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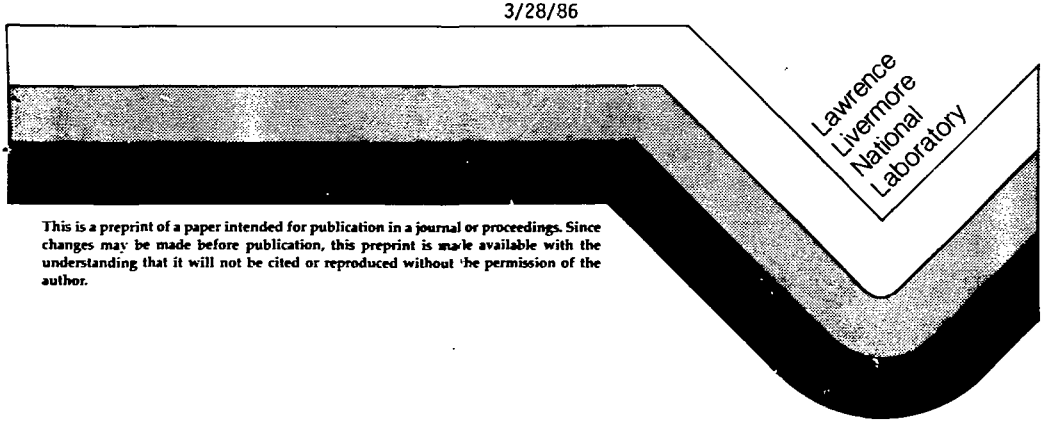

DEBRIS COLLECTION FROM IMPLOSION OF MICROBALLOONS*

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ABSTRACT Recovery of krypton from implosion of glass microballoons has been studied in the development of a radiochemical diagnostic for determination of $\langle \rho r \rangle_{fuel}$. Collection onto metal surfaces following implosions performed on the OMEGA laser with 1-3 TW (1-2 kJ) of 0.35 μm light is consistent with an ion implantation mechanism. The dependence of the intrinsic collection efficiency on the energy fluence to the collector surface and its variation in implosions carried out under the same nominal conditions indicate ion energies extending to at least 0.1 MeV and energy distribution functions that are sensitive to the details of the implosion dynamics. Intrinsic sticking efficiencies approaching 0.5 can be obtained in the limit of low total energy fluence to the collector surface ($\leq$ 0.1 J cm^{-2}).

INTRODUCTION

The direct measurement of $\langle \rho r \rangle_{fuel}$ in ICF implosion experiments has been accomplished by detection of the high-energy deuterons and tritons (knock-ons) that arise from elastic scattering of 14 MeV neutrons in the D-T fuel[1]. This method is limited to low areal densities of the fuel and ablator/pusher (< 0.1 gm cm^{-2}).

We have been investigating a number of the parameters governing the collection of krypton debris from implosions of glass microspheres for the purpose of developing a radiochemical diagnostic that can accommodate higher $\langle \rho r \rangle_{fuel}$ and moderate fusion yields[2]. The method is based on the reaction

$$^{80}Kr(n,2n)^{79}Kr$$

produced by interaction of 14 MeV D-T neutrons with trace quantities of krypton that are added to the fuel. The reaction has a cross section of 0.415 b[3] and for $\langle \rho r \rangle_{fuel} \geq 0.05$ gm cm^{-2} and a neutron yield greater than 10^9, a concentration of 0.1 atom percent ^{80}Kr in the fuel could suffice for the method if at least 1% of the ^{79m}Kr atoms formed in the implosion are collected and counted.

The choice of krypton was dictated by the requirement that the tracer be chemically inert with respect to possible shell materials (e.g., glasses, plastics, etc.) and by the desire to have a diagnostic applicable to cryogenic targets. The presence of high-Z material in the fuel at these concentrations is significant but is not expected to greatly affect the implosion physics.

The principal difficulty in the development of the diagnostic is the collection of krypton following an implosion. Due to the absence of chemical binding, the only readily applicable methods are cryogenic absorption, implantation into a substrate after acceleration in an applied field or direct implantation using the kinetic energies of the ions in the expanding plasma formed in the implosion.

COLLECTION EFFICIENCY

We have studied the characteristics of direct collection of krypton onto various metal surfaces following implosions of glass microballoons filled with natural krypton using 1-3 TW of 0.35μm light from the OMEGA laser of the University of Rochester's Laboratory for Laser Energetics (URLLE). The laser pulse was nominally Gaussian in shape with a width of 600 ps. The total energy on target (1-2 kJ) was delivered in 12 or 24 beams. The targets were

typically 1-2 μm thick shells 300-400 μm in diameter filled to a pressure of 3-7 atm. The targets had been irradiated with thermal neutrons to produce the 4.48 hr ^{85m}Kr which served as radioactive tracer for determination of collection efficiencies. The materials tested as collectors were either $(1-5)\times10^{-3}$ cm thick foils of aluminum, titanium, beryllium and zirconium or 1-5 μm thick layers of aluminum and titanium deposited onto foil backings by sputtering. The collectors were located at 10-20 cm from the target and the angle between the surface normal and the radius vector from the target to the collector midpoint was varied between 0° and 80° to affect a large range in total energy fluence on the collector.

The intrinsic collection efficiency for krypton, ϵ, - defined as the fraction of ions incident on a surface that are collected - was estimated by comparison of the ^{85m}Kr activity on a collector with the initial activity in the microballoon. The surfaces showing the highest collection efficiencies were titanium and aluminum and the data obtained with these materials are shown in figure 1 as a function of the total energy fluence to the collector surface. The latter includes all energy sources radiating from the target (i.e., particle kinetic energies, scattered laser light, x-rays, etc.). To obtain ϵ it has been assumed that all radiations are emitted isotropically following an

implosion. The scatter in the data is large. With the possible exception of the energy balance of the beams, no correlations with experimental parameters could be found to account for the variation in ϵ among seemingly comparable implosions. There was a tendency for ϵ to increase with greater imbalance in beam energies. Nevertheless, the data indicate a rough inverse variation of ϵ with increasing energy fluence and indicate that intrinsic collection efficiencies in the range 0.1-0.5 can be achieved with low total energy fluence to the collector surface ($\leq$ 0.1 J cm^{-2}).

SURFACE EROSION

The dependence of ϵ on energy fluence can be expected with an ion implantation mechanism if erosion of the collector surface is significant and if the target debris must penetrate the eroded material to reach an underlying stable surface. The large scatter in the collection efficiency is also consistent with an ion implantation mechanism if ion kinetic energies depend sensitively on the details of the implosion dynamics. The expected ranges of low-energy ^{84}Kr ions in titanium and aluminum are small. For reference, we show in figure 2 mean ranges for ^{84}Kr in titanium and carbon calculated in the low-temperature limit according to the formulation of electron and nuclear

stopping summarized in ref 4. (Ranges in aluminum lie between those shown in the figure.) For the mean energies expected from these implosions ($T_{ion} \leq 1$ keV), the depth of penetration at normal incidence is on the order of 100 Å. Thus, relatively small variations in ion energies and in the extent of surface erosion can produce large variations in ϵ.

To examine the effect of surface erosion, the thickness of titanium removed from a mirrored surface was measured. The mirrors were prepared by vacuum evaporation of Ti onto silicon wafers and one half of the surface was covered by a thick titanium foil to prevent exposure to radiation and target debris. The assemblies were located at a mean distance of 11 cm from the microballoons with the surface normal at an angle of 82° with respect to the target-collector radius vector. Following the implosions, the protective foil was removed and the step height between the original and eroded surfaces was measured with a profilometer. The results from two such experiments are shown in figure 3. For total irradiance in the range 0.8-1.2 GW cm^{-2}, corresponding to total energy fluences of 0.5-0.7 J cm^{-2}, surface thicknesses of 100-300 Å were removed. These results suggest that surface erosion may be the dominant factor limiting the collection efficiency for Kr. Reference to figure 2 indicates that ion energies on the order of 100 keV would be required for implantation

into a stable surface if the eroded material were present at the time of arrival of target debris. Crude estimates of maximum expansion velocities indicate that this is likely for ions with sufficient kinetic energy to imbed with high probability (≈ 0.2-0.5 keV). Although the range-energy correlations shown in figure 2 neglect ionization of the stopping medium, the maximum temperature of the eroded titanium is ≈ 10 eV and therefore the conclusions above are expected to be conservative [4].

ION ENERGIES

Some evidence that a fraction of the Kr ions from implosions has energies as high as 0.1 MeV was obtained in a series of experiments in which Ti foils covered with thin layers of formvar or carbon were placed adjacent to uncovered foils at target-to-collector distances sufficiently large that erosion of the exposed Ti surface was expected to be small ($I \leq 0.2$ J cm^{-2}). The relative collection fractions of the two parts of the collectors were determined. Under the assumption that any of the formvar and carbon lost from the surface was penetrated by the arriving ions, the fraction of Kr ions with energies exceeding that required to penetrate the cover foil was calculated. These data are shown in figure 4. Although

quite crude, the results are consistent with the assumption that a few percent of the ions from the implosions have kinetic energies in excess of 100 keV. These results are also consistent with the efficiency data in figure 1.

CONCLUSIONS

Implosion experiments with Kr-filled microballoons indicate that a scheme for direct collection of activated Kr from ICF implosions by ion implantation can be made viable if surface erosion can be minimized and if sufficiently high mean ion energies are produced. Additional experiments are being planned to obtain more conclusive information on ion energy distributions at URLLE, to demonstrate the direct measurement of $\langle \rho r \rangle_{fuel}$ with this method and to investigate the problems associated with Kr collection in implosions at the NOVA laser facility.

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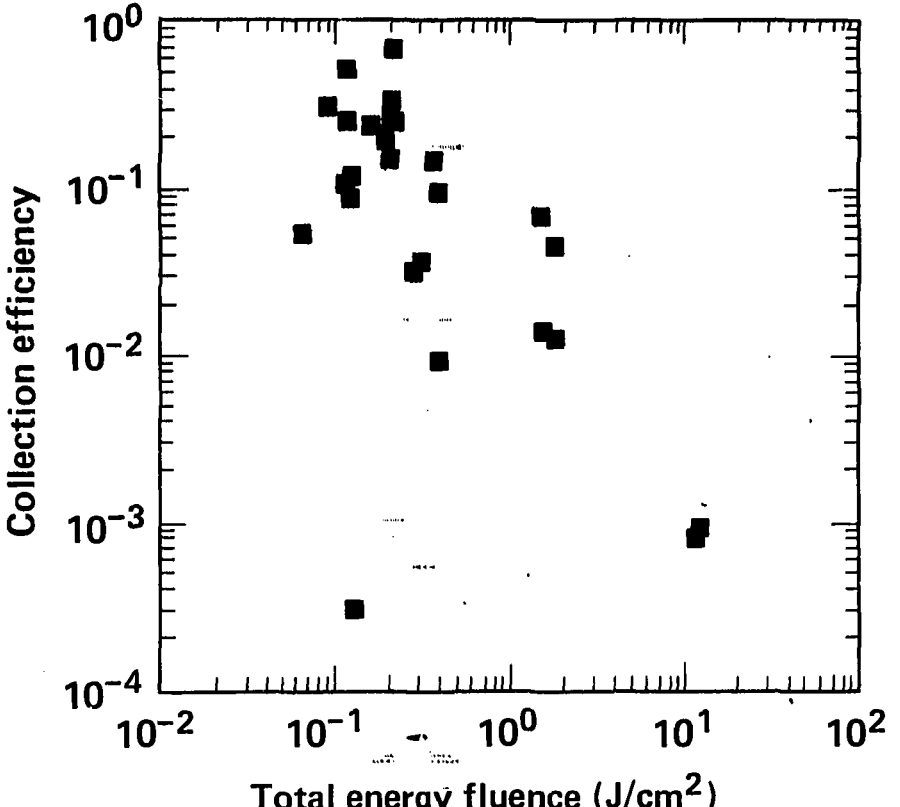
Figure Captions

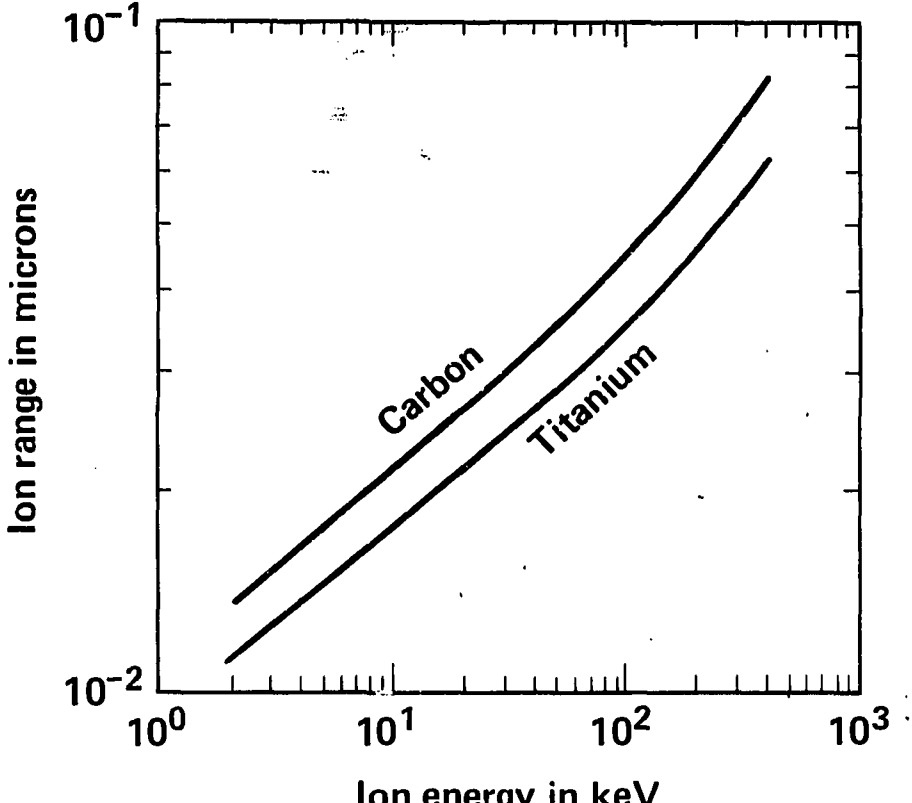
Figure 1. Intrinsic collection efficiencies for Kr ions versus total energy fluence to the collector surface. It has been assumed that all matter and radiation is emitted isotropically from the target. Statistical errors in the data are negligible compared to the scatter shown in the data.

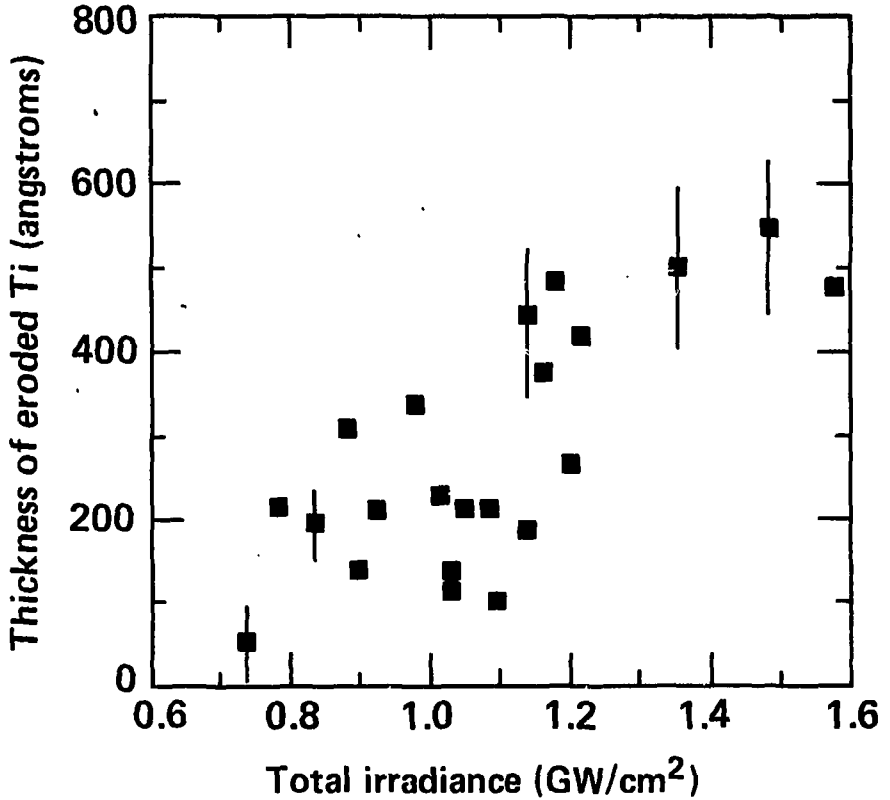
Figure 2. Range of ^{84}Kr ions in titanium and carbon in the low temperature limit. Ranges in aluminum lie between those shown.

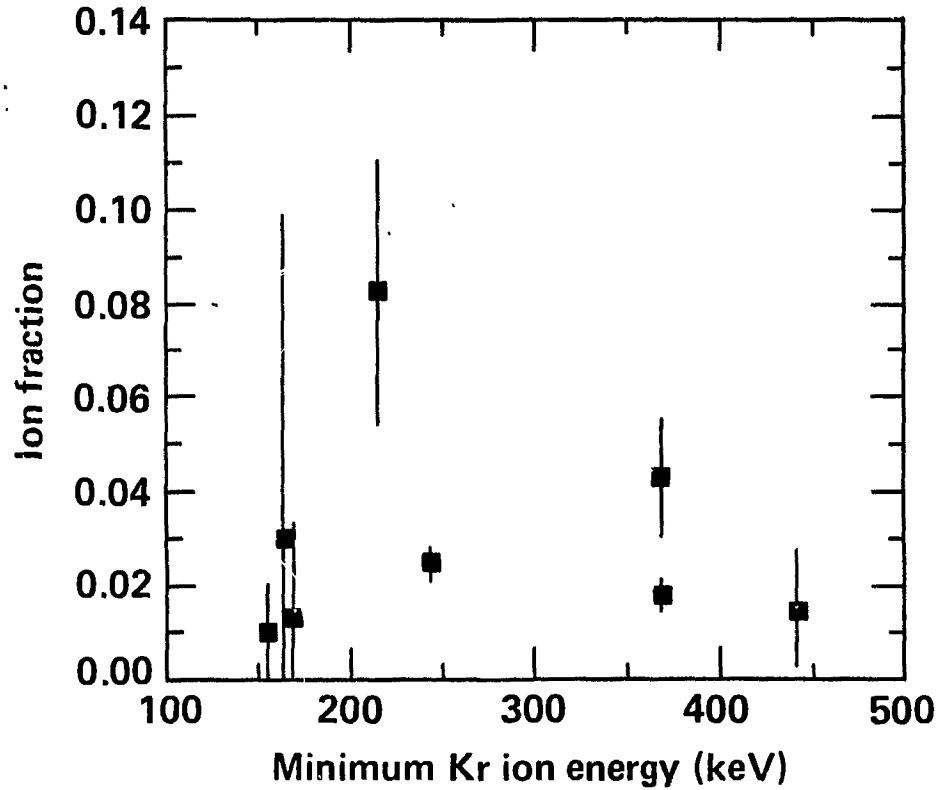
Figure 3. Thickness of titanium eroded from a mirrored surface versus total irradiance. Representative error bars are shown.

Figure 4. Estimated fraction of ^{84}Kr ions with energies exceeding abscissa values. The errors indicated are representative of total statistical errors in the measurements.


Collection efficiency
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Total energy fluence (J/cm^2)


10^{-1}
10^{-2}
Ion range in microns
Carbon
Titanium
10^0
10^1
10^2
10^3
Ion energy in keV


800
600
400
200
0
0.6
0.8
1.0
1.2
1.4
1.6
Thickness of eroded Ti (angstroms)
Total irradiance (GW/cm2)


0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Ion fraction
100
200
300
400
500
Minimum Kr ion energy (keV)