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PRELIMINARY RESULTS ON 400 FT/SEC IMPACT TESTS OF TWO 2-FOOT DIAMETER CONTAINMENT MODELS FOR MOBILE NUCLEAR REACTORS

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ABSTRACT

Impact tests at 400 ft/sec were conducted on two 2-foot diameter spherical models at the Sandia sled track in Albuquerque, New Mexico. The study is to determine the feasibility of containing fission products of a mobile reactor in the event of an impact. The first model, a hollow sphere, weighed 350 lb. The second, designated the "Metal Shield Impact Model" weighed 980 lb. Both models absorbed the energy of impact through deformation of the spherical vessels. No leaks were detected nor cracks observed on either model.

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SUMMARY

In a mobile reactor fission products must be contained in an impact accident. One method for meeting this requirement is to put the reactor in a containment vessel and design the containment vessel and its contents to absorb the impact energy without rupturing the containment vessel.

To study the feasibility of this method, experimental tests were conducted on two models at the Sandia Sled Track in Albuquerque, New Mexico. The first model was a hollow sphere while the second was a sphere containing a simulated reactor and gamma shield designated the Metal Shield Impact Model. Both models were two feet in diameter. The hollow sphere weighed 350 pounds (159 kg) and the Metal Shield Impact Model weighed 980 pounds (445 kg). The hollow sphere was impacted against a concrete block at 392 ft/sec (119 m/sec) while the Metal Shield Impact Model was impacted at 413 ft/sec (126 m/sec). Instrumentation for the test consisted of velocity sensors, high speed motion pictures, and one accelerometer mounted on the outside of the containment vessel.

The results of the test are preliminary. Later when the units have been returned and analyzed, a more detailed report will be written. Some observations, however, can be made from the preliminary information. They are

1. No leaks were detected nor cracks observed on either model.

2. The deformation, δ/R, was about 40 percent greater than predicted for a hollow shell of uniform thickness. Since the thickness of the shell varied from 0.59 to 0.66 the agreement is considered reasonable. The deformation of the Metal Shield Impact Model was also about 40 percent.

3. At the impacted face the increase in diameter which represents the meridional strain was 14 percent for the hollow sphere and 20 percent for the Metal Shield Impact Model.

4. Both units had a low rebound velocity resulting from the fact that about 99 percent of the kinetic energy was absorbed by the plastic deformation and flow of the materials of the model.

5. Average impact accelerations were about 15,000 g's.

INTRODUCTION

In a mobile nuclear reactor fission products must be contained with the same level of confidence as in a stationary powerplant. Mobile reactors can be classified in two ways. First, those that supply power for moving vehicles and second, compact land-based powerplants which can be transported. In both cases an impact accident is possible, and the fission product containment system must be designed to survive an impact accident without rupture.

The most severe impacts will occur in an aircraft accident. Impact velocities in average large aircraft accidents are several hundred feet per second. Impact velocities in very severe aircraft accidents could approach 1000 ft/sec (305 m/sec). One method for meeting the requirement of fission product containment is to put the reactor in a containment vessel and design the containment vessel and contents to absorb the impact energy. The energy of impact would be absorbed by deformation of the vessel and internal components such as the shielding and reactor parts.

Work has been performed to help answer the following questions: How much containment vessel deformation will a given velocity produce? How much deformation can a containment vessel tolerate before it ruptures? How do the contents of the containment vessel effect deformation?

Morris correlated experimental deformation and failure data on 3/4 in. (1.90 cm) to 4 in. (10.2 cm) O.D. hollow spheres (ref. 1) which had been impact tested as part of the isotope space power program (ref. 2). Some of these spheres had impacted to 700 ft/sec (213 m/sec) without rupture. The correlation, when extrapolated to large diameter containment vessels, for example, a 15 ft. (4.57 m) diameter vessel, indicated that the failure velocity and deformation versus velocity of large vessels should be similar to that for small vessels.

Tests of scale models of a reactor containment system to be impacted at high speeds against a concrete block were designed. These models represent a reactor surrounded by kinetic energy absorbing gamma shielding and a containment vessel both of which were designed to absorb impact energy. The reactor containment vessel model mocks up a reactor system that would be used to power an air cushion vehicle or a one or two million pound (45,300 or 90,600 kg) nuclear airplane. The containment vessel for these applications would be about 15 feet (4.57 m) in diameter and the reactor shield containment vessel package would weigh 200,000 to 300,000 pounds (90,600 to 136,000 kg).

Tests were conducted on two models at the Sandia Sled Tract in Albuquerque, New Mexico. They were impacted at 392 and 413 ft/sec (119 and 126 m/sec). This report describes the models, test set up, and presents results of the tests based on preliminary measurements made at the test site. The models are being measured, sectioned and analyzed in detail in the laboratory, but these results are not yet available.

DESCRIPTION OF SLED TESTS

The impact tests were conducted at Sandia Corporation on a 5000 foot (1520 m) rocket sled track. High speed motion pictures were taken and velocity and acceleration were measured.

The model with attached instrumentation is placed on a light weight styrofoam plastic pedestal between the rocket sled track rails (see figs. 1, 2(a), (b), and (c)). A reinforced concrete block cube $4\frac{1}{2}$ feet (1.37 m) on a side and weighing 15,000 pounds (6800 kg) is accelerated by an array of surplus HVAR rockets to the desired impact test speed. A cage in front of the block catches the model after impact to prevent damage to the track and model. A door in the front of the cage closes within 0.2 seconds after impact. It is released by explosive bolts triggered by the initial contact of the model with the concrete. The concrete block, cage and model are decelerated after the impact by a rocket sled water brake system.

Two movie cameras were mounted at the impact point. They operated at a speed of 7000 frames/sec. One had two exposures per frame providing 14,000 exposures per second. Two additional cameras are mounted further down the track. These cameras operate at 2000 frames/sec. Their purpose is to record secondary impacts within the cage. Also, a 400 frame/sec movie was taken from a tower showing the sled at ignition, accelerating to impact, impact, and subsequent braking. The accelerometer was mounted on the side of the sphere opposite the impact surface and connected by a cable to a recorder. The accelerometer provides a signal until the cable is broken by the impact. The velocity was measured by two sensors on the track.

TEST MODELS

Two models were tested. The first was a hollow sphere and the second was a sphere containing components which simulated a reactor and gamma shield. This model was designated the "Metal Shield Impact Model".

Hollow Sphere

The hollow sphere was 24 inches (61 cm) inside diameter with a nominal 5/8 inch (1.59 cm) wall thickness. It was fabricated from 304 stainless steel and weighed 350 pounds (159 kg). The sphere was purchased in two hemispherical sections and welded together at the Lewis Research Center by the "gas tungsten arc weld" process. A small coupling was welded to the sphere and a through hole drilled into the sphere to provide access to the inside. A stripe pattern was painted on the outside of the sphere. At each corner of the stripes, punch marks were made in 2 x 2 inch (5.08 x 5.08 cm) patterns. The stripes are used for post-impact strain measurements. The hollow sphere model was intended to serve two purposes: first, to check the operation of the new sled designed for this test series, and second, to provide a large diameter data point for the impact correlation of reference 1.

Metal Shield Impact Model

This model consists of an 11 inch (27.9 cm) diameter steel ball located in the center surrounded by a simulated energy absorbing gamma shield and containment vessel (see fig. 3). The containment vessel is the same size as the hollow sphere discussed above. The ball is supported centrally by 3/16 inch (0.475 cm) steel rods. The containment vessel is fabricated from two 304 stainless steel hemispherical shells. One shell has a $1\frac{1}{2}$ inch (3.8 cm) access pipe coupling. The hemispherical shells are welded together to form a sphere after the ball is located with the rods. Steel saddles such as shown in figure 4 are then filled in the space between the steel ball and the containment vessel through the $1\frac{1}{2}$ inch (3.8 cm) coupling. Stripes were painted on the O.D. of the sphere and punch marks made in the corner of the stripes in a 2 x 2 inch (5.09 x 5.08 cm) array.

The steel ball is intended to simulate a reactor core. It has the same average density and relative diameter as reactor cores being studied for nuclear aircraft and air cushion vehicles (ref. 3). The saddles surrounding the ball simulate a gamma shielding material that also can absorb kinetic energy. In a full-scale design these saddles would be fabricated from a heavy material such as depleted uranium metal. The voids between them would be filled with water to provide the necessary neutron shielding. The saddles are crushable providing energy absorption capability.

The total weight of this model was 980 pounds (445 kg). The steel ball weighed approximately 195 pounds (88.5 kg), the containment vessel 350 pounds (159 kg), with the remaining 435 pounds (197 kg) attributed to the saddles. (There was no water in this model.) At impact the six 3/16 inch (0.475 cm) steel rods locating the steel ball would have no effect on the results of the impact test. They were used only for positioning the steel ball which simulates the reactor.

TEST RESULTS

Two impact tests were performed. The first test was the impact of the hollow sphere at 392 ft/sec (119 m/sec). The second test was the impact of the Metal Shield Impact Model at 413 ft/sec (126 m/sec). At the conclusion of each test the units were observed at the end of the track where the sled had stopped. In each case the model was inside the cage resting at the forward bulkhead as shown in figure 5(a) and (b). Each unit was then returned to the test assembly building where preliminary measurements, photographs and pressure checks were performed.

Hollow Sphere Test

The hollow sphere after impact is shown in figures 6(a) and (b). The shape of the impacted surface is as expected. The concave surface was characteristic of the 3/4 to 4 inch (1.90 to 10.2 cm) diameter spheres impacted in reference 2. There were no visible cracks. The plug that was threaded into the coupling on the sphere was removed and a release of gas could be heard indicating that some internal pressure existed. This was a result of both a reduction in volume due to impact and an increase in temperature of the gas on the inside. The increase in temperature of the gas was a result of the sun heating effect on the surface of the sphere and the energy dissipation due to the impact. The degree of heating attributed to each is not known.

A preliminary leak test was performed. This test was performed by pressurizing the sphere with nitrogen and sealing off the lines. The pressure was then monitored over the next few hours. No leaks were detected. More exact leak checks will be made when the vessel is returned to the Lewis Research Center.

Preliminary measurements were then taken of the dimensions of the sphere. These measurements indicate how much strain occurred. The results of these measurements are shown in figure 7(a).

Maximum strain appeared to occur near the impacted face. The circumference near the impact face was $82\frac{5}{8}$ inches (210 cm). This was compared with the circumference at this location on an undeformed sphere. The increase in circumference or strain was 14 percent. This value represents the meridional strain of the sphere. Failure of the sphere is the result of the equivalent strain which considers the radial, meridional and azimuthal strains. The value of the meridional strain, however, would indicate that the sphere is not close to rupture since the hand book value of elongation of 304 stainless steel in the fully annealed condition is 50 percent.

The amount of deformation δ/R (see fig. 7 for definition) was also measured to compare with the hollow sphere data correlation of reference 1. The deformation δ/R of 0.61 was plotted on the correlation curve taken from this reference (see fig. 8). As can be seen the deformation of the 2 ft. diameter (60 cm) sphere was greater than predicted by approximately 38 percent, the predicted δ/R being 0.44. The deformation was based on anticipated ultimate strength of the material of the sphere and assuming the sphere was of constant thickness. Pre-test inspection revealed that the thickness varied from 0.59 to 0.66 inches. Upon receipt of the sphere at Lewis the material will be tested for its actual properties. The exact thickness variation will be measured. The effect of the thickness variation on δ/R will be estimated and compared to the correlation curve.

In the high speed motion pictures, sequence shots were taken of the impact. Some of these frames are shown in figure 9(a) through (p). The film speed is 7000 frames/sec. The vertical lines are the bars of the catcher box. The white surface is the concrete block. At impact the debris shown are concrete chips and dust. The straining of the sphere at the impact surface of the concrete block can be seen in figures 9(h) through (l). The photographs show the rebound velocity was less than 40 ft/sec (12.2 m/sec). This indicates that about 99 percent of the energy was absorbed plastically.

The accelerometer traces indicated that the g level exceeded the 15,000 g range of the instrumentation. The photographs show the average acceleration was about 15,000 g's. The peak acceleration is not known at this time.

Metal Shield Impact Model Test

The test for the Metal Shield Impact Model was conducted in a like manner. Figures 5(a) and (b) show side and end views of the model in the cage after the impact. It was resting forward at the bulkhead end similar to the hollow sphere. This is due to the deceleration that occurs when the sled brakes to a stop. The model was removed and the deformation measured. Figures (10(a) and (b) are photographs after impact. In the deflection of this model the impacted surface is not concave inward as in the case of the hollow sphere. The surface is flat up to the center and then a protrusion occurs. The flatness is due to the mass of the components on the inside which prevent it from buckling inward. The protrusion is probably due to the force resulting from the deceleration of the 11 inch (27.9 cm) solid steel sphere.

When the plug in the $1\frac{1}{2}$ inch (3.8 cm) coupling was removed after the test, a release of gas could be heard as in the case of the hollow sphere. The reason was the same, i.e., reduction in volume due to impact, heating of the gas due to the sun and heating of the gas due to the kinetic energy of impact. A pressure test was conducted on this model identical to that conducted on the hollow sphere. Nitrogen gas was put into the containment vessel which was then sealed. No leaks were detected. A more detailed leak check will be made.

Preliminary measurements were taken of the dimensions of the sphere. The results of these measurements are shown in figure 7(b). The deformation δ/R of this model was essentially the same as that of the hollow sphere. Its meridional strain, however, was 20 percent as compared with 14.3 percent for the hollow sphere. This difference in strain is shown in figures 6(a) and 10(b).

The high speed motion pictures show both the impact and the post impact period of the test. A sequence of photographs of the impact are shown in figure 11(a) through (l). The film speed is 7000 frames/sec. The straining of the sphere during impact can be seen in 11(d) through (g). As in the hollow sphere tests, the rebound velocity was about 40 ft/sec and therefore about 99 percent of the energy was absorbed plastically. On the Metal Shield Impact Model the accelerometer range was increased to 40,000 g's. The trace indicated peak g values of 30,000. The high speed photographs indicate the average acceleration was about 15,000 g's.

The same concrete block was used for both impact tests. The second impact was a face directly opposite of the face for the first impact. The block was severely cracked after the second impact as can be seen in figure 12.

CONCLUSIONS

This report presents preliminary data from the impact of two spherical shell models against a concrete block. The first model was a hollow sphere while the second was a sphere containing a simulated reactor and gamma shield designated the Metal Shield Impact Model. Both models were two feet in diameter. The hollow sphere weighed 350 pounds (159 kg) and was impacted at 392 ft/sec (119 m/sec). The Metal Shield Impact Model weighed 980 pounds (445 kg) and was impacted at 413 ft/sec (126 m/sec). A more detailed analysis will be made when the units have been returned to the laboratory. The following preliminary observations can be made from the tests.

1. No leaks were detected nor cracks observed on either model.

2. The deformation, δ/R, of the hollow sphere was about 40 percent greater than predicted for a hollow sphere of uniform thickness. Since the thickness of the shell varied from 0.59 to 0.66 inches the agreement is considered reasonable. The deformation of the Metal Shield Impact Model was also about 40 percent.

3. The deformation of the hollow sphere and the sphere with components on the inside which can absorb energy did not differ substantially.

4. At the impacted face the increase in diameter which represents the meridional strain was 14 percent for the hollow sphere and 20 percent for the Metal Shield Impact Model. These values would indicate that neither sphere is close to rupture since the hand book value of elongation to rupture of 304 stainless steel in the full annealed condition is 50 percent.

5. In these tests the units had a rebound velocity less than 40 ft/sec (12.2 m/sec). The very low rebound velocity indicated that about

99 percent of the kinetic energy was absorbed plastically in the deformation and flow of the materials of the model.

6. Peak forces of 30,000 g's were recorded on the Metal Shield Impact Model. Average forces of 15,000 g's were calculated from the high speed photographs.

REFERENCES

1. Morris, R. E.: Correlation of Small Sphere Impact Deformation Data and Extrapolation to Larger Spheres. NASA TM X-2067, 1970.

2. Simonis, J. C.; and Stoneking, C. E.: A Study of Impact Effects of Spherical Shells. Part II: A Theoretical and Experimental Study of the Response of Spherical Shells to Impact Loads. Rep. SC-CR-67-2540, Sandia Labs., Dec. 1966.

3. Rom, Frank E.; and Kascak, Albert F.: The Potential of Nuclear Power for High-Speed Ocean-Going Air-Cushion Vehicles. NASA TM X-1871, 1969.

E-6018

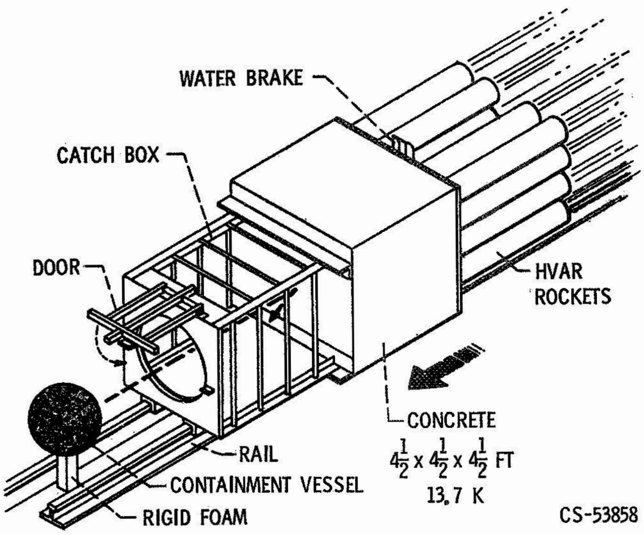


Figure 1. - Sandia sled and test facility.

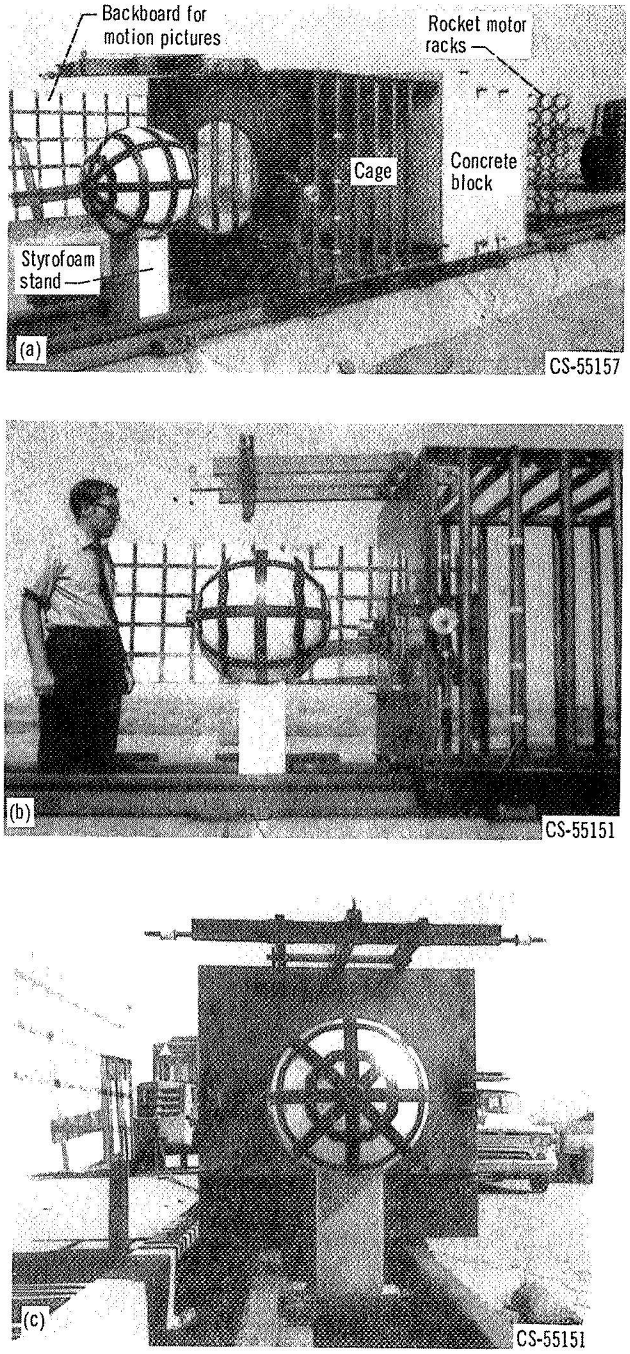


Figure 2. - Sled at point of impact.

E-6018

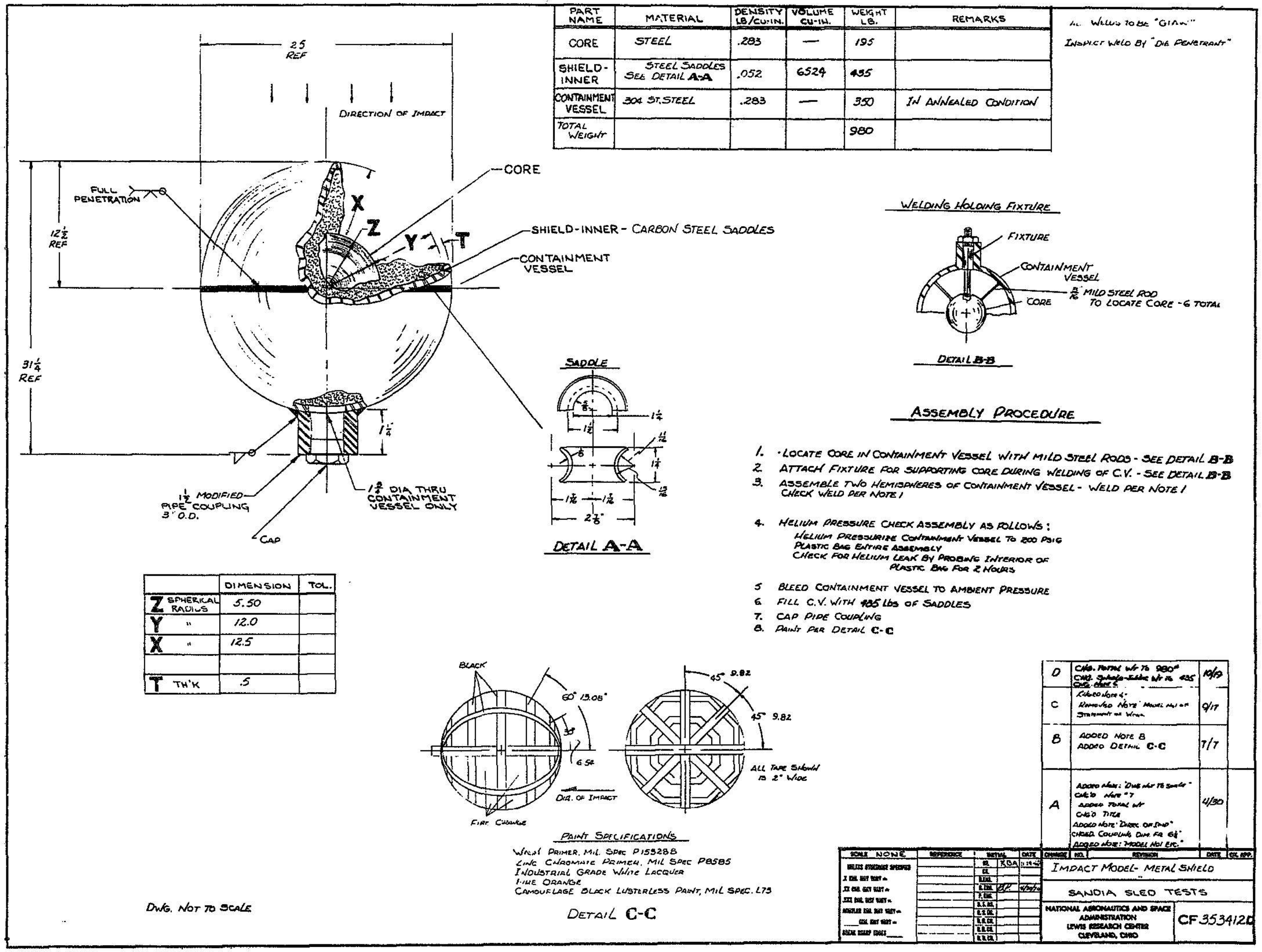


Figure 3. - Metal shield impact model.

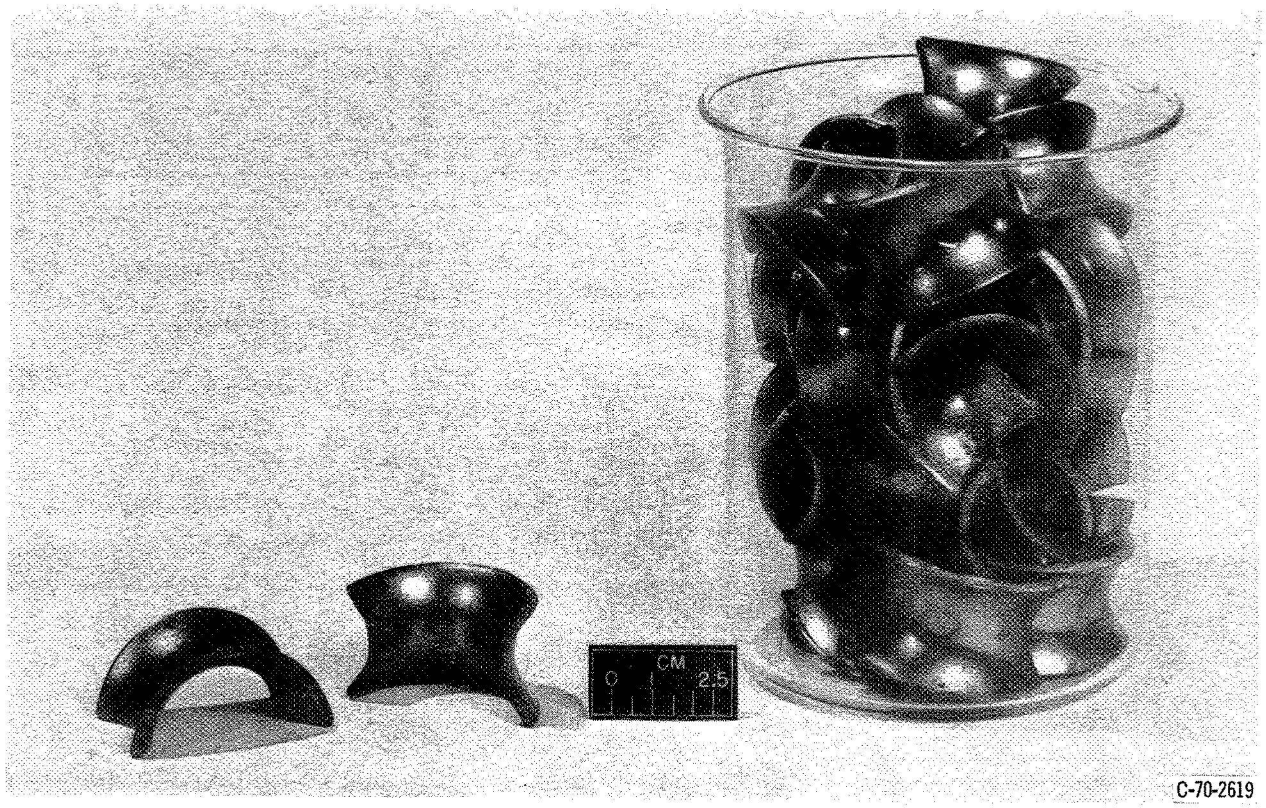
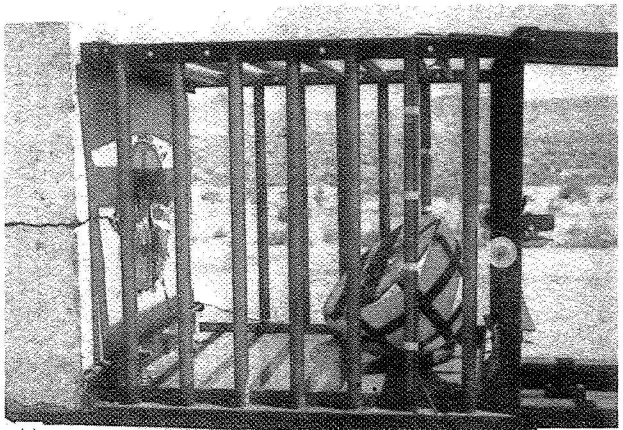


Figure 4. - Steel saddles which simulate gamma shield material.


(a) CS-55158

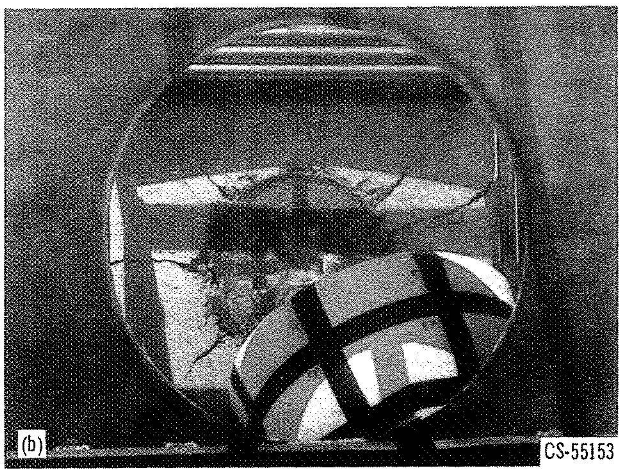
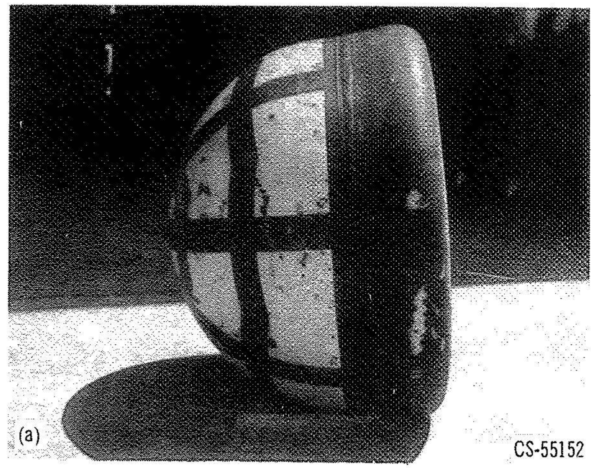

(b) CS-55153

Figure 5. - Post impact - metal shield impact model.


(a) CS-55152

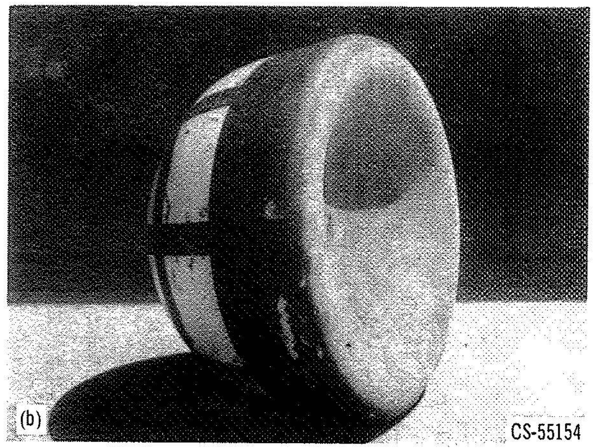
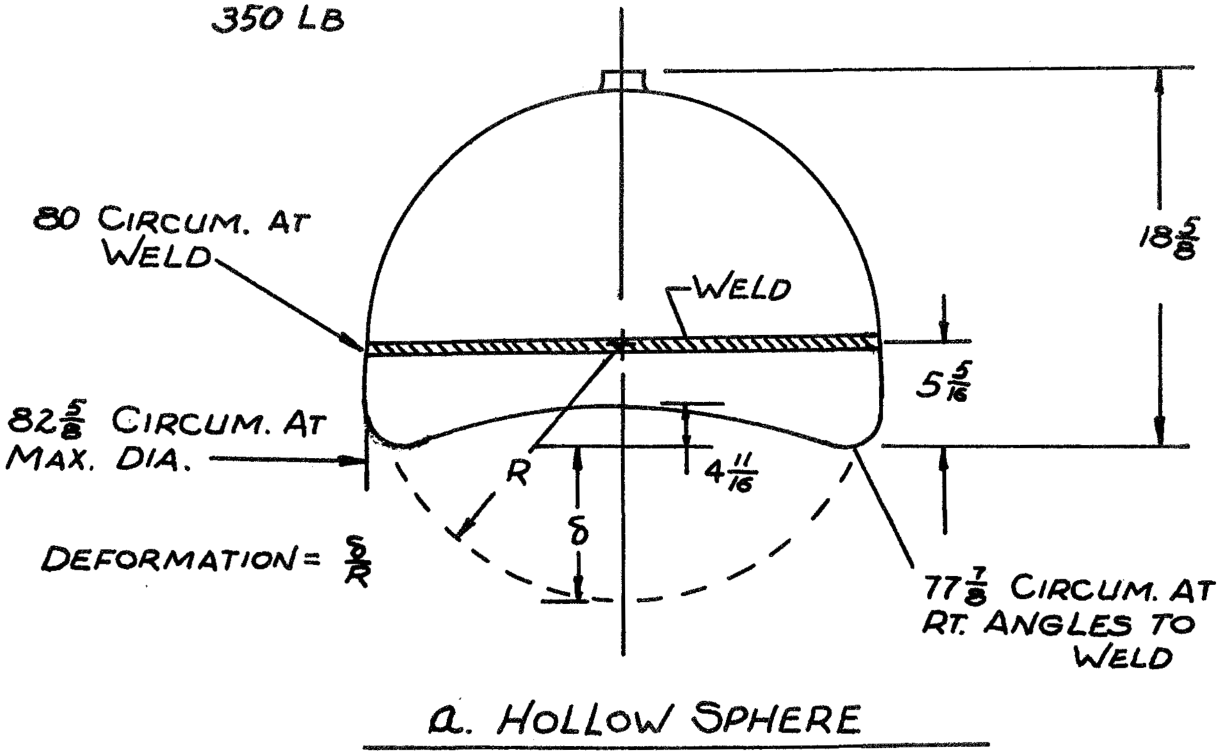

(b) CS-55154

Figure 6. - Hollow sphere - velocity 392 ft/sec (119 m/sec).



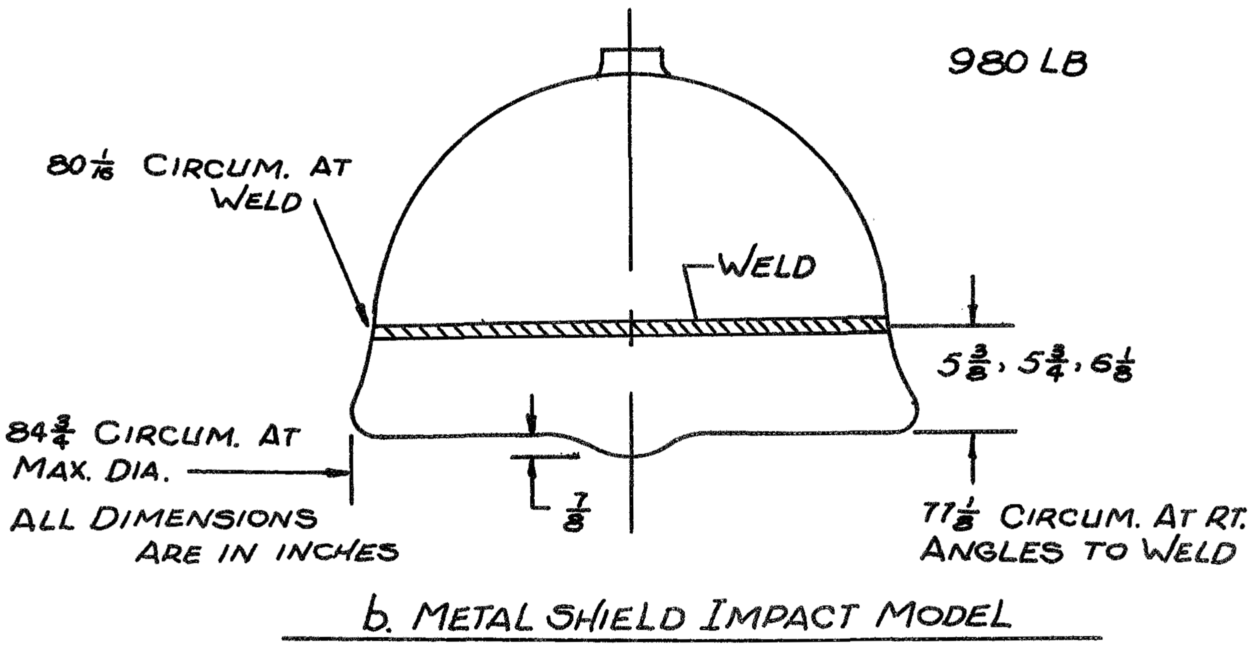


Figure 7.- Post Impact Measurements of Test Models

E-6018

E-6018

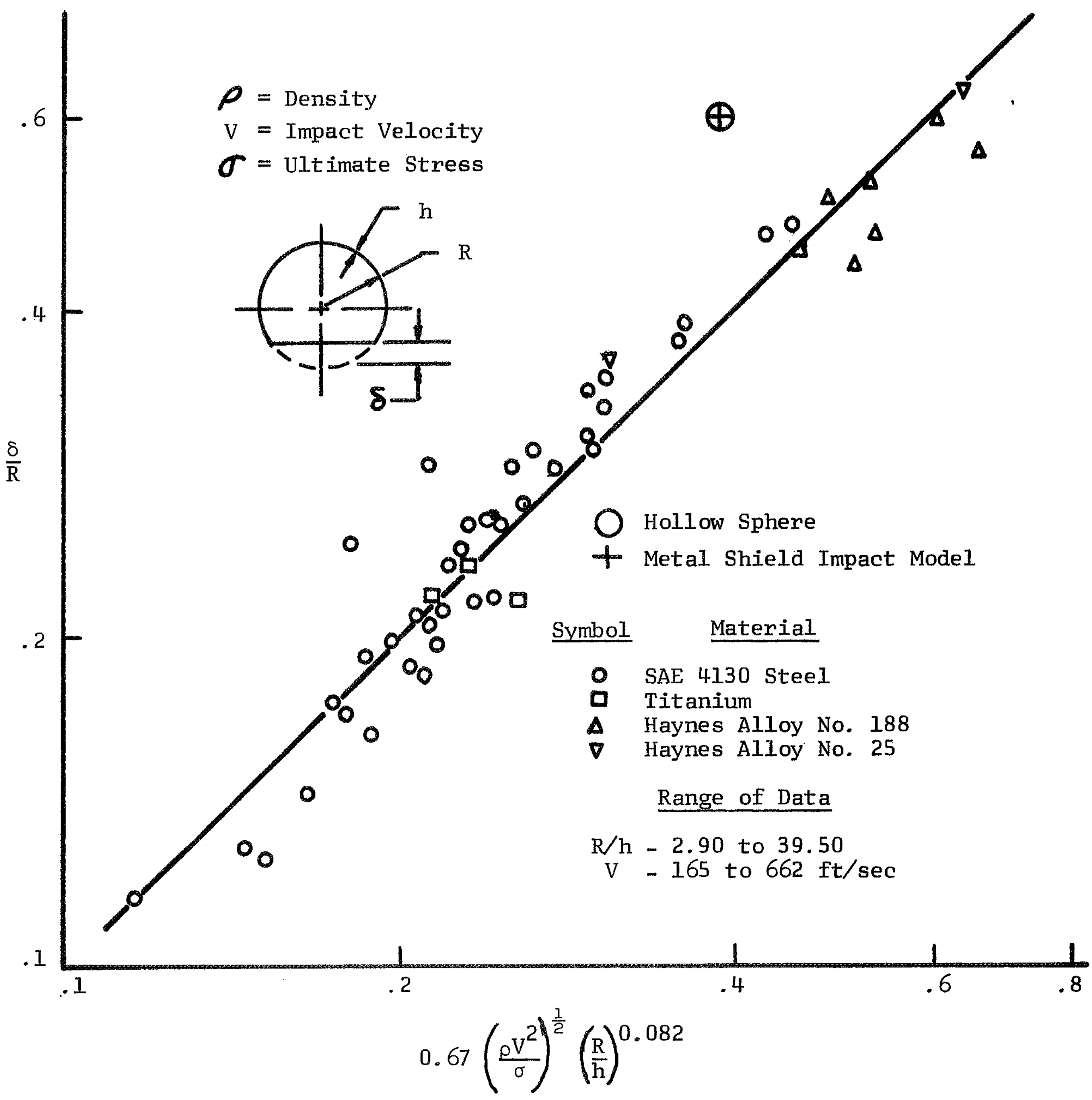


Figure 8.- Graph of Deformation to Mean Radius Ratio Versus Correlation Equation for Hollow Sphere Impact Data

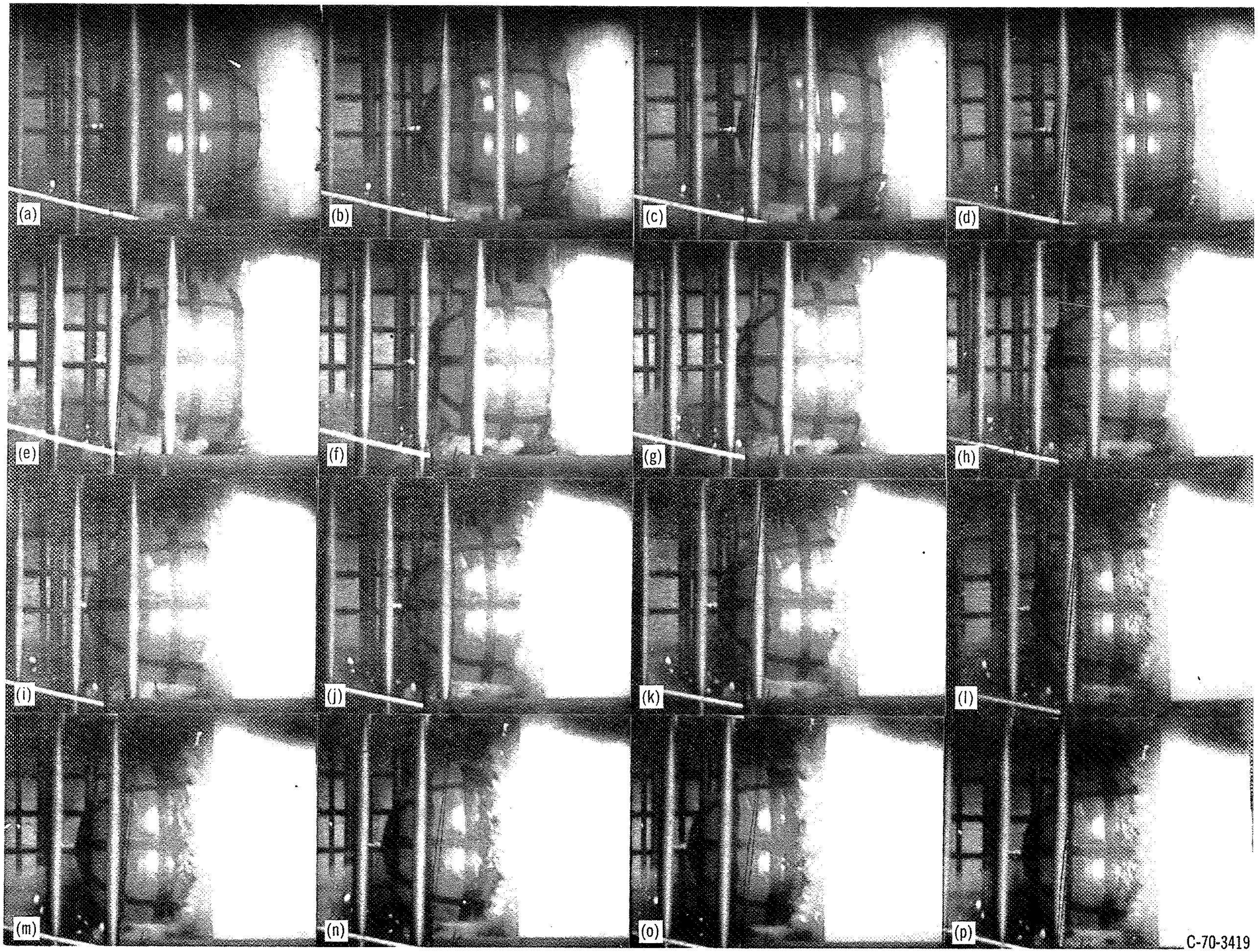


Figure 9. - Sequence photographs of impact hollow sphere.

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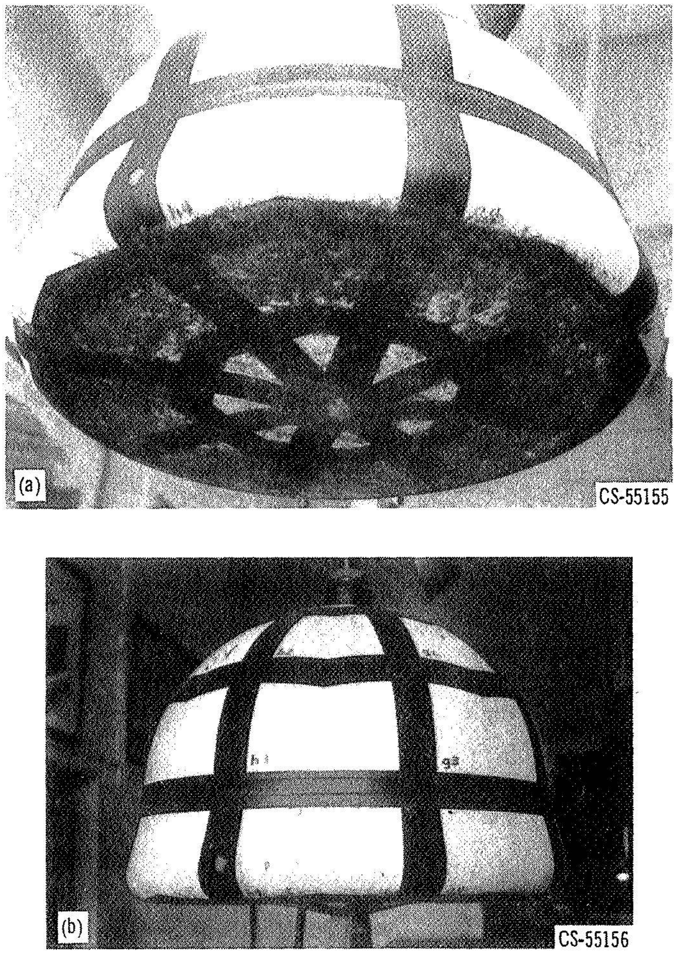

Figure 10. - Metal shield impact model - velocity 413 ft/sec.

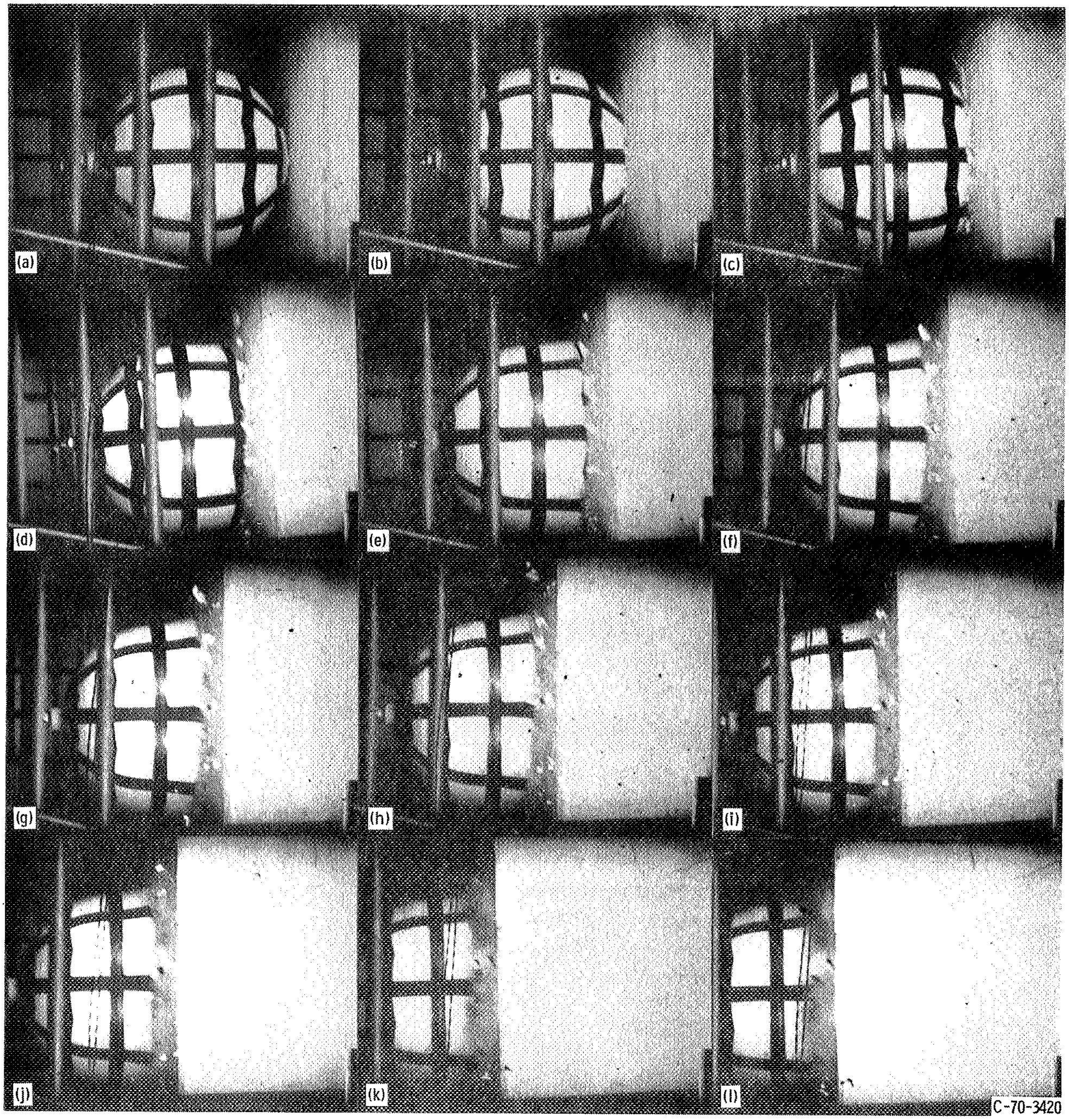

Figure 11. - Sequence photographs of impact of metal shield model.

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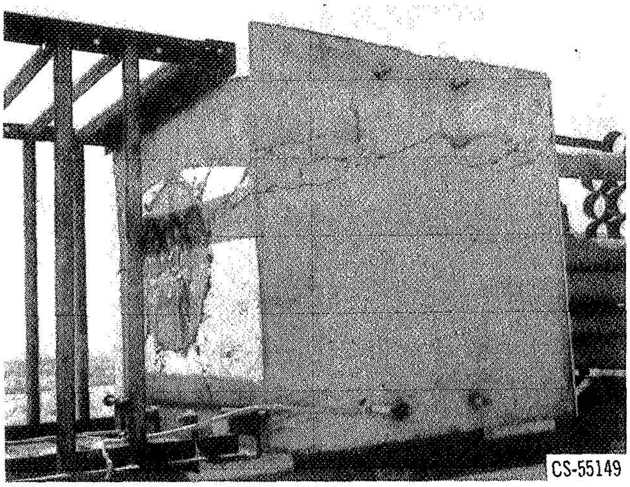

Figure 12. - 15000-lb (6800 kg) concrete block - post impact.

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