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A 810 FT/SEC SOIL IMPACT TEST OF A 2-FOOT DIAMETER MODEL NUCLEAR REACTOR CONTAINMENT SYSTEM

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ABSTRACT

A soil impact test was conducted on a 880-pound - 2-foot diameter sphere model at the Sandia Aerial Cable facility in Albuquerque, New Mexico. The impact area consisted of back filled desert earth and rock. The impact generated a crater 5 feet in diameter by 5 feet deep. It buried itself a total of 15 feet - as measured to the bottom of the model. After impact the containment vessel was pressure checked. No leaks were detected nor cracks observed.

E-7275

A 810 FT/SEC SOIL IMPACT TEST OF A 2-FOOT DIAMETER MODEL NUCLEAR REACTOR CONTAINMENT SYSTEM

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SUMMARY

Future applications of nuclear energy may require the use of a mobile nuclear reactor. One method for containing fission products in the event of an impact 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. Impact may occur against a hard surface such as concrete or a softer surface such as soil.

To determine the amount of deformation of the containment vessel and depth of burial when impacting the soil, a test model was impacted at 810 feet per second into the desert floor. The impacted model was a 2-foot diameter mock-up of a reactor containment vessel system. The design modeled a reactor surrounded by radiation shielding and a containment vessel. Both the shielding and vessel were designed to absorb impact energy. The model weighed 880 pounds. The test was conducted at the Aerial Cable Facility at Sandia Laboratories.

This test was another in a series of tests conducted by Lewis Research Center at both the Sandia and Holloman AFB tracks in New Mexico. These tests were conducted on models, similar in design, weighing 800 to 1300 pounds and impacting at speeds from 240 to 1090 feet per second against concrete and in one case armored plate. The tests determined the maximum velocity that a containment vessel could impact without rupturing the containment vessel. Vessels were impacted against concrete blocks at velocities over 1000 feet per second without rupture.

The impact area for this soil impact test consisted of back filled desert earth and rock tamped to simulate the normal desert floor. The impact generated a crater 5 feet in diameter by 5 feet deep. It buried itself a total of 15 feet - as measured to the bottom of the model. After impact the containment vessel was pressure checked. No leaks were detected nor cracks observed.

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INTRODUCTION

In all mobile reactors, fission products must be contained with the same level of confidence as in stationary power plants. In the case of a high speed mobile nuclear system, such as a nuclear airplane, impact velocities of 800 to 1000 feet per second can occur.

One method for containing fission products under these severe conditions is to put the reactor in a containment vessel and design the vessel and its contents to absorb the impact energy without rupturing the containment vessel. Impact may occur against a hard surface such as concrete or a softer surface such as soil. The energy of impact would be absorbed by both deformation of the containment vessel and by deformation of the internal components of the vessel such as the shielding and reactor parts.

To determine the amount of deformation of the containment vessel and depth of burial when impacting the soil, a test model was impacted at 810 feet per second into the desert floor. The impacted model was a 2-foot diameter mock-up of a reactor containment vessel system. The design modeled a reactor surrounded by radiation shielding and a containment vessel. Both the shielding and vessel were designed to absorb impact energy.

This test was another in a series of tests conducted by Lewis Research Center on 2-foot diameter mock-up models of a reactor containment vessel system to determine the feasibility of containing fission products at impact. Initially, five tests were conducted at Sandia Laboratories (refs. 1 and 2). The models weighed from 350 to 1305 pounds.

The first design was a 24-inch hollow sphere to check a correlation by Morris (refs. 3 and 4) which related small sphere data to larger spheres. The hollow sphere design verified that large vessels do deform like small vessels as predicted by the hollow sphere correlation. The remaining designs were similar to that described for this test. They were impacted at speeds from 241 to 580 feet per second. No leaks were detected nor cracks observed on any of the models after impact.

When these tests were completed a joint NASA/AF program was initiated at Holloman AFB. Six models were tested. Their designs were similar to that described for this test with an emphasis on different shield and containment vessel materials, and core and containment vessel designs. Impact velocities from 600 to over 1000 feet per second have been conducted (refs. 5 and 6). The models weighed approximately 1000 pounds.

All the tests conducted at Sandia and Holloman AFB evaluated the effects of a high velocity impact against a hard surface. This model is the first to be tested against a softer surface such as in the case of soil. At impact, rocks in the soil can cause local deformation. After impact the heat from the decay of the fission products must be dissipated. With the loss of the coolant system the heat must be transferred through the containment wall and dissipated from the surface of the impacted containment vessel. In the event of total earth burial heat dissipation may become a problem due to the low conductivity of the soil.

This report describes the model, test set-up and results of the test. The test was conducted at the Sandia Laboratories using their Aerial Cable Facility.

DESCRIPTION OF AERIAL CABLE FACILITY

The test was conducted at the Sandia Aerial Cable Facility located in Albuquerque, New Mexico. This facility provides a means of duplicating many air to ground impacts under controlled, well instrumented conditions. As shown in figure 1 it consists of a 1 3/8-inch cable stretched between two mountains. The cable supports a launch platform from which test vehicles can be accelerated at 25 to 40 g's toward the valley floor. The accelerating force is generated by a rocket sled approximately 200 feet away from the target area. The accelerating force is transmitted to the test model via wire rope towing lines as illustrated in the sketch. The towing lines can be separated from the test vehicle at a suitable time or position above the impact point leaving the model completely free of extraneous hardware when it impacts.

To facilitate a suitable separation of the towing basket from the model as it neared the target area, the towing lines were arranged in tandem, as illustrated in figure 2. Such an arrangement permitted the basket to open and disengage from the sphere when the towlines diverged as the sphere approached within approximately 40 feet off the ground. The nylon towing basket had eight shroud lines made of the 1-inch, 12 000-pound test nylon. Photographs of the towing basket on the sphere before the test are shown in figures 3 and 4. Shown in figure 5 is the rocket sled on the track. The rocket motors were fired in five stages to program the accelerating force along the smooth curve, as shown in figure 6. Velocity, displacement, and time parameters are also shown in figure 6.

Movie cameras were mounted on the aerial camera platform and at the various ground stations (fig. 1). Movies of the release, acceleration and impact with the soil were taken at real time and speeds of 250 and 4545 frames per second.

TEST MODEL

A drawing of the model tested is presented in figure 7. A photograph of it prior to impact is presented in figure 8. It consists of a reactor core mock-up surrounded by shielding and a 2-foot diameter spherical stainless steel containment vessel. The shielding consists of metal saddles (fig. 9) and rock salt. The metal saddles simulate an impact energy absorbing gamma shield. Rock salt representing a LiH neutron shield material was poured into the 80 percent void spaces provided by the saddles.

The fabrication stages of the core and containment vessel are shown in figures 10(a) to (c). The simulated core consists of an 8-inch diameter by 8-inch long cylinder, 1/4-inch thick, filled with approximately 850 - 1/4-inch tubes of 0.065-inch wall thickness (fig. 10(b)). This assembly is capped on both ends and placed within a 12-inch diameter spherical stainless steel vessel, 5/16-inch thick.

This assembly is then centered within a 5/8-inch thick, 2-foot diameter containment vessel by small rods which are tack welded to the containment vessel and to the simulated reactor sphere (fig. 10(c)). The rods are weak and have no effect on the results of the impact test. Saddles and salt are added via the 1 1/2-inch pipe fitting after completion of the welding of the containment vessel.

The tubes in the model core represents the fuel pins and flow passages of either a fast or thermal reactor core. The 12-inch inner vessel represents a reactor pressure vessel.

The total weight of this model was 880 pounds (fig. 7). The core including tubes, cylinder, and 1-foot diameter sphere weighed 89 pounds. The saddles and salt weighed 435 and 80 pounds, respectively. The outside 2-foot diameter by 5/8-inch nominal wall thickness vessel weighed 365 pounds.

Some difficulty was experienced in filling the model with salt. The model was placed on a shake table (fig. 11) capable of driving the model through various frequencies. The most effective frequency was 95 Hertz. Even with this effort only 80 pounds of salt was added compared to the 175 pounds that is usually added to a model of this size. The salt, when filled into the voids provided by the saddles, helps during the deformation of the containment vessel by transmitting impact forces uniformly over the containment vessel.

TEST RESULTS

The launch platform was lowered from the aerial cable and the test model suspended on the platform (ref. fig. 3). The platform and test assembly was then raised to the aerial cable. In this position the platform is adjusted fore and aft on the cable and the cable raised and lowered to adjust the entire assembly to give the correct impact point and angle. The cameras must also be adjusted on the 5/8-inch aerial cable to provide the proper coverage. This is performed after the test model is in place. Finally, the cables for the rocket sled are greased and the rockets armed and fired.

Photometric data indicated a very good flight of the sphere throughout its flight trajectory. The nylon towing basket had peeled completely free of the sphere a few feet above the target. Film data indicated the towing basket snagged momentarily either on the filling plug (ref. fig. 7) or one of the handling lugs during the peeling operation and imparted a slight angular velocity to the sphere. Impact velocity was 810 feet per second. The angle of impact was approximately 90° with the valley floor.

Figure 3 shows the impact area prior to impact. Figure 12 shows the impact point after impact. The impact resulted in a crater 5-feet across by 5-feet deep. Figure 13 is a sketch of the crater profile and the location of the model below the crater. Figure 14 and 15 are photographs of the crater looking into the crater before the model was dug out. Removing the model took some time since it was 8 feet below the crater.

Figure 16 and 17 are photographs of the model after it was removed from the earth. In figure 17 one of the lugs sheared off during the impact. The second lug was still intact along with the filler plug. Deformation was not as severe as experienced on the concrete blocks. Local deformation to a depth of 0.36 inch, as measured by a depth gage from the edge of the indentation, resulted from the rocks that were in the soil. A post pressure test verified that there were no leaks in the containment vessel wall, thus, fission products would have been contained.

PREDICTING EARTH BURIAL

The problem of earth penetration by a projectile has been studied for many years. C. W. Young of Sandia Laboratories (ref. 7) has developed an empirical equation to predict the penetration performance vehicles or projectiles impacting the earth. The equation which pertains to impact velocities over 200 feet per second is as follows:

$$D = 0.0031\ SN\left(\frac{W}{A}\right)^{\frac{1}{2}} (V - 100)$$

where

D depth of penetration, measured along the penetration path, ft
V impact velocity, ft/sec
S constant - dependent upon soil properties averaged over the depth of penetration
W total model weight, lb
A frontal area, sq in.
N vehicle nose performance coefficient

For the impact of the model of this report, using a depth of 15 feet, W/A of 1.82 and a nose constant, N of 0.7, a soil constant, S of 7.5 was calculated.

Nose performance coefficients were determined by C. W. Young from a series of tests during which all parameters were held constant except nose shape. Any variation in penetration performance was then attributed to the nose performance. A coefficient of 0.7 was recommended for a sphere.

According to C. W. Young there is no independent method of determining the soil constant. As a comparison, typical world-wide values of soil constants range from 5, representing a hard surface, to 25 which represents a very soft soil. The target area for this test consisted of back-fill tamped soil. Considering the man made type of target and soil moisture content the soil constant of 7.5, according to Young, appears to be reasonable.

The empirical equation used is applicable over a wide range of W/A's, velocities, and soil constants. As an example, a nuclear system designed to power a 1.5 million pound aircraft would weigh approximately 400 000 pounds and have a 20-foot diameter containment vessel (ref. 8). Using the same soil constant of 7.5, impact velocity of 810 feet per second, and nose constant of 0.7, the burial depth measured to the bottom of the 20-foot diameter sphere will be 35 feet.

CONCLUDING REMARKS

This report presents data of a soil impact test of a 2-foot diameter mock-up model of a reactor containment vessel system. The test was conducted at the Aerial Cable Facility, Sandia Laboratories, Albuquerque, New Mexico. The model weighed 880 pounds. It impacted soil at 810 feet per second and buried into the soil 15 feet (measured to the bottom of the sphere). The following observations were made from the results of this test:

1. No leaks were detected nor cracks observed on the model.
2. A crater 5 feet in diameter by 5 feet deep resulted at impact.
3. Containment vessel deformation was not nearly as severe as experienced in tests conducted on concrete blocks. Containment vessel failure will more likely occur from local penetrations of rocks in the soil.
4. Some local deformations due to rocks in the soil occurred on the containment vessel wall. The maximum depth of these deformations was 0.36 inch measured by a depth gage from the edge of the indentation.
5. Using a burial depth of 15 feet and a nose constant of 0.7, a soil constant of 7.5 was calculated. This was considered a valid value considering the target soil was man made, that is, back filled and tamped.

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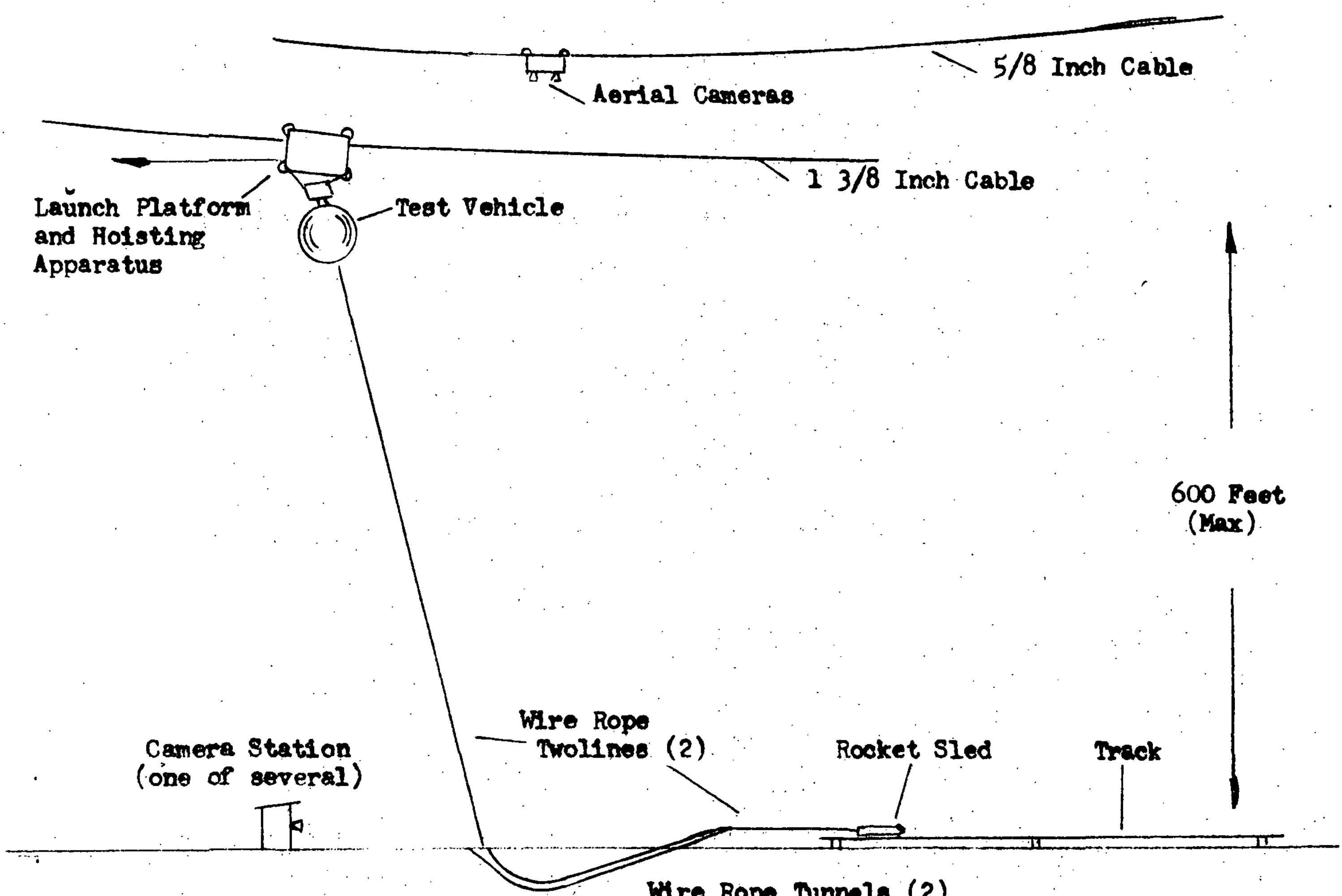


Figure 1: Aerial Cable Facility Located in the Sol se Mete Canyon

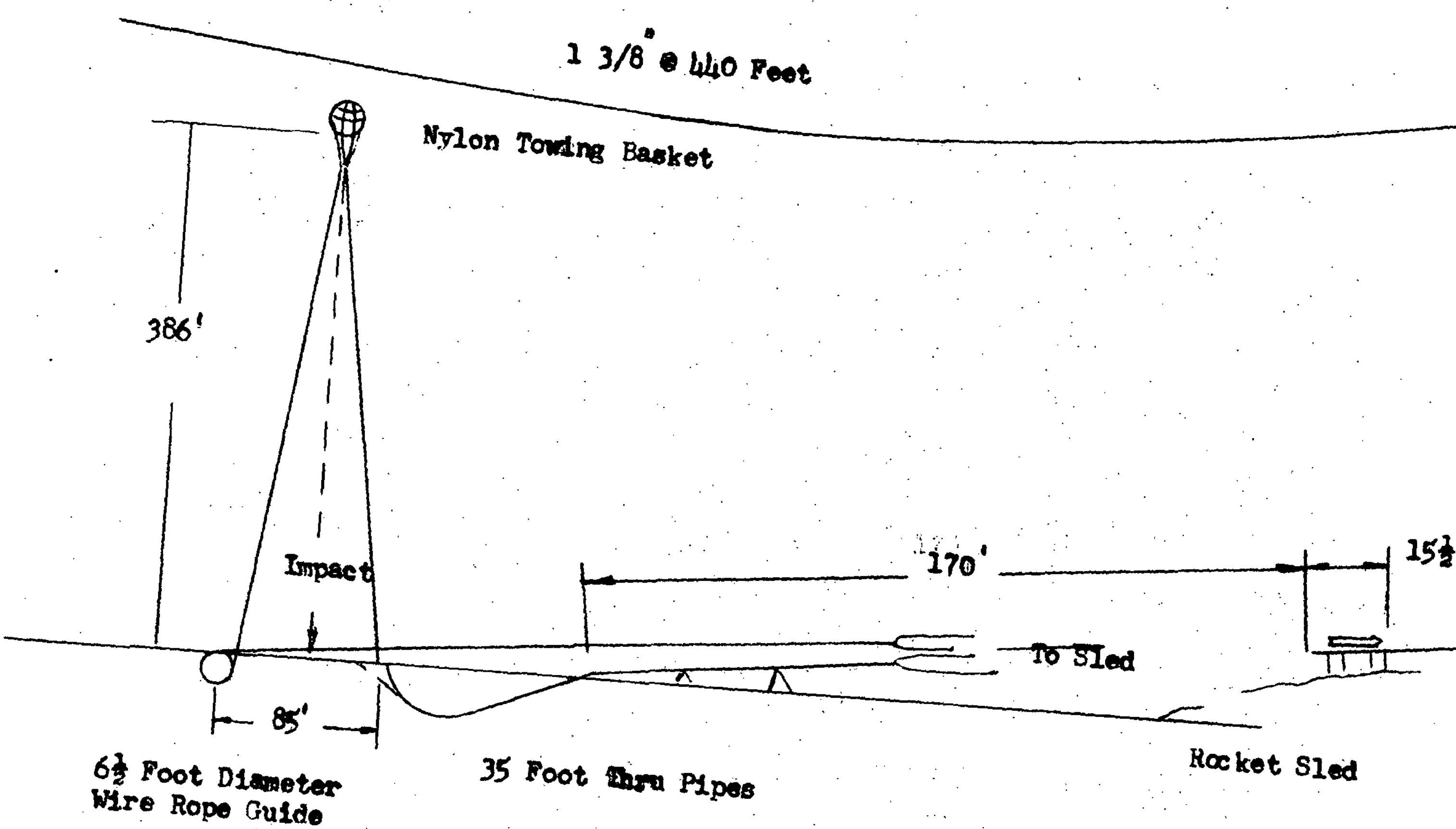


Figure 2: Towing Line Arrangement

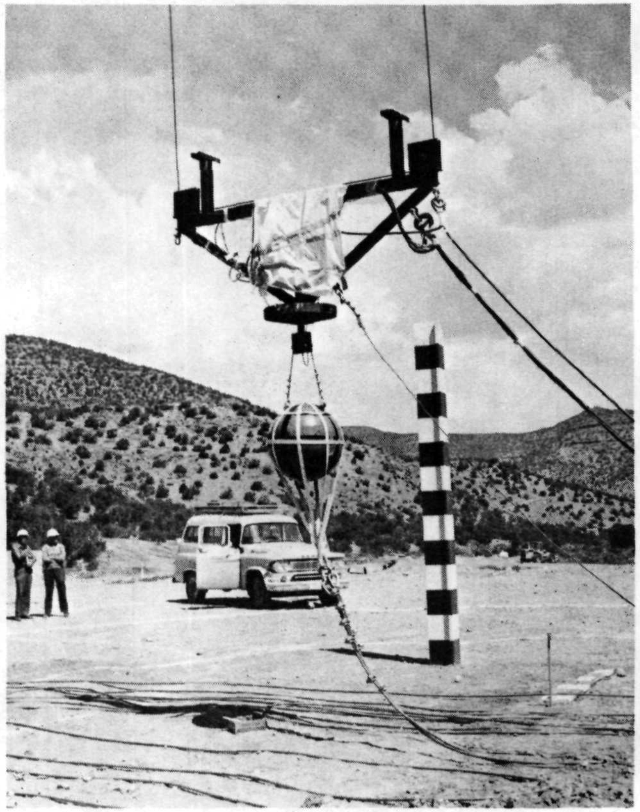
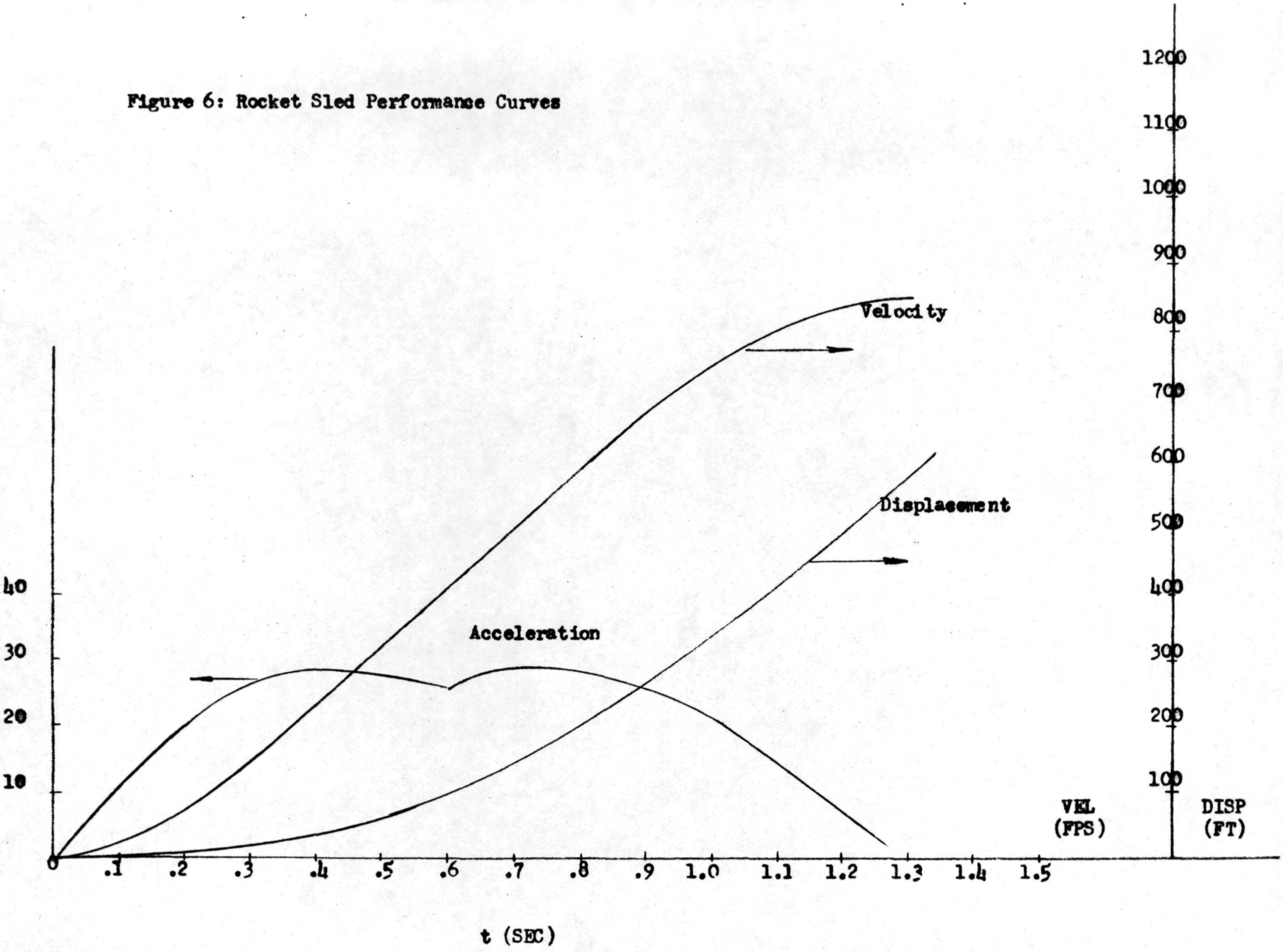


Figure 3. - Towing basket on sphere.

Figure 4. - Towing basket on sphere.

Figure 5. - Rocket sled on track.

Figure 6: Rocket Sled Performance Curves



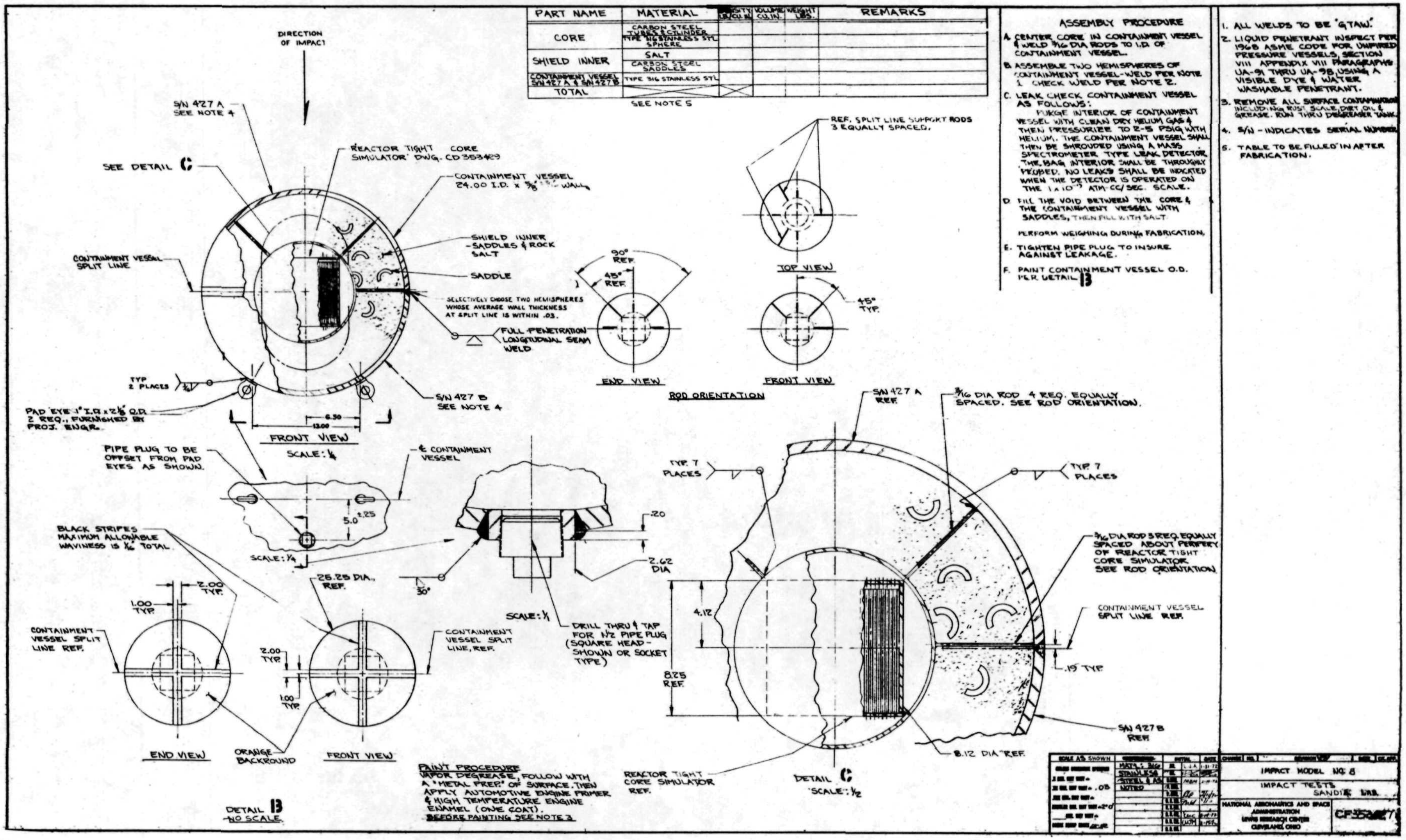


Figure 7. - Impact Model 353427 (#8).

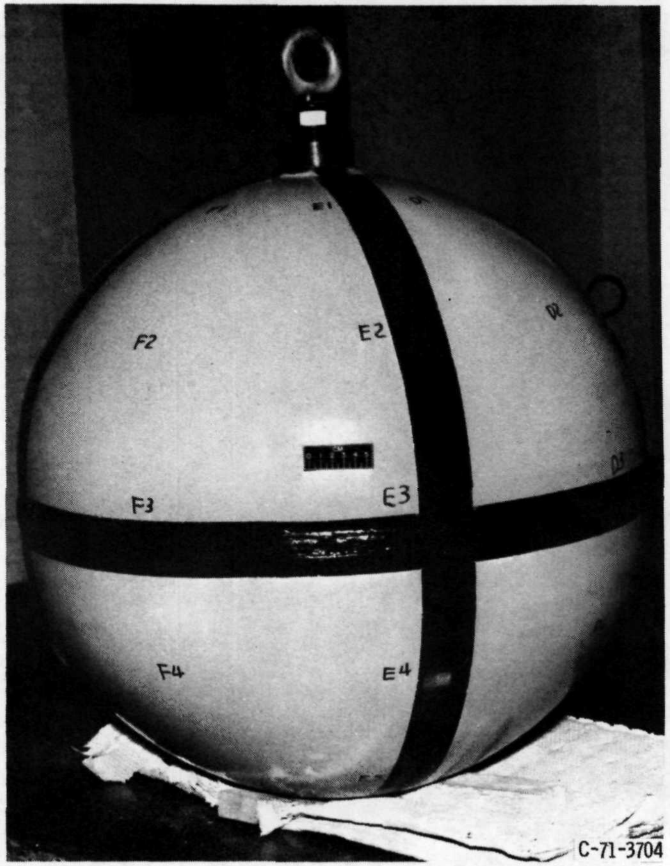


Figure 8. - Model prior to impact.

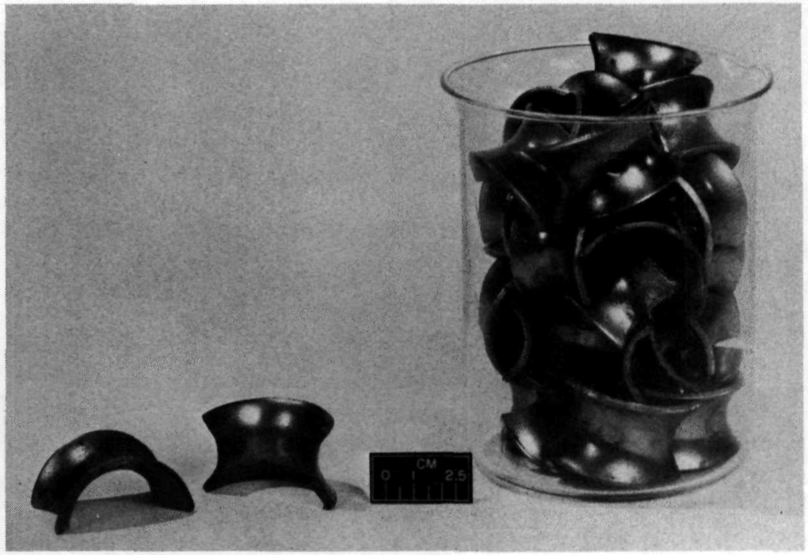


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Figure 9. - Steel saddles which simulate gamma shield material.

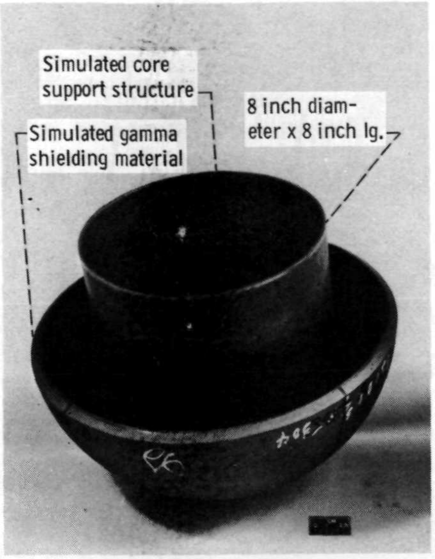

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Figure 10(a). - 8 inch diameter core cylinder welded into 12 inch diameter simulated gamma shielding material.

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Figure 10(b). - Core showing bundle of 850 tubes.

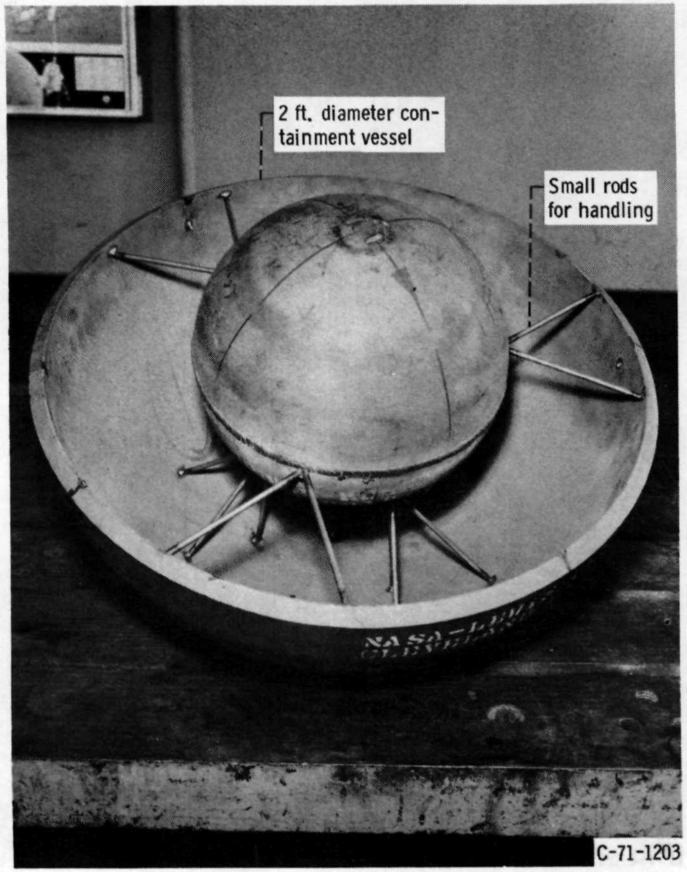

Figure 10(c). - Core centered in containment vessel.

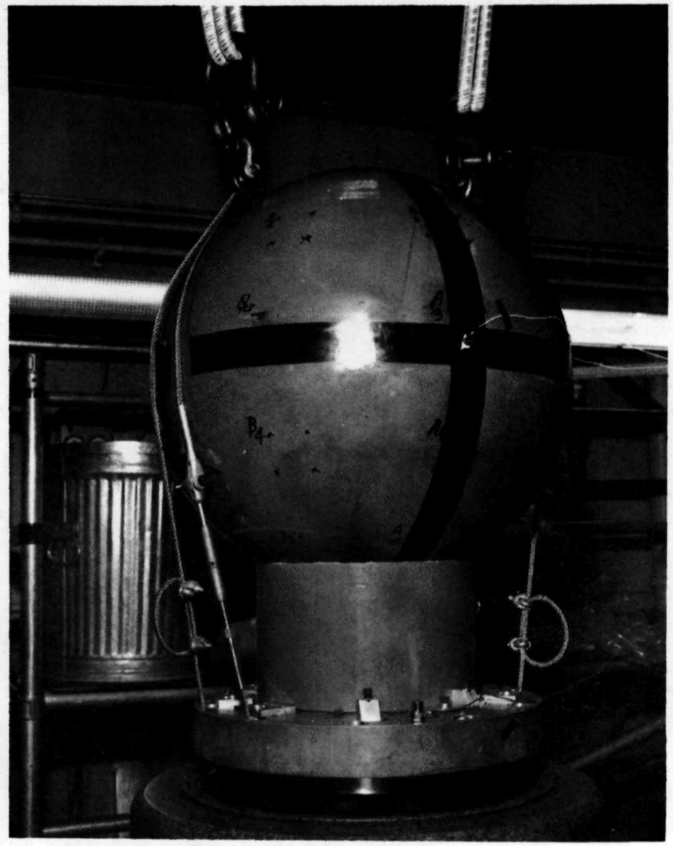

Figure 11. - Impact model on shake table.

Figure 12. - Impact area.

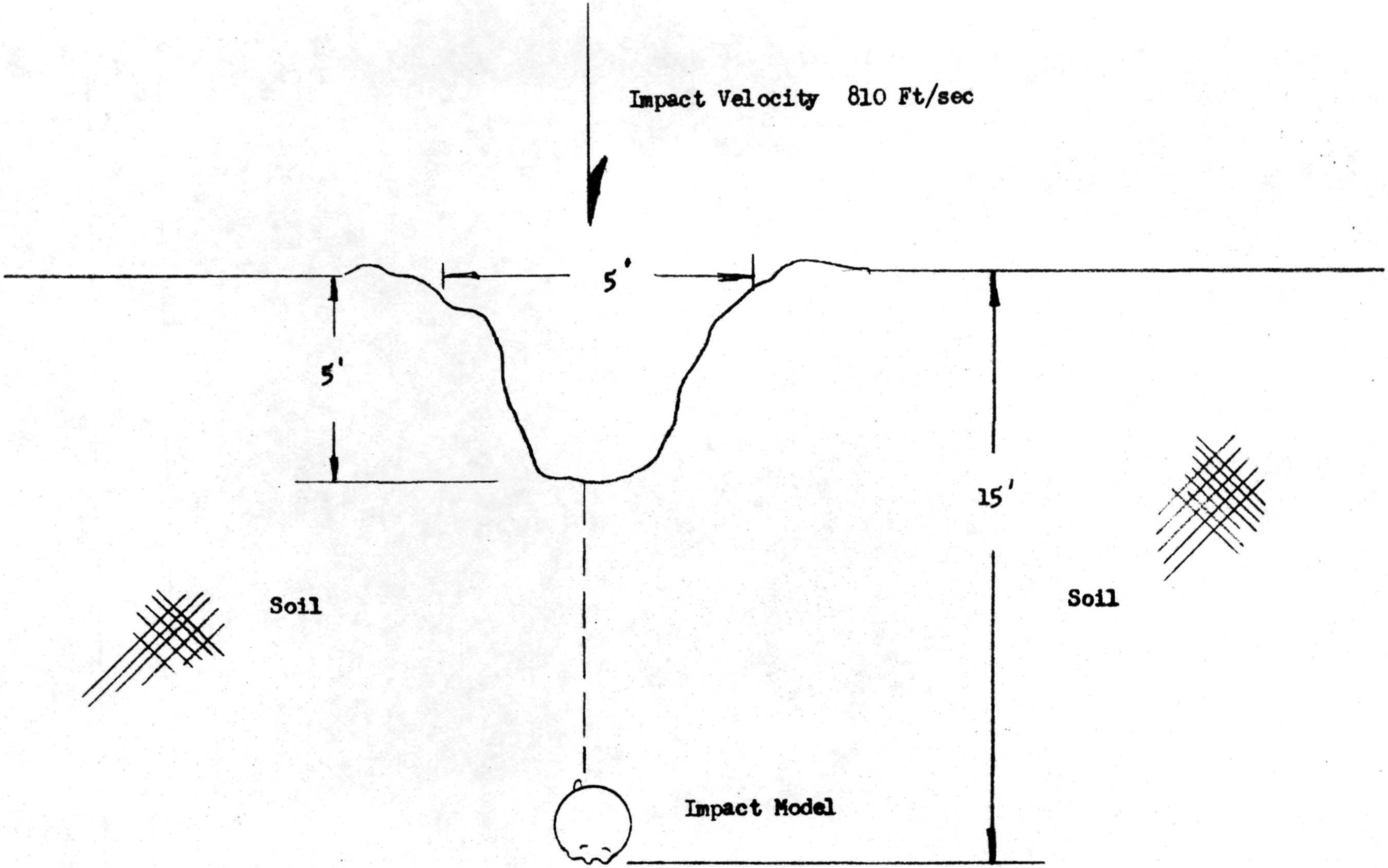

Figure 13: Approximate Crater Profile

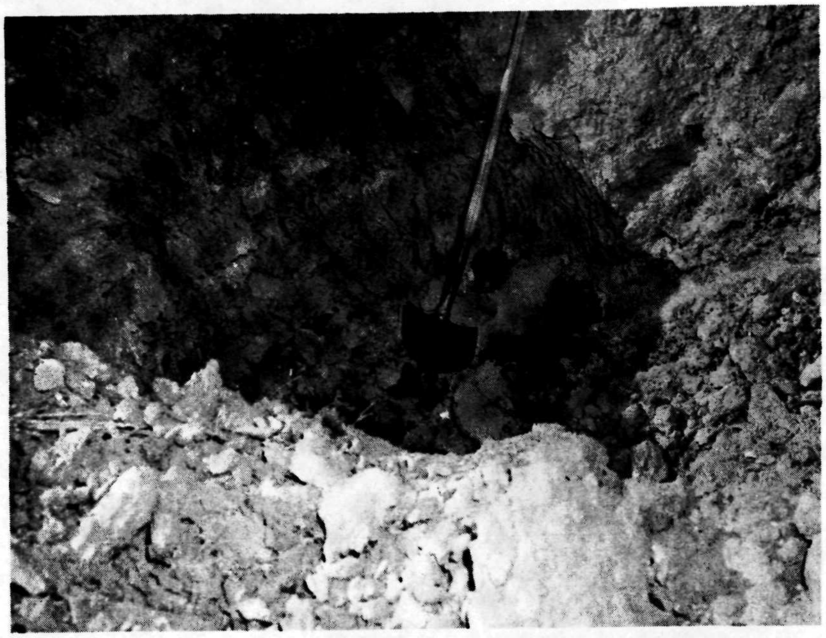

Figure 14. - Looking into crater.

Figure 15. - Looking into crater.

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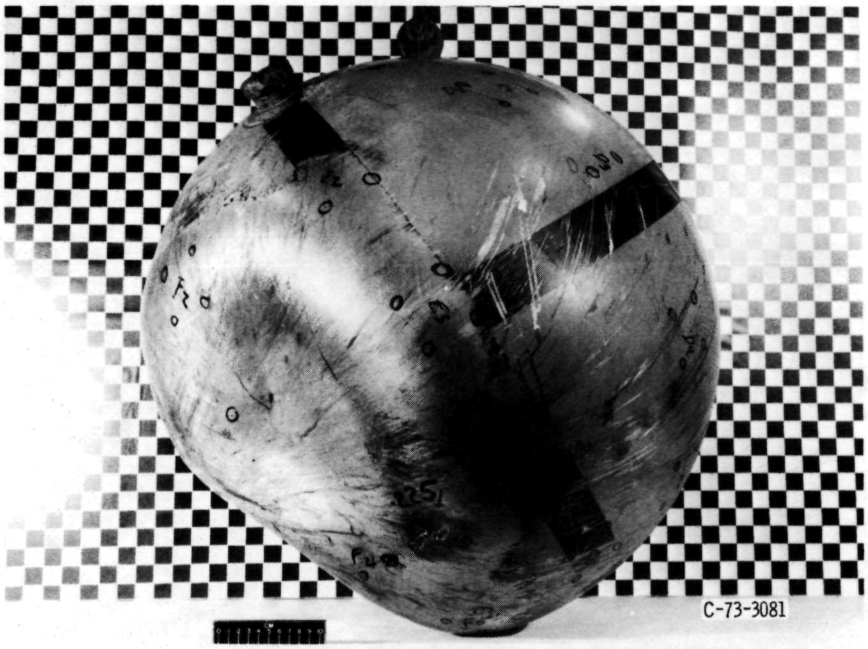

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Figure 16. - Test model after impact.

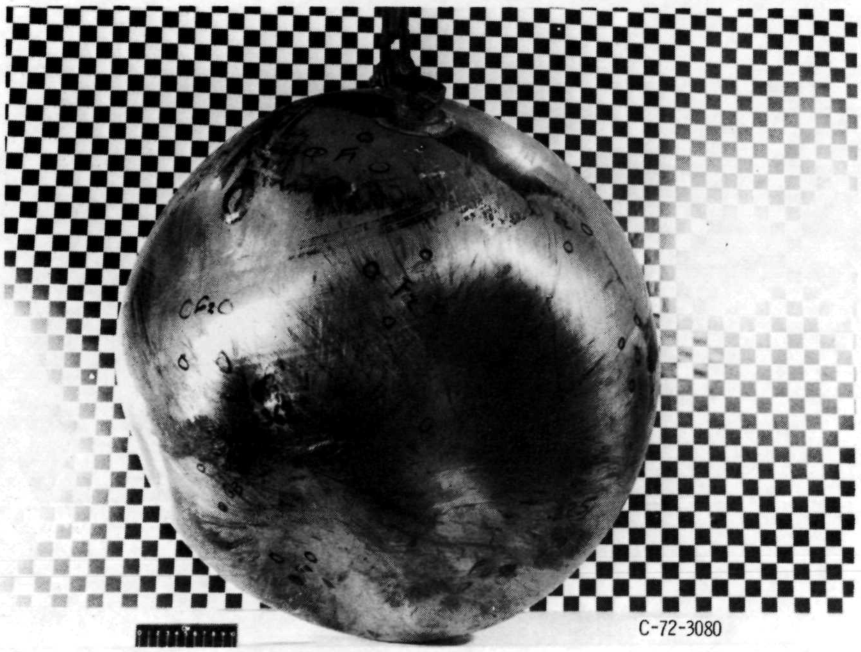

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Figure 17. - Test model after impact.