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LOS ALAMOS SCIENTIFIC LABORATORY

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University of California

Kiwi Transient Nuclear Test

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LOS ALAMOS ▇▇▇ of the ▇▇▇ NEW MEXICO
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Kiwi Transient Nuclear Test

(Title Unclassified)

by

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ABSTRACT

The Kiwi Transient Nuclear Test, or Kiwi TNT, was designed to investigate the behavior of a Kiwi reactor under conditions of rapid insertion of abnormal excess reactivity. This test formed part of the Rover Flight Safety Program which has as its objectives the understanding of accident conditions and the providing of information to enable the development of systems and procedures which will ensure safe operation during nuclear rocket flights.

The test was carried out on January 13, 1965, at the Test Cell C complex at the Nuclear Rocket Development Station, Jackass Flats, Nevada. A full scale, slightly modified Kiwi graphite reactor was used. To provide for the rapid insertion of reactivity the control drum actuators were modified to increase their speed by a factor of ~100. The abnormal amount of excess reactivity was achieved by removal of internal reactor poisons and decreasing rod shutdown worth. These two modifications enabled an insertion rate of ~\$300/sec and a total excess reactivity of ~\$6.

The experimental instrumentation measured neutron and gamma-ray reaction history, total number of fissions, core temperature and pressures, and internal and external core motions. In addition, optical measurements were made to determine brightness and temperatures of the expanding core.

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INTRODUCTION

The Kiwi Transient Nuclear Test or Kiwi TNT was the latest of a series of tests performed as part of the Rover Flight Safety Program. This program has for its objectives the investigation of the potential of and the nature of accident conditions which exist during launch and in flight nuclear rocket operations. The information from such investigations would enable development of systems and procedures to ensure safe operation during nuclear rocket flights. Previous experimental tests have been carried out to study:

1. Criticality hazard caused by compression of the core by high speed impact. These tests were carried out using the drop towers at the Los Alamos Scientific Laboratory and rocket sled facilities at Sandia Corporation.[1,2]

2. Criticality hazard and energy release caused by rapid water insertion such as might be experienced upon impact in the ocean.[3,4,5]

3. Reactor destruct mechanisms using high explosives.[6]

4. Reactor destruct mechanisms using a nuclear excursion to fragment and vaporize the fuel.[7,8]

This paper is intended to describe the Kiwi TNT tests; results are available in other Los Alamos Scientific Laboratory reports.
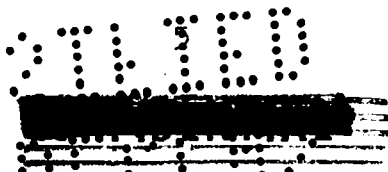
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DESCRIPTION OF TESTS

The Kiwi TNT excursion was designed to provide detailed information on the magnitude, time history, and nature of the energy release produced by a very rapid and large increase in reactivity. The objectives, then, were:

1. To measure reaction history (alpha) and total number of fissions produced under a known reactivity and to compare these with theoretical prediction. The experimental results will improve the assumptions required in the calculational program for estimating accident situations.

2. To determine the mechanisms for energy release, i.e., distribution of fission energy between core heating and vaporization, and kinetic energies.

3. To determine the nature of the core break-up under such a transient and to determine the degree of core vaporization and the resulting particle size distribution. These data although not directly applicable will provide information on the feasibility of a nuclear destruct system.

4. To measure the release to the atmosphere and dispersion of the fission debris under known initial conditions to improve techniques for estimating and evaluating the release for other accident conditions.

5. To measure the radiation environment during and after the power transient.

6. To evaluate launch site damage and clean-up techniques required for such an accident.

The reactor used for the test was a modified Kiwi core. The Kiwi core was composed of uranium carbide loaded graphite elements surrounded

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by a graphite reflector cylinder and a beryllium reflector enclosed in an aluminum pressure shell. The average uranium loading was approximately 400 mg/cm^3 which resulted in a total U^{235} inventory of ~180 kg. The core proper weighed 4,389 lb and was 52 in. long and 37 in. in diameter. The beryllium reflector weighed 2,400 lb. Reactivity control was provided by 12 rotary drums which were located in the beryllium reflector. For the Kiwi TNT excursion as large an excess reactivity as obtainable from control rods was desirable to provide the short period and required number of fissions. The excess reactivity required, relative to prompt critical, was ~\$6. To accomplish this, some of the reactor poisons normally present were removed to reduce the shutdown reactivity to 60¢ relative to delayed critical and to provide ~\$8.40 excess reactivity relative to delayed critical. In addition, the control drum hydraulic actuators were modified to increase their rotational actuation rate from the normal maximum rate of 45°/sec to approximately 4000°/sec. Based on these conditions, estimates of the reaction histories predicted a minimum period of ~0.4 ms, a peak rate of ~6 × 10^{23} fissions/sec, and a total of 9 × 10^{20} fissions. The kinetic energy, i.e., $\Sigma\frac{1}{2}m_iv_i{}^2$, was estimated at 1.26 × 10^8 joules. These estimates were considered valid within a factor of two to three for the reactor kinetics, and within a factor of five for the kinetic energy release, a large measure of the uncertainty coming from the uncertain equation of state for graphite in the high temperature region.

Figure 1 shows a cutaway schematic of the core, and Figure 2 is a schematic of the assembled test vehicle.

To provide a safeguard during test preparation in light of the very small shutdown reactivity, an auxiliary poison system was incorporated to provide adequate shutdown prior to the test. This system, mounted above the reactor, consisted of two boral vanes, each including a 60° sector which could be inserted and removed remotely between the core proper and the reflector system.

SUPPORT PLATE

PRESSURE DOME

CONTROL DRUM

PRESSURE SHELL

CLUSTER PLATE ASSEMBLY

ORIFICE JET

FUEL ELEMENT

CLUSTER ASSEMBLY

REFLECTOR SYSTEM

REFLECTOR CYLINDER

TIE ROD

SUPPORT BLOCK
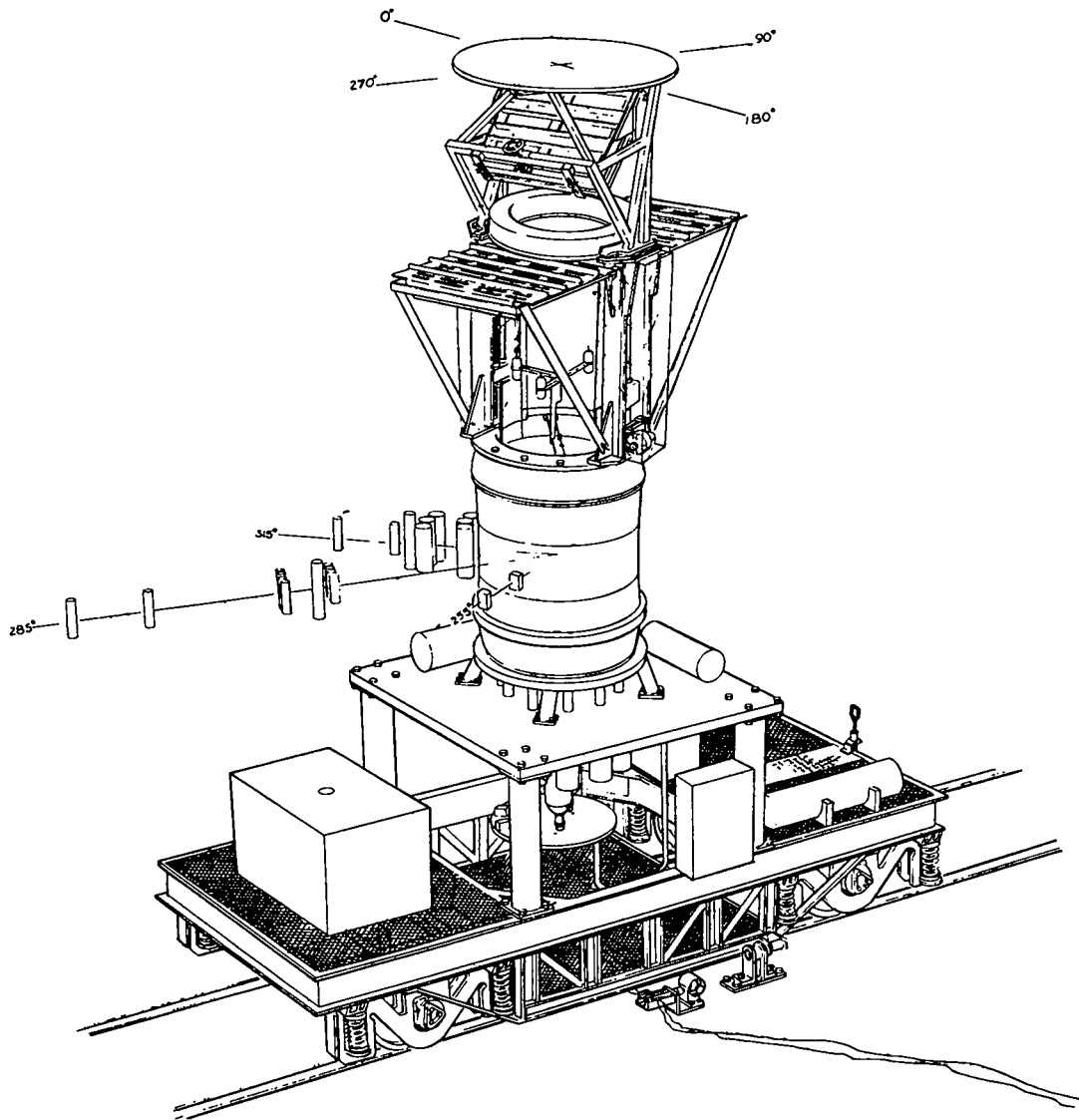
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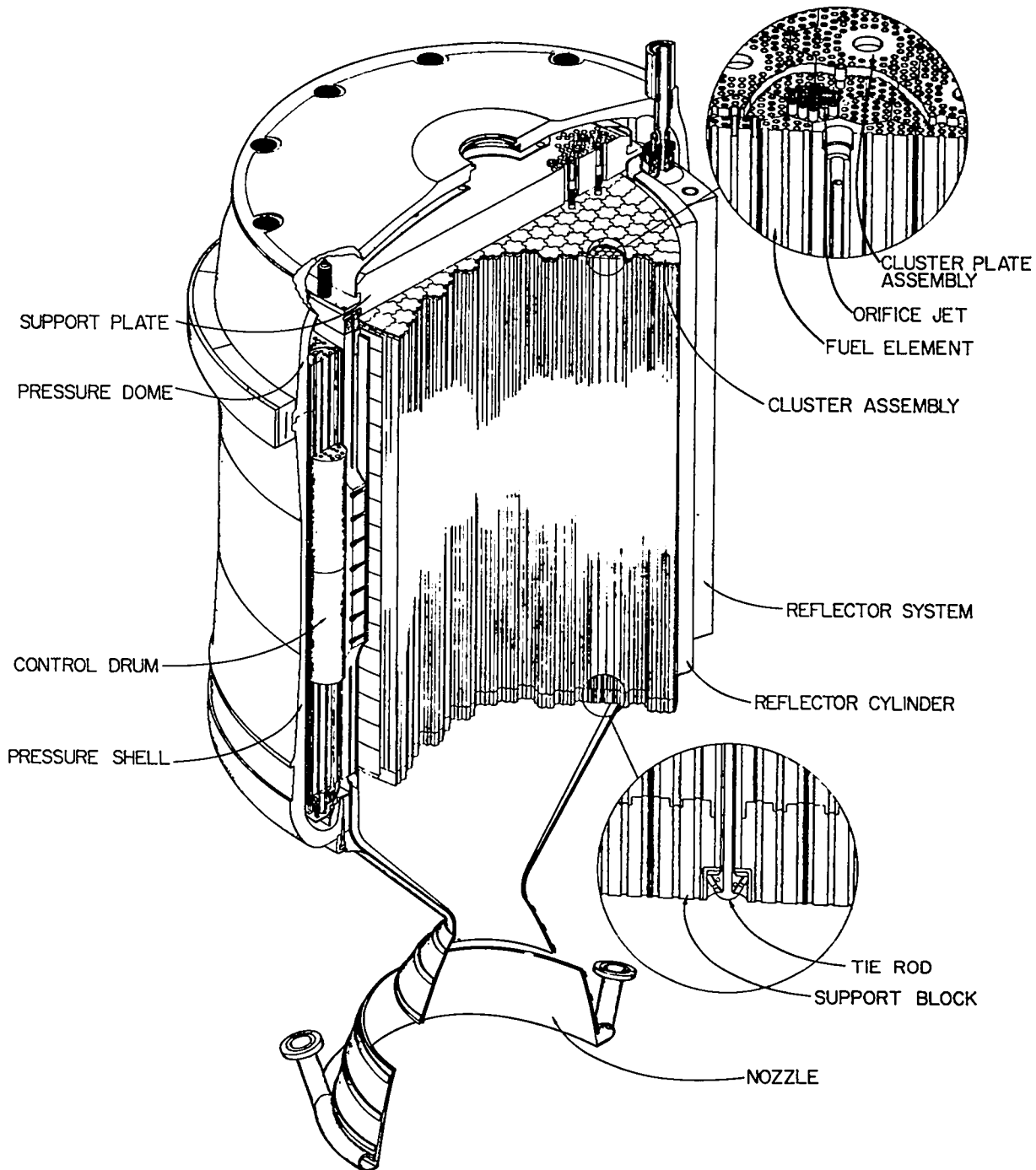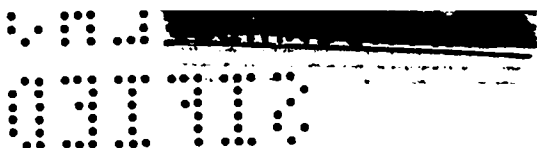
Figure 1.   Cutaway schematic of the core of Kiwi-B-4A.
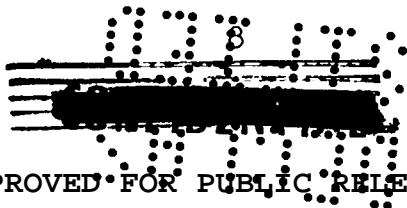
Figure 2.   Schematic of assembled Kiwi TNT test vehicle.

The entire reactor was mounted on a railroad car especially constructed for this test. Figure 3 is a photograph showing the assembled reactor and test car in test position. Figure 4 is an aerial view of the immediate test area.

The test was carried out on January 12, 1965, at the Nuclear Rocket Development Station, Jackass Flats, Nevada. The location was a site on the main railroad which connects the test cells. Figure 5 shows the geography of the test site. The site was ~600 ft from Test Cell C (the location for normal test operations) and approximately 2 miles from the control point.

An extensive diagnostics measurements program was undertaken for the test. This program included:

1. Fission rate
2. Total fissions
3. Core temperatures
4. Core pressures
5. Core motion
6. External pressures
7. Fast framing optical camera coverage (missile velocities)
8. Geographic distribution of fission debris and particulate studies
9. Heating studies of pyrocarbon coated uranium carbide fuel particles

In addition to these measurements which are described below and which were designed to yield data bearing directly on the TNT test, a number of auxiliary sample irradiation experiments were set up to take advantage of the fast nuclear transient as an irradiation source. These included various kinds of power reactor fuel samples as well as samples of high explosives which might be used in a NERVA chemical destruct system.
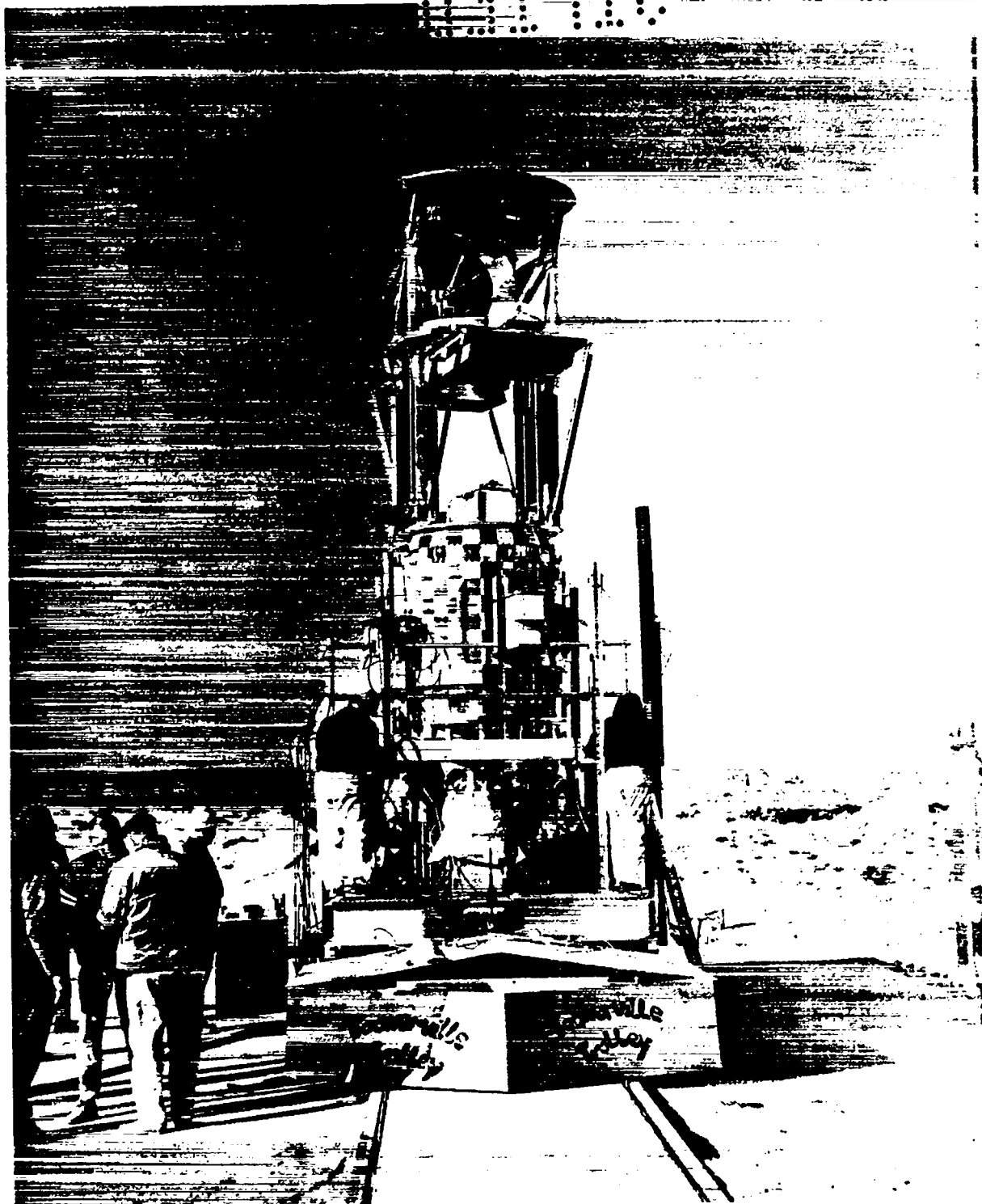
Figure 3. Assembled reactor and test car in test position.
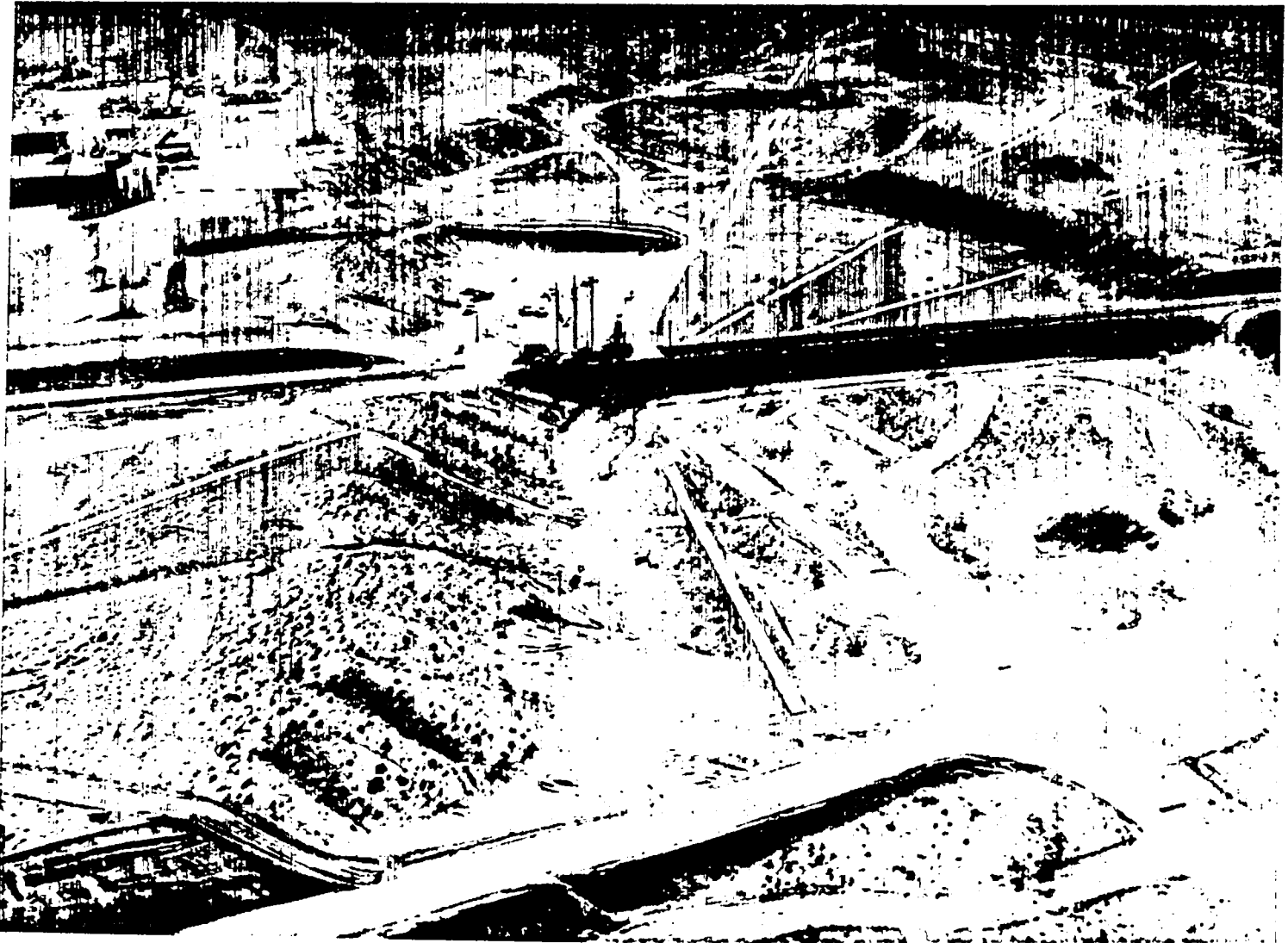
Figure 4.   Kiwi TNT test area.
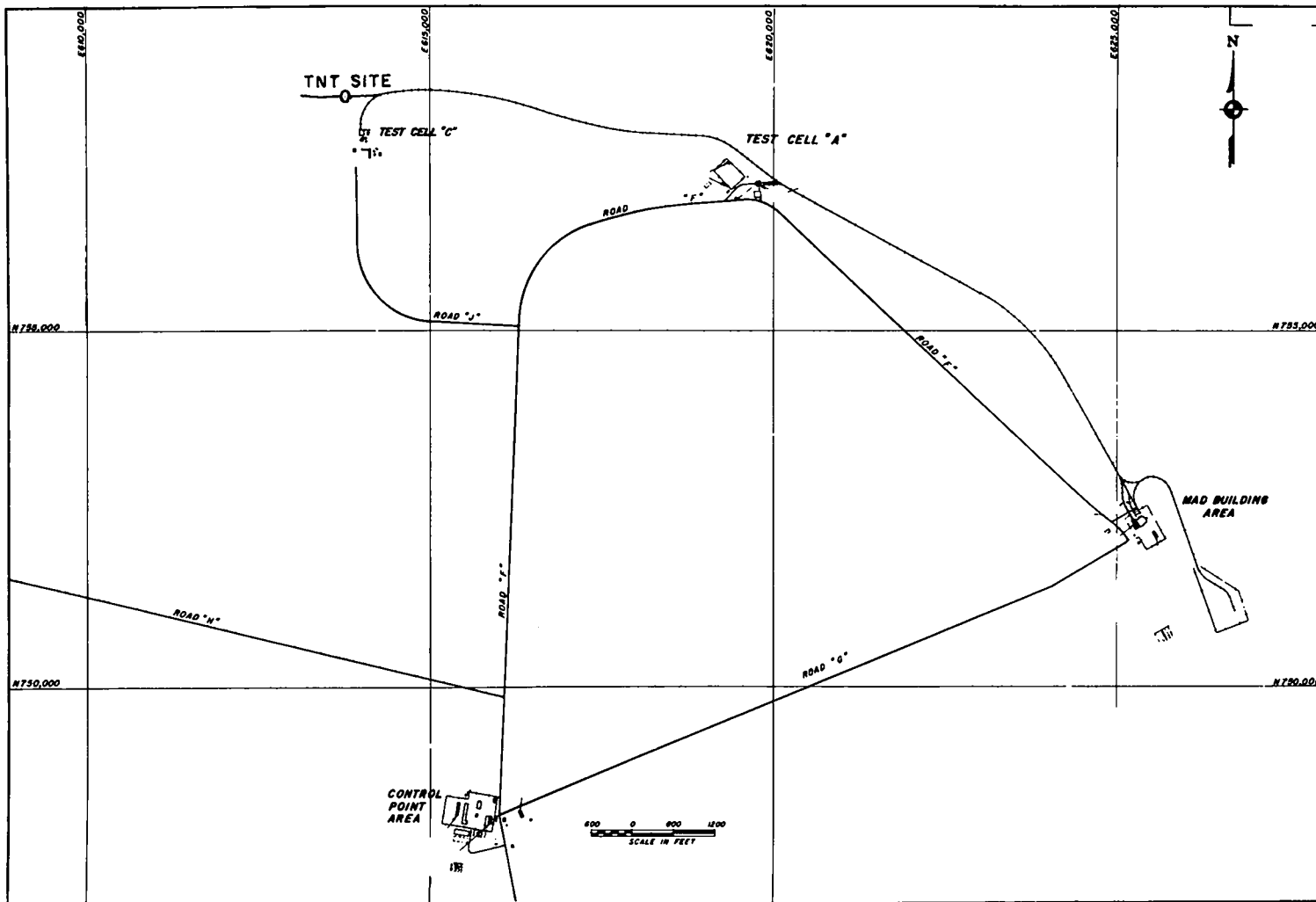
Figure 5.   Kiwi TNT site plan.

Neutron Reaction History

The time history of the energy generation was of prime importance in the understanding of the energy release mechanism. To obtain this, it was decided to measure the prompt gamma reaction history using a system of photo cells and fluors. The system consisted of six detectors located at three distances from the reactor. These detectors were calibrated during previous reactor tests in the Kiwi-B-4E-301 test series. Two were placed on the pressure shell to record early history, two were positioned at 24 ft from the reactor to detect intermediate gamma levels, and two were positioned at 800 ft to cover the peak rate of the event. The ranges of sensitivities of the detectors were selected so as to include approximately 7 decades covering power levels between 10^{18} fissions/sec and 10^{23} fissions/sec. The outputs of the detectors were recorded on magnetic tape. The bandwidth of the recording system was 20 kc. Measurement of alpha, or the reciprocal period, was obtained by taking the logarithmic derivative of these records. The early time history of the power rise was also obtained using miniature thermocouples mounted on uranium fuel particles.

Total Fissions

Several techniques were utilized to measure the total number of fissions produced during the test. The first of these involved an integration of the neutron reaction history traces. Uncertainties in this measurement arise from calibration uncertainties and from the fact that as the core geometry changes, the ratio of prompt gamma leakage flux to neutron fission rate changes in an unknown manner. Thus the integration of the curve over the peak can introduce considerable uncertainty.

A second measurement of this quantity was based on radiochemistry. It was anticipated that sufficient samples of the core would be recovered so that fission distribution and normalization of the fission distribution could be accomplished. To this end, the center unloaded elements in 13

clusters were replaced with stainless steel rods. These rods were suitably labeled as to their location, and the intent was to recover these and infer the fission distribution from the induced activity in these rods. To normalize the distribution, a series of fuel elements was also labeled as to their position in the core, and radiochemistry of the fission products in these samples was expected to yield absolute value of the number of fissions.

A third measurement of total fissions made use of the ratio of certain fission products to U^{235} in integral cloud samples.

In addition to these techniques, use was made of calibrated fission foils.

All methods yielded good results.

Core Temperatures

Although anticipated core temperatures exceeded the range in which direct measurement is feasible, the core was instrumented with six tungsten/tungsten-rhenium thermocouples to record core temperatures in the event of a low yield.

To measure the temperature and brightness of the expanding core, whose temperature was estimated to be ~4300 °K from energy release and equation of state considerations, optical methods were used. A streak spectrograph covering the region from ~3000 Å to 6000 Å was set up to obtain a time resolved spectrum of the event. This spectrum was expected to provide information on the temperature as well as the nature of the radiative processes.

The brightness estimates of the incandescent core indicated a brightness of the order of 100 W/cm² steradian over the visible spectrum. To measure the absolute brightness, three fast framing optical cameras were set up on the control point building roof at a distance of ~10,000 ft. The records from these cameras gave time and space resolved brightness data.

Core Pressures

As in the case of the temperature measurements, the range and environment (radiation and thermal) precluded durect measurement of the anticipated pressure maximum. Again, it was decided to include three pressure transducers, two of which were to measure pressures in the core and the third was mounted in the core inlet plenum to measure average pressure in the pressure shell. These transducers were of the linear variable differential transformer (LVDT) type excited by 20 kc. Included adjacent to these active transducers were two dummy transducers of the same type, the reason for their inclusion being to provide a means of subtracting radiation and thermal effects on the transducer.

Core Motion

Interest in core motion measurements arose from the objective of finding out the fraction of total energy released as kinetic energy. Two techniques were used to obtain data on this motion. Three LVDT type displacement transducers were mounted through holes in the pressure shell approximately on the mid-plane of the axis at three azimuthal locations. A second type of transducer was developed for this test which was an assembly of seven coaxial shorting pins mounted on a threaded plug approximately 1 cm in diameter. The pins were spaced to cover approximately 1 cm of radial displacement. The short circuit pulse from each pin was fed through appropriate shaping circuits to provide for pin closure identification by polarity and pulse shape. Eight such assemblies were mounted to measure core and reflector radial motion at four axial locations. Two additional assemblies were mounted on the top of the core on the centerline and at 0.7 of the core radius to obtain information on the axial motion of the core top, and two such assemblies were inserted into the core along the axis and on a radius along the centerline to get information on core expansion. Figure 6 shows a typical pin assembly and pin locations.

Figure 6. Typical pin assembly and pin locations.

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External Pressures

To find out about the effect of the pressure pulse on the environment, 11 transducers (nine active, two dummy) were positioned symmetrically at 5 ft, 30 ft, and 100 ft in a plane through the centerline of the reactor. These transducers were ranged to record 0 to 3000 psi at 5 ft, 0 to 100 psi at 30 ft, and 0 to 5 psi at 100 ft.

Optical Camera Coverage

Because of the difficult measurement environment and untried measurement techniques, an extensive photographic coverage was planned to obtain general information on .the nature of the excursion and missile velocities. This coverage included photographs of the core at 23,000 and 10,000 fps, narrow field of view (58 ft $\times$ 31 ft at 4000 fps and 75 ft $\times$ 40 ft at 2500 fps), and slower, wider field of view photography (400, 96, and 24 fps) to obtain information on missile trajectories and cloud geometry.

Geographic Distribution of Fission Debris and Particulate Studies

These measurements were made not only to obtain data on environmental effects and fission product release but also to study core fragmentation to obtain further information on the feasibility of a nuclear destruct system. A system of collectors and arrays of polyethylene strips collected data over a radius of approximately 50 miles. This system is described in considerable detail in an internal document. In addition to ground sampling, integral cloud samples were obtained using standard airplane sampling techniques.

CONCLUSIONS

The test was successfully carried out, and data were obtained on all measurements listed above. Essentially, all objectives were met. This test provided further empirical data on the nature of nuclear excursions in Kiwi reactors.

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