AIIM

Association for Information and Image Management
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

mm

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

DOE/SF/19201 - T1

FINAL REPORT

NATIONAL LASER USER'S FACILITY GRANT DE-FG03-92SF19201

UNIVERSITY OF ROCHESTER

LABORATORY FOR LASER ENERGETICS

TITLE: Fusion with Highly Spin Polarized HD and D_2

Principal Investigator: Arnold Honig, Physics Dept, Syracuse Univ

Co-Investigators at LLE: Sam Letzring and Stanley Skupsky

Period: January 2, 1992 - June 30, 1993.

Dec. 17, 1993

ABSTRACT

Our experimental efforts over the past 5 years have been aimed at carrying out ICF shots with spin-polarized D fuel. We successfully prepared polarized D in HD, and solved the problems of loading target shells with our carefully prepared isotopic mixtures, polarizing them so that the D polarization remains metastably frozen-in for about half a day, and carrying out the various cold transfer requirements at Syracuse, where the target is prepared, and at Rochester, where the cold target is inserted into the OMEGA fusion chamber. A principal concern during this past year was overcoming difficulties encountered in maintaining the integrity of the fragile cold target during the multitude of cold-transfers required for the experiment. These difficulties arose from insufficient rigidity of the cold transfer systems, which were constrained to be of small diameter by the narrow central access bore of the dilution refrigerator, and were exacerbated by the multitude of required target shell manipulations between different environments, each with different coupling geometry, including target shell permeation, polarization, storage, transport, retrieval and insertion into OMEGA. We did solve all of these problems, and were able to position a cold, high density but unpolarized target with required precision in OMEGA. (A polarized target was precluded because of the deterioration of OMEGA, in its closing year, with respect to helium leakage from its own shroud into the tank). Upon shooting the accurately positioned unpolarized high density cold target, no neutron yield was observed. Inspection inside the

OMEGA tank after the shot indicated the absence of neutron yield was due to mal-timing or insufficient retraction rate of OMEGA's fast shroud mechanism, resulting in interception of at least 20 of the 24 laser beams by the faulty shroud. In spite of this, all elements of the complex experiment we originally undertook have been successfully demonstrated, and the cold retrieval concepts and methods we developed are being utilized on the ICF upgrades at Rochester and at Livermore. Our polarized fusion experiments are ready for application upon Rochester's upgrade completion, and the polarized targets are meanwhile being used in other fusion, nuclear and particle physics experiments currently in progress. In addition to the solution of the interface problems, we obtained novel results on polymer shell characteristics at low temperatures, and continuation of these experiments is currently supported by NLUF. Extensive additional mappings were carried out of nuclear spin relaxation rates of H and D in solid HD in the temperature-magnetic field range of 0.01 to 4.2K and 0 - 13 Tesla. New phenomena were discovered, such as association of impurity clustering with very low temperature motion, and inequality of the growth-rate and decay-rate of the magnetization.

I. INTRODUCTION

For the past 5 years, we have carried out a program to investigate ICF on polymer target shells loaded with polarized D fuel in solid and gaseous HD, and high density unpolarized D fuel in solid and gaseous HD and D_2. The target shells are filled and processed at Syracuse, transported cold to Rochester, and loaded cold into the OMEGA fusion chamber, at liquid helium temperatures for polarized targets, and at temperatures between liquid helium and liquid N_2 for high density unpolarized D targets. The principal motivation for this project is the expected increase in reaction yield[1] for polarized DT, which results in reducing the laser driver energy by a factor of about 2 to achieve the same gain[2] as with unpolarized fuel. Other benefits of polarized D fusion fuel, such as favorable reaction product anisotropies and possible D - D reaction suppression for a neutronless D -^{3}He reactor, are also of interest. A further motivation was to develop cold-transfer methods (liquid helium temperatures), which is an absolute necessity for the polarized fuels, and important for high density unpolarized solid hydrogens fuels as well.

In order to carry out this program, means of polarizing the deuteron and maintaining the polarization after removal from the 10 mK dilution refrigerator and 13 Tesla magnetic field had to be developed[3-5], and cryogenic procedures never before undertaken had to be invented and implemented. These included cold-transport[6] (equivalently referred to as cold-entry and cold-retrieval) of samples at temperatures near 4K, above which depolarization would rapidly take place, permeation of polymer targets with the correct isotopic composition for the polarization method to operate efficiently[7], and permeation into polymer target shells of high pressure pure HD gas, followed by cryocondensation, transport, and utilization as a solid, or as a high density, low temperature gaseous ICF target. These aspects were accomplished and described in detail in our previous final report[8]. This past year, improvements insuring reliable survivability of the target have been implemented, resulting in mating an unpolarized frozen sample to the LLE OMEGA fusion chamber, centering the target, exchanging shroud enclosures, and carrying out a full laser shot. Other accomplishments included completion and testing of the dilution-refrigerator cold-retrieval system, essential for employment of polarized targets. "Cold-brushes" for cooling the outer tube of the dilution refrigerator cold-transport system to temperatures near 4K and thereby improving the performance of the cold-retrieval apparatus, were designed and tested. For the OMEGA itself, we designed, had constructed and inserted between ports 27 and 28 a pair of tapered NdFeB magnets which at an acceptable gap (with regard to proximity to the target) of 3.0 cm and pole face diameter of 4.5 mm provided a holding field of 0.08 T, adequate for polarization preservation after our shroud, with its internal holding magnets, would be withdrawn and replaced by the OMEGA shroud prior to firing. The nuclear particle detectors consisted of 2 large area neutron detectors outside of OMEGA, placed in exactly polar and equatorial positions, and two proton detectors inside OMEGA, one exactly equatorial, and the other almost polar

(18^o), since an exactly polar position was precluded by the magnets.

A novel technique for determining low temperature tensile strengths of shells, important to our program when we want to gasify the fuel in the target just prior to laser implosion, was developed. Finally, a broad study of spin-lattice relaxation in HD samples in the concentration range useful for polarization was carried out. This led to discovery of a low temperature (millikelvin) molecular transport mechanism in HD which through its effect on the relaxation rates, can shorten the time required for producing highly polarized D targets. These phases of our activities are described in the following sections of this report.

II. LOW TEMPERATURE IMPLEMENTATION OF MATING A TARGET TO OMEGA

In October 1991, the first full implementation of our experiment for an unpolarized target was carried out. A polymer shell of 364 µ outer diameter, 4.7 µ polystyrene wall, and 8 µ parylene-C coating, was mounted on a sample fork by two 5 µ diameter pure gold wires (for conduction cooling) and one spider silk for additional support. The whole structure was overcoated with 0.2 µ parylene. The shell was filled by permeation of D_2 from a reservoir to 43.8 atmospheres. This was carried out at room temperature in our permeation cryostat, prior to its modification with a cone guide, represented by hatched lines in the revised permeation cryostat shown in Fig. 1. This cone guide was added in 1992 to improved the centering of the compression nut which seals the detachable permeation injection system to the

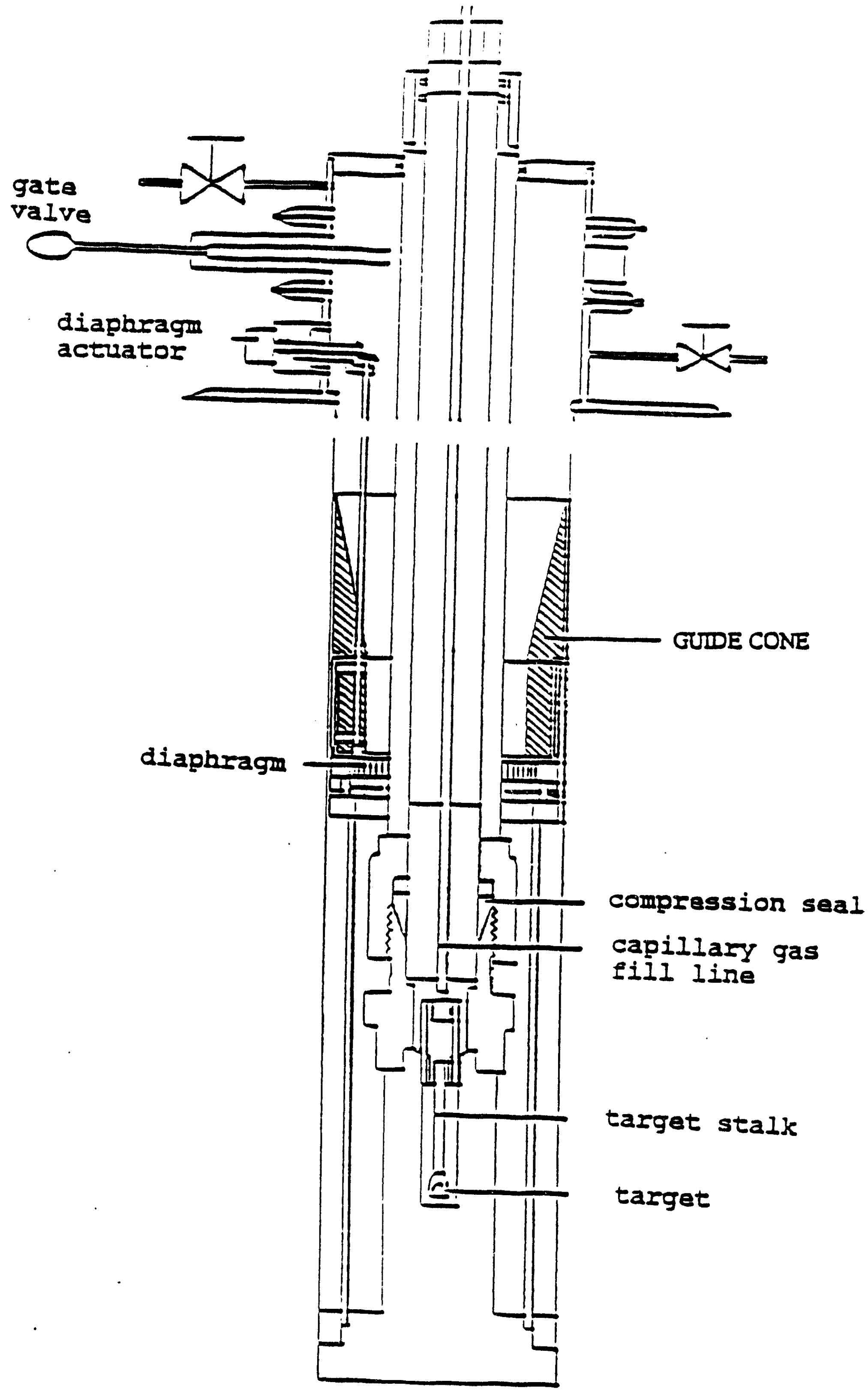


Fig. 1. Drawing of permeation cryostat, showing removable gas fill tube connected to permeation chamber by compression seal, breakable at low temperature. Shown at the left is the mechanical assembly which drives the variable-diameter diaphragm in order to close bottom shutter of shroud of cold-transfer apparatus. Guide cone, hatched region, was an addition to decrease chance of breaking off target during insertion. A second guide cone, shown in next figure, improves target survivability during removal operation.

reservoir and target holder permanently mounted in the cryostat. Total gas filling time was about 6 hours, using 7 atmosphere maximum differential pressure increments. After the fill, cryogens were transferred into the permeation cryostat, and the temperature was gradually reduced. The gas law determined the pressure of the isolated isothermal target shell as the temperature decreased, but the reservoir pressure-temperature relation was more complicated because a not-insignificant portion of the reservoir gas volume remained at room temperature. This was however calibrated in a previous experiment so that periodic gas removal during the cooling maintained the reservoir pressure approximately equal to that of the target shell, and at no time was the differential pressure in excess of the burst or implosion temperature of the shell. Ideally, this cooling of a permeated shell could be done isochorically with respect to both target shell and reservoir, in which case the shell pressure and the reservoir pressure remain equal during the cooling. However, there was insufficient room in our apparatus for a low temperature, high pressure valve to accomplish this, and our method is quite adequate for fill pressures up to about 200 atmospheres, which is the limit (for other reasons) with our present permeation set-up. When the temperature reached about 30 - 35K, the pressure in the target shell was sufficiently reduced (nearly a factor of 10 from the 300K room temperature fill pressure) so that the reservoir gas could be completely evacuated, after which further lowering of the temperature resulted in condensation in the shell. A final temperature of

4.2K was eventually reached, facilitated by introducing into the reservoir a small amount of helium exchange gas, which was subsequently thoroughly pumped out. Very low residual helium gas is required to avoid thermal shorting of our cold-transfer system which must later remove the target. The injection part of the permeation system was next detached by unscrewing the compression seal nut, and subsequently removed via a vacuum lock. The target thus prepared and residing in the storage cryostat can remain in this condition indefinitely, since at 4K, the inverse permeation rate is negligible compared with storage times even of years. In general, we prepared the target the night before a scheduled experiment at Rochester, but for this particular experiment under discussion, the prepared target remained in the storage mode for about 2 weeks while awaiting correction of problems at Rochester. The day of the experiment, we departed from Syracuse at approximately 7 AM with our target in the liquid helium cryostat and our OMEGA-compatible cold-transfer retrieval system in a warm state. Upon arrival at Rochester, all systems were brought into the target-chamber hall. The cold-transfer system was precooled with liquid N_2, following which liquid helium was transferred. The helium lasted only about 15 minutes due to failure of the indium o-ring seal at the cold finger joint in our cold retrieval tube. This necessitated warming our system, repairing the o-ring, and re-cooling, causing a 2 hour delay, after which our cold-transfer system functioned normally, with a helium loss rate such as to insure a three hour liquid-helium holding time. The cold-transfer system was next inserted through its own and the storage cryostat's vacuum locks, was attached to the target shell support via the left hand-right hand thread system[6], was raised to the position where a mechanical diaphragm closed the shutter on the shroud (see Fig. 1), and was then lifted out of the storage cryostat. In this contained, portable, cold (4K) state, the target on its support structure was then carried up the stairs to the OMEGA tank, the vacuum locks there were coupled, and the cold-transport tube with the target inside it were inserted into OMEGA. At this point, two problems arose. The motorized positioning devices of OMEGA failed, necessitating manual operation of the z-position control, and affording no lateral-positioning control. Our target was apparently too low in the shroud, and the required lateral positioning was improvised by external flexing to bring it into the field of the target imaging system of OMEGA. Only the stalk was visible through our shroud's thinly gold-coated sapphire window, and we attempted to redress this using the manual z-positioning, which as mentioned above was all that was available. Before we could proceed, the second problem occurred, namely development of a helium leak within the OMEGA tank, which turned out to be due to failure of the seal at OMEGA's liquid-helium cooled fast-retracting cold shroud. This helium leak thermally-shorted our cold-transport apparatus, and the temperature at the target quickly rose above that of liquid N_2. Anticipating destruction of our target shell by explosion upon further warming, we attempted to mate OMEGA's shroud to our shroud in order to shield our target from room temperature black-body radiation. This had to be done "blind", a risky procedure, but one which at the time seemed the best option. We thus repositioned our target using the positioning screw on our cold-transport system, which axially displaces the target with respect to our shroud. The arrival into view of the tip of the stalk revealed that the fork and target mounted to it had broken off. We attributed this to the fact that the target shell was too near the shutter segments on our shroud, and that the latter touched the target when OMEGA's shroud pushed in during the process of engaging and opening our shutter.

This initial attempt at carrying out the entire procedure was basically successful in the logistical sense, and loss of target in the final alignment can be ascribed at least indirectly to failure of some essential components at OMEGA. The following year, there was little opportunity to return to Rochester due to problems there with the laser drive systems, and delays in repairing the cold helium leak in OMEGA's shroud system. We took this opportunity to ameliorate some potential problems with our system. The first improvement was inserting a guide cone for target shell insertion into our permeation chamber, already referred to above as represented by the hatched area in Fig. 1. In a series of practice insertion and retrieval operations at Syracuse, it became clear that target shell insertion was now fool-proof, but that about half the time, dummy targets would break off during removal from our storage cryostat. This diagnosis was facilitated by adding a viewing window to the vacuum lock of our cold-transfer system. The cause of the problem was identified to be a small "snap" of the liquid-helium tube when the target was drawn free from its holder in the permeation system but was still within a region of very small clearance. We corrected this by introducing an additional guide cone during the period between insertion and removal operations. Since the first supplemental cone, sized for passage of the compression seal nut, was considerably larger than the outer diameters of either of our two cold-transport apparatuses, it was relatively easy to insert smaller diameter cones into the large existent one using a vacuum-lock and insertion screwdriver. The cone and insertion system for target removal destined for an OMEGA interface is shown in Fig. 2. A second cone assembly of smaller diameter, not shown, was made to accommodate the dilution refrigerator cold-transport system. Additional modifications in the coldfinger assembly of the cold-transport system improved the co-axial alignment with the shroud. This consisted of introducing a teflon restrainer between the liquid helium tube and the bottom of the liquid nitrogen tube, and shimming the bottom of the cold finger so as to compensate for wobble in the thread. These improvements resulted in 10 out of 10 practice successful retrievals, which was essential because of the substantial effort in carrying out even an unpolarized target mating.

In October 1992, we had our next opportunity to carry out a full scale experiment, and proceeded as in the previous one. Again, however, the OMEGA tank exhibited a helium leak emanating from its shroud, and although positioning the target and mating of the shrouds was effected, again at some point the target broke off from the stalk, possibly because of a defective initial

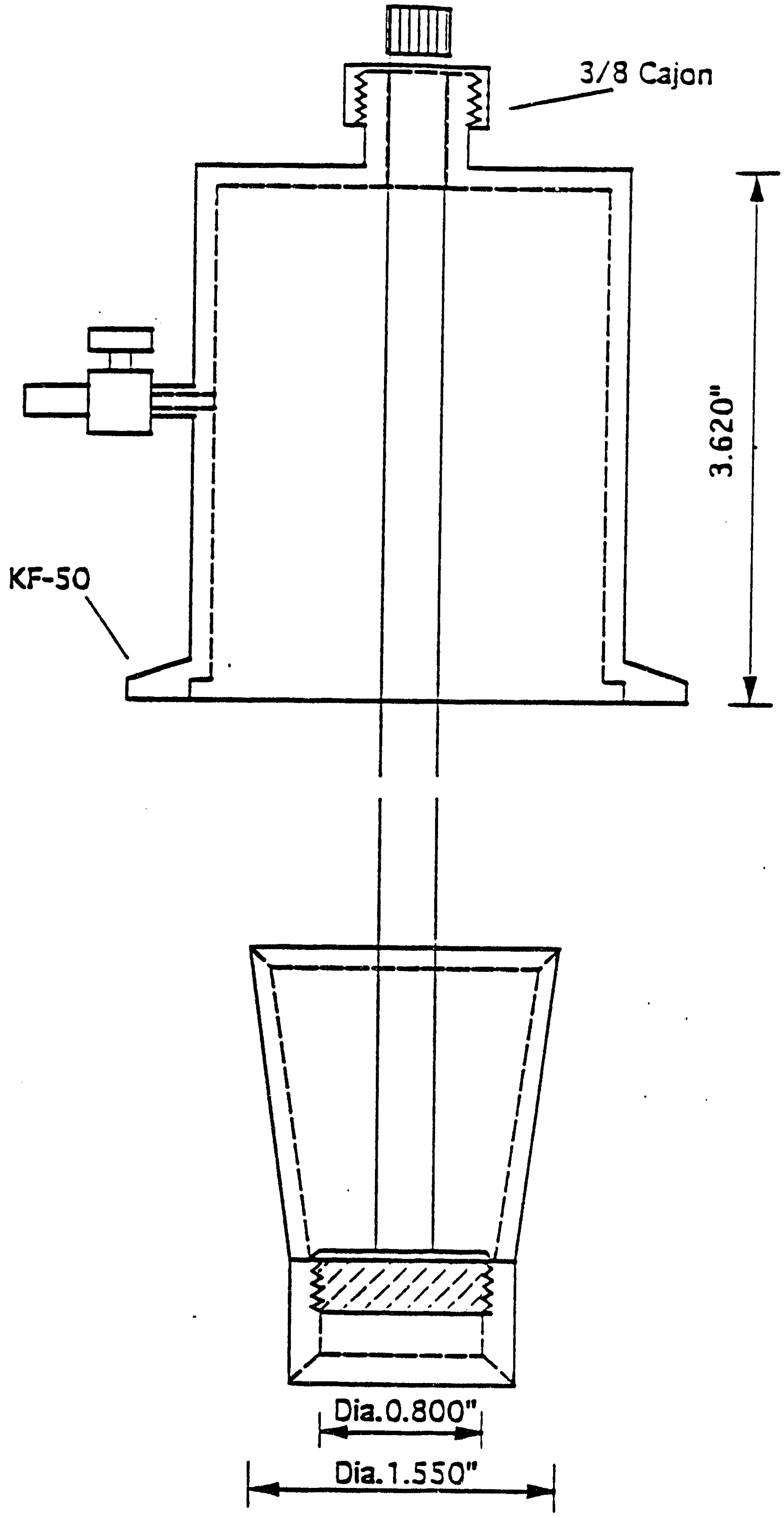
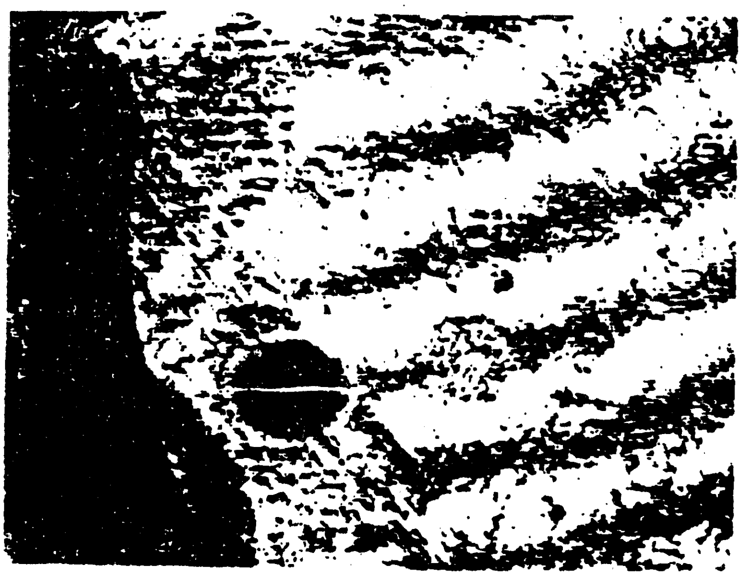


Fig. 2. Second guide cone, and insertion screwdriver and vacuum lock. This cone fits in first guide cone (see previous figure) and centers cold-retrieval tube. Dimensions correspond to OMEGA retrieval tube. A similar, but smaller diameter cone is also used for centering dilution-refrigerator retrieval tube.

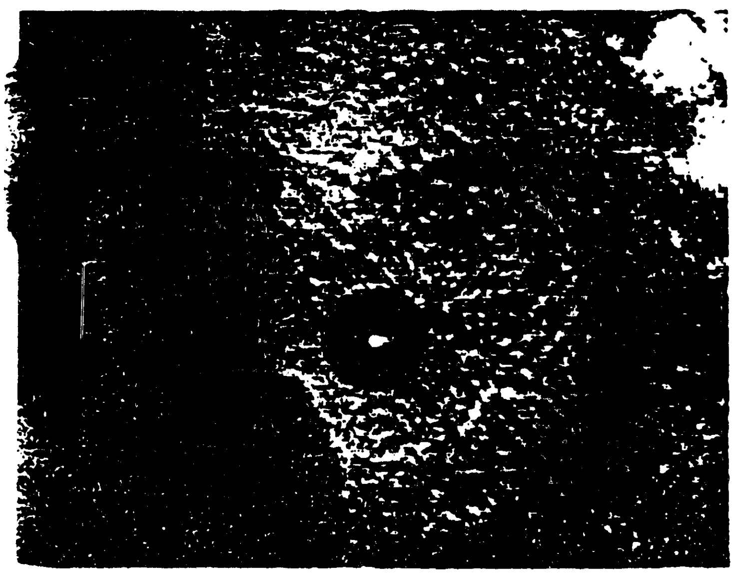
mounting. Since shutdown of OMEGA was rapidly approaching, and it was clear that the OMEGA leak would not be repaired, thereby precluding subsequent 4K entries, we decided to bypass the helium cooling, and carry out the experiment at liquid N_2 temperatures. Cold-transfer at liquid helium temperatures had already been successfully demonstrated on two occasions, albeit for short durations because of the OMEGA leak and consequent thermal-shorting. A liquid nitrogen temperature experiment involved a procedure basically the same as that with liquid-helium, as far as the mating was concerned, and thus a successful target shot at liquid N_2 temperatures would equally demonstrate the remaining element of our project, namely aligning and shooting a cold-inserted target shell. A polarized target series was already out of the question because of the small remaining time to OMEGA shutdown, and for an unpolarized target, liquid N_2 was as satisfactory as liquid helium. A normal-parylene coated polystyrene target shell was used, with gold wire conductive link to the fork as before, capable of withstanding a pressure differential of 20 atmospheres at room temperature and appreciably more at liquid nitrogen temperature. We filled it in our usual manner in the permeation cryostat to a conservative value of 30 atmospheres, which reduces to 7 atmospheres at 77K. Furthermore, the gas retention (permeation) time at 77K compared to the permeation time at 300K is a factor of 2.8×10^6, insuring retention during the shot, since the permeation time-constant at 300K was about a minute. We retrieved the sample at Syracuse and came to Rochester only with the liquid N_2 cooled cold-transer apparatus, saving the expense of a large rented truck. This cold-transport plus target apparatus was inserted directly into OMEGA. Shrouds were successfully engaged, and the target shell was excellently positioned. This is seen in Fig. 3, which is a photo of the target- positioning screen. The lasers were fired, but no neutron yield was detected. After the shot, it was evident that either the rate of retraction or the synchronization of the OMEGA fast-retracting shroud was defective, since there were visible signs on the shroud tip that at least 20 of the 24 laser beams were intercepted by the shroud. This would preclude obtaining any measurable neutron yield. Since the targeting capability was nevertheless now demonstrated, and no significant new physics was expected from a subsequent shot under these conditions with a similar target, it was decided that due to the imminent shutting down of OMEGA, the faulty retracting shroud would not be repaired for a repeat experiment.

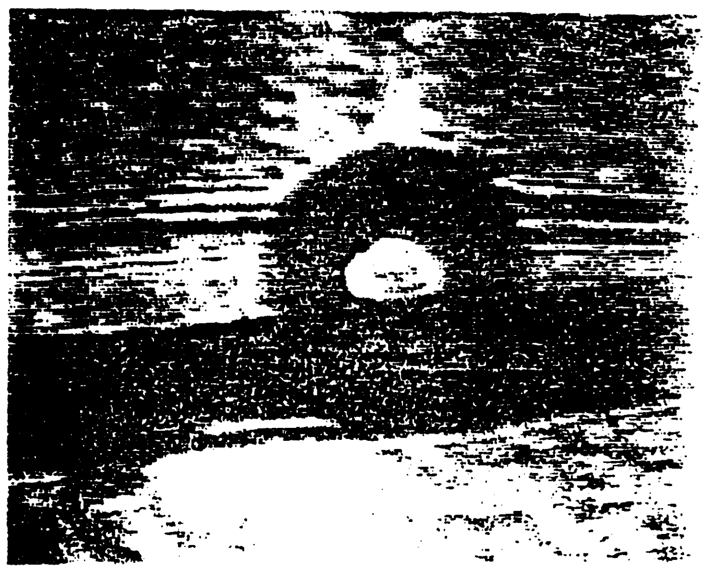
The liquid nitrogen cooled targets represent almost as much new technology as the complete liquid-helium temperature system, since they require similar cold-transfer protocols. In this case, the low temperature, 77K, allows maintaining high density fuel at neglible leak-out rates, while still permitting fast filling to high pressure at room temperature. This of course is the result of the large activation energy of a polymer's permeation constant. We proposed taking advantage of that specific feature to shoot many high fuel density targets in a single day, as opposed to the one target per day capability of our liquid-helium cooled targets. Examples of the utility of such a series of shots "y" shadowgram



"x" shadowgram

"y" interferogram





"x" interferogram

Fig. 3. Our cold target seen in LLE's Target Imaging System. Experiment at LLE's OMEGA fusion chamber with cold target prepared at Syracuse University, Nov. 20, 1992.

of cryogenic targets would be for a progression of aspect-ratios, or a range of isotopically mixed constituents. A turreted system[9] of fairly high density fuel targets was proposed to be filled at room temperature and stored at 77K in a wide diameter cryostat. These targets could be successively retrieved with a cold-transport tube as the targets in the turret were rotated into the position accessible to the cold-transport tube. However, again the imminent closing of OMEGA precluded action on this idea. In the future, such an intermediate temperature turreted system may be of use, and the concept should be readily extendable to liquid-helium temperature stored targets as well.

II. LOW TEMPERATURE EXPERIMENTS ON POLYMER TARGET SHELLS

We pursued a study of target shell properties at low temperature primarily because we planned to gasify our solid polarized fuel a few ms (with use of auxilliary laser target warming) or about 100 ms (under 300K black-body radiation exposure of the target) prior to shooting the target shell, in order to improve symmetrization of the fuel and the fusion yield. This would require knowledge of shell burst pressures at low temperatures of polystyrene shells. After initial experiments, it became apparent that we had uncovered some interesting new phenomena and characteristics of low temperature polymer shells, which were of potential interest to the ICF effort, intrinsically as well as with respect to polarized fuel efforts. The continuation of these studies then became one of our extended activities while waiting the many months for an opportunity to carry out our experiments at Rochester, a delay engendered by difficulties with the laser system there during a good part of 1993.

We give a brief description here of the more important shell phenomena and application potentialities. For details of the methods and results, we include as Appendix A a copy of a preliminary publication on the subject based on a talk given at the Ninth Target Specialist's Meeting[10] in Monterey during summer of 1993. A journal publication is near completion.

Basically, we developed a method of measuring permeation constants of a <u>single</u>, moderately sized (>250 u diameter) polymer target shell, by means of monitoring the gas leak from the shell into a small-volume reservoir containing a small dead-volume, high sensitivity Baratron pressure-measuring instrument. In addition to measurements of the temperature dependence of permeation constants at temperatures from 77K to >300K, for both helium and deuterium gas, we discovered a pre-rupture mode of rapid loss of gas from a shell, which was partly reversible on subsequent permeation cycles. Shells which underwent this pre-rupture modality did not display obvious visible signs of damage under examination with a light microscope. We also developed a means of measuring the temperature of a single isolated shell at any time based on its gas emission rate, essentially dP/dt, together with P, using a previously determined calibration of the activation temperature of permeation. This determination of temperature allowed a quantitative measurement of the heat absorbed by the shell at any temperature, the heat transfer arising from molecular transport and from black-body radiation from the surrounds of the shell. These two heat-transfer modes could be separated. The molecular heat transport component, dependent on the accommodation coefficient of the shell surface, was shown to provide a simple means of measuring surface roughness of the shell on a 1 nm atomic scale. We hypothesize this roughness may be correlated with surface roughness on a 100 nm scale which is of considerable importance to ICF, and are currently engaged in experiments to establish this.

III. NMR EXPERIMENTS FOR IMPROVING POLARIZED FUELS

Previous experiments on HD at temperatures from 10 mK to 4K were analyzed with respect to relaxation times, and a few additional dilution refrigerator experiments were carried out to test some of the hypotheses coming out of these analyses. A preliminary account of some new discoveries has been given in an APS Abstract[11], and a more detailed account of the main body of the work is in the PhD thesis of Neil Alexander[12] and in a recent publication[5]. Relaxation times, which are the central element of the D polarization process we have developed, were mapped over the entire temperature range and a magnetic field range up to 12 Tesla. We discovered that a previously suggested exponential growth of relaxation rate with T in the mK region is in fact much slower, approximately linear, which much improves the prospects of obtaining higher polarizations by going to lower temperatures, such as 5 mK. We also observed for the first time in HD an unusually rapid diffusion[4] of $J = 1$ impurities ($o\text{-}H_2$ or $p\text{-}D_2$) at mK temperatures. Though a similar effect was observed in H_2 solids, so-called quantum diffusion, i.e. ortho - para H_2

resonant exchange, could not be ruled out in that case, whereas in our HD samples, such resonant exchange is not a possibility because of the low concentration of both $J = 0$ and $J = 1$ H_2. The $J = 1$ impurity clustering which results from this motion-mechanism accelerates the increase of the spin-lattice relaxation time, T_1^H, with time spent at low temperature, and is beneficial to the polarization process of D nuclei[5]. Another interesting phenomenon discovered was a low temperature asymmetry between nuclear magnetization decay-rate and growth-rate, corresponding to situations where the initial magnetization is respectively greater than, or lower than the equilibrium magnetization. This is not yet entirely understood, although some mechanisms have been suggested. These results are of fundamental interest, and do not impact negatively on the application of our method to transportable polarized fuels, since the relaxation rate asymmetry disappears at temperatures greater than about 80 mK.

IV. CONCLUSIONS

Our ICF related work during this past year was somewhat constrained by a significantly reduced budget, as well as by very limited access to OMEGA. Under these conditions, the objective of obtaining a series of laser shots on targets with polarized D fuel became doubtful, and the recommendation of NLUF was to limit the objective to a demonstration of interfacing our cold targets with OMEGA, which we successfully did. This required making several modifications to insure target integrity during cold-transfer operations, such as improving co-axiality of the cold-transport apparatus and introducing several guide cones into the storage cryostat. In addition, we discovered several new and important properties of polymer target shells at low temperatures, and improved the D spin-polarization procedure for future polarized target ICF shots. During the construction phase of the Rochester upgrade, our polarized D and H methods will have other applications. These include polarized H and D targets for polarized gammas[13], polarized internal targets for accelerators[5] and possibly polarized D fuel in large quantities for polarized D Tokamak experiments. The polarized D fuel would be introduced via pellet or neutral beam injection, both of which have been considered by us and appear feasible from our initial considerations[14]. Three PhD candidate students took part in this work, as well as a Fusion Summer Fellowship recipient. One of the students, Neil Alexander, completed his dissertation, and has taken a position as a senior scientist at General Atomics, where he is applying many of the cryogenic and cold-transport skills learned here to the ICF upgrade efforts at Rochester and Livermore, through General Atomics' contractual link to these programs. Work related to properties of polymer shells and solid or liquid fuel symmetrization in target shells is continuing at Syracuse.

ACKNOWLEDGEMENTS

We wish to thank Hyogun Kim and Roger Gram for their continuing interest and for providing target shells for these efforts. Greg Pien was of great help during the several interfacing sessions, and we thank him for his patience and occasional delayed dinners arising from our experiments. Jim Knauer continually gave support

and exerted strong efforts on our behalf throughout the entire course of this work. We thank him for material aid and encouragement, and are cognizant and appreciative of his coping with a multitude of pressures from users of LLE's facilities.

PERSONEL ON THIS PROJECT DURING THE GRANT PERIOD

Neil Alexander, Grad. Research Asst. Completed PhD Dec 92. Employed as a Senior Scientist at Gen. Atomics, S. Diego.

Qun Fan, Grad. Research Asst., PhD candidate.

Xiangdong Wei, Grad. Research Asst., PhD candidate.

Nathan Palmer, Brigham Young Univ. Senior; Summer Fellow at our laboratory for Jun - Aug 1993, under the National Undergraduate Fellowship Program in Plasma Physics and Fusion Engineering.

REFERENCES:

1. R. M. Kulsrud, H. P. Furth, E. J. Valeo, and M. Goldhaber, Phys. Rev. Lett. 49, 1248 (1982).
2. Y.-L. Pan and S. P. Hatchett, Nucl. Fusion 27, 815 (1987).
3. A. Honig, N. Alexander, and S. Yucel, in Proceedings of the Conf. on Muon-Catalyzed Fusion, AIP Conf. Proc. No. 181, eds: S. E. Jones, J. Rafelski and H. J. Monkhorst (AIP, New York, 1989), p. 199.
4. N. Alexander, Y. Y. Yu, Q. Fan, X. Wei and A. Honig, Bull. Am. Phys. Soc. 35, 925 (1990).
5. A. Honig, N. Alexander, Q. Fan, X. Wei and Y. Y. Yu, Workshop on Polarized Ion Sources and Polarized Gas Targets, Univ. of Wisc., May 23 - 27, 1993. AIP Conf. Proc. No. 293, eds: L. W.

Anderson and Willy Haeberli (AIP, New York, 1994). p. 50.

6. N. Alexander, J. Barden, Q. Fan and A. Honig, Rev. Sci. Instrum. 62, 2729 (1991).

7. A. Honig, N. Alexander, Q. Fan, R. Q. Gram and H. Kim, J. Vac. Sci. Technol. A9, 3149 (1991).

8. A. Honig, P.I.; Final Report, NLUF Grant DE-FG03-91SF18862, Fusion with Highly Spin Polarized HD and D_2, June 29, 1992.

9. Letter from A. Honig to J. Knauer, Sept 28, 1992, on possibility of 10 per day cryogenic target shots using turreted liquid-N_2 temperature cooled targets.

10. A. Honig, X. Wei, Q. Fan, N. Alexander and N. Palmer, Ninth Target Fabrication Specialists' Meeting, Monterey, CA, July 6 - 8, 1993. Proceedings in LLNL CONF-0307127 L-15854-2. Our contribution is attached as APPENDIX A to this report.

11. N. Alexander, Q. Fan, X. Wei and A. Honig, Bull. Am. Phys. Soc. 37, 610 (1992).

12. N. Alexander, PhD Thesis, Syracuse University, Dec. 1992.

13. G. S. Blandpied, C. Djalali, B. M. Preedom and C. S. Whisnant, Univ. of S. Carolina; Q. Fan, A. Honig, and X. Wei, Syracuse University; O. C. Kistner, A. M. Sandorfi and C. E. Thorn, Brookhaven Nat'l Laboratory; S. Buhler, J.-P. Didelez, R. Frascaria and E. Hourani, Orsay; G. Matone, Lab. Nationali di Frascati-INFN; P. Picozza and C. Schaerf, Univ. di Tor Vergata and INFN Sezione di Roma 2; A. D'Angelo, INFN Sezione di Roma 2; J. P. Bocquet and C. Perrin, ISN Grenoble. Proc. of Particles and Nuclei XII Int'l Conf, Perugia, Italy, June 28 - July 2, 1993.

14. Private discussions held on May 5, 1993 with Peter Kupschus (polarized pellets) and Tim Jones (polarized neutral beam injection) at Joint European Torus (JET), Abingdon, England.

conf paper cycled separately. ds

DATE
FILMED
7/6/94

END