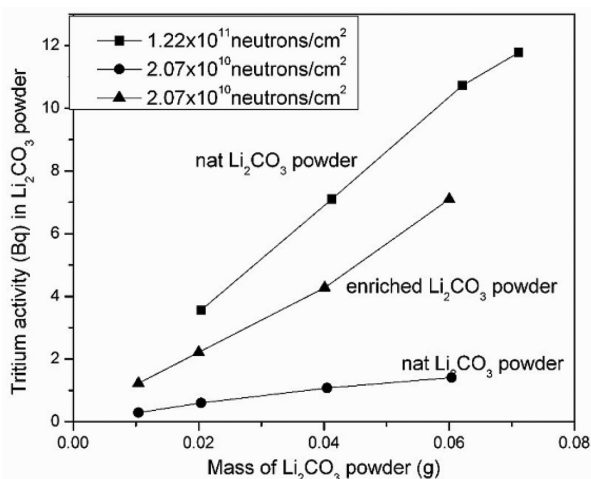


Figure 5. Calibration curve for tritium activity at two different neutron fluences.

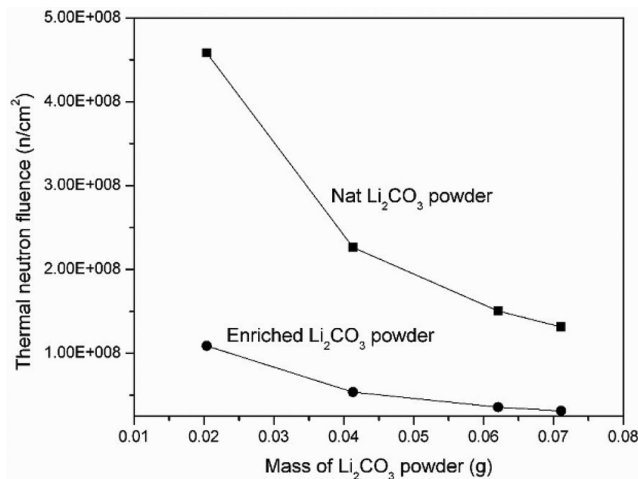


Figure 6. Minimum detectable neutron fluence with mass of Li_2CO_3 powder (g).

lower limit of thermal flux is about $1.1 \text{ E}6 \text{ n/cm}^2/\text{sec}$.

Thermal neutron measurements using Li_2CO_3 powder offer advantages such as low flux measurements, large cross-section and do not need immediate counting. The disadvantage is that the sample cannot be reused as in conventional standard gold foil methods. The minimum thermal fluence that can be measured using liquid scintillation is $1.31 \text{ E}8 \text{ n/cm}^2$ and $3.12 \text{ E}7 \text{ n/cm}^2$ for 70 mg of natural and enriched Li_2CO_3 powder respectively.

1. Dierckx, R., *Nucl. Instrum. Methods*, 1973, **107**, 397–398.

2. Sato, S., Ochiai, K., Hori, J., Verzilov, Y., Klix, A., Wada, M., Terada, Y., Yamauchi, M., Morimoto, Y. and Nishitani, T., *Nucl. Fusion*, 2003, **43**, 7–15.
3. Batistoni, P. *et al.*, *Fusion Eng. Des.*, 2005, **75**, 911–915.
4. Verzilov, Y., Maekawa, F. and Oyana, Y., *J. Nucl. Sci. Technol.*, 1996, **33**, 390–395.

ACKNOWLEDGEMENTS. We thank Dr D. N. Sharma, former Director Health, Safety and Environment Group, BARC, Mumbai for constant encouragement during the work. Thanks are due to Dr C. V. Srinivasa Rao, Dr Tejan Kumar Basu and Dr Shrichand Jakhar of the Institute for Plasma Research, Gujarat, for encouragement.

Received 18 February 2015; accepted 23 April 2015

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Biosynthesis of copper nanoparticles using aqueous extract of *Eucalyptus* sp. plant leaves

Nanobiotechnology is an enabling technology that deals with nanometer-sized materials in diverse fields of science such as biotechnology, nanotechnology, physics, chemistry and materials science. In addition to many physical and chemical methods which have been developed for preparing metallic nanoparticles, nanobiotechnology also serves as a significant technique in the progress of clean, non-toxic and environment friendly procedures for synthesis and assembly of metallic nanoparticles¹. The biosynthesis of nanoparticles has attracted attention of many researchers owing

to their physical and chemical processes being expensive and drastic reaction conditions. As a result, search for new inexpensive routes for synthesis of nanoparticles, scientists used microorganisms and plant extracts. Nature has devised diverse processes for synthesis of nano- and micro-length scaled inorganic materials which have contributed to the enhancement of fairly innovative and largely new area of research based on biosynthesis of nanomaterials². Among the metal nanoparticles, copper nanoparticles are potentially attractive, which may be due to their good optical,

electrical and thermal properties, superior strength, use as sensors, catalysts, and its bactericidal effect as antimicrobial and antifungal agents. Copper is highly toxic to microorganisms such as bacteria (*E. coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*) and non-toxic to animal cells, due to which it is considered an effective bactericidal metal. It is also considered safe for human beings for applications such as food package and in water treatment^{3,4}. Copper nanoparticles are attractive to many researchers due to its lower cost compared to noble metals such as Ag, Au and Pt.