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Stephen M. Lane and Michael B. Nelson

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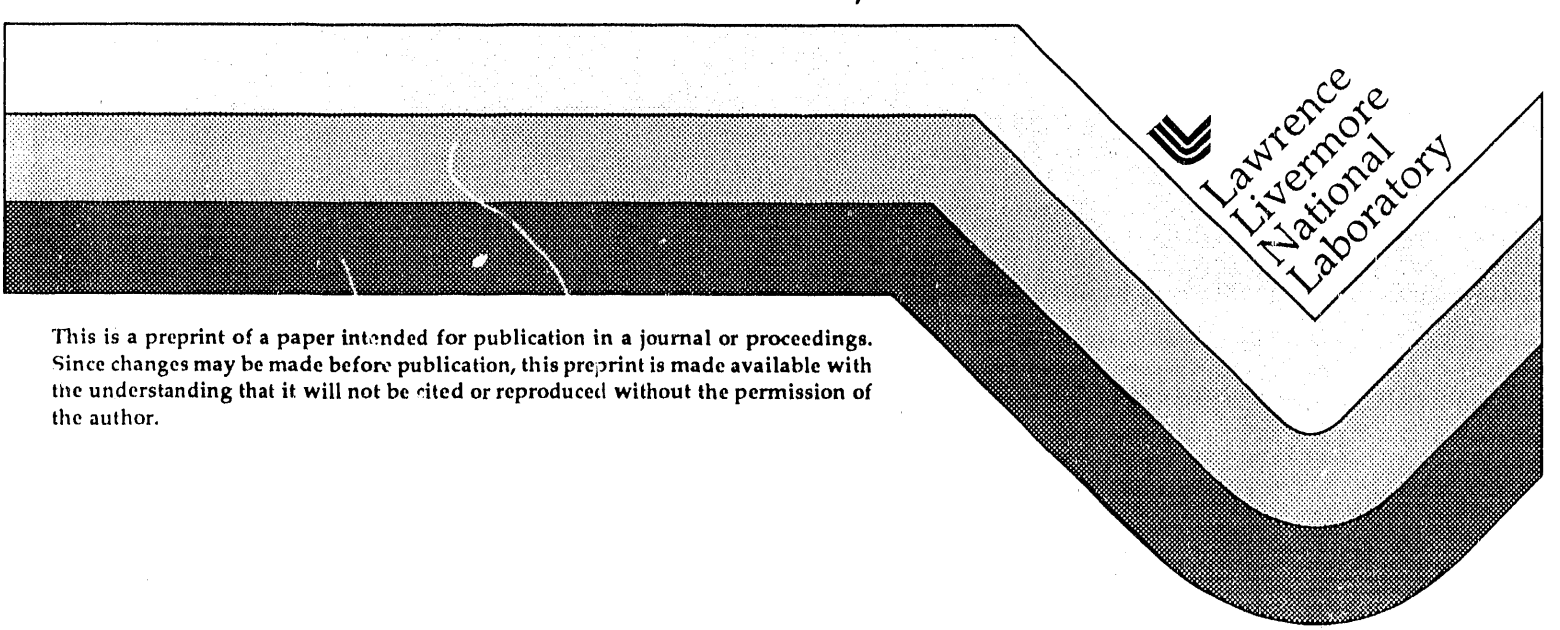

A technique for shell compression measurements of laser fusion targets by neutron activation of a rubidium tracer

Stephen M. Lane and Michael B. Nelson

Lawrence Livermore National Laboratory, Livermore, California 94550

At the Nova Laser, the activation of a rubidium tracer incorporated in the shell of ICF targets has become a standard diagnostic technique for measuring the compressed shell areal density $\langle \rho \Delta R \rangle$. The isotope ^{85}Rb is activated by 14 MeV implosion neutrons to produce the isomer ^{84m}Rb ($t_{1/2}$ = 20.5 min) which is used to determine the shell $\langle \rho \Delta R \rangle$ while the radioactive isotope ^{86}Rb ($t_{1/2}$ = 18.8 d) is used to determine the fraction of target debris collected as well as to assay the amount of rubidium in the target. The $^{85}Rb(n,2n)^{84m}Rb$ cross-section at 14.1 MeV was measured (σ=0.514±0.080 b). Details of the detector system and experimental technique are given.

I. INTRODUCTION

The measurement of the neutron averaged areal density $<\rho\Delta R>$ of the compressed pusher of an ICF target by neutron activation has become a well established technique.[1-5] Its implementation involves the activation of one or more elemental constituents of the pusher by 14 MeV neutrons produced in an implosion. Pusher debris containing these activated atoms is then collected on metal foils placed near the target. These foils are transferred to a radiation detector that measures the individual activity levels. The $<\rho\Delta R>$ is determined from the expression

$$<\rho\Delta R> = \frac{C\,A}{\sigma\,Y\,N_o\,f\,\eta_C\,\eta_D\,e^{-\lambda t_d}\left(1-e^{-\lambda t_c}\right)} \tag{1}$$

where C is the number of detected counts, A is the average atomic weight of a pusher atom, σ is the activation cross-section, Y is the neutron yield, N_o is Avogadro's number, f is the fraction of atoms of the isotope to be activated compared to the total number of pusher atoms, η_C is the fraction of activated atoms collected, η_D is the detection efficiency, λ is the decay constant, t_d is the time to load the detector, and t_c is the counting time. The angle brackets indicate the measured value is an average weighted by the neutron production rate as well as an average over all neutron paths through the shell.

Previous $<\rho\Delta R>$ activation measurements have mostly used the ^{28}Si (n,p) ^{28}Al reaction on microshell targets made of either glass[1-4] or silicon-doped plastic.[5] The principal deficiency of this technique is that the fraction of Al collected (η_C) cannot be measured directly. One must therefore

either measure the Al collection fraction by comparison with some other method of determining $<\rho\Delta R>$ and then assume η_C is constant from shot-to-shot, or, as is more commonly done, the Al collection fraction is inferred by assuming that it is equal to the measure collection fraction of ^{24}Na, a common radioactive tracer in irradiated glass shells. Although under some conditions these assumptions are reasonable, at Nova, under certain conditions, the amount of Na collected varies from shot-to-shot by as much as a factor of 6 and, furthermore, the Al (inferred from Rb $<\rho\Delta R>$) and Na collection fractions can differ from each other by as much as a factor of 2.

An extension of this activation method that does not suffer from these collection problems uses natural rubidium as the tracer. Both natural isotopes of Rb undergo (n,2n) reactions with 14.1 MeV fusion neutrons resulting in the activation products $^{84, 84m, 86, 86m}Rb$. The isomers, ^{84m}Rb ($t_{1/2}$ = 20.5 min) and ^{86m}Rb ($t_{1/2}$ = 1.02 min), have half-lives short enough to allow reasonable count rates for making the shell $<\rho\Delta R>$ measurement. By irradiating the target with reactor produced thermal neutrons prior to the implosion experiment, the radioactive tracer ^{86}Rb ($t_{1/2}$ = 18.8 d) is formed throughout the shell. Comparing the ^{86}Rb activity in the target before the implosion to the activity on the collector foils after the implosion gives the fraction of rubidium that was recovered. Thus the same element is used for both the $<\rho\Delta R>$ measurement as well as the collection fraction determination. As a further benefit, the ^{86}Rb shell activity can be compared to that of a RbCl flux monitor to accurately assay the Rb content in the shell.

II. DECAY SCHEME AND CROSS-SECTION FOR ^{84m}Rb

The most probable reactions (excluding elastic and inelastic scattering) of 14 MeV neutrons with Rb are (n,2n) reactions. Relevant properties of the (n,2n) reaction products from Refs. 6-

8 are listed in Table 1. The decay scheme for ^{84m}Rb, the reaction product we find most convenient to use, shows the three gamma rays emitted by the decay of the isomer (Fig. 1). Because internal conversion competes with gamma emission there are 6 separate decay modes as listed with their relative probabilities in Table 2.

There is a large variation among the measurements of the 14.1 MeV ^{85}Rb(n,2n)^{84m}Rb cross-section.[9] We remeasured it using our neutron generator facility which produces a well characterized source of 14 MeV neutrons by directing a 200 keV deuteron beam onto a tritiated Ti-on-Cu target. The number of DT neutrons produced was monitored using an absolutely calibrated silicon charged-particle detector that counts the DT alpha particles emitted from the accelerator target. RbCl samples (0.5 g) were irradiated with a flux of 10^5n/cm^2-s for 20 minutes at positions 4-8 cm from the neutron source and at angles of 0, 30, 45, 75, and 90 degrees to the incident beam direction. Small corrections were made for the angular spread of neutrons across the sample, neutron scattering in the tritium target and in the RbCl sample, and attenuation of gamma ray leaving the sample. The ^{84m}Rb produced in the sample was then counted in the absolutely calibrated gamma detector described in the next section. The value of our measured cross-section was 0.514±0.080 b which is close to the average of previous measurements compiled in Ref. 9.

III. GAMMA-RAY DETECTION

A pair of coaxial high-purity intrinsic-germanium well detectors are used to count the gamma rays emitted by the collected rubidium. These detectors have an active volume of 145 cm^3

each and are operated in a face-to-face geometry (Fig. 2) with the collector foils wound onto a lucite spindle and placed entirely inside the 1.5 cm diameter, 4 cm deep wells, thus providing nearly 4π detection solid angle. Resolution in the 100 to 500 keV energy range is approximately 2.2 keV FWHM. The detectors are operated independently, but with the gains matched so that the 4096 channel pulse height spectra from the two detectors can be summed for analysis after the experiment. A typical summed gamma spectrum is shown in Fig. 3.

When the 248 keV and 216 keV gamma rays are emitted in cascade, they cannot be resolved temporally and therefore produce summing effects which prevent the absolute detection efficiency from being determined in the usual way which is to use calibrated sources that produce photopeaks in the energy range of interest. Instead, we developed a 3-step calibration procedure. First a ^{152}Eu NBS standard source (1 μCi) was used to calibrate each detector at a position 20 cm away from their front faces in order to remove the effects of summing. The next step was to produce ^{84m}Rb activity (typically 5-10 nCi) in a 0.5 g cylindrical plug of compressed RbCl powder using our 14 MeV neutron generator facility. This sample was then counted in the 20 cm position to determine its absolute activity (by comparison to the Eu-152 source). The final step was to count the sample at various positions in the detectors. The efficiency for counting ^{84m}Rb at these positions for the three photopeaks was then determined from the peak area divided by the source strength as shown in Fig. 3. Accurate peak areas were obtained for all spectra using the peak fitting code MICROSAMPO[10,11] run on an IBM-AT personal computer.

IV. RUBIDIUM ASSAY

To accurately estimate $<\rho\Delta R>$, the initial amount and distribution of Rb in the shell must be known. The distribution of Rb in glass shells is assumed to be uniform. This assumption is consistent with elemental analyses using characteristic x rays produced by a tightly focussed electron micrograph beam to interrogate different locations on the exposed wall of a hemispherical shell.

The absolute amount of Rb is determined by comparing the ^{86}Rb activity in a shell to the ^{86}Rb activity in a RbCl flux monitor that was irradiated in close proximity to the shell. This is accomplished in the following way: Four target shells are irradiated in a reactor-grade graphite holder for approximately 4 hours in a thermal neutron flux of 9×10^{13} n/cm^2-s at the Los Alamos Omega West Reactor. Each holder also contains 4 1.5 mm x 1.5 mm hollow cylindrical flux monitors made of Epon 826 epoxy and Versamid 140 catalyst. (Irradiated empty epoxy cylinders produced insignificant amounts of radioactivity and showed no evidence of contamination from trace amounts of Rb in the epoxy.) Before sealing, each cylinder is filled with 1/2 microliter of a dilute (50:1) aqueous RbCl solution which is evaporated to dryness. This technique produces nearly identical (±2%) flux monitors containing an accurately known quantity of rubidium (7.1 μg) that is comparable to the amount contained in the target and consequently produces a level of activity nearly the same as the target thus allowing the two to be counted in the same physical location in the detector. We find, for instance, that in microshells used for direct-drive implosions[12], 1% of the atoms in the shell are Rb atoms.

V. SHELL $<\rho\Delta R>$ MEASUREMENTS

The debris collector is 25 μm thick titanium foil formed into a cone (4 cm dia. x 8 cm length) and is placed 5 cm from the target where typically 2% to 6% of the rubidium is collected. The foil is recovered from the target chamber, transferred to a counting lab, and loaded into the detector assembly. Transfer and loading takes 1-2 minutes. The counting data are collected from each detector in 10 consecutive 1-minute 4096 channel spectra followed by 10 10-minute spectra to accommodate the half-lives of the various activities contained in the target debris. (Typically the following activities can be observed following a direct-drive glass implosion: ^{84m}Rb (20.5 min), ^{86m}Rb (1.02 min), ^{86}Rb (18.8 d), ^{28}Al (2.24 min), ^{29}Al (6.6 min), ^{24}Na (15.02 h), and ^{42}K (12.36 h).) The collector foil is then divided into sections (usually 5) which are counted individually using ^{86}Rb to determine the fraction of Rb collected η_D as well as the distribution of debris on the foil. This distribution is then used along with the position-dependent detection efficiency (Fig. 3) to calculate an average detection efficiency η_C. Finally, the total ^{84m}Rb counts C in a 40 minute period starting 10 minutes after the shot (to allow time for background from ^{28}Al to decay) is used to compute the shell $\langle\rho\Delta R\rangle$ value using Eq. 1. The natural background (~1 cpm) is subtracted from the total counts as is a comparable contribution due to Compton events from ^{86}Rb and ^{24}Na gamma rays. The $Y\langle\rho\Delta R\rangle\eta_C$ product required to produce a statistically significant number of counts (about 30) is approximately 5×10^8.

VI. CONCLUSION

The activation of natural rubidium has become a standard implosion diagnostic technique at the Nova Laser Facility for measuring the compressed shell $\langle\rho\Delta R\rangle$. It has supplanted the silicon

activation technique because of the advantages of a direct collection fraction measurement and the accurate assay of Rb content of individual shells. The disadvantages are that it is less sensitive as than the Si technique, it demands that a high-Z material be placed in the shell which can be undesirable from a target design standpoint, and it requires multi-hour irradiations in a reactor which may damage shells made of plastic.

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Table 1. 14 MeV Neutron Activation Characteristics of Rubidium

	^{85}Rb		^{87}Rb	
Natural Abundance (%)	72.17		27.83	
Reaction	(n,2n)		(n,2n)	
Reaction Product	^{84}Rb	^{84m}Rb	^{86}Rb	^{86m}Rb
Threshold (MeV)	10.49	10.95	10.48	11.03
Cross-Section (mb)	1130	450	620	520
Half-life	32.77 d	20.5 min	18.82 d	1.02 min
Gamma-1 Energy (keV)	882	216	1077	556
Gamma-1 Intensity (%)	74	34	8.79	98.2
Gamma -2Energy (keV)		248		
Gamma-2 Intensity (%)		63		
Gamma -3 Energy (keV)		465		
Gamma -3 Intensity (%)		31		

Table 2. Decay modes of ^{84m}Rb derived from γ intensities and IC coefficients in Ref. 8.

Decay Mode	465→Grnd	465→248	248→Grnd	Rel. Probability
1	γ			0.310
2	IC			0.050
3		γ	γ	0.332
4		γ	IC	0.008
5		IC	γ	0.293
6		IC	IC	0.007

γ = gamma emission; IC=internal conversion

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