MEASUREMENT OF THE ^{208}Pb$(n,\gamma)^{209}$Pb REACTION NEAR THERMAL NEUTRON ENERGIES

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The heaviest isotope that can be produced by the astrophysical s process is ^{209}Bi. Any subsequent neutron captures lead to α-unstable nuclei that are recycled to lower masses. Production of ^{209}Bi is inhibited in the s process by the very small neutron capture cross section of the doubly-magic ^{208}Pb nucleus. The abundances of the heaviest s-process isotopes are sensitive to the ^{208}Pb$(n,\gamma)^{209}$Pb cross section, but this cross section is uncertain owing to unmeasured contributions from both direct capture and low energy resonances. Additional studies of the ^{208}Pb$(n,\gamma)^{209}$Pb reaction are needed to understand nucleosynthesis near the end of the astrophysical s process.

We are currently studying the ^{208}Pb$(n,\gamma)^{209}$Pb reaction near thermal neutron energies. Although the astrophysical s process occurs at higher energies, the ^{208}Pb$(n,\gamma)^{209}$Pb cross section and capture γ-ray energy spectrum near thermal neutron energies help constrain calculations of the Maxwellian-averaged capture cross section at temperatures relevant for the s process, $kT = 6 - 30$ keV. Direct capture of p-wave neutrons that populates single-particle states in ^{209}Pb at $E_x = 1567$ (5/2$^+$), 2032 (1/2$^+$) and 2538 (3/2$^+$) keV is expected to dominate the ^{208}Pb$(n,\gamma)^{209}$Pb capture cross section for neutron energies below 15 keV, but no direct measurements have been made thus far in the lower incident neutron energy range in which the s process occurs.[2]

We have measured the ^{208}Pb$(n,\gamma)^{209}$Pb capture cross section at the National Institute of Standards and Technology's Center for Neutron Research using a cold ($T_n \cong 20$ K) neutron beam and a thin disk sample (2.3-g, 1.8-cm diameter) that is 99.8% enriched in the ^{208}Pb isotope. The capture γ-ray energy spectrum was measured using a Compton-supressed germanium detector, and the absolute capture cross section was determined relative to the 1262-keV and 3685-keV γ-ray lines from a graphite standard that was measured simultaneously. Part of the capture spectrum taken with the lead sample and graphite sample is shown in Fig. 1 along with a spectrum collected with the graphite sample alone to determine the background from scattered neutrons captured outside the ^{208}Pb sample.

It is expected that all capture level decay should cascade through the ground-state transition from the 1567-keV excited state of ^{209}Pb. The thermal equivalent cross section for the 1567-keV line (assuming the ^{208}Pb capture cross section to have the same $(1/v)$ energy dependence as ^{12}C) was found to be substantially smaller than the 490 ± 30 μb previously measured by activation.[3] In addition to the 1567-keV ground-state transition, we were also able to identify seven other transitions from the ^{208}Pb$(n,\gamma)^{209}$Pb reaction. The strength of the 1567-keV ground

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[2]T. Rauscher *et al.*, *Phys. Rev. C* **57**, 2031 (1998).

[3]J. F. Emory, ORNL-4343, 71 (1968).

state transition is consistent with the total strength of the 7 other gamma ray lines, and we see no evidence of any other ground state transitions.

We recently collected data in a second run using only the ^{208}Pb sample with an improved detector and no graphite sample. This run resulted in improved signal-to-noise and should allow us to eliminate other ground state transitions as contributing significantly to the capture cross section. Analysis of the data from this second experiment is in progress. The improved spectrum will allow us to determine more accurately the individual capture strengths. In a run next year we will measure the capture cross section with a thermal neutron beam to establish the energy dependence of the capture cross section at thermal energies. In addition to testing the theoretical models, this will also allow us to evaluate the feasibility of direct measurements up to and including astrophysical energies using the ORELA white neutron source.

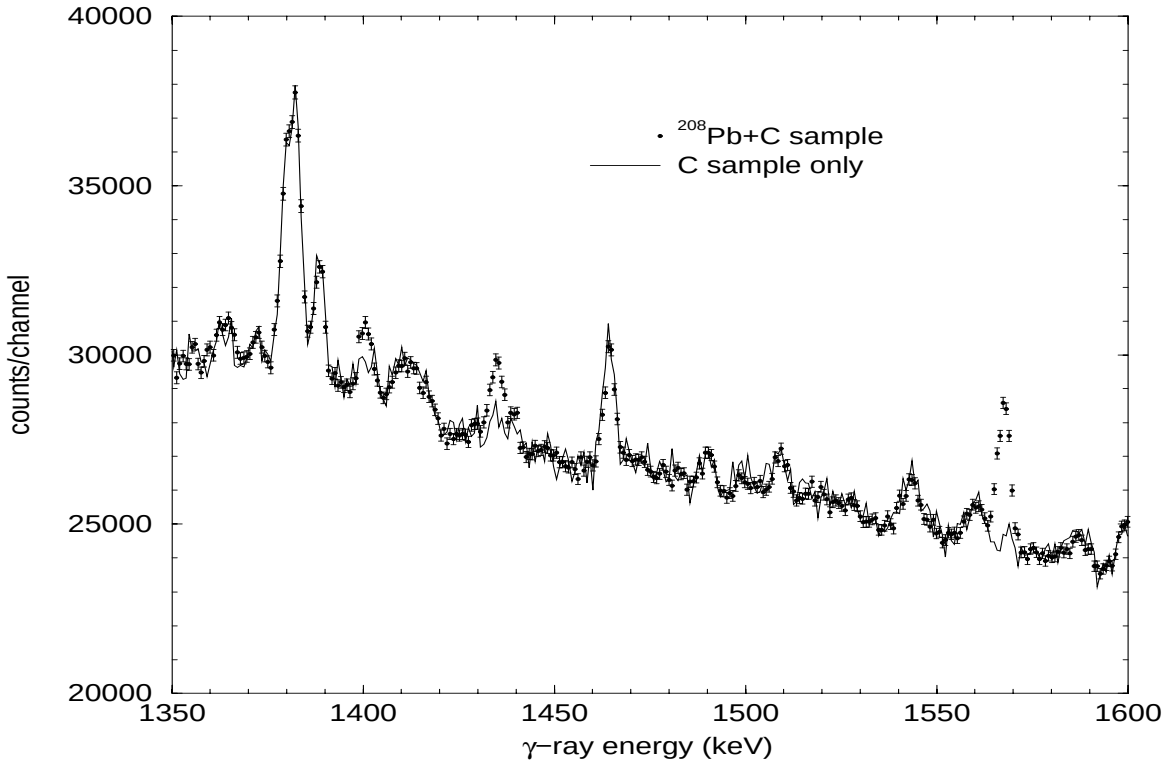

Figure 1: Capture γ-ray energy spectrum taken with the ^{208}Pb and graphite sample, and a spectrum taken with the graphite sample alone. The peaks at 1399 keV and 1567 keV are ^{208}Pb$(n,\gamma)^{209}$Pb capture lines.