DISPERSION OF PROJECTILE AND TARGET DEBRIS UPON PENETRATION OF THIN TARGETS; D. Gwynn[1], R. P. Bernhard[2], T.H. See[2], and F. Horz[3]; [1]Lunar and Planetary Institute, [2]Lockheed-Martin Engineering & Sciences Services, [3]NASA -- Johnson Space Center, all in Houston, Texas 77058.

INTRODUCTION: We continue to conduct penetration experiments of thin foils to support the development of cosmic-dust flight instruments that utilize thin films for the measurement of particle trajectories, or for the potential soft capture of hypervelocity impactors for subsequent compositional analysis upon retrieval to Earth. Each experiment is equipped with a witness plate, mounted to the rear of the target and fabricated from soft $Aluminum_{1100}$, ~30 X 30 cm in size and ranging from 2 to 5 mm thick; these witness plates essentially simulate the rear wall of a capture cell onto which the projectile material will plate out, including material that is being dislodged from the penetrated foil itself. Using compositionally contrasting projectile and foil materials in the laboratory, such as soda-lime glass impactors and aluminum targets, one produces two distinct populations of craters on the witness plates. One set of craters has essentially transparent to gray interiors, reflecting the presence of silicate melts (*i.e.*, projectile fragments), and the other displays metallic, shiny crater interiors, indicating aluminum fragments dislodged from the target foil [2, 3]. Using these optical criteria, it is possible to establish that projectile and target fragments have distinctly different dispersion (as well as fragmentation) characteristics. Generally, the impactor materials are concentrated in the central portions of the debris plume, while dislodged target material preferentially resides at the periphery. Detailed documentation and quantification of this seemingly preferential concentration of projectile and target material within specific regions of the overall spray pattern provided the motivation for the experiments described below. Understanding of the systematic dispersion characteristics of projectile and target debris seems important, as it will ultimately guide and greatly facilitate the search for projectile residues on space-exposed substrates.

Although we are confident about our previous, optical assignments of fragment sources [2, 3], as they seem consistent also with time-lapse, X-ray shadow graphs of evolving debris plumes [4, 5], such source assignments remain highly interpretative and somewhat subjective. Verification and quantification via actual chemical analysis seemed desirable. Therefore, we conducted some dedicated experiments for detailed chemical analysis of representative witness-plate crater populations by SEM-EDS methods. The objective was to analyze the impactor residue in a large number of witness-plate craters to more rigorously test and verify the "optical" criteria.

The set of dedicated experiments employed soda-lime glass spheres of 3.2 mm diameter (D_p) at 6 km/s, Al_{1100} target membranes of thickness T = 1 mm, and Cu-witness plates, such that compositional analysis of Al-fragments became possible. The only variable in the present experiments was the stand-off distance (L = 6, 12 and 49 cm) of the witness plate relative to the target's rear surface to permit increasingly larger geometric dispersion, and thereby improved spatial resolution and separation, of the resulting projectile and target debris plumes.

RESULTS: Figure 1 illustrates witness plates at L = 6 and 49 cm, respectively. Prior to SEM analysis we (1) digitized the location (x/y coordinates) of a representative crater population per each witness plate, (2) measured the crater size, and (3) performed optical assignments into projectile- or target-source of the impactors. Such optical data permit characterization of the size distribution of both projectile and target debris as a function of geometric dispersion angle for the entire debris plume, provided the optical source assignment is verified by SEM-EDS.

The large witness plates were then subdivided into 2 X 2 cm samples representing typical radial ranges of the witness plate for analysis by SEM-EDS. A total of 724 individual, representative craters were selected for elemental analysis (Si or Al). Only 10 craters (~1.5 %) were incorrectly assigned optically on the basis of color. However, EDS analysis suggested that an additional 14 craters (~2%) contained both projectile and target material, which was not recognized and differentiated optically. As a result, optical differentiation of projectile and target debris is clearly possible, if chemically contrasting projectiles and targets are being employed. It is also very clear that the major hole-saw ring (R_1 in Figure 1) is due to projectile fragments and that some rings (*e.g.*, R_2 and R_3) can be exclusively due to target debris.

The experiments at L of 12 and 48 cm immediately revealed that the R_1 ring is not caused by solid fragments, as we had suggested earlier [2], but that it is due to molten debris, as it is an integral part of the "spider-web" pattern typical for the central portions of the debris plume at D_p/T of 0.5 to 5 (at the above initial conditions). Similar experimental patterns were reported earlier [6] and are, in part, observed from space-produced penetrations as well [7, 8]. Clearly, these patterns reflect the astoundingly regular (and reproducible) dispersion of a central mass of molten projectile material. Filaments and stringers of melt impinge at sufficiently high velocity to cause gauges and compound, linear depressions in the witness plate. These features are clearly erosive structures, not surface deposits. Invariably, a relatively large melt volume occupies each intercept of individual stringers, causing a distinct crater to

form; the latter is typically of highly irregular outline and frequently characterized by a small number of subsidiary depressions that are separated by discrete septa. These "compound" craters reflect impactors of heterogeneous mass distribution (*i.e.*, small melt droplets in various stages of disaggregation). The R_1 ring typically consists of elongated and tangentially aligned, "compound" craters as well, again suggestive of melt droplets in the process of disaggregation. The latter melt droplets are larger than those located at stringer nodes, are of relatively uniform size, and of highly regular, azimuthal separation. The R_2 and R_3 rings are relatively circular craters without subsidiary depressions, reflecting equant-shaped aluminum fragments of homogeneous mass distribution; indeed these attributes characterize all aluminum craters, even those closer to the plume axis.

CONCLUSION: Optical assignment of projectile and targets sources is possible on experimental witness plates produced by millimeter-sized impactors. The present investigation extends and substantiates our earlier work which suggested that dispersion characteristics of debris plumes depend systematically on absolute target thickness [2, 3].

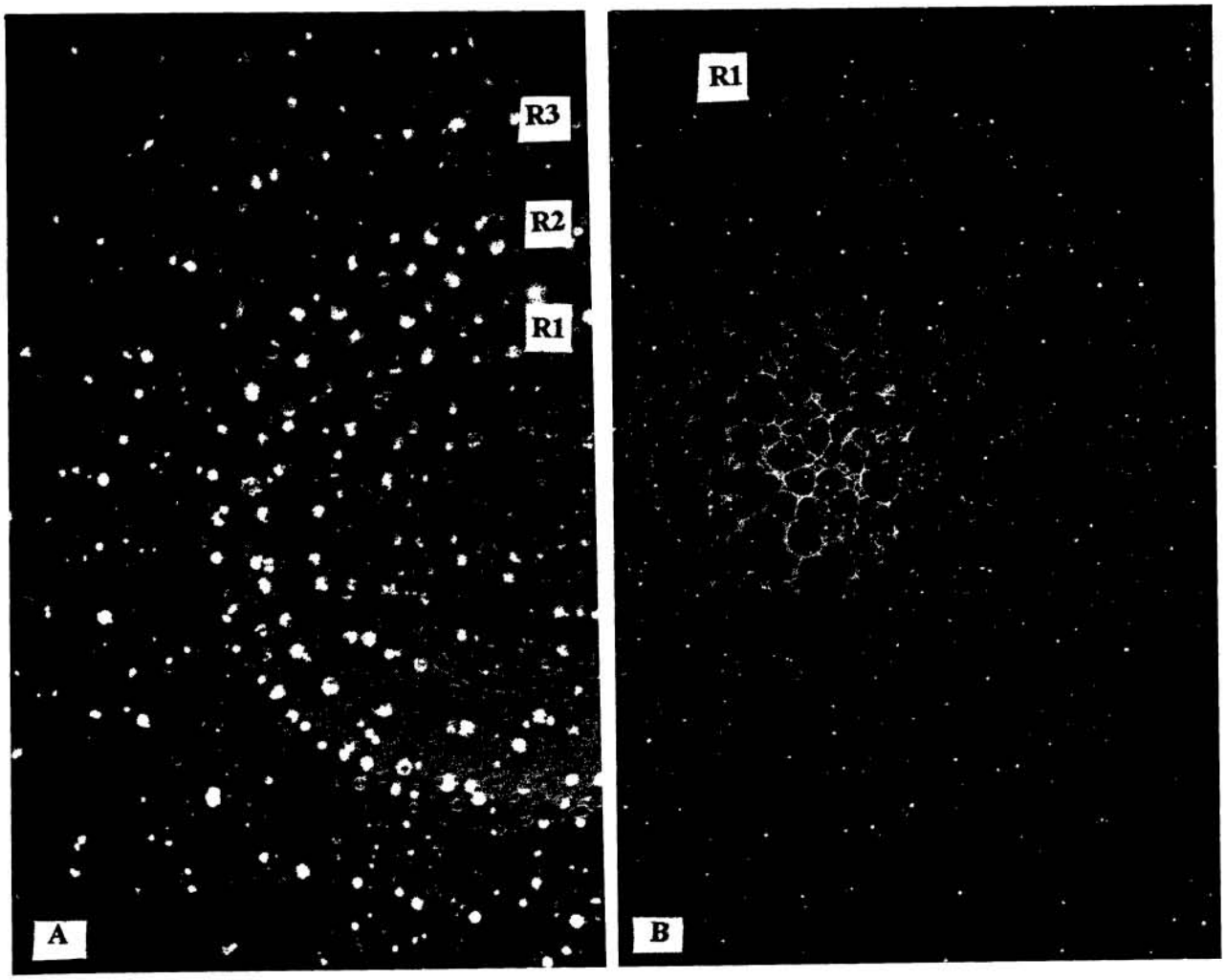

Figure 1. Typical witness-plate patterns produced at L = 6 cm (a) and L=48 cm (b). Scale: the diameter of R_1 is ~3 cm in (a) and ~23 cm in (b).

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