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STATUS REPORT: IMPACT TESTS--
RADIOISOTOPE FUELS AND SIMULANTS

W. J. Dalby, 9512

AEROSPACE NUCLEAR SAFETY DEPARTMENT 9510

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BY JH Kahn lamh
DATE 6/15/71

Date Published - April 1971

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SC-DR-710218

STATUS REPORT:
IMPACT TESTS--RADIOISOTOPE FUELS AND SIMULANTS

W. J. Dalby, 9512

Date Published - April 1971

Approved by:
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ABSTRACT

The chronology is given of the impact testing of radioisotope fuels and simulants at Sandia Laboratories, Albuquerque, subsequent to the plasma fired $^{238}\text{PuO}_2$ microsphere and samaria-tungsten cermet impact tests. Thirty-three individually encapsulated discs were impacted singly. The capsules were returned either to Battelle Memorial Institute, Columbus, or to Los Alamos Scientific Laboratory to be opened for particle size distribution determinations after impact.

The cutoff date for information in this report is December 31, 1970.

Keywords: microspheres, $^{238}\text{PuO}_2$, samaria-tungsten impact, radioisotope

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ACKNOWLEDGMENTS

The author acknowledges the cooperation and assistance given by numerous individuals in connection with these tests. Because there were many and the risk of omission is great, no attempt is made to list them.

SUMMARY

During the period extending from the fall of 1968 to the fall of 1970, thirty-three discs of radioisotope fuel materials and fuel simulant materials were impacted at Sandia Laboratories, Albuquerque.

The samples tested consisted of actual $^{238}\text{PuO}_2$ fuel forms and various fuel form simulants. All were either pressed ceramic or pressed cermet discs. Two of the discs were shards of $^{238}\text{PuO}_2$ - 10 w/o ThO_2 coated with Mo, and two were shards of $^{238}\text{PuO}_2$ coated with Mo. The several different compositions of simulant discs which were impacted included ZrO_2 , ThO_2 shards coated with Mo, $^{239}\text{PuO}_2$ - 39.2 w/o $\text{ZrO}_2(\text{C}_a\text{O})$, and ^{239}PuO sol gel microspheres coated with Mo/W.

The tests reported herein were not all part of an integrated, pre-planned test program. Rather, they consisted of several series of tests which were initiated to fulfill specific objectives. The discs were impacted in rigid sealed capsules to minimize capsule/disc interaction and to permit recovery of the complete fuel/simulant inventory for particle size distribution analyses. Disc attitude, temperature, velocity, and combinations thereof were the test parameters employed. The ranges of these parameters for the various test specimens are tabulated below.

<u>Disc</u>	<u>Attitude (°)</u>	<u>Temperature (°F)</u>	<u>Velocity (ft/sec)</u>
ZrO_2	0 (flat)	Ambient - 1000	148-306
$^{239}\text{PuO}_2$ - Mo/W	0	Ambient - 1000	92-126
$^{239}\text{PuO}_2$ - 39.2 w/o ZrO_2 (C_aO)	0	Ambient - 1000	100-127
ThO_2	0 - 45	265-880	125-445
$^{238}\text{PuO}_2$ - ThO_2 - Mo	0	860-880	125-133
$^{238}\text{PuO}_2$ - Mo cermet	0	860	305-314

A test plan was undertaken to investigate the development of an equation to predict the particle size fractions resulting from the impact of individual unconstrained discs of simulant as a function of disc impact attitude, temperature, and velocity. Favorable results from this program would have been justification for a similar test program with actual fuels. Sandia participation in the SNAP programs was terminated prior to completion of testing of the simulant.

All of the capsules which were impacted were returned either to Battelle Memorial Institute, Columbus, or to Los Alamos Scientific Laboratory to be opened for particle size distribution determinations of the impacted discs.

TABLE OF CONTENTS

	<u>Page</u>
Introduction	7
General	7
Scope and Testing Philosophy	7
Fuel Form Comparison Impact Tests	8
Solid Solution Cermet Impact Tests	9
Full Scale Disc Impact Tests	9
Molybdenum Matrix Proportion Variation Effects	9
Small Scale Fuel and Simulant Disk Impact	10
Equipment and Procedure	10
General	10
5000-Foot Sled Track	10
Vertical Vacuum Tube Launcher	13
Vertical Air Gun	16
Isotope Fuel Impact Facility (IFIF)	19
Limitations and Deficiencies of Facilities	23
Test Specimens	25
Test Plans	27
Impact Specimen Encapsulation, Inspection, and Analysis	31
Results	32
Conclusions and Recommendations	33
References	35
APPENDIX A -- Isotope Fuel Impact Facility	37
APPENDIX B -- Safe Operating Procedure for the Isotope Fuel Impact Facility (IFIF)	55
APPENDIX C -- Manufacture of SSCS	79

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STATUS REPORT:
IMPACT TESTS--RADIOISOTOPE FUELS AND SIMULANTS

Introduction

General

The evaluation of the potential hazards resulting from the application of radioisotope fuels to aerospace power supplies requires information concerning the possible dispersion of the fuel during or following either a programmed or a nonprogrammed termination of a mission. For α -emitting fuels, the primary hazard is inhalation of fuel particles; the particle size is the controlling parameter. The fuel processing can be controlled to obtain a suitable range of particle sizes initially, and the fuel can be encapsulated to prevent its escape under normal circumstances. However, the as-manufactured fuel particle size may be altered and the fuel released by any of several possible environments. Impact is one of the environments requiring consideration. Because of the inadequacy of the available fuels property data and of the analytical techniques for modeling impact, AEC/SNS/SEPO* requested that Sandia's Aerospace Nuclear Safety Department conduct impact tests of radioisotope fuels and fuel simulants.

Scope and Testing Philosophy

With the exception of the samaria-tungsten cermet impact tests,¹ this report covers the fuels and fuel simulants impact tests which were completed since the plasma fired $^{238}\text{PuO}_2$ microsphere impact tests.² The tests reported herein were not all part of an integrated, preplanned test program. Rather, there were several series of tests which were initiated to fulfill

*Atomic Energy Commission/Space Nuclear Systems Division/Space Electric Power Office

specific objectives and their scopes were sometimes limited by time scales, and test specimen and/or facility availability.

For environments and items for which analytical and modeling techniques are inadequate, testing of real items to actual environments would appear desirable. However, the high cost, limited availability, and biological hazards associated with the use of radioisotope fuels place definite restrictions on impact testing.

Safety of the personnel and environment surrounding the test area was a primary consideration. Container designs to withstand impact without rupturing were sought. Overtests, destructive, and nondestructive tests of containers were employed. Multiple containments were also provided for the impact tests of $^{238}\text{PuO}_2$.

The general test concept for all except the 5000-foot sled track was to place the fuel/simulant disc to be impacted in a closed container which held the disc in one end in the desired impact attitude relative to the impact target surface (which was simply the other end of the container); accelerate the container to the desired impact velocity with the target end of the container toward an arresting system for stopping the container; as the container was stopped the disc continued its travel to impact the target surface at the opposite end of the container. The impact attitude of the disc was established without mechanical constraints on the disc to eliminate any perturbation to the fuel break-up. A free-travel distance between the disc and the target surface was incorporated to assure that the container would be stopped and the target end of the container would be stress free prior to the impact of the disc.

Fuel Form Comparison Impact Tests

In the fall of 1968, SLA* was requested by the AEC to provide an impact test capability for the acquisition of data for a particle size distribution comparison for two different fuel forms. Impacts of two solid solution fuel form specimens and two cermet fuel form specimens were required. The solid solution specimens were to be discs of $^{239}\text{PuO}_2$ - 39 w/o

*Sandia Laboratories, Albuquerque

ZrO₂ (C_aO) and were to be furnished by the Los Alamos Scientific Laboratory (LASL). The cermet discs were to be prepared by Battelle Memorial Institute at Columbus, Ohio (BMI). They were to be ²³⁹PuO₂ sol gel microspheres coated with molybdenum (~19 volume percent) and hot pressed into discs with successive overcoats of molybdenum and tungsten. Ambient temperature and ~100 fps were determined to be acceptable test conditions.

Solid Solution Cermet Impact Tests

Following the impact tests discussed above, SLA was requested by the AEC to provide an impact test capability for ²³⁸PuO₂ and a fuel simulant. The fuel simulant consisted of shards of ThO₂ coated with Mo and pressed into discs. These tests were intended to provide: (1) experimental data concerning the fuel particle size distribution resulting from the impact of a small scale disc of real fuel, and (2) comparative data between the fuel and a simulant concerning fuel particle size distribution resulting from the impact of small scale discs. Test conditions duplicating those for the test in the fuel form comparison impact tests were selected initially. They were later changed to 850°F and 125 fps for the two ²³⁸PuO₂ discs and two of the fuel simulant discs. Two additional impact tests of fuel simulant at 850°F and 250 and 325 fps were requested.

Full Scale Disc Impact Tests

SLA was later requested by the AEC to prepare to impact full scale discs of radioisotope fuel and simulant. These tests were required to provide: (1) a comparison of the impact response of the fuel and the simulant; (2) experimental data for the particle size distribution resulting from the impact of the radioisotope fuel; and (3) preliminary data for the effects of temperature, velocity, and disc attitude on fuel particle size distribution resulting from impact. A program for the impact of 27 full scale simulant discs at five velocities (130 to 600 fps), four temperatures (270° to 2000°F), and five disc attitudes (flat to edge-on) was planned.

Molybdenum Matrix Proportion Variation Effects

In August 1970, SLA was requested by the AEC to impact five full scale discs of fuel simulant to permit study of the effects of various molybdenum matrix proportions on the particle size distribution resulting from impact.

Small Scale Fuel and Simulant Disc Impact

In November 1970, SLA was requested by the AEC to impact two radio-isotope fuel discs and two simulant discs to generate data for a Transit Interagency Review Meeting which was scheduled for December 8, 1970.

Equipment and Procedure

General

Several test facilities were investigated and/or used for the tests reported herein. The equipment and procedures are described in chronological order.

5000-Foot Sled Track

Prior to initiating the fuel form comparison impact tests, zirconia discs were impacted using a bi-rail sled (Figure 1). These tests are reported in Reference 3. The test specimen was contained in a capsule (Figure 2) with a two-stage closure, i.e., threaded and welded. The disc was held in a threaded plug by two retainers (Figure 3) which were selected to permit careful handling of the capsule without releasing the test specimen and still release the test specimen with minimum perturbation at the time the capsule was impacted. The plug holding the test specimen was screwed into the cup. Then the cap was placed in the cup and the assembly sealed by welding. The capsule was placed on a stand (Figure 4) and heated by an oven for the elevated temperature impact tests. The programmed sequence for the ignition of the rockets to propel the sled included removal of the oven from the path of the sled just before impact. The capsule entered the catch box and was impacted on the end opposite the weld closure by the granite target. As the capsule was driven down the track ahead of the target, the specimen was thrown from the threaded plug to be impacted by the inner surface of the capsule. The catch box was employed to minimize the effects from secondary impact of the capsule.

Figure 1. Sled, target, and catch box on 5000-foot sled track

Figure 2. Capsule used on 5000-foot sled track

Figure 3. Plug with test specimen

Figure 4.
Capsule mounted for impact
on 5000-foot sled track

The capsule configuration, i.e., welded cap and threaded plug, was selected to provide a reliable sealing of the capsule to minimize the probability of fuel escaping from the capsule and to facilitate opening the capsule after completion of impact testing. The welded seal was machined from the capsule and the cap was removed with the threaded plug providing a barrier to both the escape of fuel and the entry of contaminants from the machining operations. The threaded closure also permitted the final opening of the capsule to be performed with the capsule immersed in liquid to minimize the loss of small particles of fuel from the capsule.

Vertical Vacuum Tube Launcher

The Vertical Vacuum Tube Launcher (VVTL) shown schematically in Figure 5 was employed for the fuel form comparison impact tests and for four of the six solid solution cermet impact tests. These tests were reported in References 4 and 5. An assembly (Figure 6) of a lightweight piston and a capsule containing the specimen to be impacted was suspended by a cable in the upper end of the launch tube. The launch tube, impact chamber, and reservoir section were sealed and evacuated with a pump. At a predetermined vacuum, the piston/capsule assembly was released by an explosively

Figure 5. Vertical vacuum tube launcher schematic

Figure 6.
Piston/capsule assembly for
vertical vacuum tube
launcher

actuated cable cutter. As the capsule (Figure 7) accelerated down the tube, the impact specimen moved from the bottom of the capsule to rest against the threaded plug in the top end of the capsule. In the impact chamber at the bottom of the launch tube (Figure 8), the capsule was stopped by impacting seven lead cones. The specimen inside the capsule continued its downward travel to impact the inside surface of the bottom of the capsule.

Wires were inserted through the wall of the launch tube at a known spacing (Figure 8). As the leading edge of the piston passed these wires, each was bent down against the tube wall to generate a signal which was recorded on a controlled time base to permit an accurate determination of the piston velocity immediately prior to capsule impact.

Preliminary tests were conducted to obtain calibrations for the pressure differential-piston assembly weight versus impact velocity. Tests were also conducted using a slotted capsule with a dummy fuel disc and a high frame rate camera to confirm that the desired disc attitude and relative timing of stopping the capsule and impacting the disc occurred. Post mortems of overtested capsules were completed prior to impacting radioisotope fuels. These capsules were prepared and tested using the materials, processes, personnel, and equipment planned for the $^{238}\text{PuO}_2$ impact tests to gain confidence that the tests could be safely conducted.

The VVTL facility was readily adapted to provide a second stage containment for the test specimen. This was a minimum requirement to limit the contamination which could be spread in the event of the rupture of a capsule at impact. The reservoir volume was adequate to guarantee a pressure less than ambient within the impact chamber and reservoir immediately following the test. The top piston seal ring and the other seals in the system were adequate to maintain this decreased pressure for a limited time. A blower to maintain the negative pressure within the system was incorporated. An absolute filter was provided between the blower and the reservoir to entrap fuel particles which might be released from the capsule. Removal of one face of the impact chamber resulted in an airsweep of the impacted capsule. A transparent impact chamber permitted limited visual inspection of the capsule prior to opening the impact chamber.

To achieve the impacts at 850°F, a 400-watt resistance heater blanket was wrapped around the capsule. A thermocouple on the capsule monitored capsule temperature. Calibration runs were made to establish the time-temperature relationship required to achieve desired disc temperature.

The capsules were furnished and the tests were conducted by SLA. The specimens for impact were furnished and encapsulated by BMI and LASL. The capsules were opened and the debris analyzed by the respective suppliers.

Vertical Air Gun

A 5-inch air gun was adapted to perform two impact tests of small scale Solid Solution Cermet Simulant (SSCS) discs⁶ at velocities beyond the capability of the VVTL. The capsule design used for the impact tests in the VVTL was modified to incorporate a counterbore for centering the impact

specimen in the threaded plug of the capsule. An arrangement which would permit the capsule to be fired upward was requested because gravity could be used to maintain the proper orientation of the impact specimen relative to the impact surface without having to place any mechanical restraints on the impact specimen. In addition a new facility employing this concept was under development, and tests were required to ascertain its effectiveness. A 5-inch air gun was removed from its normal horizontal mount and attached to a 15-foot high column at the static rocket firing facility (Figure 9). The gun was equipped with a hydraulic clamp which served as a quick disconnect between the air gun barrel and the compressed air reservoir. A double acting hydraulic cylinder was incorporated to displace the barrel axially for loading the capsule, heater, insulation, etc., assembly (Figure 10). A 1000-pound reaction mass weldment was fabricated and bolted to the top of the column to provide an impact surface for the capsule. The test projectile was accelerated up the barrel and impacted the annulus. To minimize secondary impact of the capsule, a cage was added around the gun muzzle to prevent the capsule from falling to the concrete pad. Acceleration of the capsule and gravity retained the impact specimen positioned in the counterbore until the capsule impacted the annulus. The aluminum annulus was employed to decrease the peak deceleration of the capsule, thereby decreasing the probability of rupturing the capsule. Upon impacting the aluminum annulus, the capsule was stopped and the impact specimen traversed the void to impact the inside surface of the capsule. The projectile assembly which was accelerated up the gun consisted of the impact specimen in the capsule, the capsule, two blanket type electrical resistance heaters, thermal insulation around the outside of the heaters, and two transit discs on the ends of the container.

The impact specimens were manually placed in the counterbore in the threaded plug prior to installing the heaters, insulation, etc. The position of the impact specimen was confirmed by x-ray. The orientation of the capsule was maintained, and it was handled cautiously to prevent displacement of the impact specimen from the counterbore in the threaded plug. The air gun was valved to permit both remote filling of the reservoir and firing of the gun.

The impacted capsules were returned to LASL for opening and analysis of the test specimen.

Figure 9. Vertical air gun

Figure 10. Test hardware details for vertical air gun, launch position

Isotope Fuel Impact Facility (IFIF)

Because of the inadequacies of the forementioned facilities for impact testing of radioisotope fuels and fuel simulants, a program was initiated to acquire a special facility. The guiding factors for the facility design were as follows.

1. Safety was paramount.
2. Impact of individual unconstrained discs was specified.
3. Disc temperature, velocity, and attitude were required to be variable and repeatable.
4. A capability to cover the full range of impact parameters for all possible events was specified.
5. Recovery of impacted specimens was required without contamination, damage from secondary impact, or loss of material.

The resultant facility is described in Reference 7 which is included herein as Appendix A. The safe operating procedure for this facility is defined in Reference 8 which is included herein as Appendix B.

The approach adopted to achieve an acceptable level of safety was to provide multiple containment and to strive for a high level of confidence that each containment would remain intact or be adequate in itself. The primary containment was provided by a capsule incorporating both a threaded and a welded closure. To decrease the probability of rupturing the capsule at impact, the magnitude of the deceleration pulse was decreased and the duration was increased by the use of a metal shear braking arrangement. A secondary containment was generated immediately prior to the entry of the capsule into the metal shear brake. This was accomplished by impacting the capsule within a cask which was sealed by the sabot which carried the capsule within the gun barrel. A third containment was incorporated in the final design. This consisted of a sealable enclosure for the complete air gun assembly and included a blower and filters to entrap any fuel particles which might escape the capsule and the sealed cask.

The design of the capsule provided both radial and axial clearances to permit the impact of an unconstrained disc. The required disc temperature was obtained by applying a small electric resistance heating blanket and insulation around the outside of the capsule. The temperature was regulated by a thermocouple which was welded to the outside of the capsule and connected to a controller. The impact velocity was controlled by selecting an appropriate fire-air charging pressure for the reservoir. To accomplish

impacts of discs at different attitudes, a capsule design which permitted the use of five different caps was selected. Each cap configuration was designed to support the fuel disc at the desired impact attitude. The design of the cap permitted the disc to be placed in the proper position manually after practice with a model disc in a transparent capsule. The orientation of the capsule required to retain the disc in position within the cap was maintained throughout the handling and loading sequence. The capsule was loaded in the gun with the cap end down, and the air gun accelerated the capsule upward to retain the disc at the preselected attitude. The capsule was stopped in the shear brake, and the disc continued its upward travel at the capsule velocity to impact against the inner surface of the capsule. Since no mechanical retainers were required for the disc, there were no perturbations to change the disc attitude before impact. A free travel distance for the disc sufficient to assure that the capsule was stopped prior to impact of the disc was provided.

The details of the capsule and cap designs planned for impacts at temperatures up to approximately 1000°F are shown in Figures 11, 12, 13, 14, 15, and 16. The use of capsules of the same design but machined from either super alloy or refractory alloy was considered for higher temperature tests but was not pursued because of the transfer of responsibility for the fuels impact program.

Figure 11. Mod II container body

Figure 12. Mod II (tabulated) 0° container end cap

Figure 13. 22°30' end cap

Figure 16. Container, Mod II 90° end cap

Limitations and Deficiencies of Facilities

5000-Foot Sled Track -- Capsule designs to achieve variable and repeatable disc impact attitudes for a horizontal setup such as the sled track appeared to be more complex than those for a vertical setup such as the VVTL, the vertical air gun, or the IFIF. Complex configurations and hardware (such as the retainers shown in Figure 3) may be detrimental to the recovery and analysis of the impacted fuel specimen and should be avoided. The incorporation of multiple containment for this test setup presented formidable problems. The movement of the sled down the track carrying an impacted capsule appeared to offer a possibility of spreading the material from a ruptured capsule over an unacceptably large area. Because of these factors, other facilities were considered for impact testing of fuels and simulants.

VVTL -- The maximum velocity achieved with this facility was approximately 165 fps. Capsule temperatures approaching 1000°F generated problems with the lightweight foamed plastic piston and the seal rings shown in

IFIF -- All of the test setups used to date required that the capsule which serves as the primary containment be heated to the same temperature as the impact specimen. Because the inside surface of the capsule is the impact target, the temperature effect of the target is superposed upon the specimen temperature effect.¹¹ No test scheme to eliminate or evaluate this was proposed. The maximum capsule impact temperature attained to date was approximately 1500°F. The use of a higher wattage heater to achieve a higher temperature appears feasible.

The reliability of the secondary containment formed by the sabot impacting into the catcher cask was decreased below some minimum impact velocity (~150 fps). However, a modification of the sabot configuration appeared to have solved the problem. It should be noted that as the impact velocity decreases the probability of rupturing the capsule also decreases.

The maximum capability of the facility is probably limited to two tests per day because the safety requirements result in a complex operation.

Test Specimens

5000-Foot Sled Track -- The test specimens impacted on this facility were 2-inch diameter by 0.5-inch thick discs of high density (~96 percent of theoretical) ZrO₂, calcium stabilized, which were obtained from a commercial source.

VVTL -- BMI furnished two dummy fuel specimens and two ²³⁹PuO₂ specimens for fuel form comparison impact testing. The two dummy specimens were 1-inch diameter by 0.5-inch thick molybdenum discs. These were used for trial tests to evaluate the facility and the capsule. The two ²³⁹PuO₂ specimens were fabricated from sol gel microspheres coated with molybdenum (~19 volume percent) which were hot pressed into ~1-inch diameter by 0.5-inch thick discs. They weighed 68.7 and 74 grams. The temperature and pressure for the hot pressing is unknown, but BMI progress reports describing preparation of other specimens referred to ~14,000 psi at ~1600°C for 3 minutes. After pressing, additional coatings of approximately 0.004-inch thickness of molybdenum and approximately 0.013-inch thickness of tungsten were applied.¹²

LASL also furnished two dummy fuel specimens and two $^{239}\text{PuO}_2$ specimens for fuel form comparison impact testing. The dummy fuel specimens were ZrO_2 discs approximately 2 inches in diameter by 0.5-inch thick. Both of the Pu discs were $^{239}\text{PuO}_2$ - 39.3 weight percent ZrO_2 (calcium stabilized)^{13,14} and were approximately 1.8 inches in diameter. One of the discs was approximately 0.44-inch thick and weighed approximately 124 grams. The other was 0.28-inch thick and weighed approximately 83 grams. The ZrO_2 discs were impacted as trial tests to evaluate the facility and the capsule and to provide LASL with material to evaluate their technique for particle size distribution determination.

The solid solution cermet and solid solution cermet simulants used in the impact tests are described below.

The manufacture of the solid solution cermet simulant is described in Appendix C. The specimens used for these tests were approximately 0.46 inch in diameter by 0.27-inch thick and weighed from 6.21 to 6.93 grams. These were core drilled from the full scale (~2.2 inches diameter) discs and had the molybdenum overcoat removed.

The solid solution cermet specimens were approximately 0.46 inch in diameter by 0.25-inch thick and weighed approximately 7.44 grams each. These were furnished by LASL, and their composition is uncertain. However, they are thought to have been shards of $^{238}\text{PuO}_2$ - 10 weight percent ThO_2 at approximately 94 percent of theoretical density which were coated with molybdenum (14 volume percent) to be hot pressed into discs. It is believed that the molybdenum overcoat was not present.

Vertical Air Gun -- The LASL-furnished specimens for these two tests were the same as the SSCS specimens described above.

IFIF -- The full scale SSCS discs used for these impact tests were furnished by LASL. They were approximately 2.2 inches in diameter by 0.22-inch thick and weighed 110 to 120 grams. The manufacture of these discs is described in Appendix C except that they were subjected to an additional bake-out cycle by LASL.

The SSCS discs used for the molybdenum matrix proportion variation effects tests were furnished by LASL, and an accurate definition is not

available at Sandia. However, they are thought to have been substantially as described in Appendix C except that the percentages of molybdenum in the cermet were 10, 14, 26, 35, and 50 rather than the usual 14.

LASL furnished the two SSCS discs and the two Plutonia Molybdenum Cermet (PMS) discs which were impacted for the small scale fuel and simulant disc impact tests. The SSCS discs are thought to have been the same as the SSCS specimens described above. An accurate description of the PMC specimens is not available at Sandia. However, these are thought to have been approximately 0.5-inch diameter by 0.21-inch thick hot pressed discs of $^{238}\text{PuO}_2$ shards coated with molybdenum (estimated 15 to 20 volume percent).

Test Plans

As stated in the Introduction, the tests reported herein were not all part of an integrated preplanned test program. Rather, they constituted several series of tests which were initiated to fulfill specific objectives and their scopes were often limited by several factors.

For the impact testing of the full scale discs of SSCS, a detailed test plan for five levels of each of three factors--disc attitude, temperature, and velocity--was developed with the assistance of Sandia's Statistics and Computing Division.¹⁵ This experiment was designed to permit the prediction of particle size fractions resulting from the impact of individual discs by the full second degree polynomial $y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$. The factors x_1 , x_2 , and x_3 represent the variables of disc attitude, temperature, and velocity. The model was also expected to be useful for the selection of impact parameters for a limited number of impacts of the solid solution cermet discs. For analysis purposes, the spacing of the x 's is determined by a criterion called rotatability. This means that the experimental design has equal predictive power in all directions from a center point and that the standard error of a predicted value at some point (x_1, x_2, x_3) is a function only of the distance of that point from the origin. Although this spacing is not essential, it is advisable that the spacing of the two levels above the central points be the same as those below. The temperature levels to be investigated were decreased to four, and the experiment was designed to permit a preliminary analysis upon the completion of three of these. The

predicted impact parameters and the basis for selecting these are shown in Table I and Figure 18. The test parameters selected are shown graphically in Figure 19.

TABLE I
Fuels Impact Test Parameters

Parameter	Value	
Temperature (°F)	270 - 350	Analytically determined temperature of single disc (Reference 16).
	850	1/2-inch diameter discs (four ThO ₂ and two ²³⁸ PuO ₂ -ThO ₂), uncoated, impact temperature.
	1500	Calculated temperature of Transit heat source at launch.
	2000	TRW determined value for heat source impact following reentry. Also, SLA preliminary estimate of impact temperature for (635 thermal watt) Pioneer strength member.
Velocity (fps)	117 - 143	Analytically determined velocity of single disc. 1/2-inch diameter discs (two ThO ₂ and two ²³⁸ PuO ₂ -ThO ₂), uncoated, impact velocity.
	328 - 331	Experimentally determined impact velocity of ablated configuration of Transit source (TTR measured value corrected to SLA, times 1.1) (Reference 17).
	362	Experimentally determined value for Pioneer heat source (TTR measured value corrected to SLA, times 1.1) (Reference 18).
Attitude (°)	0 (flat)	Per discussion with aerodynamicist:
	15	End-on capsule impact not likely. Expect tumble or flat spin approaching side-on or possible side-on impacts for both Transit and Pioneer.
	30	
	45	
	60	Flat-on for disc or tumble about diameter probable. Edge-on attitude unlikely.
	75	
	90 (edge or side)

Figure 18. Predicted impact parameters

Figure 19. SSCTS full scale disc impact parameters

Impacts at 270° and 850°F appeared to be consistent with previous experience. Extension of the capability of the 1500°F temperature appeared reasonable. Acquisition of the 2000°F capability during the conduct of the 270°, 850°, and 1500°F tests was anticipated. In addition to the impacts of full scale discs of SSCS, impacts of both full and small scale new production and aged fuel discs were planned contingent upon the availability of the test specimens.

Impact Specimen Encapsulation, Inspection, and Analysis

All capsules impacted were SLA furnished items. Proof tests were completed of capsules which were welded employing materials, processes, and personnel planned for the encapsulation of radioisotope fuel prior to impacting the highly hazardous materials. Some of the SSCS discs were encapsulated at SLA. However, all of the test specimens containing Pu were encapsulated by the fuel supplier. A bubble leak check for gross leaks and either a helium or argon leakage check on a CEC-24-120A leak detector were performed on each capsule before and after every impact test. The stated sensitivities for the detector were 1.06×10^{-8} cc/sec stp and 4.55×10^{-7} cc/sec stp for the argon and helium, respectively.¹⁹ The bubble leak check was completed by submerging the capsule in a vessel filled with a low surface tension liquid, placing the vessel under a bell jar, evacuating the bell jar, and visually checking for the escape of gas from the capsule.

For each impact series involving Pu specimens, control capsules, either empty or containing a relatively innocuous simulant, were welded either prior to, during, or following the welding of the capsules containing the Pu. The control capsules were inspected, impacted, and reinspected (using both nondestructive and destructive techniques). Sandia's Nondestructive Testing Division employed several techniques to evaluate the weld of the capsules impacted in small scale fuel and simulant disc tests.²⁰

The capsules were opened and the particle size distributions of the fractions >10 micrometers were determined by sieving. For the <10 micrometer fractions, LASL used extraction replica techniques in the electron microscope.

After removal of the weld, which could be accomplished without losing the threaded seal, the capsule was submerged in Freon TF solvent. The threaded seal was broken, and the capsule was permitted to slowly fill with solvent before the cap was removed. The sieving was performed under solvent using ultrasonic agitation.

To relieve galling of the threads, which interfered with the opening of the capsule while submerged in solvent, a 0.0001- to 0.0003-inch thick coating of electroless nickel was applied to the caps. Because the nickel coating did not interfere with the recovery of the impacted specimen, the entire cap was coated to eliminate the complication of masking and stripping.

For the 850°F impacts, LASL reported that the impact of the full scale SSCS discs at other than flat disc attitudes resulted in the embedding of material from the discs in the impacted surface of the capsule. Nitriding a portion of the capsule appeared to solve this problem.

Replicas of some of the impressions in the inside surface of the capsules resulting from the impact of the discs were made using materials from a Rank Taylor Hobson Plastic Replica Kit. The contours of these replicas were measured and plotted using a Brush Clevite Surfanalyzer 1200 system. These plots were useful for evaluating the flatness of the 0° impacts or for comparing the penetration of the impact surface of the nonnitrided versus the nitrided capsule by the SSCS discs for the angle impacts.

Results

A portion of the data from the fuels impact testing was reported by personal communications and monthly progress reports.²¹⁻³⁰ LASL was asked to furnish the missing data for inclusion in this report.³¹ They responded that they desired to complete the work and publish the results.³² In deference to the LASL position, none of the particle size distribution data is included in this report.

Although no particle size distribution information is presented, a summary of the 33 fuel and simulant impact tests completed at SLA (exclusive of those reported in References 1 and 2) is given in Table II. As of July 30, 1970, evidence of an additional 17 impact tests conducted at Mound Laboratory was noted.

Conclusions and Recommendations

The IFIF provides a unique capability for impacting hazardous materials with adequate safety; a reasonable range, variability, and control of test conditions; and a posttest specimen recovery capability compatible with safety and analytical requirements. The necessary extension and modification of the facility capabilities can be accomplished during the conduct of the required fuels and simulant testing.

To improve the confidence in the equation to be developed for the prediction of particle size fractions, some degree of quality control of the specimens for impact would appear to be essential.

Additional effort is suggested to insure the proper and timely dissemination of test plans and results to avoid duplication of effort and promote the most efficient use of the data.

TABLE II

Summary - Fuel and Simulant Impact Tests
at Sandia Laboratories

	Identi- fication	Furnished by	Analyzed by	Weight (grams)	Diameter (inches)	Thickness (inches)	Velocity (ft/sec)	Temper- ature (°F)	Attitude (1)
ZrO ₂ disc	(2)	LASL	(3)	(2)	2	0.5	306	1000	0°
ZrO ₂ disc	(2)	LASL	(3)	(2)	2	0.5	300	Ambient	0°
ZrO ₂ disc	(2)	SC	(3)	(2)	2	0.5	148	Ambient	0°
ZrO ₂ disc	(2)	LASL	LASL	(2)	2	0.5	155	Ambient	0°
ZrO ₂ disc	(2)	LASL	LASL	(2)	2	0.5	152	Ambient	0°
²³⁹ PuO ₂ sol gel microspheres, Mo/W cermet	P-58	BMI	BMI	68.7	1	0.5	92	Ambient	0°
²³⁹ PuO ₂ sol gel microspheres, Mo/W cermet	P-58	BMI	BMI	74	1	0.5	126	Ambient	0°
²³⁹ PuO ₂ - 39.2 ZrO ₂ (C _a O)	7-114-1B	LASL	LASL	83.4	1.8	0.28	100	Ambient	0° (4)
²³⁹ PuO ₂ - 39.2 ZrO ₂ (C _a O)	7-114-1A	LASL	LASL	124.2	1.8	0.44	127	Ambient	0°
SSCS (ThO ₂ -Mo) (5)	1009-4-1	LASL	LASL	6.89	0.5	0.25	133	830	0°
SSCS (ThO ₂ -Mo) (5)	1009-6-3	LASL	LASL	6.93	0.46	0.27	125	860	10° (6)
SSC (²³⁸ PuO ₂ - ThO ₂ /Mo) (5)	36-1	LASL	LASL	7.44	0.46	0.25	125	860	25° (6)
SSC (²³⁸ PuO ₂ - ThO ₂ /Mo) (5)	36-2	LASL	LASL	6.80	0.5	0.25	133	880	25° (6)
SSCS (ThO ₂ -Mo) (5)	D1017-9-2	LASL	LASL	6.21	0.5	0.25	292	850	0°
SSCS (ThO ₂ -Mo) (5)	D1017-9-1	LASL	LASL	6.31	0.5	0.25	378	850	0°
SSCS (ThO ₂ -Mo)	D0203-8	LASL	LASL	117.91	2.12	0.21	320 (7)	270	22.5°
SSCS (ThO ₂ -Mo)	D0212-20	LASL	LASL	117.98	2.12	0.21	443	270	45°
SSCS (ThO ₂ -Mo)	D0209-18	LASL	LASL	116.92	2.12	0.21	445	265	45°
SSCS (ThO ₂ -Mo)	D0206-5	LASL	LASL	116.72	2.12	0.21	414	850	0°
SSCS (ThO ₂ -Mo)	D0211-19	LASL	LASL	118.18	2.12	0.21	141	850	45°
SSCS (ThO ₂ -Mo)	D0209-18	LASL	LASL	117.27	2.12	0.21	441	850	45°
SSCS (ThO ₂ -Mo)	D0211-24	LASL	LASL	119.38	2.12	0.21	432	850	45°
SSCS (ThO ₂ -Mo)	D0127-35	LASL	LASL	116.74	2.12	0.21	395	850	0°
SSCS (ThO ₂ -Mo)	D0127-36	LASL	LASL	117.83	2.12	0.21	139	850	0°
SSCS (ThO ₂ -Mo)	D0604-14	LASL	LASL	(2)	2.12	0.21	300	850	0°
SSCS (ThO ₂ -Mo)	D0127-18	LASL	LASL	(2)	2.12	0.21	320 (7)	850	0°
SSCS (ThO ₂ -Mo)	D0604-21	LASL	LASL	(2)	2.12	0.21	325	850	0°
SSCS (ThO ₂ -Mo)	D0605-13	LASL	LASL	(2)	2.12	0.21	320 (7)	850	0°
SSCS (ThO ₂ -Mo)	D0605-20	LASL	LASL	(2)	2.12	0.21	312	850	0°
SSCS (ThO ₂ -Mo)	D1017-9-3	LASL	LASL	(2)	0.5	0.25	315	850	0°
PMC (²³⁸ PuO ₂ - Mo cermet)	A	LASL	LASL	(2)	0.5	0.25	314	850	0°
PMC (²³⁸ PuO ₂ - Mo cermet)	B	LASL	LASL	(2)	0.5	0.25	305	850	0°
SSCS (ThO ₂ -Mo)	D1017-9-4	LASL	LASL	(2)	0.5	0.25	311	850	0°

NOTES: (1) 0° = disc flat; 90° = disc on edge.

(2) No information.

(3) No analysis.

(4) Impact impression in capsule indicated disc broken into three pieces prior to impact.

(5) Molybdenum overcoat omitted.

(6) Estimated.

(7) Velocity not measured. Value shown was requested.

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APPENDIX A

Isotope Fuel Impact Facility

Larry O. Seamons

ABSTRACT

The use of radioisotope thermoelectric generators as electrical power supplies for space applications has led to a need to characterize the impact sensitivity of the radioactive materials used in these generators. The knowledge is required to more realistically appraise the safety of potential uses. A facility is being developed at Sandia Laboratories for safely conducting impact tests of this class of potentially dangerous materials.

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APPENDIX A

Isotope Fuel Impact Facility

Introduction

Radioisotope thermoelectric generators (RTG's) are being used to provide electrical power for many space missions. These power supplies consist of subcritical amounts of radioisotope material from which the heat byproduct of radioactive decay in conjunction with a thermoelectric process is used to generate electricity. The radioisotope fuels involved are exposed to all the environments associated with accident situations or mission aborts. One category of these accident environments is impact. Such impact could result, for example, from a launch pad explosion, an early abort leading to subsequent aerodynamic heating and impact, or an orbital abort resulting in reentry and impact.

All radioisotope fuels are health hazards to some degree and in most instances the degree can be altered by impact. In particular, a new fuel under consideration is a solid solution of thorium dioxide and plutonium 238 dioxide with the ThO₂ playing the role of dilutant. Sintered solid solution particles, a ceramic, are coated with molybdenum to produce the basic cermet fuel particles, approximately 150 micrometers in diameter, which in turn are hot pressed together to form a large shape. From the health hazard standpoint, this material is primarily an alpha radiation emitter. In turn, alpha emitters are of most concern when the material particle size is a few micrometers in diameter and thus easily inhaled or ingested. Just a few of these small particles represents enough inhalation material to be extremely hazardous. Therefore, large pieces of this material can become very dangerous if only a small amount is sufficiently pulverized by impact.

The preceding remarks imply a need to know the impact characteristics of radioisotope fuels so that the safety of any space application can be realistically appraised. Eventually an experimental verification or determination of fuel break-up versus impact conditions becomes necessary. Because of the potential extreme toxicity of the PuO₂/ThO₂ solid solution cermet (SSC) fuel material, facilities for impact testing at other than mild impact conditions are virtually nonexistent. A facility for safely performing this type impact is being developed at Sandia Laboratories and has been named the Isotope Fuel Impact Facility (IFIF). The target date for having the facility qualified for impacting materials containing ²³⁸Pu is December, 1970.

The IFIF is intended to be used to characterize fuel form breakup and to characterize fuel simulant breakup. If a less hazardous simulant can be found that will reasonably represent actual fuel behavior under impact, impact testing can be performed on simulants at facilities not equipped to safely handle actual fuel. Other simulant advantages would be availability, low cost, and less stringent material accountability requirements.

The initial impact test specifications which determined the facility design were:

1. Impact the fuel forms at a maximum velocity of 600 fps and preheat the fuel forms to a maximum temperature of 1000°F. These two constraints were initially considered reasonable maximums for earth surface terminal velocities and operating and/or aerodynamic heating induced temperatures. More recently the temperature requirement has increased to 2000°F with 2500°F as an ultimate goal.
2. Prevent postimpact fuel residue from contamination by or entrapment in foreign materials. This is necessary because fuel breakup is determined by sorting and counting all the fuel remaining after impact. The residue is mechanically sieved through a series of screens with a 10-micrometer sieve mesh opening being the finest screen used. Particles which pass the 10 micrometer sieve are further sorted and counted by other means down to 0.1 micrometer "size" particles. Particles below 0.1 micrometer are a separate category, and only the mass fraction of this category is determined. This fines analysis process is impaired by foreign materials because additional separation procedures must be used throughout the process.
3. Establish fuel form orientation relative to the impact surface without mechanical connections to the fuel forms. This constraint eliminates any false contribution to or restriction of fuel breakup that might be created by spring clamps, positioning wires, bond joints, etc., and also eliminates one source of possible fuel residue contamination or entrapment.
4. Guarantee safety of the personnel and environment surrounding the test area by sufficient multiple or concentric containment of the toxic material. The IFIF uses triple concentric containment to satisfy this requirement. The primary and tertiary containment are established before a test is conducted and the secondary containment is formed during a test.

Vertical Air Gun Sequential Detail

The resultant IFIF uses a vertical air gun and auxiliary hardware as shown in Figure A-1 to conduct the fuel impacts. The air gun launches a piston which in turn carries a fuel container assembly shown in position atop the piston in Figure A-1 and shown in detail in Figure A-2.

The best way to explain the vertical air gun and associated hardware is to first run through the sequence of events which takes place during a typical test and then individually discuss the hardware components. Bear in mind that the object of the test is to impact the fuel specimen against the fuel impact surface shown in Figure A-2.

Primary container hardware is shipped to another laboratory where the fuel specimen is placed inside and the primary container is sealed by welding. The container and fuel specimen are returned, and a fuel container assembly is built up and positioned atop a piston. The piston and assembly are placed in launch position, and electrical power is applied to the blanket heater to bring the primary container and fuel specimen up to temperature. When test temperature has been reached and the necessary soak time has elapsed, the compressed air reservoir is remotely pressurized to the desired level. High pressure air is dumped into the trigger air line, thus forcing the piston off the piston seat and allowing the fire air access to the bottom of the piston. The fire air accelerates the piston and fuel container assembly up the air gun barrel to achieve test velocity. The piston and fuel container assembly exit the gun barrel and fire air begins venting through vent holes in the spacer and guide can (Figure A-3). Shortly after the base of the piston clears the air gun barrel muzzle, the piston intercepts the internally tapered catch tube and the fuel container assembly continues on trajectory. The piston swages into the catch tube and in the process forms a metal-to-metal seal which completes and slightly pressurizes the secondary containment of the fuel specimen. The secondary container consists of the piston, catch tube and adaptor plate (Figure A-1) and can be removed from the reaction mass and handled as a unit. The piston/catch tube impact approximates a perfectly inelastic impact and initiates the upward reaction mass displacement inside the guide can (Figure A-4). The fuel container assembly meanwhile has been in free flight inside the secondary container and now impacts the cutter and drives the cutter through eight metal shear bars. The fuel specimen separates from the bottom of the primary container and begins displacing upward relative to the container as soon as the container contacts the cutter. The metal shear bars decelerate the primary container in a controlled manner such that the container is at zero velocity relative to the reaction mass or rebounding from the reaction mass when the fuel specimen impacts the top inside container surface.

The relative impact velocity between the fuel specimen and primary container is essentially the maximum piston velocity vector relative to ground minus the primary container velocity vector relative to ground at the time of impact. The container velocity direction relative to ground can be vertically upward or downward depending on how the container rebounds off the reaction mass. In any event, the rebound and reaction mass velocities are so small compared to maximum piston velocity that they are in practice neglected.

After all the various force inputs to the reaction mass are over, the reaction mass continues displacing upwards converting all the energy it has acquired to potential energy. The reaction mass acquires energy from the piston and fuel container assembly impacts and from the fire air which is expanding up the air gun barrel and out onto the bottom of the reaction mass for many milliseconds after all the various impacts occur. When the reaction mass reaches zero velocity and tries to start back down, the ball lock mechanism (Figure A-1) engages the guide can and retains the reaction mass. The ball lock mechanism is a mechanical diode in that it restricts relative displacement between the reaction mass and guide can to one direction.

After the test is over, environmental health personnel make the necessary radioactivity checks, and facility disassembly proceeds accordingly until the primary container is reached. The primary container and fuel residue are sent to a laboratory equipped to handle the fuel, and the container is machined open and a fines analysis is performed. In the event

of primary container failure, the secondary container would be sent to the same laboratory for disassembly and fuel recovery. A fines analysis would not be possible.

Vertical Air Gun Component Detail

The air gun was designed to fire vertically upward so that the third basic test specification, as mentioned in the introduction, could be met, i.e., establish the fuel specimen orientation relative to the impact surface without using mechanical connections to the fuel forms. The primary container internal geometry and gravity are used to determine the initial fuel specimen orientation. Internal geometry plus piston acceleration are used to maintain fuel specimen orientation following piston launch.

The basic air gun consists of a compressed air reservoir, a port valve and a barrel. The air reservoir is T-shaped in the horizontal plane and is a welded assembly made up of 10-inch steel pipe and fittings. The T-shape provides a stable structural foundation for the gun and is clamped to a large foundation plate. A vertical riser takes off from the leg of the T and terminates with an 8-inch pipe flange fitting. The port valve sits on top of the air reservoir flange and is nothing more than a housing and structural support for the piston seat and a structure which provides air flow passages around the piston seat into the gun barrel. The fire air occupies a volume of 8 cubic feet within the air reservoir and port valve and is limited to a maximum working pressure of 1500 psi. The gun barrel sits atop the port valve and is terminated at each end with an 8-inch steel pipe flange. The bottom barrel flange and the air reservoir flange are tied together by eight 1-5/8-inch stud bolts, and the port valve is compressed between the two flanges as the stud bolts are tensioned.

Two port valve options are available. Mod I is nominally 12 inches high by 12 inches outside diameter and is not accessible when assembled between the barrel and reservoir except through the barrel muzzle. Mod II is approximately 30 inches high and is equipped with a concentric sleeve around the outside of the valve which will displace vertically and provide access to the fuel container assembly and top of the piston. This access can be used for final adjustment of the fuel container assembly, for in place X-ray of the fuel specimen to verify prelaunch orientation, and for routing of thermocouple and heater power cables through the port valve wall; the piston and fuel container assembly must still be muzzle loaded. Both port valves are mild steel weldments with a 1500 psi internal working pressure rating that is compatible with the air reservoir rating. Mod I can be seen between pipe flanges and among stud bolts in Figure A-5, and Mod II is shown in Figure A-6.

The gun barrel is 8-feet long overall and consists of a length of 8-inch schedule 80 steel pipe and two 8-inch steel pipe flanges all welded together. The weldment is smooth bored to a 7.72-inch diameter.

The piston serves three functions which all affect the piston design. It is used as a support for the fuel container assembly, as the only moving part in the valving of the compressed air, and as a structural member of the secondary containment. The piston is shown in Figure A-7. It is nominally 7.70 inches outside diameter by 8 inches long. The top of the

piston is counterbored to accept thermal insulation to protect it from the hot primary container, and the bottom is counterbored for weight reduction. Two O-ring grooves are machined in the piston such that with the piston in launch position one O-ring seals at the piston seat and the other seals against the port valve interior just above the air flow passages. As mentioned previously, the piston is muzzle loaded and forced down the length of the barrel until it bottoms out in the port valve piston seat. The piston seals are checked by pulling a vacuum first on the trigger air line and then on the air reservoir. The 22-pound piston is conditioned "O" aluminum alloy (2024) because of weight considerations and because this material flows nicely and forms a good metal-to-metal seal under dynamic loading into the catch tube. Vertical air gun proof tests over the 125 to 600 fps velocity range have shown that the seal formed between the piston and catch tube has a leak rate less than 10^{-6} cc of helium per second at standard temperature and 1 atmosphere pressure differential. At all but the lowest velocities a 600,000-pound hydraulic press is not capable of removing the piston from the catch tube unless the piston stress is first relieved by drilling a large hole through the piston. Even after being drilled out, several hundred thousand pounds of force are required to press out the piston.

The fuel container assembly consists of the primary container with the fuel specimen inside, a blanket heater, annular rings of commercial 2000°F thermal insulation, a transite shell, and Fiberfrax thermal insulation (Figure A-8).

The primary container shown weighs about 3-1/2 pounds and is built of 15-5 precipitation hardened stainless steel because of its good strength at temperature and oxidation resistance up to 1000°F. Since the fuel specimen is placed inside the primary container and the container is welded shut at a location other than the test facility, the container internal geometry must be such that the fuel specimen can be oriented properly within the container without having visual access to the operation. This same geometry must maintain fuel orientation throughout the test. The present test program calls for orienting a 2.12-inch diameter by 0.22-inch thick fuel disc at every 22-1/2-degree interval between edge on and flat on. At present, test temperatures have not exceeded 1000°F and the 15-5 PH containers have survived the test environment. Preliminary results indicate that similar containers of Haynes-25 alloy will be useable to 1500°F. Container materials for 2000°F have not been tested in the facility but a T-111 alloy is under consideration. Low strength and high oxidation rates at temperature will be serious material constraints at the high temperatures. The oxidation problem can be limited by providing an inert atmosphere inside the air gun barrel and inside the primary container. The low strength problem is more difficult because the primary container stopping acceleration runs as high as 50,000 g. The solution will probably require designs relying on a relatively fragile-looking structure aft of the impact end and massive primary container deformation.

The blanket heater is a 400-watt, 200-volt electric resistance heater capable of 1600°F and sized to fit the cylindrical surface of the primary container. Similar heaters can be purchased with temperature capabilities to 2000°F. The electrical leads from the heater exit the top of the fuel container assembly (Figure A-9) and are routed either out the port valve wall or up the gun barrel and out the muzzle.

Thermal insulation is positioned all around the primary container and blanket heater to reduce heat loss and to protect nearby aluminum, rubber

O-rings, and low carbon steel parts from the high temperatures. The Fiberfrax thermal insulation is a cotton-like substance good to 2000°F and is used to fill irregularly shaped volumes around the primary container. The transite is a pressed asbestos-fiber based material with fair strength and thermal insulation characteristics to a temperature of 750°F or so. The transite cylindrical shell is used to house the remainder of the fuel container assembly (Figure A-9).

The spacer is shown in Figure A-10 and provides a stand off between the catch tube and upper barrel flange as well as concentric alignment between all three parts. The stand off is required to allow fire air venting to begin before the piston impacts the catch tube. Otherwise, the fire air imparts too much energy to the reaction mass to be able to maintain a reasonable guide can length. The spacer is a mild steel tubular weldment generously vented for passage of fire air and for optical access by photographic equipment to the piston and fuel container assembly prior to piston/catch tube impact.

The catch tube is a 300-pound hollow cylinder 18 inches long by 12 inches outside diameter (Figure A-11). The tube has a 5-degree internal taper at the end which receives the piston. The tube material is D6A-C alloy heat treated to Rc 35. This heat treat results in a tough material with a tensile yield strength around 120,000 psi and the capability of withstanding the piston impact without suffering permanent strain. Experience has shown that the piston/catch tube seal can be verified remotely by monitoring the hoop strain at the bottom of the catch tube and ascertaining that it attains and maintains an expected strain level. The upper end of the tube receives the metal shear and adapter plate, and an O-ring seal exists between the metal shear and catch tube. An access hole has been machined through the wall of the catch tube so that an air valve and small HEPA filter can be attached (Figure A-11). This feature is provided so that after a test the secondary container overpressure may be vented through the filter and the filter checked for radioactivity which would indicate a primary container failure.

The metal shear is a piece of hardware for stopping the primary container in the requisite time without unduly loading the container. It is shown in Figure A-12 with three of the metal shear bars and bar holders removed for clarity. The metal shear is used in conjunction with a cutter which is a disc-shaped piece of hardened 4340 steel alloy with a cutting edge on the outer periphery. The cutter is bonded to the metal shear with the cutting edge in contact with the leading edges of the metal shear bars shown in Figure A-12. When the primary container impacts the cutter, it drives the cutter through the eight shear bars, thus stopping the container. The fuel specimen must traverse 2 inches or more inside the primary container to reach its impact surface and the shear bar thickness is adjusted to stop the container in less than an inch. As much as a 2-1/2-inch thickness of the 1018 mild steel shear bar metal is sheared to stop a 3-1/2-pound container from 600 fps. The original attempt to use this technique was to have the cutter moving with the container, but it was found that the cutter would not maintain proper orientation and penetrate all the shear bars equally. This type of difficulty disappeared when the cutter was mounted to the shear bars. The cutter mass was minimized to reduce the primary container/cutter impact severity. The metal shear fits inside the top end of the catch tube and is attached to the catch tube by eight 1/2-inch bolts which pick up the bolt circle in the metal shear flange and sandwich the flange between the adapter plate and the catch tube.

The adapter plate is shown bolted to the top of the catch tube in Figure A-11 and is a 1-inch thick mild steel plate which picks up a bolt pattern on the bottom of the reaction mass and the bolt pattern on the top of the catch tube. It can be unbolted from the reaction mass without being unbolted from the catch tube but the reverse is not true.

The reaction mass is a solid steel cylinder approximately 19 inches diameter by 34 inches long and weighs 2700 pounds. It displaces upwards inside the guide can and is retained at apogee by the row of spring-loaded balls that run on a 5-degree taper machined into the reaction mass (Figure A-13). The guide can is a mild steel tube 20 inches outside diameter by 1/2-inch wall thickness which is well vented for air flow and photography. The guide can is also shown in Figure A-13. Approximately 700-psi fire pressure is required to achieve 600 fps with a 28-pound total launch weight. These conditions result in a reaction mass displacement of 34 inches which is about as far as you can comfortably go with existing hardware. A quick calculation shows that the launch mass momentum alone would result in a reaction mass displacement of only 5-1/2 inches. The rest of the displacement is caused by fire air expansion. To accommodate higher fire pressures, test velocities, or launch weights, the reaction mass could be significantly increased by using a more dense material, the guide can could be lengthened, or the spacer stand off distance could be increased.

Miscellaneous Facility Details

One critical facility performance characteristic is to stop the primary container prior to fuel specimen impact. The hardware configuration will not allow direct observation of this phenomena. It is possible to calculate at what time the fuel impact occurs if you are willing to make assumptions of the force-time input to the container, but such calculations need verification. The best verification is provided by measurements of the metal shear bar compressive strain during container deceleration and the length of metal which is sheared. The container stop time is the same as the compressive stress duration in the metal shear bar. The time of flight of the fuel specimen inside the container is the fuel specimen free flight distance inside the container plus the shear distance required to stop the container all divided by maximum piston velocity. A comparison of these two times produces the desired verification.

Another question of interest is: Did the fuel specimen impact at the proper orientation? This question is answered by observation of the impact surface after the container has been opened and the fuel removed. The indentation left in the target surface by the fuel specimen impact can be measured to verify orientation.

It appears that the primary limitation of this whole general test technique is the maximum temperature environment that can be provided. At some high temperature the structural integrity of the primary container is nil and any breach of the primary containment voids any chance of performing the desired fines analysis. One way of eliminating this constraint would be to devise a facility where only the fuel specimen is heated and material strength at temperature would thus not be as great a concern. Also, the impact variable of target temperature would be eliminated from test data. The IFIF could be used in this manner after some modification except that it is not located where the handling of bare fuel specimens is

permissible. Such an impact scheme is possible by using quick heat source removal and fuel specimen multiple containment that is generated at the time of the test in a manner similar to the IFIF secondary containment.

The present test program and related hardware requires accelerating approximately 28 pounds to a maximum of 600 fps. The air gun is capable of accelerating 60 to 70 pounds to 600 fps, and the air flow characteristics out of the reservoir and through the port valve are probably good enough to accelerate lighter weight projectiles to somewhere in the 800 to 1000 fps range. This general capability could be used to conduct either higher velocity impacts or turn-around impacts where the impact target is fired into a stationary test item.

Chamber Details

Considering only the hardware that has been described so far, a simultaneous failure of the primary and secondary containment is possible and such an event could create a dangerous environment. For this reason, it was decided to operate the vertical air gun inside an underground sealed chamber which would provide tertiary safety containment of the toxic material. Then if both the primary and secondary containment failed, environmental health personnel would assume control of the facility and a lengthy decontamination procedure would begin.

The resultant overall facility is shown schematically in Figure A-14. All the fire air is dumped into the chamber whenever a test is conducted, and the chamber is capable of accepting this gas expansion. Referring to Figure A-14, the chamber usage during a test is nominally as follows.

1. Prepare the vertical air gun for testing, begin heating the fuel specimen, and close up the chamber.
2. Close the two positive seal butterfly valves and open the bypass valve.
3. Start the blower and verify the chamber seals.
4. Finish temperature conditioning, pressurize the air gun reservoir, and fire the air gun thus pressurizing the chamber to a maximum of 4.8 psi above the initial chamber pressure.
5. Wait for the air to pass through the bypass valve, filter system, and blower. The function of the bypass valve is to regulate the pressure applied to the filter system.
6. Check the filter system to verify no radioactivity and open the butterfly valves to continue chamber purge and radioactivity check.
7. Open chamber and begin vertical air gun disassembly when tertiary container has been verified as being free of toxic material.

The chamber is a 25,000-pound cylindrical vessel with a 12-foot internal diameter and 22-foot depth; the chamber volume is approximately 2500 cubic feet. The chamber walls are 3/16-inch thick rolled steel sheet backed up by a 4-inch thickness of reinforced concrete and dirt fill. The chamber lid and bottom are basically 1-inch steel plate with generous stiffening structure added. The chamber is shown in Figure A-15 just prior to implantation. The lid has two access hatches (Figure A-16). One hatch is located near the periphery and is used by personnel; the other hatch is located in the center of the lid and is used for air gun hardware assembly. The chamber sits atop a 12-inch thick reinforced concrete pad. All of the chamber welds, ducting, and ducting welds were helium leak checked and X-rayed before being installed underground. The 8-inch chamber inlet and outlet ducts feed a filter system consisting of a 24- x 24- x 2-inch FARR J-12 coarse filter which is backed up by a 24- x 24- x 12-inch high efficiency particulate air (HEPA) filter. The system will remove all particles larger than 0.3 micrometer. The filters are housed in a metal structure which provides a test hole for radiation detection equipment. A 1000-cfm squirrel cage blower is used for air circulation. The chamber interior is equipped with a full diameter work platform at mid-depth and with spiral staircases leading to the work platform and chamber bottom. The hemi-chambers partitioned off by the work platform are individually lighted. The chamber walls are penetrated by compressed air lines, electrical power lines, instrumentation cables, and electrical control cables. An overhead 4-ton monorail crane is provided to support routine test assembly and to install and remove all hardware inside the chamber whenever necessary.

Figure A-1. Vertical air gun assembly, launch position

Figure A-2. Typical fuel container assembly shown atop piston

Figure A-3. Impact of piston and release of fuel container assembly

Figure A-4. Impact of container assembly and fuel specimen

Figure A-5. Ground level vertical air gun checkout installation

Figure A-6. Mod II port valve

Figure A-7. Piston and thermal insulation which fits in top piston counterbore.

Figure A-8. Typical fuel container assembly components

Figure A-9. Typical fuel container assembly in position on a piston

Figure A-10. Muzzle end of air gun barrel in ground level checkout installation

Figure A-11. Catch tube and adapter plate with piston swaged into tube

Figure A-12. Metal shear device

Figure A-13. Reaction mass and guide can

Figure 14. Schematic of isotope fuel impact facility

Figure A-15. Chamber prior to underground installation

Figure A-16. View of chamber lid prior to underground installation

APPENDIX B

Safe Operating Procedure for the
Isotope Fuel Impact Facility
(IFIF)

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APPENDIX B

Safe Operating Procedure for the Isotope Fuel Impact Facility (IFIF)

1. Introduction

1.1 This procedure is for the purpose of establishing the technique for safely conducting impact tests of items containing radioactive materials with a hazardous level up to and including plutonium bearing items.

1.2 The facility developed for conducting these tests has been named the Isotope Fuel Impact Facility (IFIF) and is located at the Guns Facility, Building 6750. This facility is designed to provide three containments about the impacting test material. The test material is sealed into a can, which is the primary container.

1.3 The can is loaded into a vertical firing air gun atop a piston. The piston and can are fired upward out of the gun and into a stopping system. The piston is larger in diameter than the can and is swaged into a tapered hole through which the can passes. The can impacts a retarding device called the shear fixture which decelerates the can by shearing metal. The tapered hole that captures the piston is part of a tube called the catch tube which is sealed at the top end by the shear fixture. When the piston plugs the tapered opening at the bottom, the three items (shear fixture, catch tube, and piston) form a sealed container with the can containing hazardous material inside and is called the secondary container.

1.4 The catch tube is bolted to a mass of metal called the reaction mass. The reaction assembly absorbs the energy of the piston, can, and air blast reaction.

1.5 The equipment described thus far is located in a sunken, steel cylindrical chamber. This chamber is equipped with a micrometer-size exhaust filtering system and is otherwise sealed. This chamber is the tertiary container.

2. Responsibilities

2.1 Division 7325 is responsible for enforcing the regulations contained in this procedure except that the Health Physics Organization personnel will be present for all tests of radioactive materials and will be responsible for radiation monitoring procedures. These procedures are defined in Supplement I to this appendix.

2.2 The Division 7325 Supervisor will review this procedure every 3 months with the test personnel. Any changes deemed necessary will be discussed with Division 3351, before implementation.

2.3 Division 3351 will review this procedure with the responsible division supervisor and the test personnel every 6 months. Any needed changes will be implemented.

2.4 All 7325 personnel are authorized to assemble and operate this facility.

2.5 Anyone questioning this safety procedure may at any time request and be granted an immediate halt to the test. Such request should be made to the Test Director and/or the Division 7325 Supervisor.

3. Procedure Outline

3.1 For more details concerning the construction and function of this facility, see the paper, "Isotope Fuel Impact Facility," by L. O. Seamons, Division 7325.

3.2 The following procedure is a description of those steps necessary to conduct a test which will generate a contained impact of the hazardous material. The procedure contains the following items:

(4.) Hardware Preparation	(7.) Test Abort Procedure
(5.) Testing Procedure	(8.) Post Test Reentry
(6.) Firing the Gun	(9.) Test Check List

4. Hardware Preparation

4.1 The shear fixture is defined in Drawing P93363, Sheet 1 of 2.

The assembly is to be prepared per the drawing with the following deviations:

- a. Items 10 through 14 have not been incorporated.
- b. The cutter, Item 5, is attached by bonding it to the shear bars (Items 2, 3, or 4) with adhesive. The cutter is centered on the shear bars while bonding takes place.

4.2 The catch tube assembly is shown on Drawing P93365 and includes the assembly of Items 10, 11, 14, 39, 7, and an "O" ring, which is not shown.

4.2.1 The plate (11) and the shear fixture (14) are assembled to the catch tube with eight bolts (39). The top of the catch tube has an "O"-ring groove which must be checked for damage and cleaned. The shear fixture mating "O"-ring surface shall be clean and free of scratches. The "O" ring shall be checked for defects and the assembly made as shown. The bolts shall be torqued to 50- to 70-ft/lb torque.

4.2.2 The adapter assembly (7), Drawing P80946, provides instrumentation access to the inside of the catch tube, as well as a passage through which air entrapped by the piston within the catch tube may be vented.

If the adapter is not available, a simple street elbow shall be used to replace Item 1 of the pressure adapter assembly (P80946). Other items (7, 8, 9, 10) are assembled as shown on the drawing. These items are sealed together with pipe sealer and the assembly screwed into the catch tube.

4.2.3 The valve (Item 8) is closed when the handle is perpendicular, and open when parallel to the flow. The above assembly is leak-checked by temporarily closing the lower end of the catch tube, pressurizing with air to 12 psi and bubble checking the "O"-ring seal and the valve plumbing or the pressure adapter, if it is used.

4.3 The container bodies and end caps are defined in Drawings PW65, P93361, P80914, P83052, P80941, P80919, and P80945. Prior to being delivered to Building 6750 the container bodies and end caps will be:

1. Checked for leaks,
2. Examined for defects by appropriate nondestructive test techniques,
3. Assembled with the puck within the can in an argon atmosphere,
4. Welded shut, and
5. Checked for external contamination.

4.4 Prior to assembly of the piston and test can assembly (Figure B-1):

1. Examine the piston for damage to the "O"-ring groove,
2. Inspect and install the "O"-rings, and
3. Place the blanket heater around the can and check the heater for operation.

4.5 The piston assembly is made per Figure B-1, which shows a 0-degree end cap and is modified to accept the other style of end caps. In the assembly the transite sleeve must be checked for defects and the piston top machined to provide a close fit to the transite.

4.6 The can must be oriented so that its axis is parallel to the axis of the piston.

4.7 The firing chamber is described and operated as follows.

4.7.1 The chamber is detailed on Drawings 91423 and Sketches SK-724-4.

4.7.2 The purpose of the chamber is to contain any test item debris that may escape from containments one and two. Figure B-2 shows the chamber ventilation system air flow diagram.

4.7.3 The test gun discharges a burst of air which may increase the chamber pressure to approximately 5 psig. The chamber must be sealed so that all the air from firing the gun is vented through the absolute exhaust filter.

4.7.4 The chamber filter can support only a 1.9 psi peak blast pressure drop across it without sustaining damage. The filter pressure drop will be controlled by restricting the flow of air between the chamber and filter with valves 2 and 3 in Figure B-2. Bypass valve 3 allows fine adjustment, and butterfly valve 2 coarse adjustment, of the air flow out of the chamber and through the filter. The position of these valves must be determined experimentally so that the gun air discharged is vented from the chamber in a reasonably short time without generating a high pressure drop across the exhaust filter.

The valve settings can be determined by the following steps.

- (a) Determine the expected peak chamber pressure produced by the expansion of the gun reservoir air.
- (b) Pressurize the chamber through tank pressure test valve 4 to a pressure higher than that determined in (a) by approximately 0.5 psi.
- (c) Open butterfly valve 2 rapidly to the desired trial position and observe the filter ΔP gage for a safe pressure drop (anywhere within gage range).
- (d) Repeat (a) through (c) above, while increasing the valve opening in (c) until the desired pressure drop is reached.

4.7.5 The pressure transducers in Figure B-2 may be used to record the pressure of the chamber and the filter inlet during firing so that valves 2 and 3 may be adjusted to limit the peak pressure at the filter inlet to 1 psi, and yet vent the chamber as rapidly as possible. During test operations, the chamber pressure will be reduced to below atmospheric with the exhaust fan. Valve 1 will be closed during testing to prevent air from escaping from the air inlet pipe.

4.7.6 The filter pressure drop gage is used to determine when the filter needs replacement, as determined by Division 3311.

4.7.7 First valve 2 and then valve 1 will be opened after the filters have been checked for contaminants following a test. The air flow through the chamber should sweep airborne contaminants into the filter where they can be detected. With valves 1 and 2 open, the air passes through the chamber at the rate of approximately 600 cfm, or one chamber volume (2500 ft³) every 4 minutes.

5. Testing Procedure

The following sequence of operations will be followed in preparing to fire the gun. See Figure B-3, IFIF Plumbing Diagram.

- 5.1 Check that the air pressure supply system (Trailer) is not connected to the gun.
- 5.2 Check to be sure that no pressure remains in either the fire pressure or gun reservoir systems.

- 5.3 No personnel will be allowed to be in the chamber while there is pressure in the gun reservoir or fire pressure systems.
- 5.4 Wipe the gun barrel bore with a clean, oil-free fabric.
- 5.5 Establish the test item orientation with the can by a sense of feel developed by training with a plexiglass container. Once oriented, the can must be handled so that the test item will not be dislodged.
 - 5.5.1 Insert the piston assembly into the barrel.
- 5.6 Push the piston to the bottom with the insertion tube that fits over the heater assembly.
- 5.7 Install a new Conax explosive valve kit in the gun fire valve and the explosive vent valve if it has been used. See SOP 70:139, September 1970.
- 5.8 Leak check the "O"-ring seal at the bottom of the piston as follows.
 - (a) Open vacuum pump valves 1 and 2.
 - (b) Close the fire line vent solenoid which is normally open by energizing it from the console programmer.
 - (c) Turn on the vacuum pump.
 - (d) The vacuum gage should drop to approximately 23 inches Hg rapidly (10 seconds) because the volume is small
 - (e) Close pump valve 2.
 - (f) Observe that the vacuum does not appear to drop for a period of 10 minutes.
 - (g) If the vacuum drops, there is a leak and it must be found and corrected.
 - (h) When it is established that the system is free of leaks, set the valves as follows.
 - (1) Close pump valve #1.
 - (2) Open pump valve #2.
 - (3) Shut off the vacuum pump.
 - (4) Open the vent solenoid from the console programmer.
- 5.9 Attach the heater power leads to the heater power supply.
- 5.10 Connect the can thermocouple lead wires.
- 5.11 Turn on the temperature controller in Building 6750 and allow the heater to function until the temperature rise on the can is observable on the temperature monitor in Building 6750.

- 5.12 Make a visual check of the experiment from the muzzle of the gun. Check that the cables and/or the insertion process have not disturbed the position of the experiment on the piston.
- 5.13 Check that the proper range pressure gage (strain-gage type) is installed into the reservoir and check that it is functioning.
- 5.14 Place the stand ring on the muzzle. Position to clear laser beam.
- 5.15 Assemble the catch tube assembly to the reaction mass in a vertical position.
- 5.16 Drop the guide can over the reaction mass assembly and pick up the entire assembly. Be sure to put a safety strap from the crane hook to the reaction mass to prevent it from dropping if the detent system should fail.
- 5.17 Lower the guide can, reaction mass, and catch tube assembly through the center hole in the tank and assemble it to the top of the barrel.
- 5.18 Check the explosive valve bridgewire circuit continuity with a current-limited detonator checker.
- 5.19 System check the gun explosive fire valve initiation system by firing the fire set into a spark-gap that has been attached to the fire lead. System check the explosive vent valve initiation system monitoring the fire line with a Simpson Meter for 110 VAC while a console operator energizes the control switch.
- 5.20 Check the three gun solenoid valves, which are the fill, vent, and bleed valves, by energizing them one at a time from the console, while a second operator listens for their operation.
- 5.21 System check the emergency stop switch which performs the following functions.
- (a) Stops the programmer that fires the gun.
 - (b) Closes the fill valve.
 - (c) Fires an explosive valve that vents the gun reservoir. This valve is included as a highly reliable safety vent in the advent of a bleed valve failure.
- 5.22 System check the console programmer which controls the following.
- (a) Starts cameras.
 - (b) Starts tape recorder.
 - (c) Starts chart paper recorder.
 - (d) Turns on laser velocity system.
 - (e) Triggers the fire-set which fires the gun.

- 5.23 Calibrate the catch tube strain gage-recorder system.
- 5.24 Calibrate the reservoir, tank, and filter inlet pressure gage-recorder system.
- 5.25 Check the laser velocity system by energizing the laser from the programmer and observing the detector response on an oscilloscope.
- 5.26 System check the camera and flash equipment with the participation of the photo instrumentation personnel.
- 5.27 The chamber operating personnel shall take possession of the console fire-set lockswitch keys and keep them until the remaining test preparations are complete.
- 5.28 Attach the explosive valve fire lines to the console fire circuit. (There is no hazard since the valves are self-contained and there is no pressure in the reservoirs.)
- 5.29 Visually check the inside area before leaving the tank. Remove all unnecessary equipment.
- 5.30 Carefully check the chamber center and personnel hatch seals for defects.
- 5.31 The Test Director shall establish that all personnel are clear of the test chamber before closing the personnel hatch.
- 5.32 Bolt the hatches shut.
- 5.33 Close the inlet and outlet air butterfly valves.
 - a. Attach a hose to the tank pressure test valve and pressurize the test chamber to approximately 1 psi.
 - b. Close the fill valve and remove the pressurizing hose.
 - c. Make an audio and visual check of the complete test chamber and associated filter system to determine if there are any air leaks.
- 5.34 Open the exhaust butterfly valve to the proper position as established for the particular test conditions per 4.7.4.
- 5.35 Insure that the test chamber ventilation blower is on.
- 5.36 The Test Director shall clear the area within 50 feet of the facility of all personnel except the operating personnel.
- 5.37 Attach the pressure trailer hose to the gun fire pressure line, fill the fire pressure volume to 900 ± 50 psi, close the inlet line valve, and remove the hose.
- 5.38 Attach the pressure trailer hose to the gun reservoir line and set the pressure trailer regulator to a pressure adequate for firing the gun.

5.38.1 The reservoir of the gun is designed for a safe operating pressure of 1500 psi, but when testing without further development shots, the pressure should never exceed 800 psi. The combination of 27-pound piston assembly weight and 800-psi reservoir pressure will generate a reaction mass vertical displacement that is close to the chamber overhead clearance.

5.39 Close the Building 6750 facility perimeter fence.

5.40 Clear the area outside Building 6750 and inside the perimeter fence of all personnel.

6. Firing The Gun

6.1 The check list (section 9 of this procedure) shall be initiated by the facility operators as they complete each function. The Test Director shall ascertain that all items have been properly checked before a test is fired.

6.2 The 7325 Console Operator will perform the gun firing functions in the following manner.

6.2.1 Use the reservoir fill solenoid valve switch to fill the gun reservoir to the pressure prescribed by the Test Director. Adjustments may be made using the reservoir bleed solenoid valve switch.

6.2.2 Arm the console fire-set with lockswitch keys.

6.2.3 Observe that the fire-set ready light appears.

6.2.4 Start the console programmer.

7. Test Abort Procedures

7.1 If there is an apparent emergency, the console operator shall use the emergency stop switch then continue with 7.2.

7.2 Shut off console programmer if started.

7.3 Turn off and remove console fire-set lockswitch keys. Determine that the fire set voltage meter reads zero.

7.4 Vent the gun reservoir of air with the reservoir bleed solenoid valve switch.

7.5 The Test Director and Health Physics representative shall establish the hazard potential of the abort problem and proceed accordingly.

7.6 Remove the pressure trailer hose from the gun reservoir fill line.

7.6.1 If the gun has not fired, open the fire pressure valve and allow the fire volume to vent.

7.6.2 Check that the gun fire pressure system has vented by observing the line pressure gage, and check that the chamber is not pressurized by observing the chamber pressure gage.

7.7 The gun has now been disarmed, and the chamber can be reentered with due regard to 7.5.

8. Posttest Entry

8.1 Check the following before anyone leaves Building 6750.

8.1.1 Observe the strip chart recorder for:

- a. Permanent strain in catch tube gages indicating the piston stuck and the secondary containment held.
- b. That the chamber pressure transducer has returned to zero.

8.2 Generally, two Health Physics (HP) and one Facility Operator (FO) are required to recover the test item. In order for each organization to provide training to other personnel, the total number of persons entering the test area will be restricted to six or less. The Test Director and HP are responsible for the control of entering personnel.

8.3 The HP's and FO, in full protective clothing, will go to the test chamber and check the filters externally with a scintillator.

8.3.1 The FO will vent the pressure trailer supply line and remove it from the gun reservoir fill line.

8.4 If no radiation is detected:

8.4.1 Open exhaust butterfly valve.

8.4.2 Then open the intake butterfly valve.

8.4.3 Periodically monitor the chamber exhaust filters for a period of at least 5 minutes. Approximately one air change occurs every 4 minutes with the valves so positioned.

8.5 If any radiation is detected up to this point, proceed as follows.

8.5.1 Close the intake butterfly valve.

8.5.2 Keep the fan running until a recovery procedure can be instigated.

8.6 If no radiation is detected at this point, proceed as follows.

8.6.1 The two reentry personnel will don their full face respirators and open the personnel hatch.

8.6.2 The HP will enter the chamber, checking the area with an Alpha PAC as he goes.

- 8.6.3 If contamination is found within the chamber, the HP will leave the chamber, close the hatch, and institute Item 8.5.
- 8.7 If no contamination is found within the chamber, the FO shall enter the chamber and continue as follows.
 - 8.7.1 Install the catch tube exhaust filter.
 - 8.7.2
 - a. Open catch tube vent valve cautiously.
 - b. Listen for venting of the catch tube. Do not vent completely down on the first inspection for contamination (when primary container is hot). Do vent completely down on the second examination (after primary container has cooled for 12 hours). Close valve.
 - c. Remove and check filter for contamination.
 - 8.7.3
 - a. If no venting of air is heard when the catch tube vent is opened, attach tubing from the catch tube vent valve filter to the mechanical vacuum pump.
 - b. Open vent valve and evacuate the catch tube.
 - c. Close vent valve.
 - d. Remove the catch tube filter and pass it to the back-up HP outside the chamber for an examination for contamination.
 - e. If the filter is not contaminated, open the catch tube vent valve to bleed off the vacuum.
 - f. Close catch tube vent valve.
 - 8.7.4 If contamination is found within the catch tube by the test of its filter, the test equipment will not be disturbed until a handling procedure can be instituted for its removal.
- 8.8 If no contamination is found inside the secondary container, the masks can be removed and photo personnel will be allowed to enter the chamber and recover film from cameras.
 - 8.8.1 The Test Director will insure that all persons are out of the chamber and close it for a cooling period of 12 hours.
 - 8.8.2 During the cooling interval, the chamber will be closed and the fan turned off. Check that the following are closed.
 - a. Chamber lids
 - b. Inlet and outlet butterfly valves
 - c. Bypass valve
 - d. Tank pressure test valve
 - e. Fire pressure fill valve

8.8.3 Reentry after the cooling period will proceed as follows.

- a. Turn on chamber filter exhaust fan.
- b. Open chamber exhaust butterfly valve.
- c. Resume at 8.3

8.9 With face masks removed, the gun reaction mass assembly will be removed from the chamber and disassembled down to the catch tube assembly.

8.9.1 The facility operation personnel will don masks and full protective clothing; then the reaction mass adapter plate will be removed.

8.9.2 A plastic bag will be taped over the lid end and the lid removed.

8.9.3 The contents of the secondary container will be checked for contamination by the HP with an appropriate instrument.

8.9.4 If contaminated, the lid will be secured and the plastic bag left in place.

8.9.5 If no contamination is found, the primary container will be removed and placed in a plastic bag for further testing to determine the possibility of a primary container leak.

8.10 The primary container will become the responsibility of the Health Physics organization.

9. Check List

- ___ 1. Assembly - general (weigh piston ___ lbs)
- ___ 2. Catch tube leak check
- ___ 3. Piston fire line leak check
- ___ 4. Blanket heater function test
- ___ 5. Vacuum pump valve closed
- ___ 6. Explosive valves System check
 - ___ a. Fire
 - ___ b. Vent
- ___ 7. Fill valve
- ___ 8. Bleed valve
- ___ 9. Catch tube strain gages
- ___ 10. Reservoir pressure transducer and indicator calibration

- ___11. Check cameras
- ___12. Check Det. resistance
- ___13. Connect fire lines Fire ___ Vent ___
- ___14. Constant air monitor on
- ___15. Panic button check
- ___16. Programmer system restored to "On" position
- ___17. Arm remote fire-set lockswitch
- ___18. Remove vent valve plug
- ___19. Catch tube bleed valve closed
- ___20. Tank closed - check seals on lids
- ___21. Tank intake valve closed
- ___22. Tank exhaust valve position ___
- ___23. Pressure test chamber
- ___24. Tank fill valve closed
- ___25. Tank by-pass valve position
- ___26. Tank filter fan on
- ___27. Pressurize fire line ___ psi
- ___28. Attach hose and set trailer regulator to reservoir ___ psi
- ___29. Close facility perimeter fence
- ___30. Area cleared
- ___31. Environmental Health Personnel present
- ___32. Can temperature ___ °F
- ___33. Reservoir pressure ___ psi
- ___34. Arm the fire-set
- ___35. Start the programmer

Approved: S/M. McWhirter - 7320 Date 2/3/71

Approved: S/V. W. Christy - 3351 Date 2/17/71

Approved: S/W. H. Kingsley - 3310 Date 2/12/71

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Figure B-1. Typical fuel container assembly shown atop piston

Figure B-2. Schematic of isotope fuel impact facility

Figure B-3. IFIF plumbing diagram

Supplement I

UNITED STATES
ATOMIC ENERGY COMMISSION
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico, 87115
April 28, 1970

L. W. Otoski, Area Manager, Sandia Area Office

IMPACT TESTING OF RADIOISOTOPE FUELS AND SIMULANTS

We have reviewed the enclosures to the letter from W. D. Burnett, Sandia Corporation, Org. 3311, to you dated April 22, 1970, on the above subject.

It is our opinion that the project referred to as case number 0205.123 can be safely accomplished if undertaken in the facilities and in accordance with the procedures described in the enclosures. The secondary containment enclosure and filter system should be adequate to prevent spread of contamination should a rupture occur in the primary sealed container. The proposed radiological monitoring of the sealed chamber should be adequate to establish the need for initiation of special actions set forth in Appendix A of H. D. Christiansen's memorandum dated April 22, 1970, same subject (Enclosure 2).

We recommend that the project be approved.

S/W. F. White, Acting Director
Operational Safety Division

WOH:RLM

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SANDIA CORPORATION

ALBUQUERQUE, NEW MEXICO 87115

April 22, 1970

Mr. L. W. Otoski, Area Manager
Sandia Area Office
U. S. Atomic Energy Commission
Sandia Base
Albuquerque, New Mexico 87115

Dear Mr. Otoski:

Subject: Impact Testing of Radioisotope Fuels and Simulants

At the request of Mr. R. L. Miller, Chief, Health Protection Branch, Operational Safety Division, AEC/ALO, the enclosures are submitted to enable a review of the proposed operation of the facility to be built to conduct the subject tests.

Since an extensive testing program is proposed on a rather immediate time scale, an early response from the Health Protection Branch concerning their acceptance of the proposed test plan, or comments for improvement, would be appreciated.

Very truly yours,

S/W. D. Burnett, Supervisor
Environmental Health Operations
Div. - 3311

WDBurnett:3311:eu

Enclosures:

1. Letter, Jeffers to Burnett, dtd 4/13/70, subject, "Impact Testing of Radioisotope Fuels and Simulants."
2. Interim Radiation Safety Procedures for Operation of the Isotopic Fuels Impact Facilities for the Testing of $\text{ThO}_2\text{-Mo}$, $^{238}\text{Pu-ThO}_2\text{Mo}$ and $^{239}\text{Pu-ThO}_2\text{Mo}$.
3. Letter, Clark to Brin, dtd 3/20/70, subject, "Impact Testing of Radioisotope Fuels and Simulants for Transit and Pioneer Programs."
4. Letter, Jeffers to Rarrick, dtd 9/22/69, same subject as Enclosure 3.

WDBurnett:3311:eu

Copy to:
Original and 2 copies w/enc to SAO
S. L. Jeffers, 9512 wo/enc
H. D. Christiansen, 3311 wo/enc
File, 3311 w/enc

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ALBUQUERQUE, NEW MEXICO; LIVERMORE, CALIFORNIA; TONOPAH, NEVADA

TO : Distribution

DATE: April 22, 1970

S/H. D. Christiansen

FROM : H. D. Christiansen - 3311

SUBJECT: Interim Radiation Safety Procedures for Operation of the
Isotopic Fuels Impact Facilities for the Testing of ThO₂-Mo,
238Pu-ThO₂Mo and 239Pu-ThO₂Mo

A. General

1. These procedures supersede all written or oral radiation safety procedures previously issued concerning this facility.
2. Personnel operating this facility must be familiar with the radiation safety operational procedures.
3. The operator of this facility is responsible for maintaining adequate radiation protection safeguards at and about the equipment.

B. Specific

1. All personnel working at this facility will wear a gamma-neutron film badge.
2. Health Physics personnel will be present during all tests involving radioactive material.
3. All personnel working at this test facility will be fitted with full face respirators and have them in their possession during the testing of plutonium.
4. Prior to starting any setup for testing, the capsule will be checked for contamination and radiation levels.
5. Based on the observed levels of radiation and contamination, handling procedures, time allowable, etc., will be established by the Health Physics technician for the specific test.
6. For disassembly, the following Health Physics procedures will be followed.
 - a. Allow underground chamber to bleed off to ambient pressure through HEPA filter system.
 - b. Energize blower and purge underground chamber through filter system.
 - c. Check chamber filter for contamination. (If contamination is found at this point, it will be assumed that the primary and secondary containers have ruptured. If this is the case, see Appendix A.)

April 22, 1970

- d. Remove chamber lid.
 - e. Lift impact assembly out of can and place on work area.
 - f. Manually open valve on impact seal tube and bleed down to atmospheric pressure through a filter.
 - g. Check filter for contamination. If contaminated, remove ball lock reaction mass from impact assembly and send balance to outside agency equipped to accomplish recovery of radioactive material.
 - h. If filter is not contaminated disassemble impact assembly, and package capsule and primary container for shipment to Los Alamos Scientific Laboratory.
 - i. All of the above will be accomplished while a Health Physics technician is present.
 - j. Health Physics personnel will thoroughly check the facility and when free of contamination and/or radiation release it for further tests.
7. If it is found necessary to deviate from these procedures, or if any unusual circumstances occur while testing radioactive material at this facility, the Environmental Health Operations Division 3311, and the testing division will be consulted before deviating from these procedures.

Approved: _____ 4/22/70
S/W. D. Burnett - 3311

Approved: S/Walter J. Dalby for 4/22/70
S. L. Jeffers - 9512

HDC:3311:eu

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R. B. Abbott, 7250 P

PROCEDURES IF PRIMARY AND SECONDARY CONTAINMENT FAILS

1. A frame and plastic air lock structure with two separate small rooms will be built over the test chamber. All entries will be made through these rooms using the appropriate Health Physics practices.
2. A vacuum cleaner equipped with an absolute filter will be used to clean the test chamber followed by water, detergents, etc., as needed.
3. All waste will be double or triple bagged, as is necessary, as it is passed to the outside.
4. During this period the blower will be kept running to keep the test chamber negative to the outside to prevent the spread of contamination.

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APPENDIX C

Manufacture of SSCS

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APPENDIX C

Manufacture of SSCS

I. Preparation of ThO₂ (Thoria)

- A. National Lead gel is calcined and pulverized; mean size 0.5 μM , range 0.4 to 0.7 μM .
- B. Doped with calcia (commercial supply <1 μM) blended by impact (paint mixer and nylon balls).
- C. Product (B above) packed into rubber balloons and isopressed (30 K psi). Broken and milled, milled for 5 minutes to coarse particulate 100- to 140-mesh size (100 to 150 μM).
- D. 100 to 150 μM fraction, fire strengthened, heated in hydrogen for 1 hour at 1200°C.
- E. Fraction screened after firing (100 to 150 μM).

II. Preparation of Molybdenum

- A. Ultra fine molybdenum (0.6 to 0.8 μM) purchased from Sylvania. Ball milled overnight ($\approx$ 16 hours) under argon atmosphere.
- B. 0.6-percent solution of camphor in acetone slurried with the molybdenum powder. Agitation continuous while the acetone evaporated.

Two alternate routes here:

- 1. Camphor added to ThO₂-CaO
- 2. No camphor added to ThO₂-CaO (most likely route for material shipped to LASL).

III. Blending

- A. ThO₂-CaO weighed into a pan from 8-inch diameter screen (325 mesh).
- B. Excess of Moly-camphor poured onto the screen and sieved through until the molybdenum added is in correct weight percent for the quantity of ThO₂-CaO in pan.
- C. Blend thoroughly (blending technique unknown).
- D. Blended powder weight into oversized die (2.6 inches) and cold pressed at 40 K psi (120 to 124 grams).
- E. Fifteen green pucks are stacked with tungsten screen between each; the stack is then loaded into tungsten crucible and placed in a vertical tungsten furnace.

IV. Heating Cycles

- A. Programmed treating cycle - flowing H₂ gas used during heating cycle for purge and protection against oxidation.
 - 1. Temperature raised slowly to remove camphor (by sublimation).
 - 2. Then heated to 1850°C over a period of 6 hours, held at 1850°C for 2 hours, and allowed to cool to room temperature while in oven - usually overnight (≈8 hours).
 - 3. Preparation ready for density measurements and grinding.
 - 4. Surfaces ground 1 - 2 - 1 using water cooling with inhibitor - no residue.
 - 5. Finished product air baked at 150°C overnight - (usual weight loss 6 to 10 µg/puck).
- V. A 0.004-inch thick molybdenum overcoat (approximately 4.5 volume percent of total) was applied to the disc.

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