LA-9934-PR
Progress Report

140
12-7-83 JS ①

Dr. 1970-4

I-18413

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

DO NOT MICROFILM
THIS PAGE

Space Nuclear Safety Program

June 1983

MASTER

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The four most recent reports in this series, unclassified, are LA-9839-PR, LA-9894-PR, LA-9906-PR, and LA-9918-PR.

This work was supported by the US Department of Energy, Office of Special Nuclear Projects.

DO NOT MICROFILM
THIS PAGE

Photocomposition by Chris West

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

LA--9934-PR

DE84 003555

Space Nuclear Safety Program

June 1983

Compiled by
S. E. Bronisz

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

SPACE NUCLEAR SAFETY PROGRAM

June 1983

Compiled by
S. E. Bronisz

ABSTRACT

This technical monthly report covers studies related to the use of $^{238}\text{PuO}_2$ in radioisotope power systems carried out for the Office of Special Nuclear Projects of the US Department of Energy by Los Alamos National Laboratory. Most of the studies discussed here are ongoing. Results and conclusions described may change as the work continues.

I. GENERAL PURPOSE HEAT SOURCES (GPHS)

A. Solid Propellant Fire Test (D. Pavone and C. Seabourn)

Two GPHS samples were exposed to a 10.5 min fire from a 0.91 m cube of UTP 3001 solid propellant and both survived the fire with no release of the fuel simulant.

1. **Bare clad** A bare GPHS fueled clad (IRG 114) containing a UO_2 pellet in place of the $^{238}\text{PuO}_2$ fuel pellet was preheated to 1091°C , the expected launch temperature, and dropped next to the solid propellant immediately before its ignition. The tested capsule is shown in Fig. 1. A mass of sintered soil adhered to about one half of the vented end and a thin glassy deposit appeared on the capsule wall diagonally opposite the sintered soil. A black deposit was present on the end of the shield cup. The distribution of the exterior deposits indicates that the capsule was oriented with the diagonal plane nearly vertical. The iridium clad, sectioned axially to remove the UO_2 pellet and expose the interior surface, showed no damage to the interior (Fig. 2).

Metallographic examination of a complete axial cross section of IRG 114 revealed that the iridium did not interact with the sintered soil or the black deposit on the

end of the capsule, as shown in Figs. 3 and 4. Electron microprobe analysis of the sintered soil adhering to the capsule indicated that the matrix material contained primarily silicon with aluminum, potassium, calcium, iron, and oxygen. Islands of silicon oxygen compound contained within a filamentary phase of silicon oxygen carbon were dispersed within the matrix phase. The black deposit contained crystals of aluminum oxygen in a matrix of aluminum, potassium, calcium, iron, and oxygen.

The exterior surfaces of the iridium clad that were coated with the glassy deposit appeared to have been eroded. Figure 5 illustrates the effect, which was most severe on the corner of the capsule. The maximum reduction of thickness observed was approximately 15%. Lightly etched photomicrographs, shown in Fig. 6, demonstrate that the erosion mechanism involved the formation of a grey intermetallic compound (liquid at the test temperatures) that penetrated along grain boundaries, allowing individual grains to be lifted from the surface and blown away by the action of propellant combustion gases and entrained soil materials. The intermetallic compound in the boundaries consisted of iridium and silicon.

Figure 7 illustrates the coarsest grained microstructure observed (near the eroded corner) and may be contrasted

with the microstructure on the vent end shown in Fig. 8. The average intercept grain size in the coarse-grained microstructure was 94 μm and that of the fine-grained microstructure was 24 μm . Assuming a propellant burn time of 10.5 min and extrapolating Oak Ridge's grain-growth data* to high temperatures, one calculates that the eroded corner had been at 1900°C. The iridium would not have remained at this temperature throughout the fire because of the receding flame front, so it must have been somewhat hotter for a shorter time. Obviously, the vent face (Fig. 8) was significantly cooler.

2. Impact assembly. A GPHS impact assembly consisting of two simulant fueled clads (IRG-135 and IRG-136) in a standard graphite impact shell (GIS) was preheated to 1091°C (iridium temperature) and exposed to the same fire as the fueled clad.

As recovered from the test site, the impact assembly had a dark grey deposit of very hard material adhering to the surface that faced the burning propellant and a 6-mm layer of sintered soil adhering to the surface that rested on the ground. A thin, glassy coating that covered parts of the top surface is not discernible in the photograph (Fig. 9), which illustrates the condition of the test object. The GIS was dissected with a longitudinal cut and opened to expose the sides of the capsules oriented toward the burning propellant. No apparent damage occurred to either iridium clad (Fig. 10). A superficial, grey deposit was present on about one-third of the surface of the nonvented end of the capsule in the closure end of the GIS (the capsule at the left in Fig. 11). Electron microprobe analysis indicated that the deposit contained more carbon and aluminum than the adjacent uncoated iridium. The source of these elements was most likely the combustion products of the propellant. In view of the superficial nature of the deposit, no further analytical examination of the capsules was performed.

Figure 12 is a photomacrograph of a cross section through the front half of the GIS. The wall thickness that faced the fire (to the left in the figure) was reduced by about 20%. The region in contact with the soil (bottom)

was not eroded by the fire. The z-axis rods were somewhat more resistant to erosion.

Microscopic examination of the nonmetallic deposits showed them to consist of several nonmetallic phases with metallic inclusions of varying sizes (Fig. 13). Electron microprobe analysis indicated that metallic inclusions seen in Fig. 13a consisted of silicon, and those in Fig. 13b contained primarily iron with silicon and lesser amounts of manganese and copper. The grey intermetallic phase associated with the iron-rich globule in Fig. 13b was principally silicon.

The nonmetallic phases varied widely in composition. The most frequently observed phase consisted of aluminum and oxygen, but others contained silicon, potassium, calcium, with minor amounts of sodium, magnesium, titanium, and iron, in addition. Obviously, the aluminium, iron, and oxygen were derived from the propellant, and other elements, principally silicon, came from the soil. The conditions of deposition were sufficiently chemically reducing to form small amounts of metallic silicon and iron alloys.

The results of this test indicate that the exposure of intact GPHS fueled clads to a long-duration, single-proximity, solid-propellant fire would probably not lead to an appreciable release of ^{238}Pu to the environment. The test exposure resulted in a 15% thickness reduction in a non-self-heating capsule. In the real case, a ^{238}Pu pellet would raise the temperature somewhat, which would result in marginally greater thinning.

The environment in the GIS was relatively benign. It is unlikely that real fuel pellets would have changed the response of the impact assembly to the fire.

B. DIRECT COURSE (C. Seabourn)

The neutron activation of four GPHS iridium capsules containing UO_2 fuel simulant was completed. The loaded capsules, IRG-91, -92, -93, and -94 were irradiated in the Los Alamos Omega West reactor with a neutron dose sufficient to produce an ^{192}Ir gamma level of 20 mr/h at 10 cm. This level will decay to 10 mr/h at 10 cm by the time of the DIRECT COURSE event. The capsules were shipped to Monsanto's Mound Facility, where they will be assembled with the graphite components to make the GPHS module for the test.

*A. C. Schaffhauser, "Technical Highlights of Isotopic Power Materials Development at Oak Ridge National Laboratory for May 1979," Oak Ridge National Laboratory report CF-79/234 (June 1979).

II. LIGHT-WEIGHT RADIOISOTOPE HEATER UNIT (LWRHU)

A. Solid-Propellant Fire Test (C. Land and C. Seabourn)

A complete LWRHU assembly (LRF-017) was exposed to the same solid-propellant fire in which the GPHS samples were tested. The assembly was placed on the sand 50 mm from the face of the propellant. It was not preheated because its operating temperature is low.

After the 10.5-min fire, the surface that faced the fire was eroded and encrusted with propellant burning products (Fig. 14a) and the surface on the sand bed was partially covered with a layer of fused sand (Fig. 14b). No alpha activity was detected on the exterior of the assembly.

B. Impact Test (C. Land and C. Seabourn)

The post-mortem examinations of two fueled LWRHUs that had been impacted at ambient temperature at 48 mps were completed. Neither capsule failed.

1. LWRHU RU-9-04. This assembly, containing fueled capsule 138, was oriented so that it hit the flat steel target on the vent corner while the capsule axis was at 45° to the target face. The impact crushed the corner of the aeroshell and split off a longitudinal segment (Fig. 15). The aeroshell cap was displaced but was retained by the threads. The pyrolytic graphite sleeves were cracked but in place.

The fueled clad was damaged only slightly by the impact: the corner was flattened slightly (Fig. 16), but it was otherwise undamaged. The capsule was notched circumferentially and pried open under water to obtain the fuel for a particle-size analysis. The two halves were then sectioned longitudinally and prepared metallographically.

The longitudinal sections are shown in Fig. 17. The bends in the side walls occurred during the fuel recovery; they were not caused by the impact. Impact conditions were well below those required to damage the capsule seriously. Only a very small departure from planarity occurred at the vent end (Fig. 17a) and none at the closure end (Fig. 17b).

The four sections of the weld joints exposed in the examination showed complete weld penetration. The microstructure of the closure weld was satisfactory, as shown in Fig. 18.

2. LWRHU RU-9-06. This assembly, containing fueled capsule 142, was impacted on the closure end of the aeroshell (the nonvented end of the capsule). The aeroshell was only very slightly damaged. A small amount of powdering occurred over the impacted end and a small region of the corner was crushed, presumably by a secondary impact (Fig. 19). After a slot was cut in the cap, it was unscrewed and the apparently undamaged capsule was retrieved (Fig. 20).

The capsule was cut circumferentially, the fuel was removed under water, and the capsule halves were sectioned longitudinally and prepared for examination. The weld penetration was complete in the four sections exposed, but the weld shield was incorporated in the closure weld (Fig. 21). The microstructure of the closure weld was satisfactory (Fig. 22).

C. Welding (C. Land)

In preparation for resuming the fueling of the remaining LWRHU production capsules, seven capsules were welded and examined. Three capsules were test welds to prove that the equipment still functioned properly, three were for operator qualification, and one was an example weld for the planned production run.

The three test welds were satisfactory. Penetration was complete and the porosity was well within specification. In one case, the weld shield was tacked lightly to the closure weld.

The three qualification welds showed full penetration, even less porosity than the test welds, and no incorporation of the weld shield in the closure weld. On the basis of these results, permission to resume welding was given.

The example weld (RHU-60) was made and sectioned. The normal field examination revealed no abnormalities and a welding production run was made. During a subsequent in-depth post-mortem examination, the capsule showed a fully penetrated weld that partially incorporated the weld shield. The molten pool did not go through the shield. In addition, a crack originating on the inner surface and through about a fourth of the closure weld was found in one section (Fig. 23). The crack followed the boundaries of columnar grains in the weld.

The crack region was analyzed with an electron microprobe and the section shown in Fig. 23 was autoradiographed. No positive identification of a grain boundary contaminant was obtained. No other crack comparable with this has been seen in any other fueled LWRHU capsule.

During scanning electron microscope examinations of RHU-60 and other capsules in the search for the cause of the crack, the inner surfaces of the capsule cylinders were found to contain shallow (4- μ m) longitudinal cracks (Fig. 24). A review of the records showed that all the Pt-30Rh alloy cylinders have had these superficial cracks, but in no case has their presence affected the performance of the LWRHU. They are harmless and can be ignored.

The four radiographs of each of 66 production LWRHUs were examined for evidence of cracks. One view (the 90° radiograph of RHU-78) showed an apparent defect in the weld. It was not visible in any of the other three views of this capsule. The small diameter of the LWRHU capsule coupled with its relatively thick wall makes it difficult to imagine that the defect is a weld crack. Nevertheless, the capsule will be reserved and not used as a flight unit without additional intensive examination.

As a by-product of the search for weld crack indications of the LWRHU radiographs, we were able to determine that most of the pellets were cracked (only two or three appeared intact from the four angles at which

they were radiographed) and that 61% of the weld shields were incorporated into the closure weld at some point.

The cracking of the fuel pellet is caused by heat from the closure weld. The UO₂ simulant pellets were also cracked by the welding. The fragmented pellets will have no effect on either the performance or the safety of the LWRHU.

The weld shield was put in the LWRHU capsule to prevent the molten metal from touching the fuel pellet during closure welding. Contact would result in some incorporation of the fuel in the weld, leading to porous, difficult-to-decontaminate welds. In none of the cases examined, either directly or by radiography, did the weld puddle penetrate through the weld shield and juxtapose liquid Pt-30Rh and fuel. In all cases, we could see sharp original corners on the fuel pellet. These facts make it extremely unlikely that incorporation of parts of the weld shield in the LWRHU closure weld would jeopardize the safety of deploying such units. It can be argued that those areas of weld shield incorporation are reinforced and more resistant to impact than the areas with no shield incorporation.

(a)

(b)

(c)

(d)

Fig. 1. Bare simulant-fueled clad IRG-114 after exposure to burning solid propellant: (a) and (b) side views with vent end up, (c) nonvented end, (d) vent end (1.5X).

Fig. 2. The interior of the clad of capsule IRG-114 was unaffected by exposure to burning solid propellant (1.5X).

Fig. 3. Photomicrograph of the interface between the sintered soil deposit and the iridium clad of IRG-114 (50X).

Fig. 4. Photomicrograph of the interface between the black deposit and the iridium clad of IRG-114 (100X).

Fig. 5. The corner of IRG-114 was eroded during exposure to burning propellant (50X).

(a)

(b)

Fig. 6. Lightly etched photomicrographs of the eroded surface of IRG-114 following exposure to burning solid propellant show grain boundary penetration by a grey intermetallic compound containing iridium and silicon (250X).

Fig. 7. The microstructure of iridium capsule IRG-114 in the eroded region had the maximum grain size, indicating that it had been the hottest (100X).

Fig. 8. The microstructure of iridium capsule IRG-114 in the vent face was fine grained, indicating that this part of the clad stayed relatively cool (100X).

Fig. 9. GPHS impact assembly following exposure to burning solid propellant. The deposit on the front surface is from the propellant. The sintered soil is on the bottom.

Fig. 10. There was no visible change of capsules IRG-135 and -136 or of the interior of the graphite impact shell following exposure to burning solid propellant.

Fig. 11. Ends of the shield cups of clads IRG-135 and -136 following exposure to burning solid propellant. The capsule on the left was in the closure end of the impact shell.

Fig. 12. Wall thickness of the graphite impact shell directly exposed to the burning solid propellant was reduced by 20% (4X).

(a)

(b)

Fig. 13. The deposit on the front of the GIS contained metallic globules (white) in nonmetallic matrices. (a) Silicon rich (40X). (b) Iron rich (250X).

(a)

(b)

Fig. 14. After exposure to the solid-propellant fire, LWRHU LRF-017 was partly covered with debris (2X). (a) the side facing the fire was eroded and covered with propellant fire products. (b) The bottom surface was partly covered with fused sand.

Fig. 15. The impact of RU-9-04 removed part of the aeroshell. The impacted corner is at the bottom (2X).

Fig. 16. Except for the flattened area on the lower corner, capsule 138 appeared undamaged by the impact (2X).

(a)

(b)

Fig. 17. The ends of capsule 138 were undamaged by the impact. The walls were bent during fuel recovery (8X).

Fig. 18. The microstructure of the closure weld in capsule 138 was satisfactory (100X).

Fig. 19. The impact powdered a superficial layer of the end of the RU-9-06 aeroshell. The slot was cut so that a screwdriver could be used to remove the cap (2X).

Fig. 20. The end-on impact did no damage to RU-9-06 (2X).

Fig. 21. The welds were fully penetrated, but the weld shield was incorporated in the closure weld (8X).

Fig. 22. The microstructure of the closure weld of RU-9-06 was satisfactory (100X).

Fig. 23. A narrow crack, one-fourth of the way through the capsule, was found in the closure weld of RHU-60 (50X).

Fig. 24. All the LWRHU cylinders have shallow longitudinal cracks on the inner surfaces (50X).

ADDITIONAL DISTRIBUTION

B. J. Rock, Dept. of Energy/OSNP, Washington, DC
 G. L. Bennett, Dept. of Energy/OSNP, Washington, DC
 J. J. Lombardo, Dept. of Energy/OSNP, Washington, DC
 R. B. Morrow, Dept. of Energy/OSNP, Washington, DC
 R. Brouns, Dept. of Energy/OSNP, Washington, DC
 J. Griffio, Dept. of Energy/OSNP, Washington, DC
 D. K. Stevens, Dept. of Energy/BES, Washington, DC
 M. Norin, Dept. of Energy, Washington, DC
 G. Ogburn, Dept. of Energy, Washington, DC
 J. A. Yoder, Dept. of Energy, Washington, DC
 C. Osterberg, Dept. of Energy, Washington, DC
 I. Van Der Hoven, Dept. of Energy, Washington, DC
 R. L. Clark, Dept. of Energy/ALO, Albuquerque, NM
 J. P. Crane, Dept. of Energy, Albuquerque, NM
 K. Elliot, Dept. of Energy, Albuquerque, NM
 D. L. Krenz, Dept. of Energy, Albuquerque, NM
 J. R. Roeder, Dept. of Energy, Albuquerque, NM
 R. B. Crouch, Dept. of Energy, Albuquerque, NM
 J. N. Bailey, Dept. of Energy, Albuquerque, NM
 H. N. Hill, Dept. of Energy/DOA, Miamisburg, OH
 L. C. Sjostrom, Dept. of Energy, Aiken, SC
 R. J. Hart, Dept. of Energy/ORO, Oak Ridge, TN
 J. Pidkowitz, Dept. of Energy, Oak Ridge, TN
 W. L. Von Flue, Dept. of Energy, SFOO, Oakland, CA
 T. B. Kerr, NASA, Washington, DC
 F. R. Schmidt, NASA, Washington, DC
 E. Gabris, NASA, Washington, DC
 N. Sculze, NASA, Washington, DC
 B. R. McCullar, NASA, Washington, DC
 Operations and Systems Requirements, NASA, Washington, DC
 A. V. Diaz, NASA, Washington, DC
 R. G. Ivanoff, NASA/JPL, Pasadena, CA
 R. Campbell, NASA/JPL, Pasadena, CA
 L. T. Shaw, JPL, Pasadena, CA
 R. J. Spehalski, JPL, Pasadena, CA
 AFISC/SNS, Attn: Col. J. A. Richardson, Kirtland AFB, NM
 AFISC/NTYNS, Attn: Capt. D. K. Zimmerman, Kirtland AFB, NM
 Lt. Col. James H. Lee, Jr., AFWL/NTYN, Kirtland AFB, NM
 Capt. Michael K. Seaton, AFWL/NTYNP, Kirtland AFB, NM
 Maj. Ray Baca, HQ AFSC/IGF, Andrews AFB, Washington, DC
 Col. William Licht, ATSD/AE, Washington, DC
 Lt. John Erb, ESMC/SGPH, Patrick AFB, FL
 L. J. Ullian, ESMC/SE, Patrick AFB, FL
 D. W. Keesler, AFML/MPE, Wright-Patterson AFB, OH
 Lt. Col. Mel Nosal, AFISC/SES, Norton AFB, CA
 Lt. Col. Ken Morrison, AFISC/SES, Norton AFB, CA
 Maj. Walt Wilson, AFISC/SEM, Norton AFB, CA
 John Marshall, AFRPL/LKC, Edwards AFB, CA
 Lt. Col. Williams B. Moyer, AFMSC/SGPZ, Brooks AFB, TX
 W. Riley, WSMC/SE, Vandenberg AFB, CA
 Capt. Charles Snow, SAMSO/SE, Los Angeles, CA
 HQ Space Div./YLVS, Attn: Lt. Col. Needham, Los Angeles, CA
 G. L. Albert, SRP Aiken, SC
 J. B. Mellen, SRP, Aiken, SC
 J. R. McClain, MRC, Miamisburg, OH
 W. T. Cave, MRC, Miamisburg, OH
 W. Amos, MRC, Miamisburg, OH
 E. W. Johnson, MRC, Miamisburg, OH
 R. Cooper, ORNL, Oak Ridge, TN
 C. Alexander, BCL, Columbus, OH
 E. E. Rice, BCL, Columbus, OH
 J. Hagan, APL, Baltimore, MD
 B. Bartram, NUS Corporation, Gaithersburg, MD
 R. W. Englehart, NUS Corporation, Gaithersburg, MD
 H. H. Van Tuyl, PNL, Richland, WA
 A. Schock, Fairchild-Hiller Ind., Germantown, MD
 E. Skrabek, Fairchild-Hiller Ind., Germantown, MD
 C. W. Whitmore, GE, Philadelphia, PA
 C. T. Bradshaw, GE, Philadelphia, PA
 R. Kelley, GE, Philadelphia, PA
 R. Hemler, GE, Philadelphia, PA
 V. Haley, GE, Philadelphia, PA
 R. Hartman, GE, Philadelphia, PA
 W. Mecham, ANL, Argonne, IL
 D. C. Anderson, Teledyne Energy Systems, Timonium, MD
 P. Dick, Teledyne Energy Systems, Timonium, MD
 Dr. Marvin Goldman, University of California, Davis, CA
 Charles Smith, Sandia National Laboratories, Albuquerque, NM
 R. Harner, Sandia National Laboratories, Albuquerque, NM
 C. M. Barnes, L. B. Johnson Space Center, NASA SPS, Houston, TX
 R. H. Brown, L. B. Johnson Space Center, NASA FM, Houston, TX
 R. G. Rose, L. B. Johnson Space Center, NASA FA, Houston, TX
 Harold Battaglia, L. B. Johnson Space Center, NASA PF, Houston, TX
 W. H. Boggs, NASA, DE-A, J. F. Kennedy Space Center, FL
 Lloyd Parker, NASA, SF, J. F. Kennedy Space Center, FL
 George M. Marmaro, NASA, MD-ESB, J. F. Kennedy Space Center, FL
 W. A. Riehl, Marshall Space Flight Center, NASA, EH31, Marshall SFC, AL
 W. C. Pitts, NASA, STPM, Ames Research Center, Moffett Field, CA
 J. J. Givens, Ames Research Center, Moffett Field, CA
 R. Corridan, Ames Research Center-NASA, Moffett Field, CA
 J. C. Robinson, Langley Research Center, NASA, MS395, Hampton, VA
 G. J. Schaefer, Jr., Lewis Research Center, NASA, MAIC 500-120, Cleveland, OH
 R. C. Turkolu, TRW, Defense and Space Systems Group, Redondo Beach, CA
 D. Eaton, European Space Research and Technology Centre, Zwarteweg 62, Njordwijk, The Netherlands
 Dr. Ralph R. Fullwood, Science Applications, Inc., Palo Alto, CA
 Dr. William Ailor, The Aerospace Corporation, Los Angeles, CA
 T. Carter, Nuclear Regulatory Commission, Washington, DC
 C. R. Chappell, Nuclear Regulatory Commission, Washington, DC
 D. Eagan, Office of Radiation Programs, USEPA, Washington, DC
 N. Elsner, General Atomics, San Diego, CA
 J. Boland, Argonne National Laboratory, Idaho Falls, ID
 Charles Salisbury, Naval Ocean Systems Center, San Diego, CA
 Dr. Herbert Weiss, Naval Ocean Systems Center, San Diego, CA
 S. S. Hecker, Los Alamos National Laboratory, Los Alamos, NM
 R. N. R. Mulford, Los Alamos National Laboratory, Los Alamos, NM
 J. Birely, Los Alamos National Laboratory, Los Alamos, NM
 W. F. Miller, Los Alamos National Laboratory, Los Alamos, NM
 S. E. Bronisz, Los Alamos National Laboratory, Los Alamos, NM
 W. Stark, Los Alamos National Laboratory, Los Alamos, NM
 R. W. Zocher, Los Alamos National Laboratory, Los Alamos, NM
 J. A. Pattillo, Los Alamos National Laboratory, Los Alamos, NM
 E. M. Wewerka, Los Alamos National Laboratory, Los Alamos, NM
 T. K. Keenan, Los Alamos National Laboratory, Los Alamos, NM
 T. C. Wallace, Los Alamos National Laboratory, Los Alamos, NM

DO NOT MICROFILM
THIS PAGE

Printed in the United States of America
Available from
National Technical Information Service
US Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Microfiche (A01)

NTIS		NTIS		NTIS		NTIS	
Page Range	Price Code	Page Range	Price Code	Page Range	Price Code	Page Range	Price Code
001-025	A02	151-175	A08	301-325	A14	451-475	A20
026-050	A03	176-200	A09	326-350	A15	476-500	A21
051-075	A04	201-225	A10	351-375	A16	501-525	A22
076-100	A05	226-250	A11	376-400	A17	526-550	A23
101-125	A06	251-275	A12	401-425	A18	551-575	A24
126-150	A07	276-300	A13	426-450	A19	576-600	A25
						601 up*	A99

*Contact NTIS for a price quote.

DO NOT MICROFILM
THIS PAGE

Los Alamos